2018

ASSESSMENT OF WATERSHED NUTRIENT LOADS AND EFFECTIVENESS OF BEST MANAGEMENT PRACTICES

Saeid Nazari
University of Kentucky, saeed_nazari67@yahoo.com
Author ORCID Identifier:
https://orcid.org/0000-0002-9972-2737
Digital Object Identifier: https://doi.org/10.13023/ETD.2018.091

STUDENT AGREEMENT:

I represent that my thesis or dissertation and abstract are my original work. Proper attribution has been given to all outside sources. I understand that I am solely responsible for obtaining any needed copyright permissions. I have obtained needed written permission statement(s) from the owner(s) of each third-party copyrighted matter to be included in my work, allowing electronic distribution (if such use is not permitted by the fair use doctrine) which will be submitted to UKnowledge as Additional File.

I hereby grant to The University of Kentucky and its agents the irrevocable, non-exclusive, and royalty-free license to archive and make accessible my work in whole or in part in all forms of media, now or hereafter known. I agree that the document mentioned above may be made available immediately for worldwide access unless an embargo applies.

I retain all other ownership rights to the copyright of my work. I also retain the right to use in future works (such as articles or books) all or part of my work. I understand that I am free to register the copyright to my work.

REVIEW, APPROVAL AND ACCEPTANCE

The document mentioned above has been reviewed and accepted by the student's advisor, on behalf of the advisory committee, and by the Director of Graduate Studies (DGS), on behalf of the program; we verify that this is the final, approved version of the student's thesis including all changes required by the advisory committee. The undersigned agree to abide by the statements above.

Saeid Nazari, Student

Dr. Lindell Ormsbee, Major Professor

Dr. Yi-Tin Wang, Director of Graduate Studies

ASSESSMENT OF WATERSHED NUTRIENT LOADS AND EFFECTIVENESS OF BEST MANAGEMENT PRACTICES

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Civil Engineering in the
College of Engineering at the University of Kentucky

By

Saeid Nazari

Lexington, Kentucky

Director: Dr. Lindell Ormsbee, Professor of Civil and Environmental Engineering

Lexington, Kentucky

2017

ABSTRACT OF THESIS

ASSESSMENT OF WATERSHED NUTRIENT LOADS AND EFFECTIVENESS OF BEST MANAGEMENT PRACTICES

Several methods have been developed for use in estimating the water quality loads associated with urban and agricultural landuses and practices. These include the use of sophisticated computer models, typically based on using pollutant loading and runoff functions, regression equations, load export coefficients (LECs), and event mean concentrations (EMCs). This research has examined the feasibility of using a simple EMC approach with the Kentucky Nutrient Model (KYNM). The thesis includes an extensive literature review of EMCs and a synthesis of recommended values for a range of typical urban and agricultural landuses. The thesis also includes an extensive literature review of potential BMPs along with a summary of the typical removal efficiencies and costs associated with each type of BMP. The research also explored the potential to use the results from multiple applications of site specific BMP models like the Source Loading and Management Model (WinSLAMM) in the development of general functional relationships that could then be used to evaluate BMP performance on a more site-specific basis. The developed EMC table and the associated BMP performance curves should provide valuable tools for use in better managing nutrient loads for urban and agricultural watersheds.

KEYWORDS: LEC, EMC, BMP, KYNM, WinSLAMM

Saeid Nazari

08/15/2017

ASSESSMENT OF WATERSHED NUTRIENT LOADS AND EFFECTIVENESS OF BEST MANAGEMENT PRACTICES

By

Saeid Nazari

Dr. Lindell Ormbsee

Director of Dissertation

Dr. Yi-Tin Wang

Director of Graduate Studies

08/15/2017

Date

DEDICATION

I would like to dedicate this body of work to my parents and my uncle who have always been my incentive to improve in my life and pursue my education. I could not conduct this research without their great support and help. I hope that my efforts can be a great appreciation to them.

ACKNOWLEDGEMENT

I would like to acknowledge all the people who have assisted and inspired me to conduct this research. My deep gratitude first goes to my knowledgeable advisor, Dr. Lindell Ormsbee, who provided me a very friendly and flexible space to achieve one of my educational goals. He knows how to promote his students and teach them to perform a research step by step. My appreciation also goes to the professors in Civil Engineering department who taught me different materials which I used to conduct my research.

Table of Contents

List of Tables

List of Figures

1 CHAPTER 1. Introduction

1.1 Problem Statement

Water plays a significant role in the ecological environment, and is essential to life and the activities of human. The quantity and quality of water affect the locations that people can live and the quality of their life. In addition, all plants and animals must have clean water to survive.

