EVALUATION OF CONSTRUCTION STORMWATER RUNOFF TURBIDITY: STATE-LEVEL TRENDS AND FORECAST OF FUTURE IMPACTS

by

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ABSTRACT

ARUNAN MANICKAVELU. An Evaluation of Construction Stormwater Runoff Turbidity and Forecasting of its Future Impacts. (Under the direction of DR. JACELYN RICE)

Construction and development projects alter an environment from its natural state into a man-made setting. Construction land use areas have been found to contribute the highest sediment loading to urban runoff when compared to loadings from other urban land use types (i.e. commercial, parking lot, industrial). According to the Environmental Protection Agency (EPA), it has been estimated that 6000 lbs/acre-yr of total suspended solids is contributed from construction areas. In 2009, the EPA introduced numeric turbidity limits and guidance on the allowable levels of sediment (measured as turbidity) within stormwater runoff from construction sites. This was later withdrawn in 2014, due in part to a major shortcoming in data insufficiency regarding current loading estimates. In support of this, this study centers on three main research objectives to gain insight into this shortcoming and forecast future potential impacts of construction stormwater runoff. Through an analysis of stormwater data reported by facility owners in California State Water Resources Control Board (CSWRCB), we can understand the scale, severity, and trends of the stormwater runoff. A stormwater prediction model has been developed to provide estimates of turbidity within construction stormwater runoff to aid in future planning of construction sites in the event that turbidity regulations are put in place of the current industry standard metric of total suspended solids. Potential future impacts of construction within North Carolina have been forecasted through a spatial analysis that highlights sediment loading and receiving water risk levels with respect to the probable

development area in the future. In the preplanning stages of construction, best management practices are decided by knowing trends of turbidity level during storm events, loading risk levels and prediction model provided by the study.

DEDICATION

I would like to dedicate this to my parents, who are responsible for everything I have achieved in my life. Their undying confidence in me and their unconditional love and support helped me through the toughest of times. I would also like to dedicate this to my advisor Dr. Jacelyn Rice. Her words of wisdom and consistent guidance have given me the strength to set goals and helped me complete this research.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASCE	American Society of Civil Engineers
ATS	Active Treatment System
BMP	Best Management Practices
CBIA	California Building Industry Association
CBIA	California Building Industry Association
COD	Chemical Oxygen Demand
DWR	Division of Water Resources
EPA	Environmental Protection Agency
GIS	Graphical Information System
K	Soil Erodibility
LS	Hillslope-Length Factor, L, and A Hillslope-Gradient Factor, S.
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
NTU	Nephelometric Turbidity Units
R	Rainfall Erosivity
SMARTS	Stormwater Multiple Application and Report Tracking System
SWPPP	Storm Water Pollution Prevention Plan
SWRCB	California State Water Resources Control Board
TSS	Total Suspended Solids
URS	URS Corporation
USDA	United States Department of Agriculture

USGS	United States Geological Survey
USLE	Universal Soil Loss Equation

CHAPTER 1: INTRODUCTION

1.1 Background and Significance

Increase in population and the growth of urban/urbanized regions are chief contributors to the amount of pollutants in the runoff along with the volume and rate of runoff from impervious surfaces (EPA, 2018). Global human population is growing at a rate of approximately 1.3% year and it is expected to continue (Cincotta, Wisnewski, & Engelman, 2000). The increase in population will increase the demand for the construction and development projects. According to the U.S. Census Bureau, construction spending is about 1.3 trillion USD, about 7.6% higher than 2006. The nature of any construction or development project involves land-disturbing activities such as vegetation clearing, excavating, and grading. These activities have a high potential to increase pollutant loads to surface water during storm events.

Building new residential buildings, infrastructure, and commercial facilities increases the amount of impervious surface and the runoff pollutants that could potentially end up in water bodies and cause impairment from urban runoff (Stephenson, 2003). The most recent National Water Quality Inventory reports that runoff from urbanized regions is the prominent water quality impairments source to estuaries and the third-largest cause of impairments to surveyed lakes (EPA, 2018). Urban stormwater runoff impairment constitutes roughly 5,000 square miles of estuaries, 1.4 million acres of lakes, and 30,000 miles of rivers (EPA, 2016).

In 2009, the U.S. Environmental Protection Agency (EPA) introduced numeric turbidity limits and guidance on the allowable levels of sediment (measured as turbidity) within stormwater runoff from construction sites. In 2014, this regulation was withdrawn by the EPA, but the door was left open for future actions by reserving sections for additional effluent limitation guidelines. However, in the absence of federal numeric limits some states (including California, Georgia, Vermont, and Washington) have chosen to include more stringent turbidity limits and/or guidelines in the absence of federal numeric limits. In the state of California, a numeric limit was placed on turbidity values within stormwater runoff from active construction sites. Additional guidelines were provided regarding the method of control practices and procedures to be followed during the sampling process. California has adopted a regulatory approach that incorporates sediment and water risk levels and provides turbidity data available online from current and previous permit holders. A major shortcoming of the original EPA ruling was data insufficiency regarding current loading estimates. In support of this, the work proposed here aims to utilize California's dataset to further understand the magnitude of sediment loading from construction stormwater runoff.

1.2 Objectives and Scope

The goal of this project is to perform a state-level evaluation of turbidity measurements during construction activity using data from California as a case study and extrapolate their risk approach to examine the risk level of probable development areas within the State of North Carolina. This goal will be achieved through the completion of three research objectives. First objective of the research is to statistically analyze turbidity concentrations of stormwater runoff at active and previously active construction sites across the state of California using stormwater data available on the California State Water Resources Control Board (SWRCB). The scope of this objective is to identify the traits and trends of turbidity measurements during storm events. Additionally, an evaluation of whether the observed turbidity measurements differ for sites categorized as having higher water or sediment risk levels will be performed.

The second objective is to develop a construction stormwater runoff model to estimate turbidity concentrations within stormwater runoff from construction sites to provide a tool that can be integrated during the planning phase of construction activities. This tool can be used as a guiding factor for engineers and contractors to plan for sediment control and more readily meet numeric turbidity limits that may potentially be set in the future. The final objective of this study is to forecast risk levels for future probable development areas within North Carolina by using the California risk level methodology which is performed using ArcGIS.

1.3 Organization of Content

Chapter 1 provides an overview of this purpose and approaches of this research study. Chapter 2 is a literature review that offers relevant information on the sediments and erosion, construction impacts on the stormwater runoff, the factors influencing the pollutant loads such as rainfall characteristics, soil characteristics, land cover, the topography of the land and seasonal influences. The sediment loads are measured in turbidity and total suspended solids and their relationship correlation are reviewed. Construction site runoff regulations followed by various governmental agencies, and current erosion prediction models are also reviewed. Chapter 3 deals with the scope of the research along with the limitations and the methods to overcome it. Chapter 4 describes the materials used and the methodology adopted for the data analysis, model creation and spatial analysis. Chapter 5 discusses the results of the research. Finally, Chapter 6 presents conclusions and recommendations of the study.

CHAPTER 2: LITERATURE REVIEW

This chapter provides an overview of the impact of stormwater on the environment and the factors affecting stormwater water pollutant loads. Sediment and erosion impacts are reviewed with focus given to the methods used to measure loading (turbidity and total suspended solids). Federal and state policies regarding stormwater are reviewed. Also provided is a literature review regarding the Universal Soil Loss Equation for predicting sediment erosion.

2.1 Overview of Construction Impacts to the Environment

Construction projects have a significant impact on our environment at the local and global scale. Each stage of the construction process has measurable impacts including the mining processes used to source material, material transport, construction process, and the waste and disposal process at the project's end. The American Society of Civil Engineers (ASCE) infrastructure report card grades the United States with a D+, which depicts the infrastructure needed for development (ASCE, 2017). During times of rapid development, it is important to understand how construction impacts the environment and how we can mitigate these impacts in the future. Locally, individual construction projects can have a significant impact on local environments and nature. Potential impacts on the quality of surface water are one of the major concerns associated with the construction industry (Davies, 1995). Surface water pollution is caused when rainwater or the water used for other purposes flush away the dust from the atmosphere, soil, organic and inorganic compounds, nutrients, oils, greases and heavy metals into the natural water resources (Gnecco, Berretta, Lanza, & La Barbera, 2005). Construction sites are prone to have harmful constituents onsite causing stormwater pollution to be a problem that must be addressed

2.2 Sediments and Erosion Impacts

According to the United States Environmental Protection Agency, roughly 20 to 150 tons of soil per acre are lost every year to stormwater from construction sites. Stormwater contributes a significant source of water pollution to water bodies used for drinking and household purposes (Characklis & Wiesner, 1997; Chui, Mar, & Horner, 1982). Stormwater runoff from construction sites transmits sediments and pollutant loads which are harmful to water bodies such as rivers, lakes and coastal waters. Due to this occurrence, stormwater runoff pollution is considered non-point source pollution and it is one of the chief causes of quality deterioration in recipient water bodies.

2.2.1 Sediments

Sediments are naturally occurring substances that are broken down into smaller particles due to abrasion or erosion and are carried away by flowing water. Land erosion is the process of detachment, transportation, and deposition of solid particles which are termed as sediments. The raindrop impact and the shearing force of flowing water impact the detachment process (Wurbs & James, 2002). In construction stormwater runoff, the chief sediments are sand, silt, clay and some organic substances. Sediment particles come in different sizes and are primarily classified as clay, silt and sand. The sand can be a very coarse sand grain (2 mm), coarse sand grain (1 mm), medium sand grain (0.5 mm), fine sand grain (0.25 mm), and fine sand grain (0.125 mm). The particles which are of 1/16 mm diameter are termed as silt. Clay defined as particles less than 1/256 mm in diameter (Wentworth, 1922).

Sediment is transported downslope by flowing water and gravity speeds up the process. As the water flows overland, sediment particles can become carriers of other pollutants. Ultimately, sediment loading to natural water may be composed of various individual solid materials such as primary soil particles, aggregates, organic matter, and chemical substances (Wurbs & James, 2002). Each pollutant has different erosion removal rates because of their physical characteristics and it is tabulated in Table 1.

Table 1 : Removal rates of pollutants in stormwater runoff (Wurbs & James, 2002)

Pollutant	Removal Rate %
Total Suspended solids	50-70
Total Phosphorus	10-20
Nitrogen	10-20
Organic Matter	20-40
Pb	75-90
Zn	30-60
Hydrocarbons	50-70
Bacteria	50-90

2.2.2 Erosion

Sediment erosion is a natural process; however, human alteration of the natural environment has led to increased erosion (Alsharif, 2010). Erosion is the transportation of earthy substances by factors such as wind or water. Surface water pollution is caused when rainwater or the water used for other purposes flush away dust from the atmosphere, soil, organic and inorganic compounds, nutrients, oils, greases and heavy metals into the natural water resources (Gnecco et al., 2005). Soil is protected from erosion by vegetation. Human activities like mining, logging, agriculture and construction activities impact land erosion greatly. These activities increase soil erosion from 2 to 4000 times the normal rate of natural erosion. Sediment eroded from watershed are delivered to downstream streams and rivers. (Wurbs & James, 2002).

Water erosion can be classified based on factors such as land use and slope aspect into generally four types, namely splash erosion, sheet erosion, gully erosion, and rill erosion. Splash erosion happens on top of the slope where the slope is from 0-8 degrees and the soil is thick. Splash erosion is dominant on the sites with high aggregate stability and rapid infiltration whereas sheet erosion occurs where topsoil is prone to liquefaction. Sediment is detached and transported primarily by flowing water and also by raindrop splash. Soil erodibility increases as infiltration decreases. Overland flow includes sheet flow and rill flow. Rills are small channels formed from the concentration of sheet flow and the quantity and size of sediment increases with velocity of the flow (Wurbs & James, 2002). Rill erosion occurs where slope gradient is from 8-20 degrees. It accounts for almost 50% - 75% of the sediment yield. Gully erosion occurs where slopes are above 25 degrees and gully erosion occurs in steep slopes of gully valleys and gully heads (Bojie, Xilin, & Gulinck, 1995).

2.3 Factors Influencing Pollutant Loads

Stormwater pollutant loads are impacted by external factors that can either increase or decrease the level of impact. Strategies aimed at decreasing load levels can be used in pollution control techniques, whereas factors that have potential to increase loading will warrant construction workers to review and correct their stormwater pollution prevention plan. Pollutant factors that generally influence stormwater loads include rainfall characteristics, field topography, soil type, land cover and stormwater control practices. Geographical area also impacts the pollutant loads through some factors which include the rainfall zone as termed by the EPA, season of rainfall, sampling methods, manmade activities and the amount of imperviousness (Maestre & Pitt, 2006). Stormwater pollution is a non-point pollution making it difficult to assess due to its non-point source trait, further making it a challenge to satisfy sustainability criteria (Opher & Friedler, 2010).

2.3.1 Rainfall characteristics

Rainfall intensity and duration are important factors in the magnitude of pollutant loads. Rainfall events with low intensity and longer duration can create the same impact as short high-intensity rainfall events. Research was carried out on the highways of California, USA and almost 600 storms were assessed to determine rainfall factors affecting pollutant load concentrations. Results of the correlation study show water quality parameters were positively correlated with storm characteristics and land use parameters. Suspended solids, dissolved solids, turbidity, and chlorine content were strongly correlated with site and rain event parameters, which displays their significant influence on water quality parameters (Kayhanian, Suverkropp, Ruby, & Tsay, 2007). The concentrations increased with the increase in duration of the storm as the transference of elements happens throughout the duration of the rainfall. Characteristics of the previous storm can also influence the load concentration (Opher & Friedler, 2010). When parameters like total suspended solids, chemical oxygen demand (COD), and heavy metals are analyzed with rainfall characteristics, the most significant constituents from road runoff was total suspended solids (TSS), COD and heavy metals whereas roof runoff showed strong presence of Zinc concentration (Gnecco et al., 2005).

Rainfall characteristics significantly impacted pollutant load concentrations within stormwater runoff from highways in Texas, USA. The characteristics include duration of the event (min), volume of runoff per area (L/m^2), intensity of the runoff per area of watershed ($L/m^2/min$), duration of the dry period (hrs) and the previous storm event. The storm event was artificially created using a rainfall simulator over a 230-meter length of 3-lane highway (Irish et al., 1995). The variables found to affect selected pollutant runoff loads are tabulated in Table 2.

Table 2 : Factors affecting load concentrations (Irish et al., 1995)

	Duration of Storm Event	Intensity of Storm	Storm Volume	Time of Dry Period	Previous Storm Duration	Previous Storm Volume	Previous Storm Intensity
Iron		X	X	X			
TSS		X	X	X			X
Zinc	X		X		X	X	X
COD	X	X	X	X			
Nitrate		X	X				

The first flush phenomenon is the initial period of the stormwater run-off which will have higher concentrations than the later periods. During this phenomenon pollutant load concentrations are generally higher for the first rainfall event as the loads in the ground prevailing through the dry season are taken by the first storm event. In simpler terms, the first part of the runoff is the most polluted (Deletic & Maksimovic, 1998). It has been demonstrated that pollutant loads related to first flush during storm events can be higher than the load from wastewater in dry weather conditions (Artina et al., 2000). Additionally, the magnitude of the first flush phenomenon varies based on pollutant type where it was greater for suspended solids and lesser for others like chemical oxygen demand (J. Lee, Bang, Ketchum Jr, Choe, & Yu, 2002).

2.3.2 Soil Characteristics

Soil characteristics such as resistance to erosivity, soil stability, imperviousness and particle size distribution have an influence on sediment loading due to runoff. Soil-erodibility factor is a main parameter that represents an integrated average annual value of the total soil and soil profile reaction to a large number of erosion and hydrological processes (Renard, Foster, Weesies, McCool, & Yoder, 1997). These processes involve detachment of soil and transport through raindrop effect and surface flow, localized settlement due to topography and tillage-induced roughness, and rainwater penetration into the soil profile (Renard et al., 1997). Sediment in stormwater runoff consists primarily of particles having smaller diameters, such as fine silt, clay and colloidal particles (Patil, 2010). According to EPA, fine silt, clay, and colloidal particles in stormwater runoff are a major target for pollution control from construction sites (Patil, 2010). Size distribution of eroded sediments has a major impact on soil-erosion deposition process. Larger particles are more stable and can resist transportation forces whereas the smaller particles are transported easily.

2.3.3 Topography of the site and land cover

Site topography can influence the loads through gravity. The slope angle and slope length are the parameters most often considered. Flow length and slope influence mobility of the soil particles once they are disturbed by rainfall (Renard et al., 1997). Higher slope angle and longer slope length will increase erosion.

Vegetative land cover can reduce erosion levels. In agricultural fields, current cropping and even previous cropping influence erosion levels due to their impact to land cover and soil characteristics. In construction site erosion control, the cover is extremely important. The vegetative cover provides protection from rainfall impact and runoff water. If the condition of the cover is poor, the erosion will be high (Balousek, Roa-Espinosa, & Bubenzer, 2000). Furthermore, agricultural and constructional activities involving removal of vegetation results in an increase of erosion rate (Wurbs & James, 2002).

2.3.4 Erosion Control Practices

Erosion control practices are man-implemented practices performed to reduce erosion. They are planned by construction firms in order to reduce the sediment pollution from their construction sites. Agriculturalists follow practices like contouring farming, terracing, and tillage; whereas construction sites follow practices that include silt fence, inlet protection, sediment traps, ditch checks, sediment basins, vegetative buffers, and manufactured sediment control practices. (Balousek et al., 2000).

2.3.5 Seasonal Influences

Traffic characteristics (mean vehicle speed, traffic load, etc.), long dry weather periods, climate, rain intensity and rain duration are regarded as important factors in generating pollutions in road runoff (H. Lee, Lau, Kayhanian, & Stenstrom, 2004). A study on highway stormwater runoff in Munich, Germany demonstrated that the constituents like copper, TOC, TSS, pH and zinc showed steady increase with respect to seasonal influences.

The mean values during winter time were several times greater than measured during the warm season (Helmreich, Hilliges, Schriewer, & Horn, 2010).

2.4 Measuring Suspended Sediment

2.4.1 Turbidity

In general, turbidity is loosely defined as the lack of water clarity as perceived by the human eye. It is a measure of the light-transmitting properties of water. Turbidity measurements can be used to indicate the quality of a water sample with respect to suspended matter (Tchobanoglous, Burton, & Stensel, 2003). The technical definition of turbidity is the measured optical response of a medium to an artificial, constant radiant flux (Gippel, 1995). ASTM defines turbidity as an "expression of the optical property that causes light to be scattered and absorbed rather than transmit- ted in straight lines through the sample."

Two main types of commercial turbidimeters are used to measure turbidity, attenuance and nephelometric turbidimeters. A Nephelometric turbidimeter provides a response directly to the average volume scattering function over an angular range centered on the nominal angle of detection (Gippel, 1995). Turbidity is measured in Nephelometric Turbidity Units (NTU). The World Health Organization (WHO) standard for drinking water is ideally below 1 NTU and not more than 5 NTU. Surface water turbidity ranges from 10 – 280 NTU (WHO, 1998).

2.4.2 Turbidity vs Total Suspended Solids

Suspended solids are small solid particles that remain in suspension in water. Total suspended solids (TSS) include all particles that are suspended in water and does not pass through a 2-micron filter or less (Rossi et al., 2013). TSS is measured in milligram per liter (mg/l). Estimating the concentration of TSS in stormwater runoff requires collection of samples and laboratory testing, therefore it is expensive and time-consuming process in comparison to measuring turbidity (Patil, 2010). Therefore, many researchers have sought to derive a relationship between turbidity and TSS from which the TSS can be predicted from corresponding turbidity values. The relationship between turbidity and suspended soil concentration can be influenced by various factors such as soil type, particle size, particle composition and watercolor. These factors are different for every site, which makes developing a one size fits all equation very difficult.

Researchers have traditionally approached this dilemma by developing TSS and turbidity relationships manually for each study-site, but more recent research has aimed to develop methodology that can be adapted for multiple sites. Holliday et. al assessed the relationship between turbidity and TSS by comparing measured values of both for the same samples (Holliday, Rasmussen, & Miller, 2003). A relationship $NTU = A * TSS^B$ was developed after assessing samples of clay, silt and combinations of both silt and clay. TSS and turbidity showed strong correlation when plotted in a graph with R^2 value of 0.99 for all three combinations. The coefficient A was highest for silt-clay (1.0283) followed by clay (0.7733) and the whole soil (0.4833) showed the least value and the coefficient B was highest for silt-clay (1.0282) followed by whole soil (1.012) and the clay (0.9936) (Holliday et al., 2003). Another study in Singapore compared the TSS and turbidity of the same sample and plotted in a graph. It showed a strong positive correlation with R^2 of 0.809. The ratio TSS values of 'before rain' and 'after rain' was found to be 1:1.8 which depicts the increased discharge rate by stormwater can influence the suspension of materials (Daphne, Utomo, & Kenneth, 2011). An investigation of whether turbidity could produce an acceptable estimation of TSS in urbanizing streams of the Puget Lowlands was done by (Packman, Comings, & Booth, 1999). The study showed a log-linear model showed strong positive correlation between TSS and turbidity ($R^2 = 0.96$) with a regression equation of ln (TSS) = 1.32 ln (NTU) + C, with C not significantly different than 0 for 8 of the 9 sampled streams (Packman et al., 1999). The relationship between TSS and turbidity was assessed within the combined sewer system and it had a strong correlation with a R^2 value of 0.92-0.97 (Hannouche et al., 2011). Overall, many studies have demonstrated the ability to develop predictive equations based on site specific TSS and turbidity values. The R^2 between the relations of TSS and turbidity are tabulated below in Table 3.

Table 3 : TSS and turbidity correlations reported in the literature

Study	R^2	Location
(Holliday et al., 2003)	0.99	Southeastern Piedmont
(Daphne et al., 2011)	0.809	Singapore
(Packman et al., 1999)	0.96	Puget Lowlands
(Hannouche et al., 2011)	0.92-0.97	Western part of France
(Patil, 2010)	0.9	India
(Lin et al., 2011)	0.91-0.93	Taiwan
(Ziegler, Xi, & Tantasarin, 2011)	0.96	Northern Thailand

The Relationship T = K * TSS (in mg/L) was derived where K is the turbidity factor by comparing TSS and turbidity. Soil type and particle class impact the relationship, so samples were classified with respect to both. Separation of clay, silt and sand from the discharge with the help of experiments. The TSS in mg/L and turbidity in NTU is calculated for samples with clay, silt and sand respectively and plotted in a graph. The K turbidity factor was formulated from the correlation. TSS and measured turbidity showed strong R^2 over 0.9 for all. Turbidity estimates were also derived from a calculation based on weighted K-factor made to represent the percentage of clay, silt and sand in the soil sample. Results of the calculated estimate and the experimentally determined value were compared and found to be similar, providing an approach towards correlating TSS and turbidity based on soil particle size in the absence of field measurements (Patil, 2010).

2.5 Construction Site Stormwater Runoff Regulations

The United States Environmental Protection Agency works with construction site operators to make sure they have sufficient stormwater controls so that construction can proceed in a way that protects a community's clean water and surrounding environment. National Pollutant Discharge Elimination System (NPDES) requires permits for discharges from construction activities that disturb one or more acres. Depending on the location of the construction site, either the state or EPA manages the permit.

General construction permits must contain a Storm Water Pollution Prevention Plan (SWPPP). SWPPP is a document that reflects the specific actions on the construction site to find, prevent, and control the pollution of stormwater. The description of stormwater controls under SWPPP include natural buffers, perimeter controls, sediment track-out controls, sediment basins, treatment chemicals, stabilization measures, spill prevention and response procedures, waste management procedures and application of fertilizers. SWPPP also includes regulations and information regarding inspection, maintenance, and corrective action. Current EPA regulations contain non-numeric standards for constructions sites based on the incorporation of best management practices (NPDES, 2016).

However, states such as Washington, Oregon, Vermont, Mississippi, and California have numeric turbidity standards for construction sites to maintain when it comes to stormwater pollution. Washington State has a benchmark for turbidity and pH values of site runoff. Indication of whether a project's BMPs are working to prevent pollutants from contaminating stormwater on site is evaluated using a benchmark. It is not standard numerical water quality that has to be maintained. 250 NTU is the benchmark for turbidity in sites and any values that are above 250 NTU are likely to cause a disruption to water quality (Ecology, 2007). If it exceeds the value, the SWPPP should be reviewed and enhanced within 7 days. The state of Vermont summarizes the sequence of steps that have to be followed for inspection, maintaining, sampling and evaluation discharge (*Stormwater Management Program* 2017). California State has a limit of 250 NTU for the turbidity. California State's Storm Water Resources control board has a tracking system for the storm events across the state. Stormwater Multiple Application and Report Tracking System (SMARTS) provides a platform where dischargers, regulators, and the public can enter, manage, and view stormwater data including permit documents, compliance with the General Permits of the state. Stormwater data is available for the industrial, municipal, construction and highway construction sites (SWRCB, 2018).

2.6 Erosion Models

2.6.1 USLE History

The Universal Soil Loss Equation (USLE) is used for predicting the erosion rates from agricultural land. USLE was developed by the United States Department of Agriculture (USDA) for estimating sheet and rill erosion from farming grounds

(Wischmeier & Smith, 1978). This process of predicting soil loss mathematically developed over the last seventy years. In 1936, Cook listed three factors which may impact the erosion volume. They are rainfall and runoff intensity, soil's vulnerability to erosion and plant cover during the rainfall event. Zingg (1940) added the impact of the slope steepness and slope length and derived the equation to predict soil loss. This work was followed by Smith (1941) which included a practice factor and cropping factor into the equation. The practice factor depends on the soil practices that are done on the land such as contouring and terracing. Progress continued on the prediction process and the shortcomings of the predecessors have been improved upon. Wischmeier (1972) aimed to have each and every factor accurately predicted, insight of this erodibility data has been incorporated from various soil analysis data, the influence of management and cropping parameters (Renard et al., 1997).

2.6.2 USLE for Construction Sites

The USLE is primarily used for determining the soil losses for the agricultural lands. Traditionally, it is not a widely used as a tool for determining the soil losses on construction sites. In prior years, planners relied more on intuition to locate erosion control practices on construction sites. But recent focus has been placed on utilizing USLE based equations to provide an objective method to predict soil loss from construction sites. USLE can be used on construction sites for erosion control practices during the planning stages. Some of these factors used in the USLE may be retained for construction sites without any changes (Balousek et al., 2000).

2.6.3 USLE Factors

The rainfall-runoff erosivity (R) factor is the number of erosion index units in an average year's rain. The rainfall factor is the product of total storm energy (E) times the maximum 30-minute storm intensity I_{30}. The storm energy E is the volume of rainfall. A long but slow rain can have the same E value as the shorter rain with the higher intensity. Raindrop erosion increases with intensity (Renard et al., 1997). So, greater the duration and intensity higher the capability of erosion. Generally, the R-factor ranges from 20-350.

The soil-erodibility (K) factor is the rate of loss of soil particles per rainfall erosion index unit (tons/(acre-year) / ft-tons-in/(acre-hour)) measured in a unit plot (Renard et al., 1997). Wischmeier and Smith (1978) defined this factor as the rate of soil loss per erosivity index unit as measured on a standard plot 22.1 m long, has a 9% slope and is continuously in a clean-tilled fallow condition, with tillage performed up and downslope (Wischmeier & Smith, 1978). The soil erodibility factor (K) is a description of the erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff (Wijitkosum, 2012). The K-factor ranges from 0.02 to 0.69 (Goldman & Jackson, 1986).

Site topography can influence loads through the gravity. Slope angle and slope length are the parameters primarily considered. The LS-factor used in USLE is based on the slope length (L) and percentage of slope (S) in the area. Slope length is the measured distance between the top slope and bottom slope of the disturbed area. Slope (%) is steepness factor for a representative portion of disturbed area. The longer and steeper the slope, the higher the rate of erosion.

The cover and management (C) factor is the ratio of soil loss from an area with specified cover and management to soil loss from an similar area in tilled continuous fallow (Renard et al., 1997). In a construction site, the cover management plays a vital role in controlling soil from becoming eroded. If the condition of cover is bad, the C-factor will be high which implies high erosion.

The support practice (P) factor is the ratio of soil loss with a support practice such as contouring, strip cropping, or terracing to soil loss with straight-row farming up and down the slope. These support applications mainly affect erosion by changing the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard & Foster, 1983). The average annual soil loss is calculated as the product of all of the aforementioned factors (R, K, LS, C, and P).

CHAPTER 3 SCOPE AND LIMITATIONS

The overall goal of this project is to perform a state-level evaluation of turbidity measurements during construction activity using data from California as a case study and extrapolate their risk approach to examine the risk level of probable development areas within the State of North Carolina. Stormwater turbidity from general and highway construction sites within California is evaluated by utilizing data from the California State Water Resources Control Board (SWRCB) public access stormwater reports. California Building Industry Association (CBIA) developed a methodology for predicting runoff risk levels of the state of California using spatial analysis through ArcGIS. The work presented here utilizes their risk approach to examine the sediment and receiving water risk level of probable development areas within the State of North Carolina. This knowledge can aid in determining future suitable methods and adapting the guidelines for stormwater control.

Pre-planning process of a construction site involves planning to reduce pollutant loading within stormwater runoff, Best Management Practices (BMP) can be planned and adopted for sediment control. The amount of sediment loading mostly relies on the geographic location and soil type. By knowing both of these factors, management can predict the loading impacts and formulate sediment control practices during the planning stages. A tool that can facilitate future planning by providing a turbidity-based estimate for stormwater runoff quality can be helpful to satisfy the mentioned condition. The study aims to develop a construction stormwater runoff model to estimate turbidity concentrations. The model is based on the Universal Soil Loss Equation which determines the average soil loss per unit area considering factors impacting the soil loss. The soil loss is converted to total suspended soils and turbidity (where available data permits).

Limitations in this study are primarily a result of the data used in the statistical analysis, and in the predictive power of the adopted erosion models. Data available from the California Water Resource Board website is uploaded by the facility owner which provides a level of uncertainty for human and experimental error. Owners potentially have different sampling devices and techniques which can increase the probability of variability in measurements. This variability is generally because of the potential for readings tod be rounded off or contain human error. Future applications of the model developed in this study is limited by the lack of availability of user-defined data to support the analysis.

CHAPTER 4 RESEARCH METHODOLOGY

4.1 Statistical Analysis

4.1.1 Dataset

Stormwater data from each construction site in California was used for assessing pollution caused by stormwater runoff. SWRCB has given the public access to stormwater reports of industrial, construction and municipal discharges. Data is provided by the facility/site owners during the stormwater waiver application process and recorded parameters during storm events. This study uses daily average parameter database query results, erosivity waiver report and annual reports publicly available on the website. Daily average parameters include pH and turbidity recorded during each storm event. The start date, amount of rainfall, turbidity value, site owner details, latitude and longitudinal positions were also available. Data utilized in this study was sourced from data available from 2005 to present. This study utilizes data for the latest five calendar years from 2013-14 to 2017-18 to assess the current trends of the turbidity reports.

Risk report data provides details about the R-factor, K-factor, LS-factor, and total disturbed area and whether it lies within a high receiving water. Risk levels were determined based on the sediment risk and high receiving water risk. According to the (CBIA, 2008), risk levels are determined as depicted in Table 4.

Table 4 : Risk level determination ("*California State Water Resources Control Board*," 2012)

		Sediment Risk		
		Low	Medium	High
Receiving Water Risk	Low	***LEVEL 1***	***LEVEL 2***	
	High	***LEVEL 2***		***LEVEL 3***

4.1.2 Data Analysis

Data was analyzed from the California website with three different approaches aimed at evaluating trends in the data. The approaches include: (1) summary statistics of the daily average parameters from general construction and highway construction sites (Caltrans data), (2) frequency of exceedance based on set benchmarks, and (3) comparison of groups for statistical difference of turbidity measurements (highway construction, general construction, sediment risk levels, receiving water risk levels).

4.1.2.1 Summary Statistics

Data was separated into two groups, highway construction, and all other construction sites. Daily parameter data for turbidity measurements taken during or immediately following a storm event was analyzed by group. Summary statistics for the past 5 years were analyzed, including mean, median, standard deviation, minimum, maximum, 10^{th} percentile, 25^{th} percentile, 75^{th} percentile and 90^{th} percentile for turbidity values (in NTU) for each group. Results were plotted in a series of box-and-whisker plots. All data was analyzed over a 5-calendar year period from 2013-14 to 2017-18.

4.1.2.2 Frequency of Exceedance

Frequency of exceedance charts were produced to display the percentage of values that were over the allowable limit (or set benchmark). Two different benchmarks were established based on a previously suggested EPA guideline and current California practice. Prior EPA regulation suggests that the permissible limit of turbidity should be set to 280 NTU. California State government has a limit of 250 NTU. The data reported is from the state of California and the proposed EPA regulation was the closest numeric Federal guideline. Hence, both values were set as benchmarks used to define the frequency of exceedance of the turbidity values. The percentage of exceedance was calculated from the ratio of total number of values exceeding 250 NTU to the total number of data reported every year. Each percentage of exceedance was arranged with respect to months to track the seasonal effect of the exceedance of levels. The seasonal effect was further analyzed by assessing the median value and the 90th percentile values of the five-year data with respect to the months. The California data has a time range with the start and end date for the storm events. The first day of the rain was used to assume the month of the storm.

4.1.2.3 Statistical Group Comparisons

IBM SPSS and Minitab software packages were used to determine whether turbidity measurements were statistically different when grouped by type of construction (general vs. highway), sediment and receiving water risk levels. California SWRCB risk reports provided information regarding the sites risk for receiving water. As depicted in

Table 4, each site was given a risk level based on the sediment risk and the receiving water risk. After the data was been obtained from SWRCB website it was be coded for compatibility with the appropriate Minitab routines.

Once the data was successfully uploaded into the software, the turbidity data was tested for normality using the Kolmogorov-Sminov and Shapiro-Wilk tests. Shapiro-Wilk tests were used for data groups that contain more than 2000 data points, and for others, the Kolmogorov-Sminov test was be used (Lilliefors, 1967). Results of the normality test were used to validate methods used to statistically compare the groups. Many statistical tests including the tests used in this study were based on the assumption that data is normally distributed. In the event that the data was not normally distributed alternative techniques were used. Overall Data failed the Kolmogorov-Sminov and Shapiro Wilk normality tests. In this case, the two-standard t-test which is used to analyze the means is not appropriate for use, since a primary assumption of the t-test is normality of the two samples. Although the t-tests doesn't require normality for large samples, this does not hold true when there was a large difference in group size between the groups which were testing. Statistical differences between types of construction in turbidity measurements were assessed by comparing the medians and variances of data from different types of construction sites. Mann-Whitney tests were performed for non-normal samples to assess the differences in median when data of two groups have similarly shaped distributions.

The differences between the risk levels were analyzed by one-way ANOVA. A one-way ANOVA (analysis of variance) compares the means of two or more groups for one dependent variable. A one-way ANOVA was required when the study includes more than two groups i.e. when two sample t-test cannot be used (Ross & Willson, 2017). The

ANOVA test requires the assumption of whether the variances of the populations were equal or not. Population comparison was performed using Levene's test at a 95% significance level. The One-way ANOVA was done using Minitab at a 95% confidence (alpha = 0.05), where a resulting *p*-value of less than 0.05 will reject the null hypothesis and determine that the group means were significantly different.