Water pollution is the contamination of natural water bodies by chemical, physical, radioactive or pathogenic microbial matter (C. Michael Hogan, 2010). Water pollution sources can be divided into two categories: Point source (PS) pollution and Non-point source (NPS) pollution. Point source pollution can be the result of pollutant discharge from a specific point such as a wastewater treatment plant. On the other hand, non-point source pollution can be a result of an extensive drainage from urban and agricultural areas within a subcatchment.

According to EPA's final comprehensive National Water Quality Inventory Report to Congress in 2004 (i.e. EPA transitioned to an online state reporting system in 2004 – see EPA ATTAINS) 64% of lakes and 44% of rivers and streams are impaired and the percentage of impaired waterbodies has increased over the last 12 years (EPA, 2009). Stormwater runoff has been identified as one of the leading causes of the degradation of water quality in receiving waters in the United States (Lee *et al*. 2002). In addition, urbanization results in an increase of the impervious area and a decrease in infiltration, causing a flashy urban water system. This increase in runoff results in higher pollutant loads. The report also identified agricultural activities such as crop production, grazing and animal feeding operations as one of the top sources of river and stream impairment (EPA 2009).

Nutrient pollution, especially from nitrogen and phosphorus, is a widespread problem and concern in the United States. The Environmental Protection Agency (EPA) has estimated that there are now more than 15,000 stream segments that do not meet state nutrient standards and more than 7,000 that are impaired due to excess nutrient concentrations (Shapiro, 2013). Nutrients enter natural water bodies in a multitude of ways, including stream bank erosion, runoff from agriculture, stormwater, and discharges from untreated and treated municipal wastewater (Puckett, 1995).

Environmental sustainability (especially associated with water quality issues) has become one of the major concerns of government, private agencies, researchers, stakeholders and the public. In 1972, the Clean Water Act established comprehensive water quality standards based on stream designated uses. It also established a National Pollutant Discharge Elimination System (NPDES) in an effort to comply with such standards through the creation and enforcement of discharge permits. Subsequent work has shifted the focus from point source discharges to non-point source discharges from urban and agricultural landuses. In more recent years, the focus has shifted from pathogenic pollutants, to physical and chemical pollutants such as eroded sediments and nutrients like nitrogen and phosphorus.

In recent decades, water quality professionals have sought to develop methodologies and strategies to reduce the occurrence and magnitude of such non-point source loads. Many of these approaches involve the use of computer programs. Such simulation models can be categorized as physical and conceptual models. In the later case, model inputs will normally include watershed data, rainfall, and water quality data. In many applications, the pollutant loads can be characterized either through the use of daily loading values, or through the use of average event mean concentrations (EMCs) or annual load export coefficients (LECs). One of the challenges of watershed modelers lies in the selection of appropriate EMCs or LECs when there is no observed data available for the studied region.

One of the ways to reduce nutrient loads is by selecting and implementing urban and agricultural best management practices (BMPs). In general, BMPs may be divided into structural and non-structural BMPs. Structural BMPs can involve physical modifications of different landuses or the construction of different physical control measures such as detention ponds, grass swales and porous pavement. Non-structural BMPs include management-related strategies such as crop conversion and conservation tillage and more stakeholder driven strategies such as the reduction of yard fertilizer, especially phosphorus.

One of the challenges facing engineers and watershed planners is the lack of site specific cost and performance data associated with many of the BMPs currently being promoted in support of watershed management. Unfortunately, much of the relevant literature related to such metrics is expressed in terms of general conditions and average performance metrics and not in terms site specific conditions or the actual design specifications of the BMP. As a consequence, a more robust database is needed for use by engineers and planners in designing and evaluating such BMPs. One way to obtain such a database is by conducting detailed experiments in the field. In most applications, this is not economically feasible. An alternative approach is to derive such relationships from the multi- application of recognized water quality models configured for different design options.

Once the performance and the total costs of different BMPs are obtained, decision makers can then perform an analysis of the cost-effectiveness of the BMPs for a specific watershed. Several approaches exist for use in performing a cost-effectiveness analysis and comparison for different potential BMPs. One way is to incorporate different BMPs within a watershed simulation model which quantifies BMP performance. This model can then be coupled with an optimization model which seeks to identify the most cost-effective combination of BMPs while meeting some type of water quality or load constraint. Another approach is to specify some operational policies and rank them by using a multi-criteria decision analysis (MCDA) method of compromise programming (CP) (Andre´ *et al*. 2008) based on some type of evaluation criteria. The evaluation criteria can include such things such as the nutrient load, runoff reduction, cost, and the social acceptance of implementing the BMPs. The CP approach calculates a distance function for each operational policy based on a subset of efficient solutions (called a compromise set) that is the nearest solution with respect to an ideal point for which all the criteria are optimized (Andre´ *et al.* 2006).