4.2 Construction Stormwater Runoff Model Development

4.2.1 USLE factors

USLE was used to determine the average soil loss per unit area considering factors impacting the soil loss. The USLE is calculated as the product of six factors which include R (rainfall-runoff erosivity factor), K (soil erodibility factor), LS (topographic slope factor), C (cover factor), and P (support practice factor) (Wischmeier & Smith, 1978) as represented in the Equation 1.

$$A = R * K * LS * C * P \qquad \text{[Equation 1]}$$

Where the calculated average annual soil loss per unit area (A) is equal to the product of the rainfall-runoff erosivity factor (R) measured in ft-tons-in, soil erodibility factor (K) measured in tons/ acre-year / ft-tons-in / acre-hour, Slope length factor (L), Slope steepness factor (S), Cover Management factor (C), Support Practice factor (P).

Rainfall erosivity factor was the factor which provides the annual average year's rain. R-factor was calculated based on intensity and the amount of rain. The annual value was considered if the loading was calculated for the entire year, but if it calculated for a particular period the Percentage of R-factor was calculated with the help of Equation 2.

R-factor = (% of R factor) * Annual R-factor [Equation 2]

The percent of R-factor was calculated for the interval of time that was entered and when it was multiplied by the Annual factor, the R-factor for that particular period was calculated. For Instance, Table B-1 in Appendix B gives the Percentage of R-factor occurring from January 1st to December 31st in North Carolina. Previous studies have contributed to the annual R-factor with the help of ArcGIS and Isoerodent mapping process. It was performed for the California, Washington and Oregon regions, Western United States and Eastern United States. The annual rainfall factor was derived from the Figure 1. The R-factor for three geographic regions of North Carolina is obtained from Figure 1 and listed in Table 5.

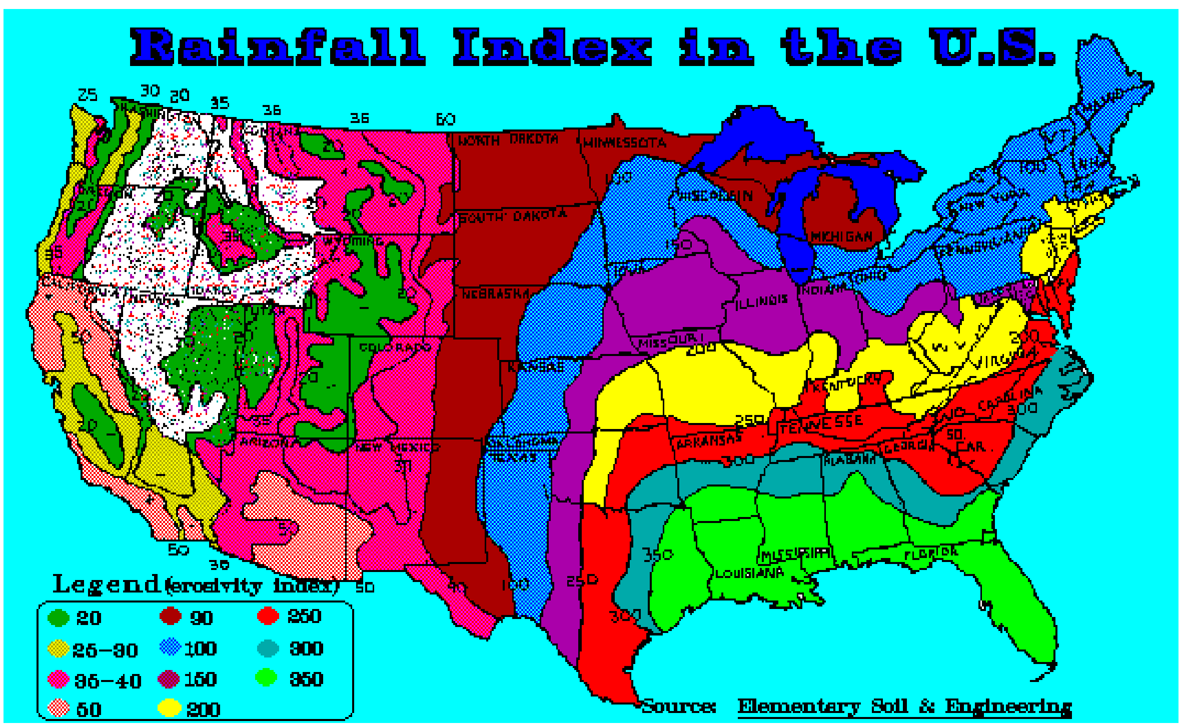

Figure 1: Annual R-factor (Laflen et al., 1997)

Table 5: Annual R-factor for North Carolina (Laflen, Elliot, Flanagan, Meyer, & Nearing, 1997)

Region	Annual R-factor
The Mountains	250
Piedmont	250
Coastal Regions	300

The soil erodibility factor depends on the type of the soil, stability of soil, and amount of imperviousness. (Goldman & Jackson, 1986) developed a formula which is depicted in Equation 3 to determine mathematically determine K-factor:

$$K = 1.292 * (2.1 * 10^{-6} * f_p^{1.14} * (12 - P_{om}) + 0.0325 (S_{struc} - 2) + 0.025 (f_{perm} - 3)) \quad \text{… [Equation 3]}$$

where,

$f_p = P_{silt} (100 - P_{clay})$

f_p is the particle size parameter (unit less)

P_{om} is the percent of organic matter (unit less)

S_{struc} is the soil structure index (unit less)

f_{perm} is the profile-permeability class factor (unit less)

P_{clay} is the percent clay (unit less)

P_{silt} is the percentage of silt (unit less)

Many studies contributed to the development of the K-factor based on soil texture and organic matter percentage and K-factors used for corresponding soils in the model are listed in Table B-2 in Appendix B.

The LS-factor depends on the angle of the slope and the length of the slope. The Equation 4 was used for estimating the LS-factor:

$$LS = [0.065 + 0.0456 (S) + 0.006541 (S)^{2}] (L / constant)^{x} \qquad \text{[Equation 4]}$$

where,

S = slope steepness in %

L = length of slope in m (ft)

Constant = 22.1 metric (72.5 Imperial)

$x = 0.2$ if $S < 1$; 0.3 if $1 \leq S < 3$; 0.4 if $3 \leq S < 5$ and 0.5 if $S \geq 5$

Disturbed land is covered by either vegetation or manmade techniques to resist erosion. If there is no cover, it was considered to bare land and the LS-factor is 1. Commonly used C-factors are listed in Table B-3 in Appendix B. For construction sites, the support practice factor (P) doesn't influence the erosion rate. Therefore, it was considered as 1. The USLE supporting data for R-Factor, K-Factor, C-Factor used in the model are placed in the Appendix B.

4.2.2 Modeling Approach

The model was created in a user-friendly Microsoft Excel Worksheet format. The user must enter data with respect to the site features. The model was created for the state of North Carolina which was divided into three geographic regions namely The Mountains, The Piedmont and Coastal regions. The R-factor was generated when the geographic location was selected. Selecting the cover factor from the list will generate the C-factor. The start range and end range was selected from a list which has a timeline divided in biweekly format. The percentage of R-factor was calculated. The soil texture was selected from the list of soils and that contributes to the K-factor. The slope percentage and the slope length in feet must be entered by the user according to site characteristics and the LS-factor was calculated. The Soil loss A (tons/acre) was calculated when all the data required was entered.

The region where the construction activity was taking place was selected from the drop-down menu and Annual R-factor for that region was generated. The start range and end range was given by the user and the percentage of Annual R-factor was generated. The percentage of R-factor was calculated for the period of the range entered and when it was multiplied with annual R-factor, the rainfall factor for the period was calculated. The soil texture was selected from the menu, and that generates the K-factor. The Slope angle (in %) and slope factor (in feet) added with respect to the site topography and that generates the LS-factor. The land disturbing activity that was the type of cover was selected from the drop-down menu and that generates the C-factor. When all these factors were generated the Soil Loss A (in tons/acre) was calculated.

The model calculates the sediment load with the help of the user inputs of the site in tons/acre. The sediment/load was converted into suspended solids with through the following equations. The suspended solids value can be calculated for the area disturbed in the construction site and it was dependent on both sediment load and amount of rainfall in the construction site for the entered duration. Sediment loads from site was calculated by dividing sediment weight (in tons) by unit area (in acre). Soil loss in tons/acre was converted into soil loss in kg/square-meter as shown in Equation 5. The total disturbed area was entered and the total soil loss in kg was calculated with the help of the formula in

Equation 6. Total rainfall in meters was entered during the given time range and that contributes to the total precipitation. If the total precipitation was not known, the rainfall in meters can be predicted for the construction period specified. The amount of water in cubic meters was calculated using the Equation 7. Total soil lost and total amount of water in the disturbed area contributes to the total suspended soils in mg/L as depicted in the Equation 8.

Sediment loads from site = Sediment weight in tons * 10^3/ unit area (acre) * 4046.86 [kg/m^2] …[Equation 5]

Soil lost in kg = Sediment load in kg/m^2 * Area of Disturbed land [m^2] … [Equation 6]

Amount of water in m^3 = Amount of rainfall in meters * Area of Disturbed land [m^2]

…[Equation 7]

TSS (in mg/L) = soil lost in kg * 10^6 / Amount of water in m^3 * 10^3 …[Equation8]

Turbidity was estimated from the calculated TSS levels. Many previous studies have suggested that the turbidity and TSS values were positive correlation with a strong R^2 value. Patil et. al, 2010 presented a study where they were assessing the relationship between turbidity and TSS with respect to particle size and soil type. They formulated a relationship T = K * TSS (in mg/L) where turbidity values were calculated using TSS values measured in the field. These values (displayed in Table B-4 in Appendix B) were built into the model to compute turbidity from TSS for a limited range of soils (Cecil B and C, and Pacolet soil).

4.3 Spatial Analysis

4.3.1 Spatial Datasets

In this study, North Carolina construction sites were assessed for sediment and receiving water risk levels through use of ArcGIS. The risk of sediment loading was determined based on USLE methodology using factors including rainfall, soil and slope. The methodology expressed here was adapted from a prior study conducted by URS Corporation for the state of California (CBIA, 2008). All spatial data was collected from the United States Department of Agriculture (USDA), United States Geological Survey (USGS), National Resources Conservation Service (NRCS) and ESRI data sources. Rainfall erosivity (R) factor was derived from study done by (Laflen et al., 1997). Raster data for the K-factor was obtained from ESRI (ArcGIS, 2017). The file contains soil characteristics file mapped for the entire country along with the K-factor in a table format. LS-factor was considered for 2 different slopes and lengths respectively. The results for slope factor were considered from lengths of 300 feet and 1000 feet and angles 2% and 4%. These factors were used to define sediment risk analysis for 2000 by 2000 resolution parcel. To support receiving water risk analysis data was obtained from ESRI for 303D impaired waterbodies in North Carolina in the form of a GIS shapefile file (NCDEQ, 2016).

4.3.2 Risk Level Determination

Risk level determination for sediment load and receiving water risk across North Carolina was performed using spatial analysis tools within ESRI ArcGIS software. Each raster layer described in Section 4.2.1 was used to calculate sediment load (A = R * K * LS, C and P factors were considered as 1 to show that the construction sites were considered as bare ground). The USA basemap was imported and the North Carolina boundary was exported into a separate layer file. Soil characteristics data file (with .E00 extension) was converted into a polygon using the convergence tool in the ArcToolbox. After conversion, the join and relates tool was used to join the K-factor table to the soils polygon with respect to the common identifier for the values of North Carolina. The resulting K-factor polygon was converted into a raster file with the K-factor as the value field.

Using the ArcGIS raster calculator tool, which was included in the spatial analysis license, the R-factor, K-factor and LS-factor of North Carolina were used to create a new raster layer of calculated soil loss values as represented in Equation 9 using Raster calculator tool. Raster maps were generated for each LS-factor. The values were then categorized into sediment risk levels based on the amount of sediments load (in tons) per acre. Sediment levels were categorized as low for values <1 ton/acre, medium for values $\geq$ 1 and < 75 tons/acre, high for values $\geq$ 75 and <500 tons/acre and extreme for values $\geq$ 500 tons/acre (CBIA, 2008).

Soil loss A = K-Factor * 300 * Corresponding LS-factor. [Equation 9]

A GIS layer shapefile of the most probable land development areas was overlaid with the sediment risk and receiving water risk layers. The clip tool was used with North Carolina as the input feature to get the predicted development for 2030 and 2070 of North Carolina. The amount of land pertaining to each risk level will be quantified and used to assess the overall risk level for projected development in North Carolina using the raster calculator tool. Each risk level type for respective LS-factor possibilities was extrapolated. Using the raster calculator tool, the common pixels of predicted development and risk levels were found. The attribute table of the final raster was used to find the percentage of risk levels in predicted development.

The receiving water risk was taken as the area in close proximity to impaired water. A buffer was placed around impaired water layer file and any modeled land development occurring within those bounds were assigned a higher risk level. Scores were given based on watershed characteristics and site characteristics. The location of the watershed and whether discharge directly or indirectly affects the impaired waterbody. Flood-prone width, channel stability index, whether the construction activity located within the sensitive receiving water body, and whether the project utilizes an Active Treatment System (ATS) were the factors considered for site characteristics score. Receiving water risks was categorized as Low for <10 points, Medium for values ≥ 10 and <20 points, High for values ≥ 20 points (CBIA, 2008). Several of the risk factors like channel stability index and construction site located within a receiving water body cannot be specifically determined through this exercise as the spatial data was unavailable.

Next, the DWR 303D listed impaired water shape files were imported and processed using the Buffer tool from the Geoprocessing toolbar. Layer files were specified as input features and given a suitable output feature class. The distance field was set to miles and a one-mile buffer with ‘full’ side type, for which buffers will be generated on both sides of the line was assigned. The end type of the buffer was assigned as round and planar method was selected. Once the buffer layer was created, the total buffer area of integrated impaired waters was identified and quantified.

CHAPTER 5: RESULTS

The detailed analysis, findings and calculations of results from applying the methodology is presented in this section. To begin, the data analysis to assess the trends of the runoff is presented followed by the stormwater runoff prediction model and spatial analysis to predict risk levels in the state of North Carolina.

5.1 Data Analysis Results

5.1.1 Analysis of Trends in California Stormwater Reports

The turbidity measurements during storm activities of construction sites were available from the daily average parameter data provided by the construction owners in California Stormwater Resources and the data analysis was performed for the years 2013 to 2017. Turbidity data was assessed for the mean, median, standard deviation, minimum, maximum, 10^{th} percentile (P_{10}), 25^{th} percentile (P_{25}), 75^{th} percentile (P_{75}) and 90th percentile (P_{90}) for turbidity values (NTU) for each group. There were 24,436 entries for general construction and 2,344 entries for highway construction over the course of these five years. Overall mean of the turbidity data for the last five years was found to be 131.6 NTU for general constructions and 123.48 NTU for highway constructions. Mean was maximum for the year 2017-18 for both general and highway construction. Years 2016-17 and 2015-16 had the most entries of turbidity reports compared to other calendar years. The overall summary statistics of the California data are tabulated in Table 6 and 7.

Table 6 Summary statistics of California construction data from 2013-2017 (Min- Minimum, Max-Maximum, SD – Standard Deviation, Med- Median, N - Total number of reported values)

Year	Mean	Min	Max	SD	P_{10}	P_{25}	P_{75}	P_{90}	Med	N
17-18	158.6	0	5780	311.1	8.1	25.2	160.5	374.5	65.5	2967
16-17	128.5	0	19355	331.8	5.6	21.1	141.6	240.0	64.8	9721
15-16	153.7	0	27400	469.5	1.7	18.4	163.0	277.0	66.8	8405
14-15	153.7	0	2882	230.4	5.9	22.4	192.2	364.2	76.1	932
13-14	63.6	0	3944	217.8	0.7	1.80	58.0	155.8	6.0	2411

Table 7 Summary statistics of California highway construction data from 2013-2017 (Min- Minimum, Max-Maximum, SD – Standard Deviation, Med- Median, N - Total number of reported values)

Year	Mean	Min	Max	SD	P_{10}	P_{25}	P_{75}	P_{90}	Med	N
17-18	199.8	0	1000	237.3	7.0	29.1	240.8	447	130.8	54
16-17	111.0	0	4000	208.8	10.5	25.6	131.0	209.7	64.75	829
15-16	88.4	0	1000	139.5	6.1	17.2	101.0	202.7	46.8	541
14-15	109.1	0	1000	139.5	12.7	30.7	145.5	226.9	64.6	511
13-14	109.2	0	1772	183.4	4.9	19.2	130.8	234.2	55.0	428

A box and whisker plot drawn for the reported turbidity using the software Minitab is depicted in the graphical format and presented in Figures 2 and 3. Y-axis represents the turbidity measured in NTU and X-axis depicts the years. The top and bottom of the box represent the 25th and 75th percentile values that range from 17 NTU to 240 NTU. The line in between the box represent the median values. Whisker values outside the box plot were mostly ranging from 250 to 1000 NTU. 90% of the overall data was below 375 NTU for the general construction and 450 NTU for highway construction. There is a straight line near 1000 in the whisker plot, due to the abundance of turbidity values reported exactly as

1000 NTU by construction owners. Method of sampling, sampling technique and the rounding off technique were the possible reasons for this occurrence. The traits and trends of turbidity measurements during storm events was identified from the above results. During each year there were turbidity measurements from storm events that result in greater than the proposed California limit (250 NTU), this was especially the case for 2017-18 where greater than 10% of the samples exceed the limit.