1.2 Research Objectives

The overall goal of this thesis was to develop a computational tool which could be used to optimize the selection of urban and agricultural BMPs for a mixed used watershed. This goal was pursued through the fulfillment of five separate research objectives. The first objective was to compile a dataset of nutrient EMCs and LECs for both agricultural and urban landuses using published values. This dataset was developed for use in parameterizing a nutrient watershed model developed as part of the research. The second objective was to develop a dataset of BMP performance and cost data. The cost data was constructed using published literature values and the performance values were obtained from the synthesis of multiple applications of WINSLAM (Pitt *et al.* 1978) and SWAT (Arnold *et al.* 1998) for different BMP types and configurations. The third objective was to develop functional relationships associated with these data sets for use in the Kentucky Nutrient Model. The final and fourth objective was to expand the Kentucky Nutrient Model by incorporating a revised EMC and LEC database along with BMP performance and cost data (E White *et al*. 2015). Each of these objectives were met by implementing the steps summarized in Figure 1.1.

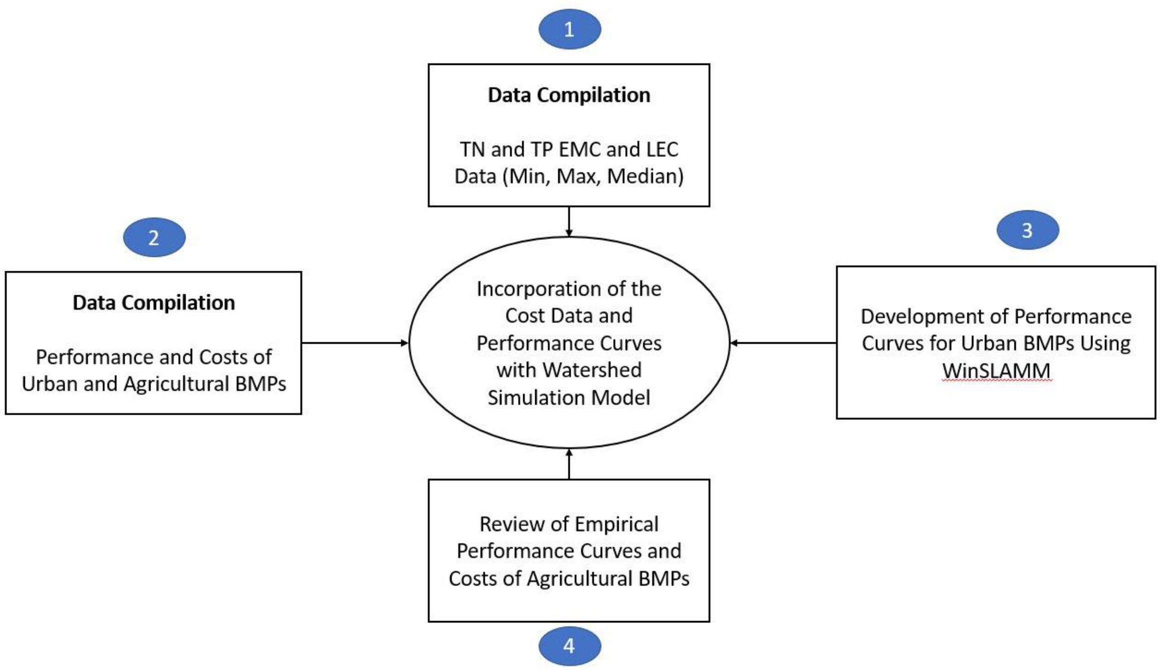


Figure 1.1. Steps in research methodology

1.3 Organization of the Thesis

The thesis has been organized around the stated objectives. Chapter 1 provides an overview of the basic problem along with a summary of the research objectives. Chapter 2 explains the development of an EMC and LEC database for total nitrogen and total phosphorus for both urban and agricultural landuses. Chapter 3 explains the development of a database of BMP cost and performance data. The BMP cost data were synthesized from literature values while performance data were synthesized from multiple applications of simulations models used to predict the performance of urban and agricultural BMPs. Chapter 4 explains the development of performance curves and cost estimations of urban BMPs for use in Kentucky Nutrient Model. Chapter 5 discusses methodologies and recommendations for selection of agricultural BMPs for use in simulation models. Finally, chapter 6 provides a summary and conclusion of the research along with several recommendations for the future works.