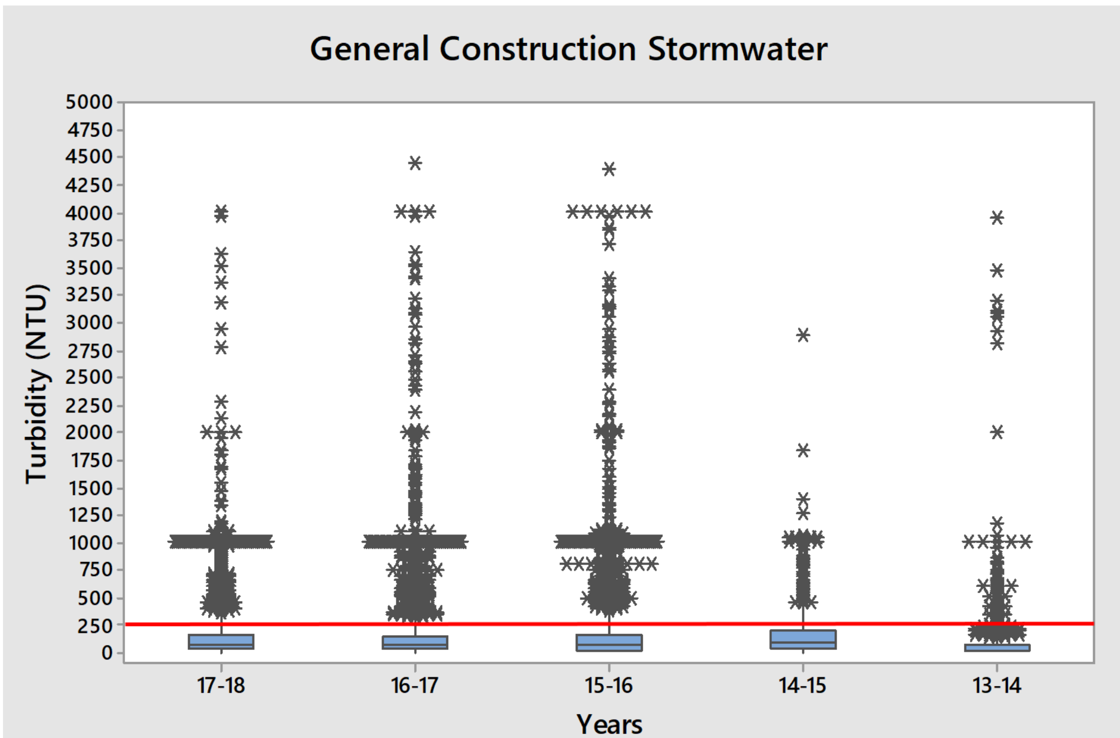

Figure 2 Box and whisker plot of turbidity values for general construction stormwater data

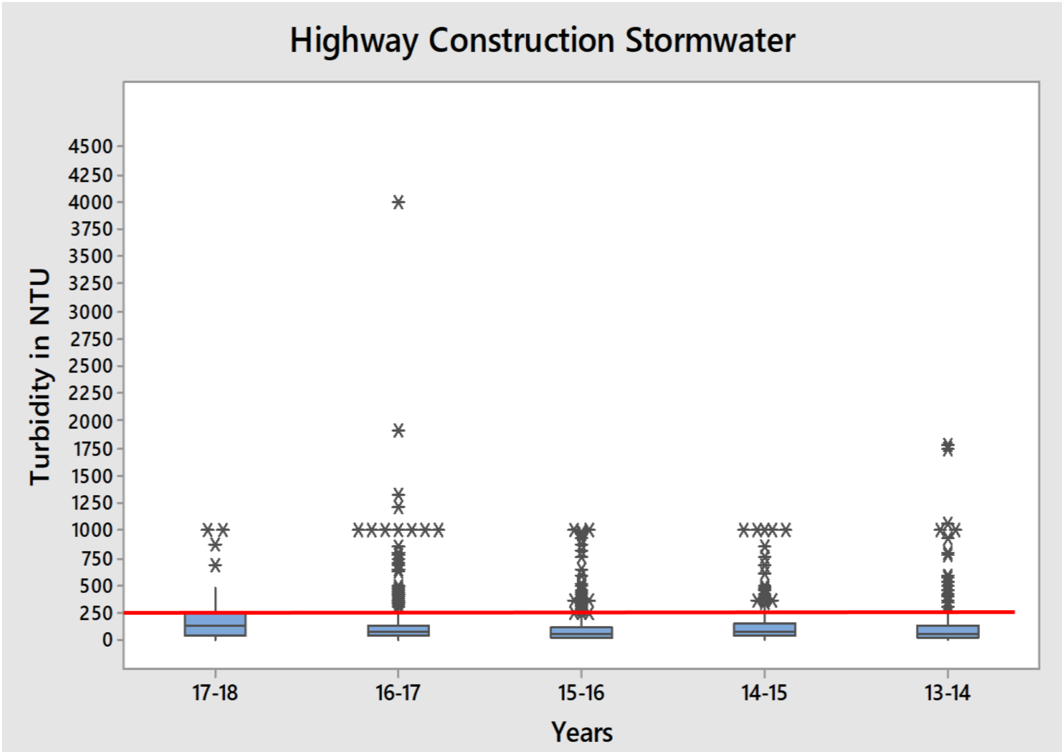

Figure 3 Box and whisker plot of turbidity values for Highway Construction Stormwater data

5.1.2 Standard Benchmark Exceedance Analysis

The U.S EPA held a benchmark of 280 NTU as the allowable turbidity limit in the proposed 2009 regulation, whereas the state of California has a limit of 250 NTU. Considering the California limit, the frequency of exceedance was calculated and analyzed. Out of the 24,000 values reported in the five years, the months January, February, March, and December had the most number of values reported. 20,976 values were reported in these four months. The drop in the months from May to October represents the dry months where the storm events occur less frequently.

The percentage of exceedance reported in Figure 4 gives the percentage of values exceeding the limits compared to total data reported. The results suggest that around 10 percent of the values were exceeding the limits. Out of 24,000 entries around 2,400 entries were exceeding the 250 NTU mark. 9.85% of the overall values were exceeding the California limits and 9.03% of the overall values were exceeding the EPA limits for general construction. The months from December to March had high recordings had a similar percentage of exceedance which was around 10 percentage exceedances. Frequency of exceedance over the general construction for California limits is represented in graphical format in Figure 5. Highest number of exceeding values (1,069) was found in the month of January. Months from May to August had the least numbers which were cumulatively 19. From the analysis, it was found that one in ten values were exceeding the turbidity limits, hence the construction owners should take this seriously and incorporate sediment control plans during preplanning phase, especially for construction planned from December to March.

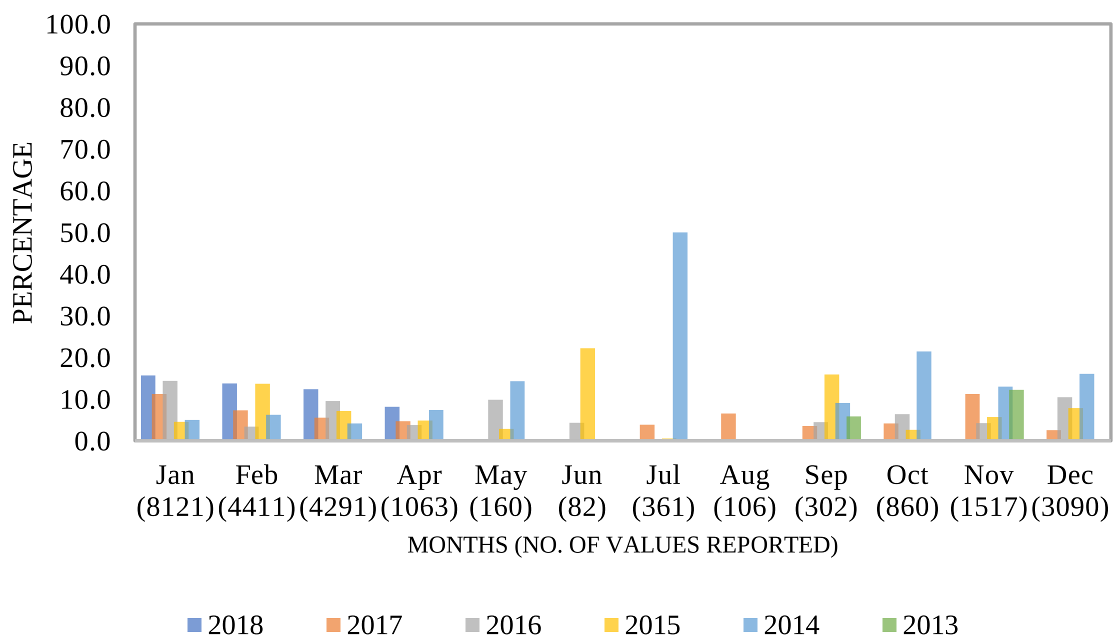

Figure 4 Box and whisker plot of turbidity values for highway construction stormwater data

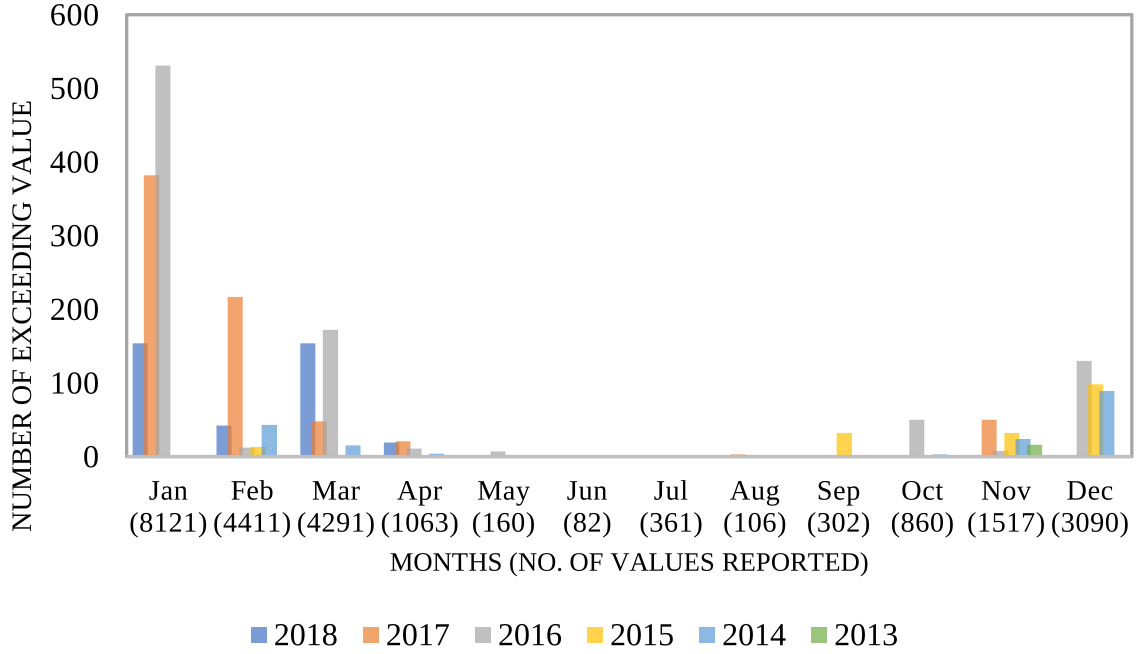

Figure 5 Frequency of exceedance of the values over California Benchmark (250 NTU)

The values exceeding the limits were prone to be in higher risk levels. The risk reports available in the SWRCB website has information about the risk level of the sites with respect to the guidelines followed by the California Water Board. The application ID and unique identifier (UID) of the risk reports and the daily average parameters were matched. 16,925 values were matching out of the 24,000 values reported over the five years. Out of the matched values, 13,376 sites were reported as Risk Level 2 which accounts for 79.73% of the data. 3,491 sites were Risk Level 3 and 68 sites were reported as Risk Level 1. Data that exceeds the 250 NTU benchmark were broken into each risk level category. 1,038 sites were reported as Risk Level 2 which accounts for 81.6% of the data. 286 sites were Risk Level 3 and 29 sites were reported as Risk Level 1. The above results are represented in Figures 6 and 7. 79% of the total data and 82% of the exceeded values were reported under risk level 2. In both conditions, majority of the sites showed either Medium-Risk or High-Risk.

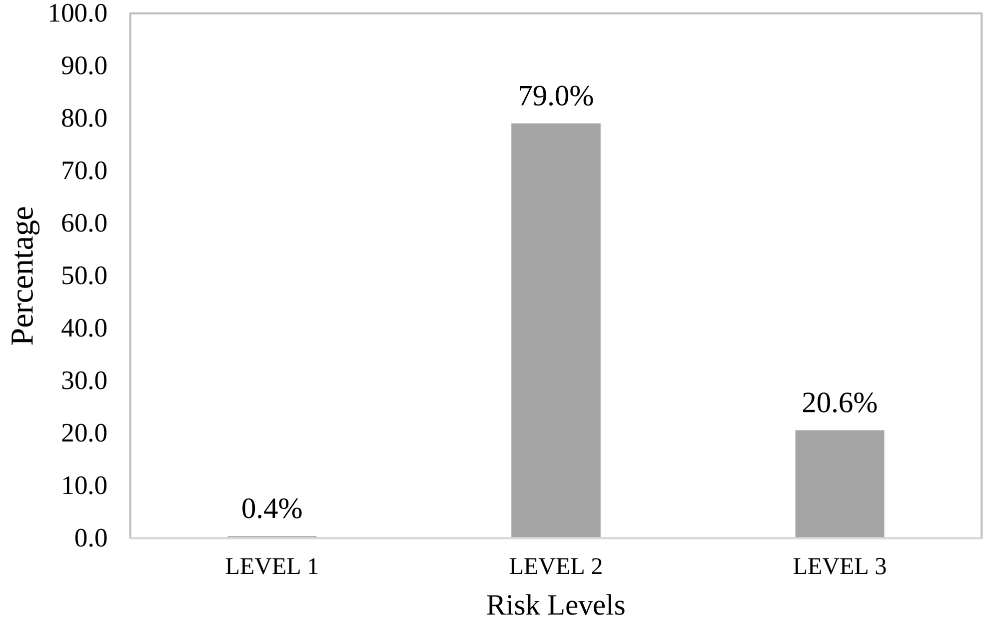

Figure 6 Risk levels of total values

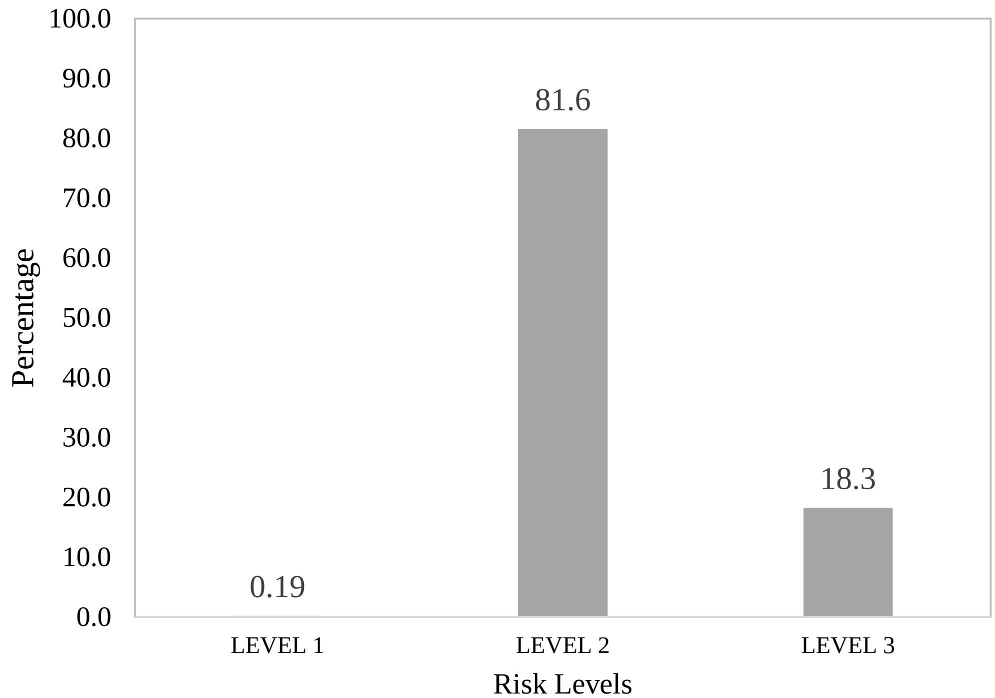

Figure 7 Risk levels of exceeding values

5.1.3 Statistical Group Comparisons

Turbidity data was compared to find whether the statistical difference exists between the types of construction and types of risk levels. General construction and highway construction data were assessed with respect to the year. Mann-Whitney tests were performed for non-normal samples to assess the differences in median when data of two groups have similarly shaped distributions. The null hypothesis was that both populations were approximately equal, which interprets that Sample X has no influence on Sample Y. Alternate hypothesis states the median of both populations were significantly different where Sample X has significant influence on Sample Y.

Construction and highway data were assessed together irrespective of year, the *p*-value was found to be 0.235. Therefore, the null hypothesis was accepted, and the median of both populations were approximately equal construction data has no influence on Caltrans data. The Mann-Whitney test was performed for the two groups with respect to years and 3 out of the 5 years were rejecting the null hypotheses which depict that the medians were significantly different, and the construction data has significant impact on the Caltrans data. The results are tabulated in Table 8. As the *p*-value was large in the Mann-Whitney test, the data do not give any reason to reject the null hypothesis. The Mann-Whitney test for the overall data irrespective of years concluded that the type of construction has no influence in the turbidity measurements.

Table 8 Mann-Whitney Test for evaluating medians between general construction and Caltrans data (* denotes p value significant for 95% confidence interval)

Years	Mean		Median		*p*-value	95% CI
	General	Highway	General	Highway		
2017-18	158.6	199.8	65.4	130.8	0.0421	(-73.39, -0.66)
2016-17	128.5	110.9	64.8	64.8	0.834*	(-4.529, 3.597)
2015-16	153.7	88.4	66.8	46.8	0.000	(6.30, 18.12)
2014-15	153.67	109.1	76.1	64.6	0.1602*	(-1.95, 13.19)
2013-14	63.6	109.2	6	54.9	0.000	(-35.55, -24.00)

One-way ANOVA tests were performed for assessing the risk levels and the turbidity values. Turbidity values were added as the factor and the risk levels were added as the response and the hypothesis was tested for 0.05 significance level. Firstly, ANOVA test was done for all turbidity values and corresponding risk levels. Then ANOVA test was done for turbidity values exceeding California benchmarks (250 NTU) and corresponding risk levels for the turbidity values exceeding benchmark.

The tests for equal variances (Levene's test) was completed for both scenarios using Minitab. The *p*-value was found to be 0.053 and 0.201 which was greater than 0.05. Therefore, the variances were assumed to be equal while performing One-Way ANOVA. Tables 9 and 10 display one-way ANOVA results. The three risk levels of the general turbidity had a *p*-value which was less than 0.05, so there was a statistically significant difference in the mean of turbidity values between the lengths. As the *p*-value was 0.284 for the three levels of the exceeding turbidity values were the means were statistically similar.

Table 9 One-Way ANOVA results all turbidity values vs. risk levels

Relations	Sum of Squares	Degree of Freedom	Mean Square	F-Value	*p*-value
Between Groups	1,320,187	2	660,093	10.11	0.000
Within Groups	1,094,141,859	16,764	65,267		
Total	1,095,462,046	16,766			

Table 10 One-Way ANOVA results exceeding turbidity values vs. risk levels

Relations	Sum of Squares	Degree of Freedom	Mean Square	F-Value	*p*-value
Between Groups	948,764	2	474,382	1.26	0.284
Within Groups	586,121,269	1,558	376,201		
Total	587,070,033	1,560			

5.2 Stormwater Runoff Prediction Model

A model to predict the turbidity levels in construction sites during storm events was developed. The model was built for the state of North Carolina. The user has to feed data with respect to site characteristics in order to predict the soil loss at a particular period of time. The program uses Microsoft Excel 2016, a common and easy tool used in the industry. Stormwater runoff predictor model can be integrated during the planning phase of construction activities as the construction owners can input data about their worksite and predict the turbidity expected. Table 11 displays the user-defined input and model estimated output of the model.

Table 11 : Model Input / Output

Data	Type
Geographic Location	User Entered
R-factor	Automatically Generated
Start Range / End Range	User Entered
Percent of R-factor	Automatically Generated
Soil type	User Entered
K-factor	Automatically Generated
Cover Type	User Entered
C-factor	Automatically Generated
Slope Length	User Entered
Slope angle	User Entered
LS-factor	Automatically Generated
Sediment Load	Automatically Generated
Soil Lost	Automatically Generated
Total Area	User Entered
Soil lost in Kg	Automatically Generated
Input type (Rainfall)	User Entered
User defined rainfall	User Entered
Predicted Rainfall	Automatically Generated
Total Precipitation	Automatically Generated
Total Suspended soils	Automatically Generated
Soil type	User Entered
Turbidity factor	Automatically Generated
Turbidity in NTU	Automatically Generated

5.2.1 Model Validation

A preliminary model validation was achieved using data from California State Water Resources Control Board. USLE factors, total precipitation, and duration of storm events were obtained from the reported data. Due to the limitation of soil types available for the TSS to turbidity conversion, the model was only partially validated. It's expected that the reported soil types (as represented by the K-Factor) will greatly influence the estimated turbidity, making the values quantitatively incomparable. However, the model was preliminarily validated qualitatively through a ranking of values and evaluation of overall trends. Percent differences between model estimates and field calculations are included for illustrative purposes.

The corresponding reported turbidity for each site was compared with the calculated turbidity values for the preliminary validation of the model. R-factor for the site location, K-Factor and the LS-factor for each site were input to the model and turbidity values were calculated. General construction site examples were used in the validation; therefore, cover was considered to be bare ground (C-factor = 1). Unique identification numbers were matched, and K-factor and LS-factor were recorded. The period % R was calculated with respect to the event start and end date reported. Figure A-1 in Appendix A depicts the calculation of Soil Loss A (tons/acre). Soil Loss (A) was converted to soil lost in kg/square-meter and the total disturbed area was assumed as 2000 m^2. The rainfall defined was taken from the amount of rainfall in inches. It was converted to meters and used in the calculation of total precipitation. Figure A-2 in Appendix displays the calculation of the suspended solids in mg/l.

Turbidity conversion from suspended solids is depicted in Figure A-3 (Appendix A). The dominant soil type was assumed with respect to the K-factor of each construction site and the turbidity factor was generated. Turbidity was calculated and compared with the reported turbidity from the site. The calculated soil loss was the result of the factors from the California stormwater reports which was converted into TSS then to turbidity. The factors, calculations and reported turbidity are depicted in Table 12. In general, Table 12 depicts that as measured turbidity increases so does reported turbidity. This qualitatively validates that the model estimates were following the correct trend. While the percent difference cannot be statistically compared due to limitations within the turbidity calculation, it is worthwhile to note that the estimated turbidity was within 25% of reported turbidity without correcting for soil type.

Table 12 Model validation (model estimate vs. reported value)

Site No	% R	R	K	LS	Soil Loss (tons/acre)	Suspended Soils (mg/l)	Est. Turbidity [1] (NTU)	Rep. Turbidity [2] (NTU)	% Diff
1a	0.01	24.24	0.38	0.38	0.04	154.46	133.76	108.1 [3]	-23.74
2	0.03	84.61	0.37	0.2	0.19	448.04	388.00	426.2	8.96
1b	0.02	24.24	0.38	0.38	0.07	617.84	535.05	492.3 [3]	-8.68
3	0.1	51.38	0.43	0.29	0.64	706.83	636.15	812	21.65
4	0.04	49.88	0.43	0.29	0.25	1032.85	929.56	890	-4.45

1 – Estimated turbidity in NTU from the model
2 – Data reported from construction sites in California Website
3 – Values represented here are average values of two different turbidity measurements at the same site for the same storm event

5.2.2 Case-Study: Influence of Soil Type

A scenario-based study was completed to evaluate the influence of soil type on turbidity calculations. The assumptions include that the construction activity was taking place from the 21st March to 15th May in the Piedmont region in North Carolina. The cover type was assumed as bare ground and soil texture was assumed as fine sand. The slope angle was considered to be 2% and the slope length was assumed to be 260 feet. Using the user-generated data, the factors were automatically generated. Additionally, through using the factor values the soil loss was generated. For the assumptions above, the soil loss was estimated to be 0.802 tons/acre. The sample soil loss calculation performed within the model spreadsheet is shown in Figures A-4 in the Appendix A.

Firstly, the soil loss (tons/acre) was converted into soil lost in kg/square-meter. The area of disturbance was user entered with respect to the construction site. The user must enter whether the rainfall level was predicted with respect to the season of construction or whether it needs to be user defined (in m). The rainfall was generated, and the suspended soils was calculated in mg/l. With the area of 2000 square-meter and rainfall between this timeframe was assumed to be 0.119 meters. The total suspended soils were calculated as 1506.94 mg/l. The suspended soils in mg/l was converted into turbidity in the final step. The soil type (dominant texture) was selected by the user and the turbidity factor was generated from which the turbidity was calculated. If the soil dominant type was assumed as Cecil B (All) and the turbidity was calculated 757.99 NTU.

As the turbidity factor changes for each soil type the final calculated turbidity changes and this is depicted in Table 13. Cecil C (All) shows turbidity values 11.72% higher than Cecil B (All) whereas, Pacolet (All) shows turbidity values 61.23% higher than

Cecil B (All). Thus, the soil type influences the calculation of the turbidity in the model. Addition of other soil types and their corresponding turbidity factor will enhance the model's ability to be applied for more areas.

Table 13 Influence of soil type in the model

Soil type (Dominant Texture)	Turbidity Factor (Kt)	Suspended Soils (mg/l)	Turbidity (NTU)
Cecil B (All)	0.503	1506.94	757.99
Cecil C (All)	0.562	1506.94	846.40
Pacolet (All)	0.811	1506.94	1221.63

5.3 North Carolina Spatial Turbidity Risk Analysis

5.3.1 Sediment Risk

The sediment risk was calculated by combining the several raster layers like soil erodibility (K-Factor) layer, R-Factor (considered 300 for North Carolina), LS factor was considered for 2 different lengths and slopes. The results for slope factor were considered from lengths of 300 feet and 1000 feet and angles 2% and 4% and percentage of their respective risk levels are depicted in Table 14. The project duration of one year was assumed, hence the sediment soil loss was calculated annually.

The following statistics have been derived from the supporting GIS exhibits and results. The K-factor ranges from 0.01 to 0.38 and the K-factor layer was presented in Figure C-1 in the Appendix C. The majority of the state and area of probable development in 2030 and 2070 were a Medium Sediment Risk level and High-Risk level for the Maximum LS factor levels (Sediment Risk A) which is depicted in Figure 8. The majority of the state and area of probable development were a Medium Sediment Risk level regardless of the slope length and angle. The maps of other LS factor levels (Sediment Risk B) which is showed in Figure 9. Less than 4 percent of the state and area of probable development were a Low Sediment Risk Level.

Table 14 Risk levels in state of North Carolina

Sediment Risk	L	S	LS	Low (%)	Medium (%)	High (%)
A	1000	4	1.00571	2.03	63.04	34.93
B	1000	2	0.4007	3.67	96.33	0
C	300	4	0.6213	3.67	96.33	0
D	300	2	0.2792	3.67	96.33	0

Sediment risk level spatial maps predict the risk levels of North Carolina total area and future probable development areas for 2030 and 2070. The percentage of risk levels for predicted development in 2030 and 2070 was mapped and compared with the total state, results are presented in Table 15. Percentage of risk levels were similar for development in 2030 and 2070. As shown in Table 15, the percent difference for 2030 and 2070 predicted development ranged from 1.5 to 7.6% when compared to values for the entire state.

Additionally, the differences in percentage between state and the probable development for 2030 and 2070 was similar for Sediment risk B, C and D. Low-Risk of probable development was 3.1% lesser than the Low Risk of the overall state whereas the Medium Risk zone was 3.1% higher than the state. For Sediment Risk A the Low-Risk Zone was around 1.5% lesser than the state for both 2030 and 2070. Medium Risk Level was 6.1% and 7.63% lesser than the state for 2030 and 2070 respectively. High-Risk Level was 7.62% and 9.22% higher than the state for 2030 and 2070 respectively. Majority of the risk levels for predicted development was either Medium or High-Risk Level and the Low-Risk Level was under 1 percent.

Low-Risk Levels of the state show an overall 2.03% for Sediment Risk A and 3.67% for the rest. Whereas, Low-Risk Zones for predicted development show under 0.6% for both 2030 and 2070 for all the sediment risks. Most of the Low-Risk Zones was found in the coastal regions as the region predominantly contains soil type as fine sand and sand which have very low K Factors. Sediment Risk B, C, and D have different ranges of soil loss values but still most of them fall in between 1 ton/acre and 75 tons/acre hence they show similar percentages for different risk levels. The ranges of soil loss levels in tons/acre are tabulated in Table C-1 in Appendix C.

The proportion of land within the Medium-Risk Zone was higher at the state-level than for predicted developmental areas. Figures 8 and 9 represents the results of sediment risks with slope length 1000 feet along with predicted development in 2030 and 2070. GIS maps for sediment risk with slope length of 300 feet are provided in the Figures C-4 through C-7 in Appendix C. The spatial analysis asserts the trends understood in the first objective that most of the reported risk levels of construction sites were Medium and High-Risk and the risk levels of the future probable levels were forecasts to follow similar trends.

Table 15 Percentage of risk levels (RL) for entire state vs predicted development in 2030 vs predicted development in 2070

	% of Risk Levels for Entire State				% of Risk Levels for Development in 2030				% of Risk Levels for Development in 2070			
	A	B	C	D	A	B	C	D	A	B	C	D
L	2.03	3.67	3.67	3.67	0.51 *-1.52*	0.57 *-3.1*	0.57 *-3.1*	0.57 *-3.1*	0.44 *-1.59*	0.51 *-3.16*	0.51 *-3.16*	0.51 *-3.16*
M	63.04	96.33	96.33	96.33	56.94 *-6.1*	99.43 *3.1*	99.43 *3.1*	99.43 *3.1*	55.41 *-7.63*	99.49 *3.16*	99.49 *3.16*	99.49 *3.16*
H	34.93	0.00	0.00	0.00	42.55 *7.62*	0 *0*	0 *0*	0 *0*	44.15 *9.22*	0 *0*	0 *0*	0 *0*

(L – Low, M - Medium, H – High, Values which are italicized denote the percentage differences between risk levels for entire state and predicted development)

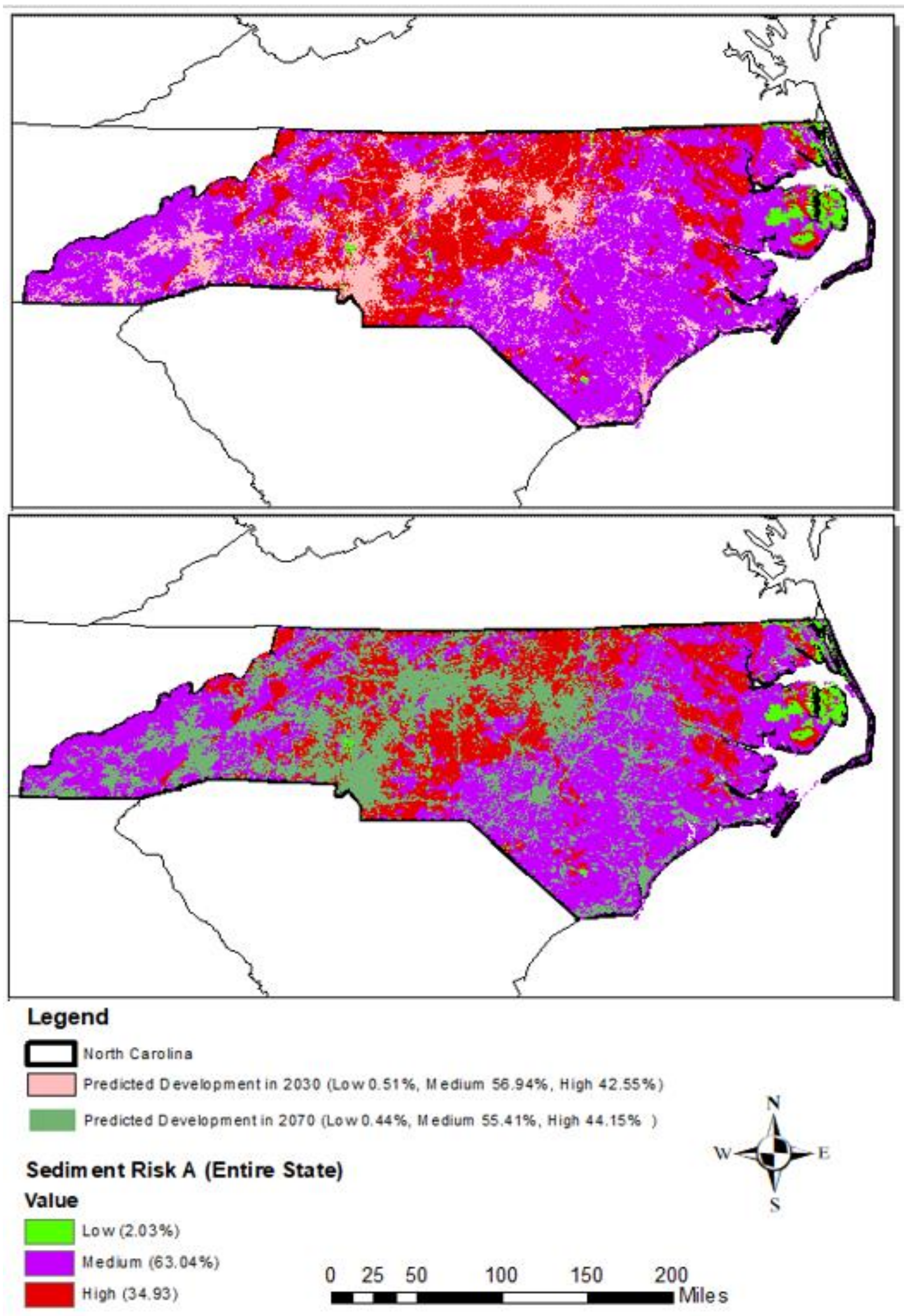

Figure 8 Sediment Risks for 1000 feet slope length and 4% slope angle with predicted development in 2030 and 2070