2 CHAPTER 2. Compilation of EMC and LEC Data for Urban and Agricultural Landuses

2.1 Introduction

Several different methods have been developed for use in predicting annual and daily nutrient loads for the purposes of developing TMDLs for impacted watersheds. These include computer models (Metcalf and Eddy, 1971; USACOE, 1976; Johnson *et al*. 1980; Tetra Tech, 2009), regression equations (Tasker and Driver, 1988; Elvadi and Moore, 1994), event mean concentrations (EMCs) (Huber, 1992), and load export coefficients (LECs) (Omernik, 1976, Reckhow *et al.* 1980). Most modeling approaches involve a traditional rainfall-runoff approach, where rainfall is converted to runoff using some type of infiltration model and then pollutant loads are generated using a pollutant build up – washoff model (Metcalf and Eddy, 1971; Johanson *et al.* 1980). More recently, Ormsbee *et al.* have proposed a runoff disaggregation modeling approach in which observed runoff from a watershed is disaggregated into surface runoff and baseflow components (Ormsbee *et al.* 2017). Pollutant loads are then generated by multiplying the daily surface runoff by average EMCs for different landuses in the watershed. By applying the model over an entire year, and estimate of the total annual load can be obtained. These results can then be compared with estimates for annual loads derived from landuse based load export coefficients for validation purposes. The accuracy of such a modeling approach will be dependent upon the accuracy of the associated EMCs or LECs.

Despite their widespread use, there exists a lack of consensus in the modeling community with regard to accepted EMCs and LECs for use in generating pollutant loads from impacted watersheds. Part of the reason is because of the diversity of published field studies, a lack of consensus or documentation on field collection methods, significant variations in soil types and antecedent rainfall, non-homogeneous landuses, etc. This chapter will provide the results of a review of the existing literature of EMCs and LECs with a goal of developing average, median, and related statistics for such parameters for different landuses. It is expected that such values could then be used in runoff disaggregation approaches such as proposed by Ormsbee *et al*., or be used to develop probability distributions of the loads which could then be used in stochastic applications.

2.2 Pollutant Build-Up Models

One of the traditional approaches to simulate runoff quality is by employing pollutant buildup washoff theory. The pollutant buildup process is associated with the accumulation of pollutant loads on different landuses (e.g. urban, agricultural) as a result of different landuse practices (e.g. application of fertilizers to agricultural fields, application of fertilizers to urban lawns, etc.) or natural processes (e.g. air deposition). The pollutant washoff process is associated with the discharge of pollutant loads from such landuses as a result of runoff and erosion processes (EPA, 2016). The Hydrological Simulation Program--Fortran (HSPF) developed by Johanson *et al.* 1980, the Stormwater Management Model (SWMM) developed by Metcalf and Eddy, 1971, and the Loading Simulation Program in C++ (LSPC) model developed by Tetra Tech 2009, are three examples of watershed models that employ a buildup washoff method to predict the surface runoff pollutant load from urban and agricultural landscapes.

Since the 1960s, numerous studies have been conducted to collect data for use in formulating typical buildup relationships. In most cases, relationships were developed for use in predicting the amount of the dust and dirt that accumulate over time for different landuses. Pollutant loads were then typically expressed in terms of percentages of the mass of dust and dirt. While some researchers found that such accumulation is a linear function of time (APWA, 1969; AVCO, 1970; Shaheen, 1975), other research have found that pollutant accumulation is a nonlinear function of dry days (Pitt, 1979; Sartor and Boyds, 1972). In 1979, Ammon proposed the use of a range of possible functions for buildup relationships (see Table 2.1) which were then ultimately incorporated into SWMM III (Huber *et al.* 1981). In this case the user can pick a function arbitrarily, or use the function that best matches the observed watershed response.

Table 2.1. Different forms of buildup functions (EPA, 2016)

Buildup Functions	**Equation**
Power	$b = \text{Min}\ (\text{Bmax}, K_B t^{NB})$
Exponential	$b = \text{Bmax}(1\text{-}e^{-KBt})$
Saturation	$b = (\text{Bmaxt})/\ (K_B\text{+}t)$

Where: b = Buildup (pounds), t = Buildup time interval (days) raised to some power, Bmax = Maximum buildup possible (pounds); N_B= Buildup time exponent (dimensionless); and K_B = Buildup constant (whose units vary with the particular function: 1) pounds-days^{-NB} for the power function, 2) days^{-1} for the exponential function, and 3) days for the saturation function. Note that the K_B is assumed to be equal to half the value of Bmax in the saturation function (days to reach the half of maximum buildup). In addition, when NB is equal to one, the power function reduces to a linear function (EPA, 2016). Figure 2.1 shows a comparison between the buildup functions for a hypothetical pollutant. In this example, it is assumed that the pollutant reaches 3 kg/acre (Bmax) in two weeks. The assumed values for each coefficients of the buildup functions are shown in Figure 2.1.