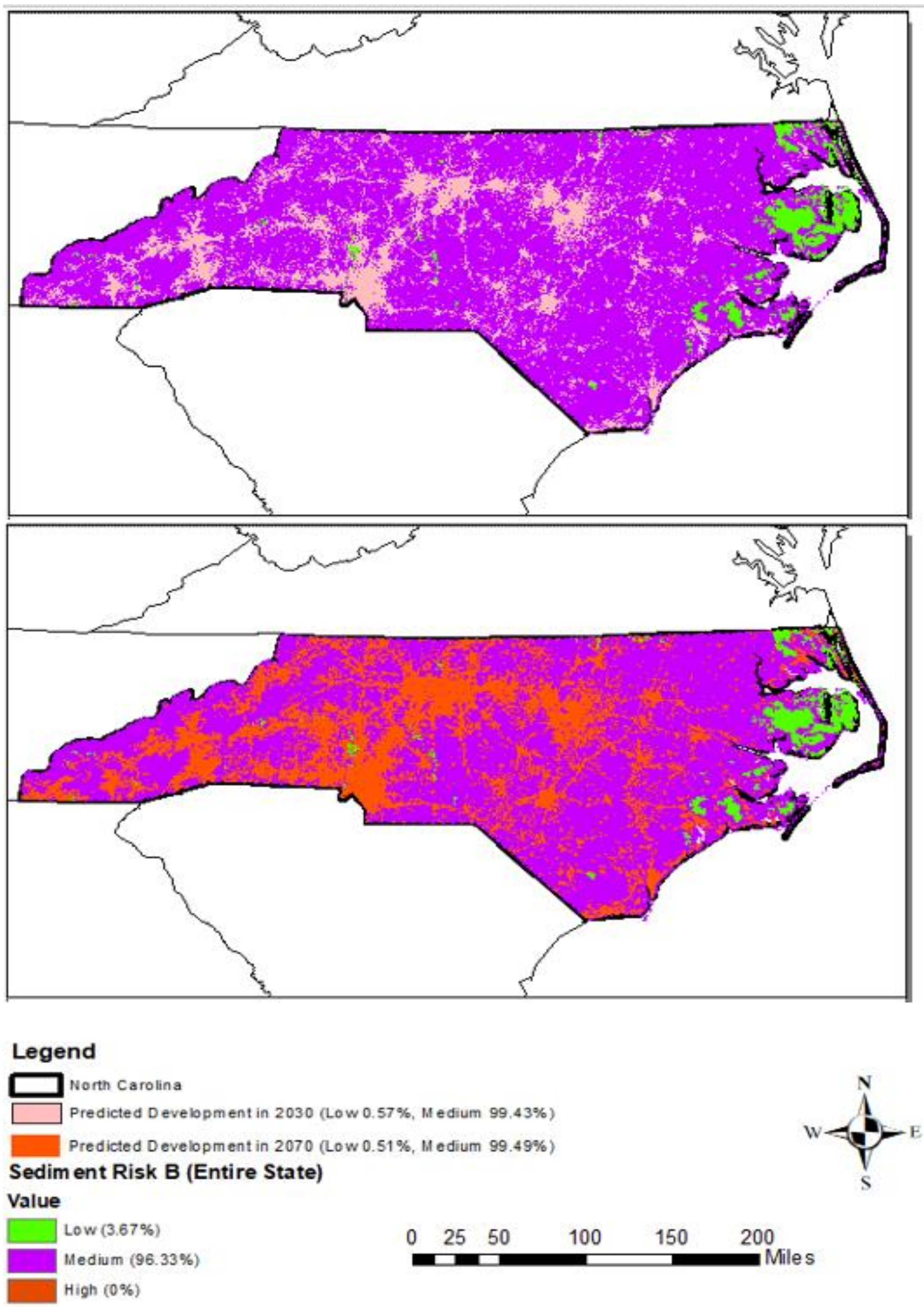

Figure 9 Sediment Risks for 1000 feet slope length and 2% slope angle with predicted development in 2030 and 2070

5.3.2 Receiving Water Risk

URS Corporation (URS) developed a series of GIS shape files for the Division of Water Resources 303d Impaired Water List, these were used to determine the Receiving Water Risk Factor for North Carolina considering the area of probable development. Figure 10 shows the DWR 303(d)-Listed Waters Impaired by Sediment. A one-mile buffer was created for all the water bodies for 2016 DWR 303d impaired waters. Figure 11 depicts the 303D receiving water risk with probable development in the year 2030 and the probable development in the year 2070. Most of the development was predicted around the cities Charlotte, Raleigh and Greensboro and the DWR Impaired Water one-mile buffer was predominant around those regions. Table 16 depicts the areas of the buffers of 303D and State of North Carolina. It was found that 25.4% of the state's area was under the one-mile buffer of impaired waters.

Table 16 Results of the receiving water risk analysis

	Total Area (in square-miles)
State of North Carolina	49048.35
DWR Impaired Water one-mile buffer	12456

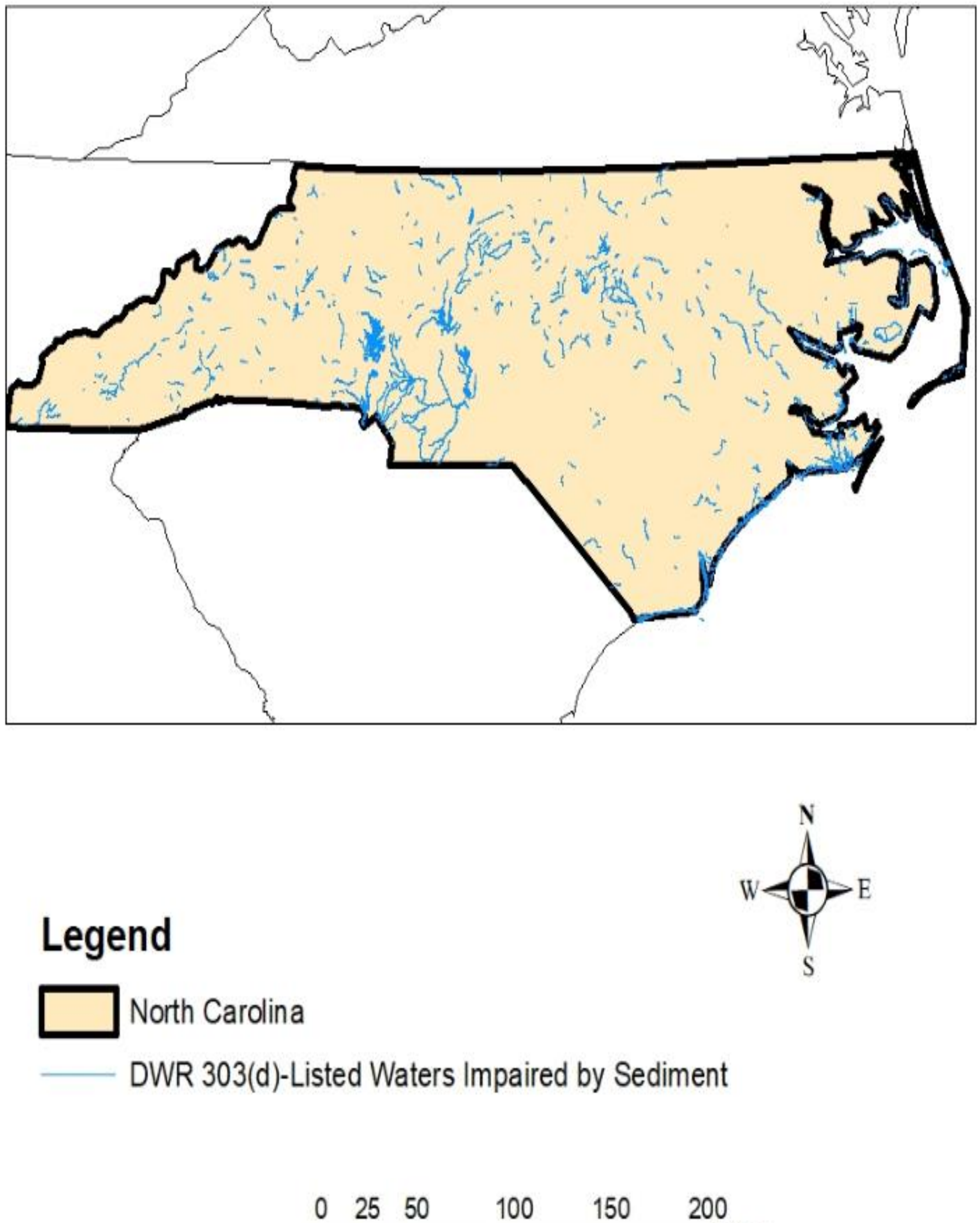

Figure 10 DWR 2016 303(d) - listed waters impaired by sediment

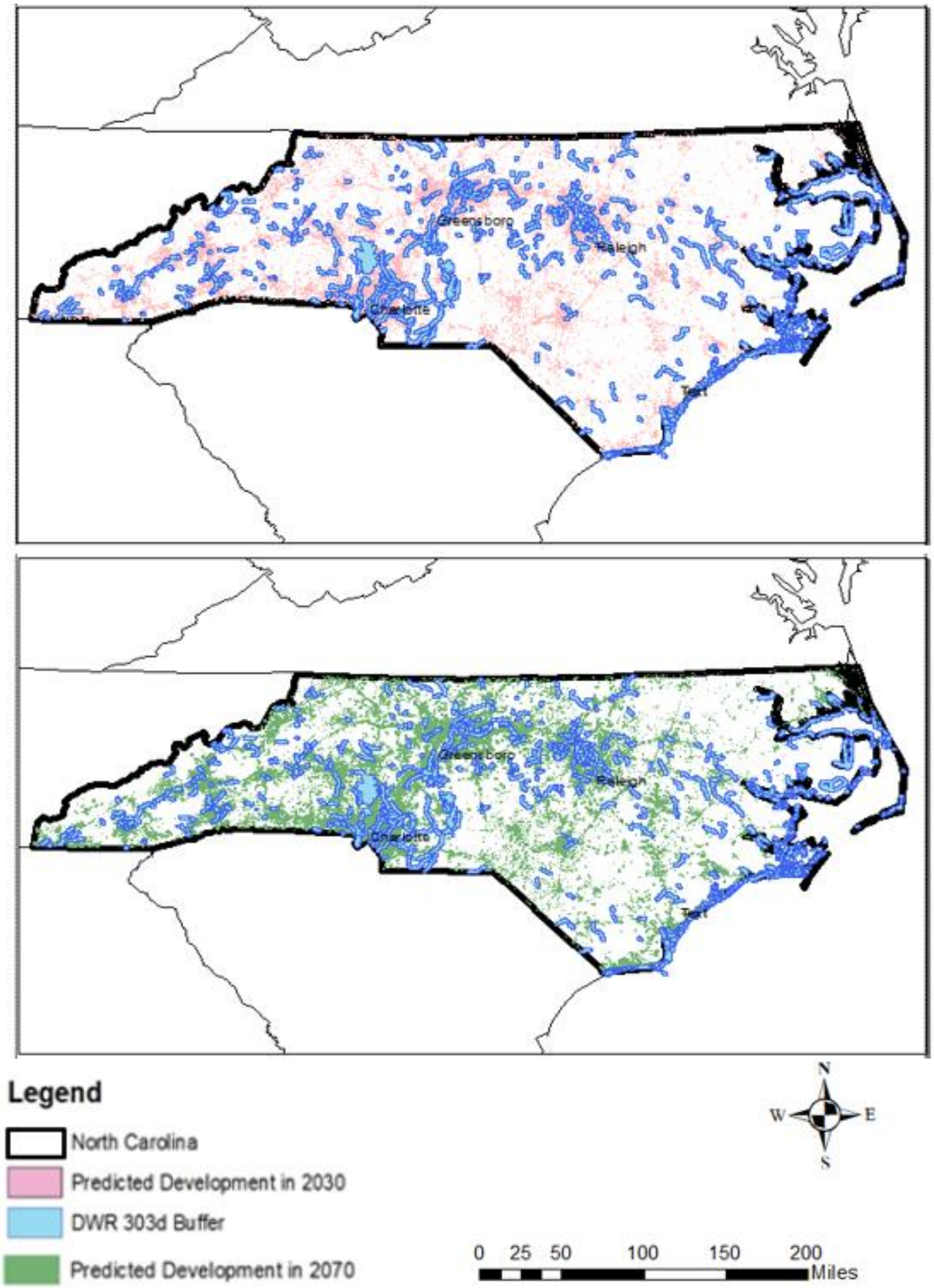

Figure 11 DWR 2016 impaired waters (1-mile buffer) with probable development in 2030 and 2070

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Development of EPA's 2009 proposed guidelines was limited by a lack of turbidity data reported during construction activities. The overall goal of this research was to increase understanding of current construction stormwater trends and forecast the future impacts of construction stormwater runoff. The study consisted of three primary objectives in order to achieve the goal; (1) data analysis of the California stormwater reports, (2) spatial analysis for predicting risk levels, and (3) development of a stormwater runoff prediction model.

6.1 Analysis of Stormwater Reports

Stormwater runoff is the highest non-point source pollutant for natural water resources (Opher & Friedler, 2010); construction stormwater contributes the highest pollutant load amount to stormwater runoff (Davies, 1995). This research aimed to analyze trends in construction stormwater turbidity. This was done using an available dataset from the California Water Board website. California was used as a case study to identify trends for turbidity concentrations in construction stormwater runoff and the following conclusions were drawn. The overall mean of the turbidity data for the last five years was found to be 131.6 NTU for general construction and 123.48 NTU for highway construction. It denotes that the mean of the turbidity levels for the last five years was lesser than both EPA (280 NTU) and California limits (250 NTU). However, there are turbidity levels reported within this study which were higher than these benchmarks. 90% of the overall data is below 375 NTU for the general construction and 450 NTU for highway construction.

Frequency of exceedance was calculated for the turbidity levels that were reported. 9.85% of the values were exceeding the California limits and 9.03% of the values were exceeding the EPA limits for general construction. About, one in ten reported values was exceeded both the state and federal limits. 79.73% of the sites were reported as Risk Level 2 and around 20% of the sites were Risk Level 3 and very few sites were reported as Risk level 1. Of the values that exceeded the California benchmarks 81.56% of the sites were rated as Risk level 2 and 18.26% were rated Risk level 3. If future EPA guidelines are put in place, construction sites may be at more risk of not meeting the turbidity limits. Therefore, tools estimating turbidity will be required to aid the preplanning stages of construction sites.

6.2 Spatial Analysis for Risk Level Determination

The main goal of the objective was to determine risk levels of sediment load and receiving water risk through spatial analysis using ArcGIS software with North Carolina as a case study. The sediment risk level was determined using the USLE. Raster layer of different USLE factors was considered in calculation of the final raster layer which represented the soil loss in tons/acre. Multiple raster layers were combined using the raster calculator tool and the final raster layer of soil loss was calculated. In accordance to the risk approach adopted by (CBIA, 2008), the values over 75 tons/acre were considered as High-Risk Level, values 1 to 75 tons /acre are considered Medium-Risk Level and values lesser than 1 ton/acre were considered Low-Risk Level.

The majority of the state and area of probable development were a Medium Sediment Risk Level, irrespective of slope length and slope angle assumed. Less than 4 percent of the state and area of probable development were a Low Sediment Risk Level. The receiving waters and the impaired waters were given a one-mile buffer and the total area of buffer was calculated. It was found that 25.4% of the state's area was 2016 303D listed impaired water buffer from the GIS maps.

6.3 Stormwater Runoff Prediction Model

Sediment level measurement can be a tedious process when total suspended solids are measured; whereas, it is easier to measure turbidity. When turbidity is predicted during the planning process, a suitable sediment control plan can be implemented. This study aimed to develop a construction stormwater runoff model to estimate turbidity. Current models in practice calculate the mass of soil lost from storm events. Whereas, the tools developed in this research predict turbidity levels.

Turbidity concentrations were determined by calculating the annual sediment load using the USLE. The model was created in a user-friendly Microsoft Excel spreadsheet requiring the user to define parameters for the construction site including soil type, location slope length, slope angle, type of land cover and time of construction. The sediment load is converted into total suspended solids which are measured in mg/l. The user has a choice to either give the amount of rainfall recorded manually or select another option for the model to predict the rainfall with respect to the time of the construction. The TSS is then converted to turbidity using correlations found in prior literature. But the model is limited to three soil types and addition of further soil types and their corresponding turbidity factor will enhance the workability of the model. This model will help with the prediction of turbidity in the pre-construction stages of future projects. Our sediment risk analysis of North Carolina found that roughly 95 percent of the state is in Medium to High-Risk Zones.

Engineers and contractors can use this tool for planning sediment control and can adapt to any potential numeric turbidity limits in the future.

6.4 Recommendations

This section highlights recommendations for applying the lessons learned in this study to future activities.

- This study selected California stormwater reports for analyzing trends because of the strict limits they possess which are imposed in absence of federal limits. The study displays the importance of analyzing reports and suggests the need to assess turbidity measurements within other states.
- Construction planners in their preplanning stages can track the location of a site and plan suitable sediment control methods considering its respective risk zones and nearby receiving waters. K-factor raster for the entire country is available and with the availability of R-factor the sediment risk levels can be determined. Therefore, planners can utilize the available data to perform their own analysis for areas not currently represented in the model.
- Results displayed exceedance of turbidity levels was minimal in dry months from April to July. When possible, construction processes involving earthwork should be scheduled during drier periods, and extra precaution should be taken for work completed outside of this period.
- Predicting the turbidity for the site can aide in development of stormwater control guidelines by decision makers and regulators. For instance, regulators can use a similar approach to modeling turbidity based on various present and

future scenarios, ultimately publishing guidance in implementing Best Management Practices on construction sites or developing new regulatory limits.

6.5 Future Research

This section focuses on how the current study can be enhanced through future research. Recommended next steps for future work are presented below.

- Currently the model validation is preliminary, due to TSS vs. turbidity relationships being limited to three soil types. A more complete model validation is warranted. To validate the model based on the California dataset, TSS vs. turbidity correlations must be developed for each soil type represented in the dataset. From there, a more complete model validation can be performed.
- Expanding soil types within the construction stormwater runoff turbidity model will allow it to be applied to more locations. As stated in the research, soil type highly influences turbidity model estimates. In order to be applied to a wider area of North Carolina, it TSS vs. turbidity correlations should be experimentally determined for soil types most commonly present in North Carolina.
- Spatial sediment risk is calculated for four various LS factors (2 different length and 2 different slopes). The LS factors were adopted from the CBIA study performed in California. Alternatively, future work can center on determining more representative values based on actual geospatial data. This will increase the accuracy of the sediment risk levels.

- Breakpoints used to classify California risk levels may prove to not be suitable for North Carolina. The framework to define Low, Medium, High Risk Levels was adapted from the risk approach of the CBIA. Sediment risk up to 75 tons of sediment per acre are categorized as Medium Risk, which causes 96.33% of the data to fall into this category. To better capture higher risks, the breakpoint for High Risk Level should be lowered to better characterize the level of risk.

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APPENDIX A: MODEL BACKGROUND

A.1 Model Validation

S. NO	WDID	Cover	Period % R	Annual R Factor	R factor	K Factor	LS Factor	C factor	Soil Loss A (tons/acre)
1	1 49C382180	Bare Ground	0.03	84.61	2.5383	0.37	0.2	1	0.1878342
2	5S31C379965	Bare Ground	0.1	51.38	5.138	0.43	0.29	1	0.6407086
3	5S31C381530	Bare Ground	0.04	49.88	1.9952	0.43	0.29	1	0.24880144
4a	2 49C376313	Bare Ground	0.01	24.24	0.2424	0.38	0.38	1	0.03500256
4b	2 49C376313	Bare Ground	0.02	24.24	0.4848	0.38	0.38	1	0.07000512

Figure A-1: Calculation of Soil Loss A with reported values in California Website (Model Validation)

Soil Lost (kg/square-meter)	Total area (square meter)	Soil lost in Kg	User Defined Rain fall (in m)	Total Precipitation	Suspended soils (mg/l)
0.042106793	2000	84.21358523	0.09398	187.96	448.0399299
0.143627647	2000	287.2552937	0.2032	406.4	706.8289708
0.055773819	2001	111.6034114	0.054	108.054	1032.848496
0.007846524	2000	15.69304775	0.0508	101.6	154.4591314
0.015693048	2000	31.3860955	0.0254	50.8	617.8365256

Figure A-2: Calculation of suspended solids with reported values in California Website (Model Validation)

Suspended soils (mg/l)	Soil type (Dominant Texture)	Turbidity Factor (Kt)	Turbidity (NTU)	Reported Turbidity	% Difference
448.0399299	Cecil B (Clay)	0.866	388.0025793	426.2	8.96
706.8289708	Cecil C (Silt)	0.9	636.1460737	812	21.65
1032.848496	Cecil C (Silt)	0.9	929.5636467	890	-4.45
154.4591314	Cecil B (Clay)	0.866	133.7616078	108.1	-23.74
617.8365256	Cecil B (Clay)	0.866	535.0464312	492.3	-8.68

Figure A-3: Calculation of suspended solids with reported values in California Website

(Model Validation)

A.2 Case Study: Example Calculation

UNIVERSAL SOIL LOSS EQUATION for Construction sites - North Carolina

Region	Piedmont

Cover - Disturbing Activity	Start Range	End Range	Period % R	Annual R Factor	Soil Texture	K Factor	Slope %	Slope Length (Feet)	LS Factor	C factor	Soil Loss A (tons/acre)
Bare ground	March 2nd half	May 1st half	9	250	Fine sand	0.133333333	2	260	0.26750365	1	0.80251095
End Activity			#N/A	250		#N/A	2	260	0.26750365	0	#N/A
			#N/A	250		#N/A	2	260	0.26750365	#N/A	#N/A
			#N/A	250		#N/A	2	260	0.26750365	#N/A	#N/A

Total Soil Loss	0.80251095

INPUT	Defintion	TYPE
Region	Region where the Construction Site is located.	User Entered
Start / End Range	Time range	User Entered
Period % R	Percenatge of Annual R for the given time range	Automatically Generated
Annual R Factor	Annual R factor for the region	Automatically Generated
Soil Texture	Type of Soil in the Region	User Entered
K Factor	Soil Erodibility Factor	Automatically Generated
Slope % S	Percentage of Slope of Distrubed Area	User Entered
Slope Length	Distance between top and bottom of the slope (in feet)	User Entered
LS factor	Slope Factor	Automatically Generated
C Factor	Cover Factor	Automatically Generated
Soil Loss A	Total Soil Loss in Tons/Acre	Automatically Generated

Figure A-4: Example soil loss model output (tons/acre)

Conversion of Soil Lost to TSS

Soil Lost (kg/square meter)	Total area (square meter)	Soil lost in Kg	Input type	User Defined Rain fall (in m)	Total rain (Pred) in Metres	Total Precipitation	Suspended soils (mg/l)
0.17989888	2000	359.7977591	Predicted Rainfall		0.11938	238.76	1506.943203

INPUT	Defintion	TYPE
Soil Lost (kg/square meter)	Soil Lost (in kg/square meter)	Automatically Generated
Total area (square meter)	Total Disturbed Area	User Entered
Soil lost in Kg	Soil Lost in Kilograms	Automatically Generated
Input type	Defines whether prdeicted/user defined data	User Entered
User Defined Rain fall (in m)	Total rain (in metres)	User Entered
Total rain (Pred) in Metres	Total precipitation levels in disturbed area	Automatically Generated
Total Precipitation	Total precipitation levels in disturbed area	Automatically Generated
Suspended soils (mg/l)	Total Suspended soils	Automatically Generated

Figure A-5: Example conversion of soil loss to suspended soils (mg/l)

Conversion of Soil Lost to TSS

Suspended soils (mg/l)	Soil type (Dominant Texture)	Turbidity Factor (Kt)	Turbidity (NTU)
1506.943203	Cecil B (All)	0.503	757.992431

INPUT	Defintion	TYPE
Suspended soils (mg/l)	TSS in (mg/l)	Automatically Generated
Soil type (Dominant Texture)	Soil type and dominant textural type	User Entered
Turbidity Factor (Kt)	Turbidity Factor	Automatically Generated
Turbidity (NTU)	Turbidity measured in NTU	Automatically Generated

Figure A-6: Example conversion of soil loss to TSS (in NTU)

APPENDIX B: SUPPORTING DATA FOR SOIL LOSS MODELING

Table B-1: Percent of R-factor for North Carolina region (Renard et al., 1997).

Time Ranges	Mountains	Piedmont	Coastal Regions
Jan 1st half	0	0	0
Jan 2nd half	1	1	1
Feb 1st half	3	3	2
Feb 2nd half	5	5	3
March 1st half	7	7	4
March 2nd half	9	9	5
April 1st half	12	12	7
April 2nd half	15	15	9
May 1st half	18	18	11
May 2nd half	21	21	14
June 1st half	25	25	17
June 2nd half	29	29	22
July 1st half	36	36	31
July 2nd half	45	45	42
Aug 1st half	56	56	54
Aug 2nd half	68	68	65
Sept 1st half	77	77	74
Sept 2nd half	83	83	83
Oct 1st half	88	88	89
Oct 2nd half	91	91	92
Nov 1st half	93	93	95
Nov 2nd half	95	95	97
Dec 1st half	97	97	98
Dec 2nd half	99	99	99

Table B-2: Soil Erodibility factor (K) (Energy, 2003)

Textural Class	P_{om} (%)		
	<0.5	2	4
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.1
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.1	0.08
Loamy fine sand	0.24	0.2	0.16
Loamy very fine sand	0.44	0.38	0.3
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.3	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.6	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay		0.13-0.2	

Table B-3: C-factor (Balousek et al., 2000)

Type of Cover	C-factor
Bare land	1.00
Directional Tillage	0.90
Land applied polymer	0.90
Mulch or Erosion mat	0.20
Seed with Mulch	0.12
Seeding	0.40
Sod	0.01

Table B-4: Total Suspended Solids (TSS) relationships obtained for each particle class of three soil (Patil, 2010)

Soil type	Particle Class	Calibration coefficient (K_{ij}) (NTU-L/mg)
C_EB	Clay	0.866
	Silt	0.601
	Sand	0.042
	All	0.503
C_EC	Clay	1.130
	Silt	0.529
	Sand	0.026
	All	0.562
P_CE	Clay	1.360
	Silt	0.900
	Sand	0.172
	All	0.811

APPENDIX C: SPATIAL ANALYSIS FOR ANALYZING RISK LEVELS

C.1 Supporting GIS layers

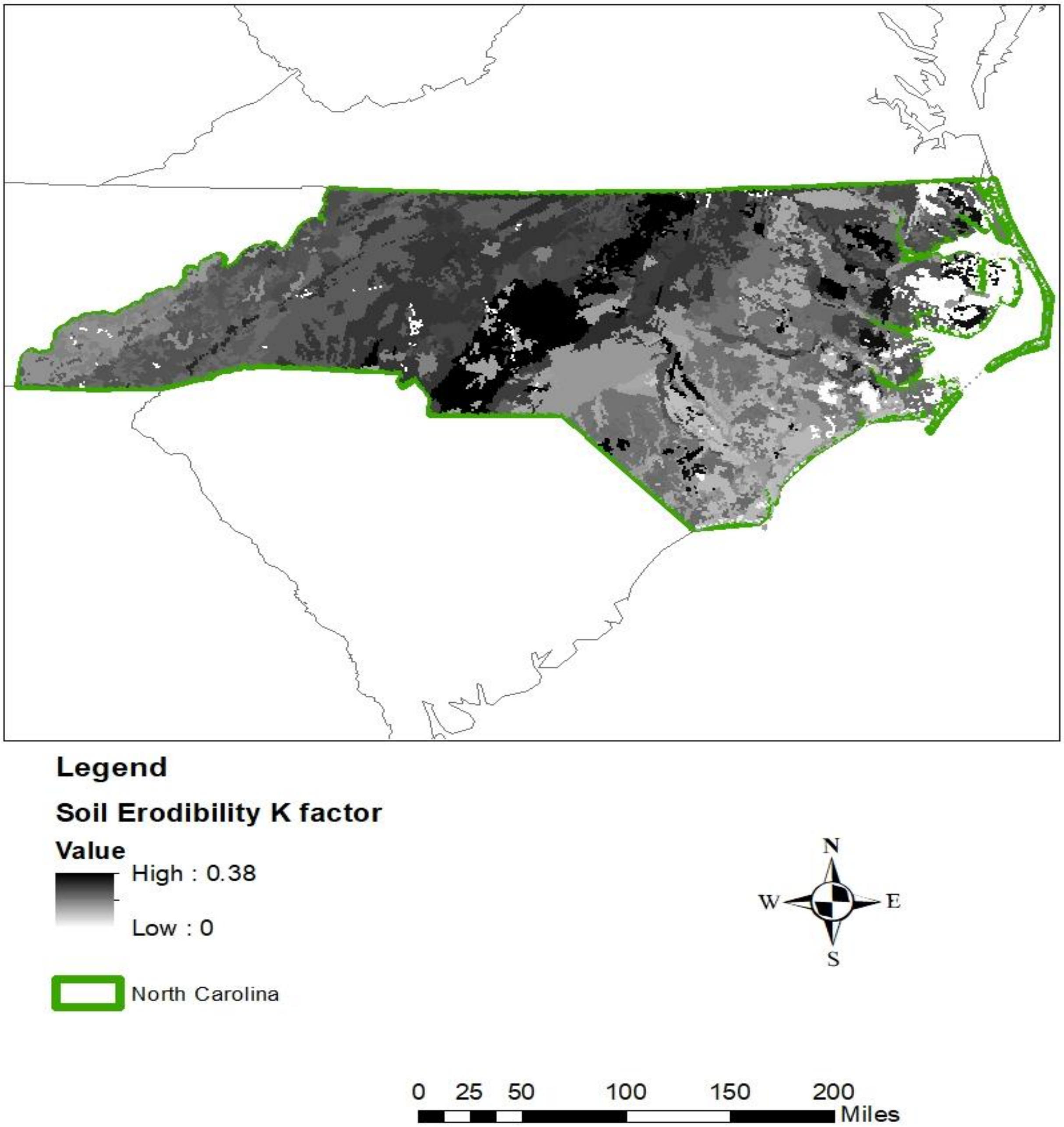

Figure C-1 Soil Erodibility K-Factor Raster

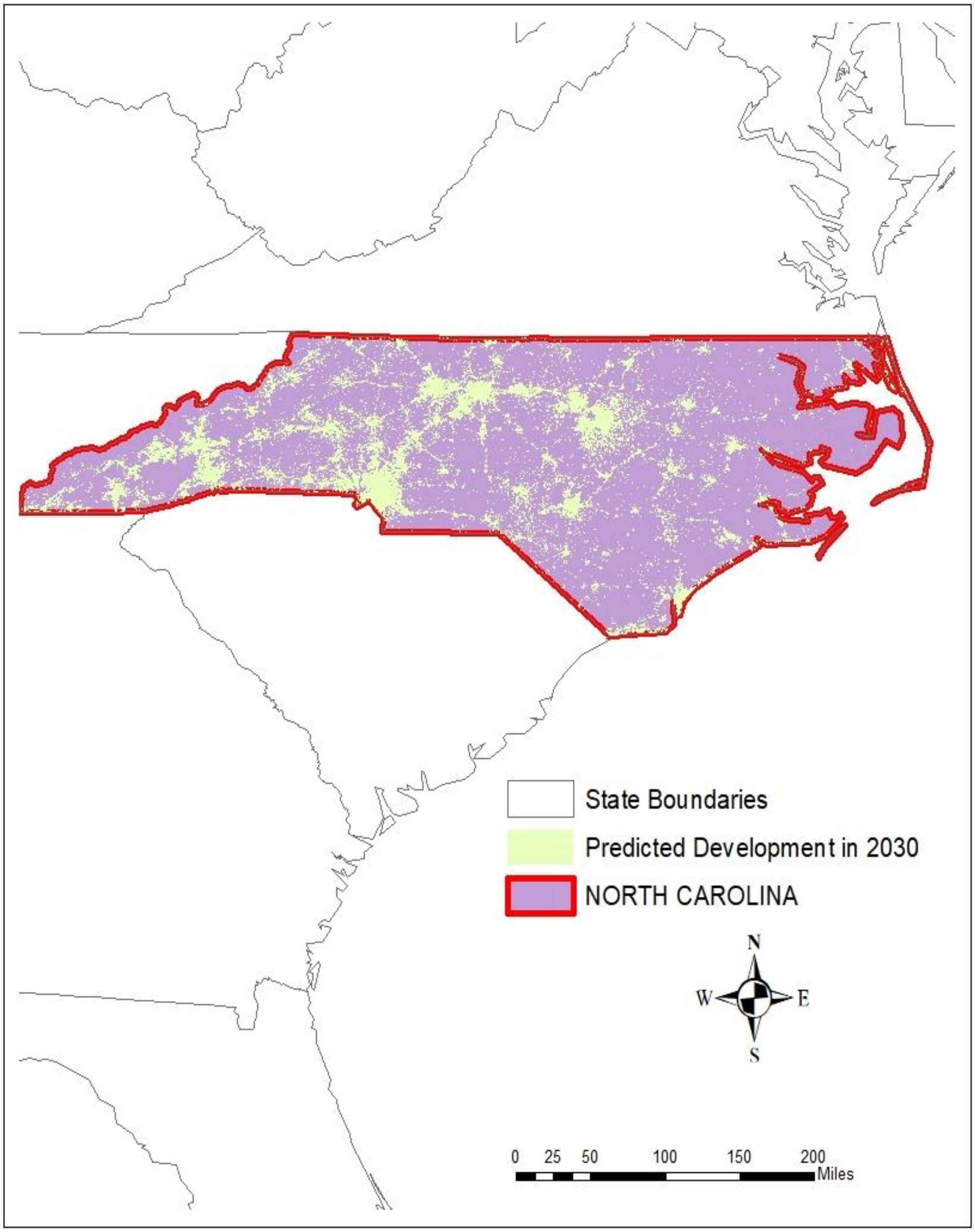

Figure C-2 Predicted development in 2030 in North Carolina

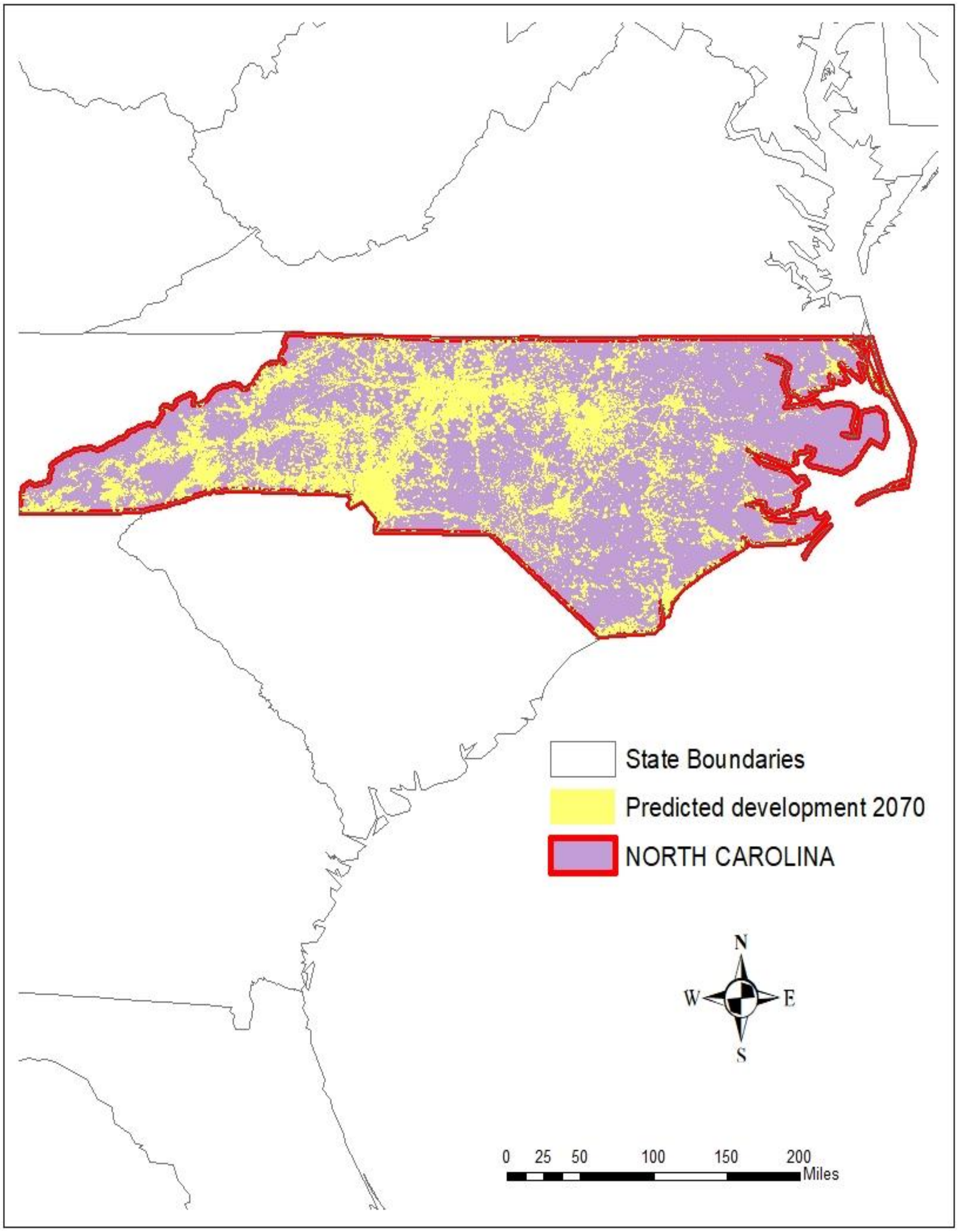

Figure C-3 Predicted development in 2070 in North Carolina

C.2 Sediment Risk Levels with Slope length 300 feet

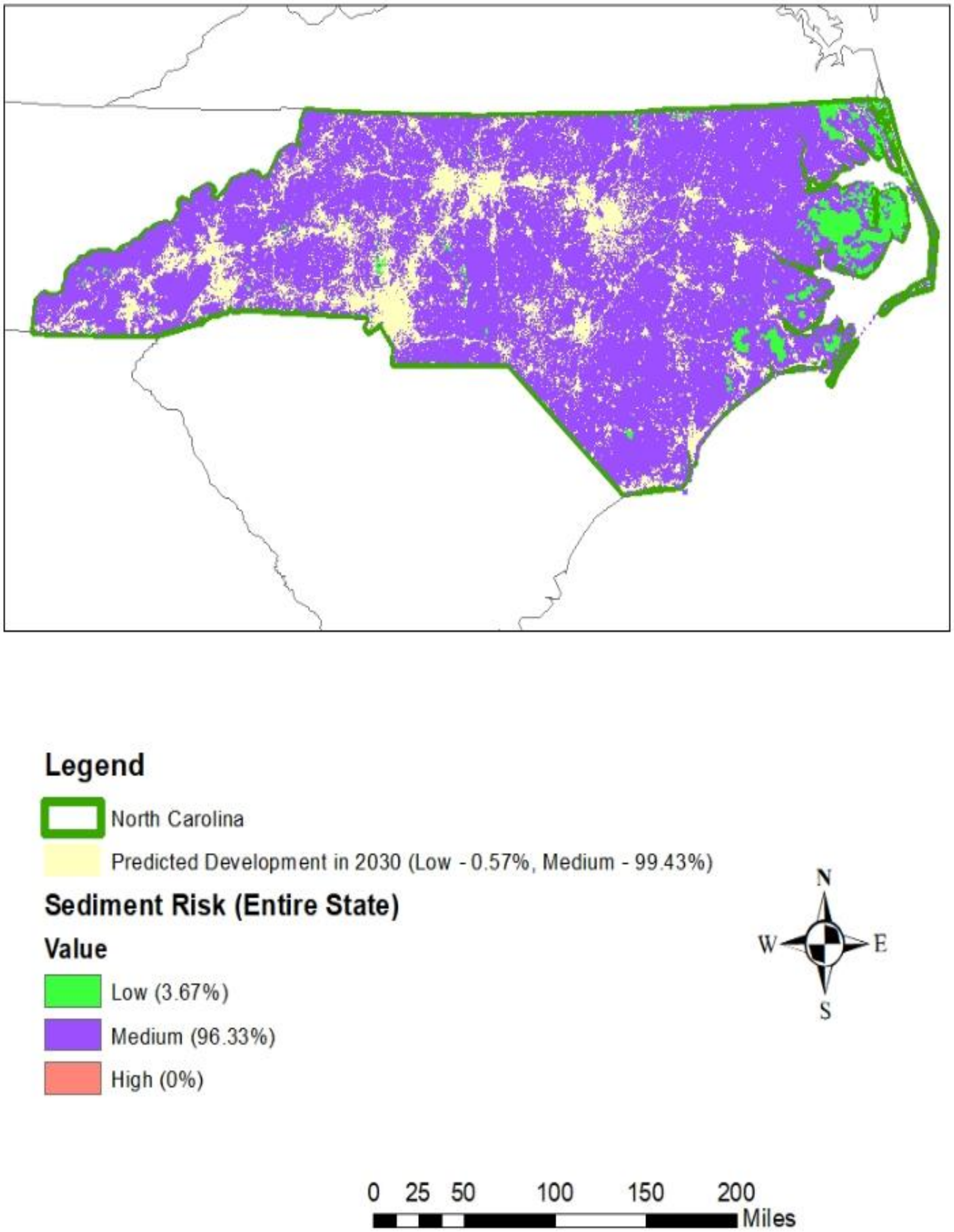

Figure C-4 Sediment risks for 300 feet slope length and 4% Slope angle with predicted development in 2030

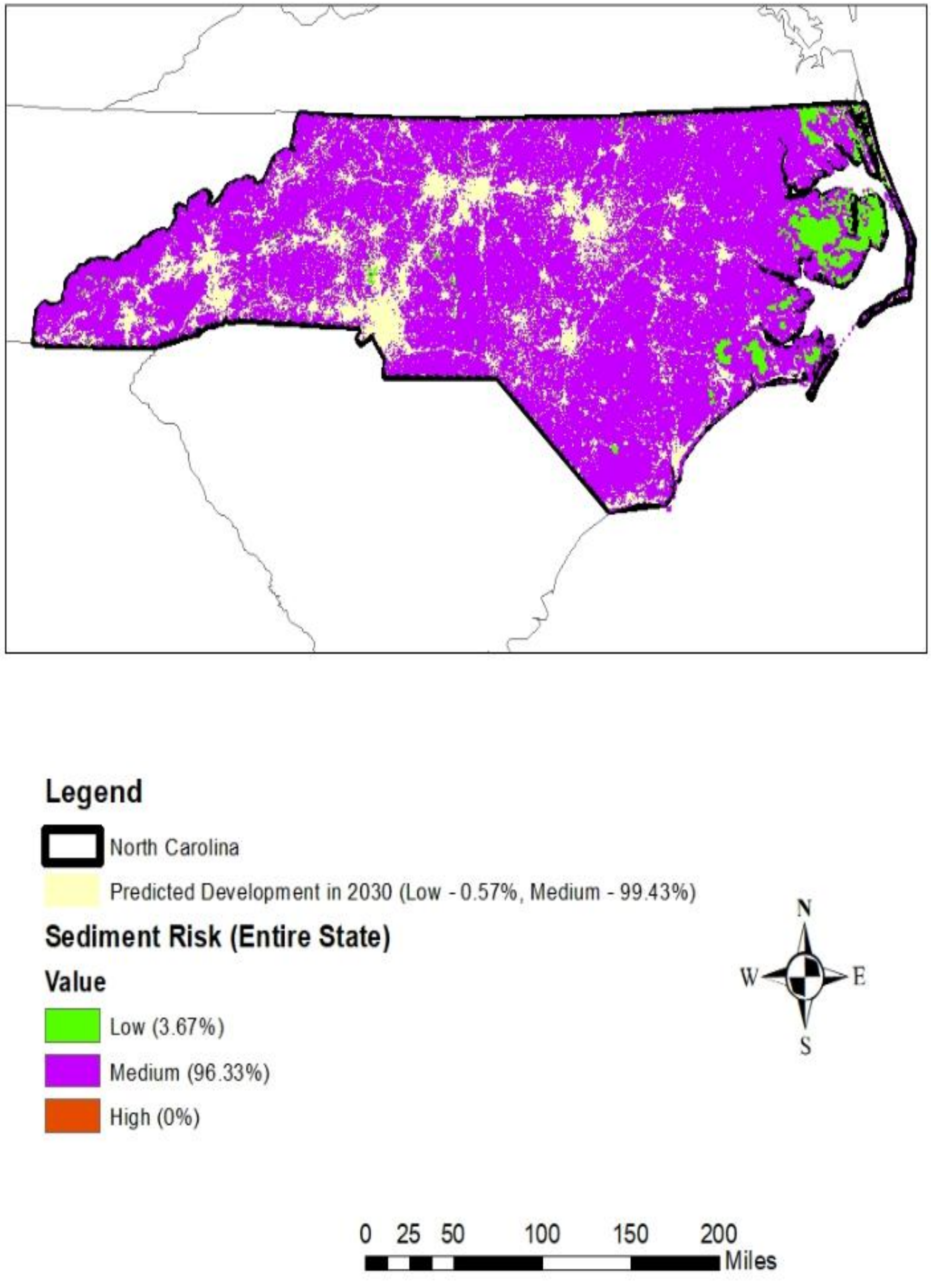

Figure C-5 Sediment risks for 300 feet slope length and 2% Slope angle with predicted development in 2030

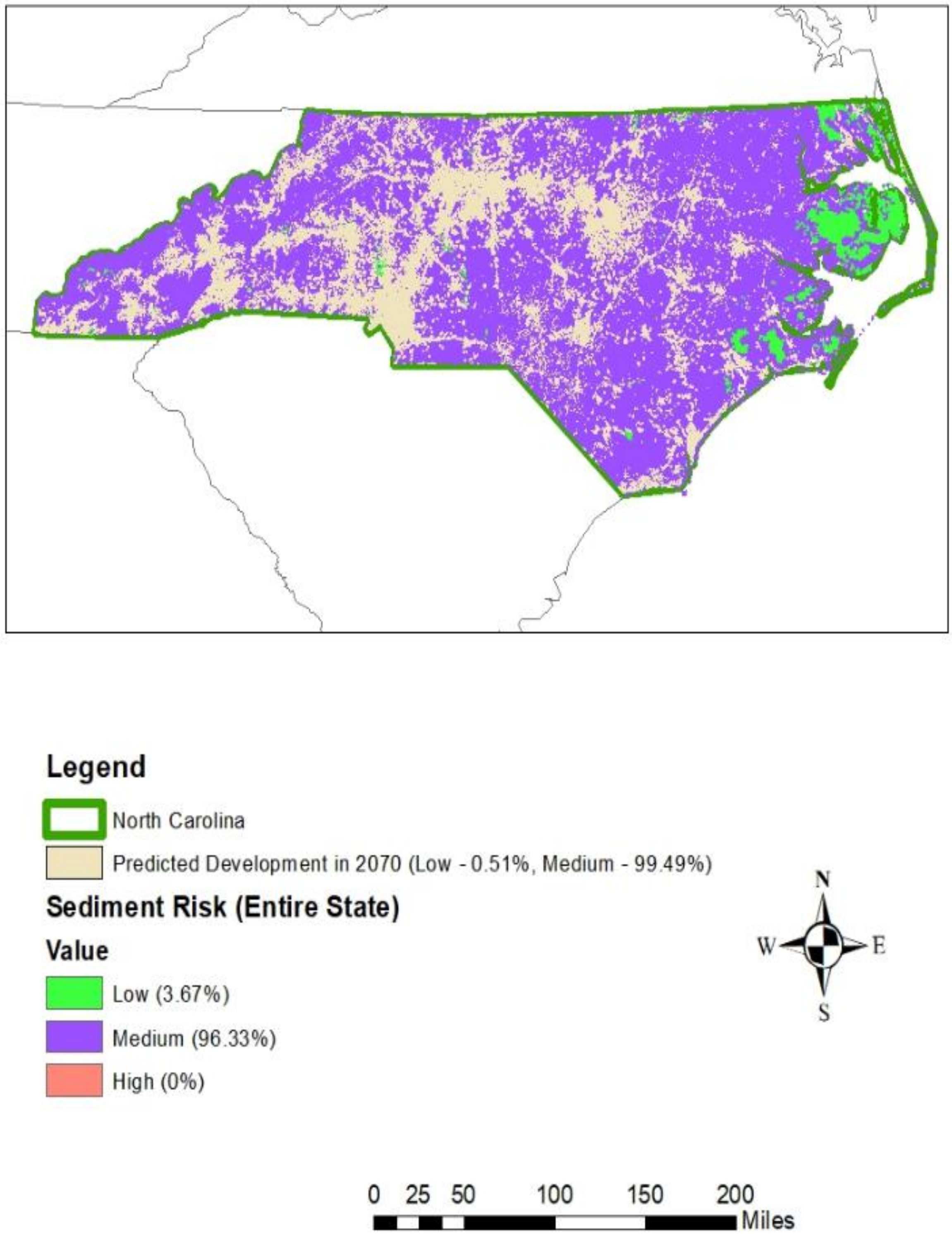

Figure C-6 Sediment risks for 300 feet slope length and 4% Slope angle with predicted development in 2070

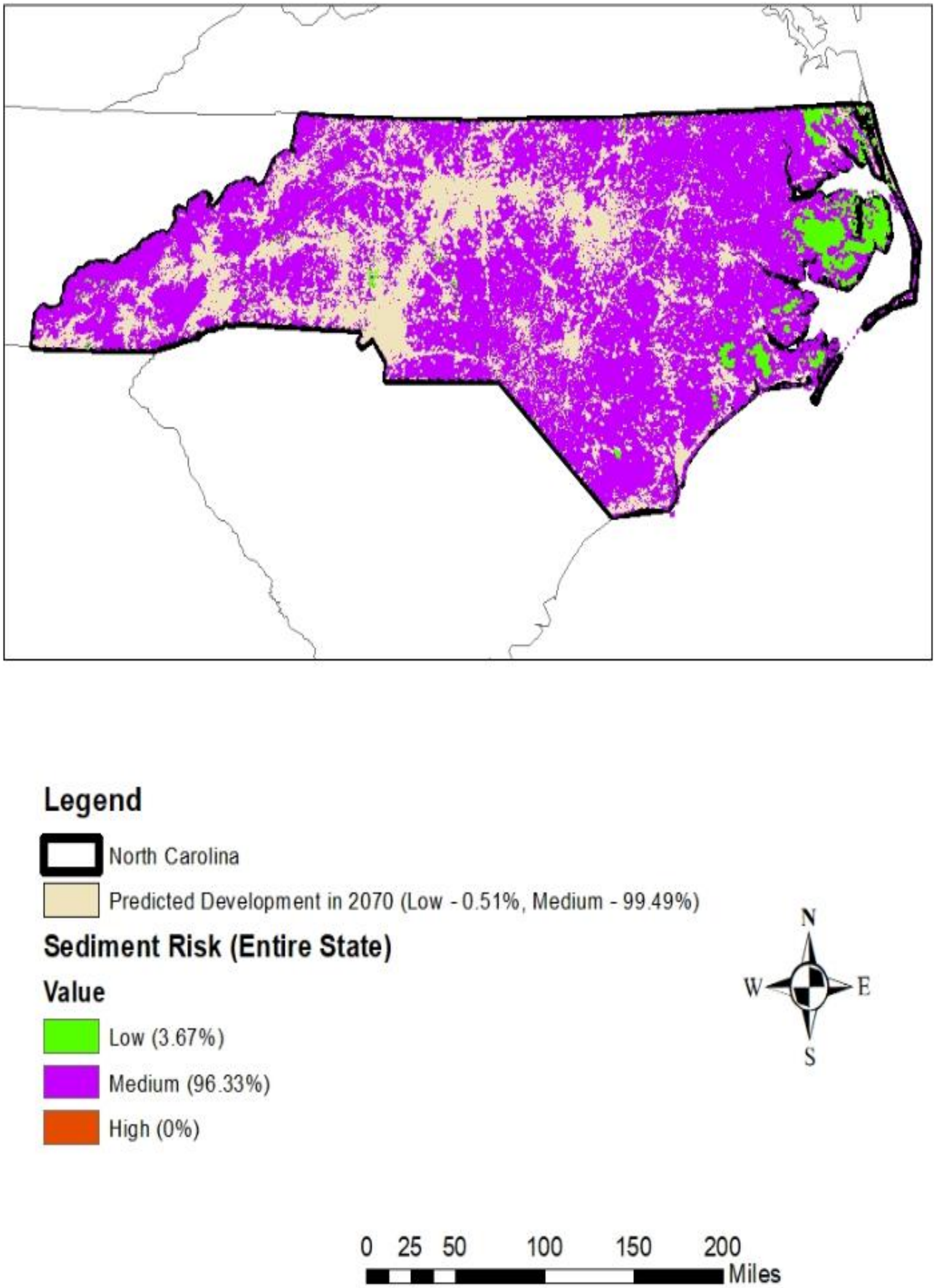

Figure C-7 Sediment risks for 300 feet slope length and 2% Slope angle with predicted development in 2070

Table C-1 Soil Loss (tons/acre) Range

Sediment Risk	L (Feet)	S (%)	Range (Tons/Acre)
A	1000	4	0.01 - 120
B	1000	2	0.01 – 45.67
C	300	4	0.01 – 70.79
D	300	2	0.01 – 31.81