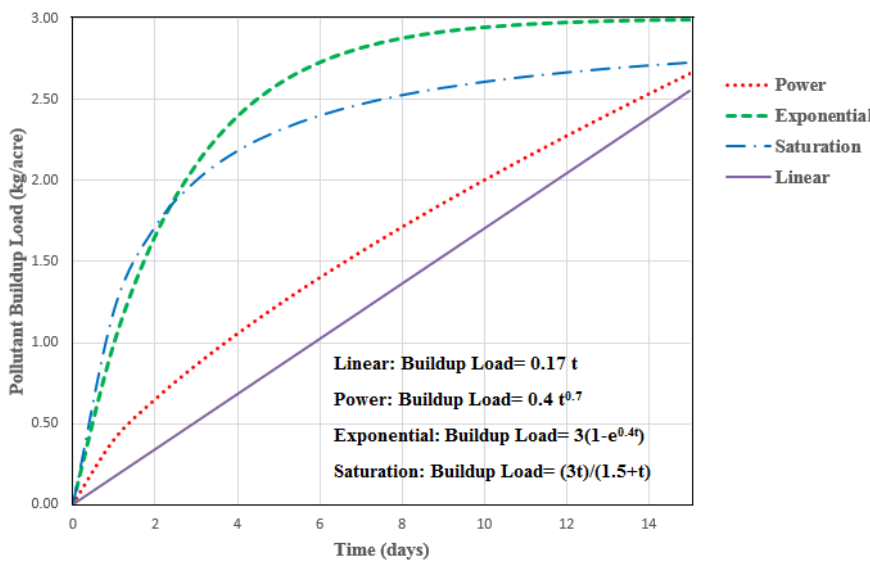


Figure 2.1. Buildup functions for a hypothetical pollutant

In 1977, Manning *et al.* provided a comprehensive summary of mean linear buildup rates for dust and dirt in an urban environment expressed in terms of (kg/curb-km/day). These data were collected from a review of data from across the United States and were based on linear dust and dirt buildup rates for several different urban landuses (see Table 2.2)

Table 2.2. Mean Dust and Dirt Pollutant Loading Rates as a function of different landuses

Pollutant	Landuse				
	Single Family Residential	Multiple Family Residential	Commercial	Industrial	All Data
Dust and Dirt (kg/curb-km/day)	17	32	47	90	45

These values can be used to estimate the corresponding pollutant loads of other constituents by multiplying the mass of the dust and dirt by the mass fraction of the associated pollutant. These values are shown in Table 2.3.

Table 2.3. Typical Pollutant Loads (g or mg) Expressed as a Fraction of Dust and Dirt Load (kg)

Pollutant	Landuse				
	Single Family Residential	Multiple Family Residential	Commercial	Industrial	All Data
Total N-N (mg/kg)	460	550	420	430	480
Kjeldahl N (mg/kg)	-	-	640	-	640
NO3 (mg/kg)	-	-	24	-	24
Total P (mg/kg)	-	-	-	-	170
PO4-P	49	58	60	26	53
BOD g/kg	5.26	3.37	7.19	2.92	5.03
COD g/kg	39.25	41.97	61.73	25.08	46.12

Example 2.1

If one assumes a linear buildup rate (i.e. NB =1) then the linear accumulation rate for dust and dirt for a commercial landuse is equal to 47 (kg/curb-km/day). The associated total nitrogen load from commercial landuse is equal to 420 mg per kg of dust and dirt. Thus, the total buildup load of total nitrogen (TN) on a commercial landuse can be calculated as below:

$$\text{TN Buildup} = 47 \text{ (kg/curb-km/day)} \times 420 \text{ (mg/kg)} = 19{,}470 \text{ (mg/curb-km/day)}$$

2.3 Pollutant Washoff Models

Similar to the buildup functions, different forms of equations have been proposed for the pollutant washoff process (Metcalf and Eddy, 1971; Huber and Dickson, 1988). Three different potential functions are shown in Table 2.4. Figure 2.2 provides a comparison between the washoff equations for an initial load of 2 kg of over a one-acre catchment during a 6-hour storm. In order to make the equations comparable, the washoff coefficients (see Figure 2.2) were selected so that the pollutgraphs can fit in one figure.

Table 2.4. Different forms of washoff functions (EPA, 2016)

Washoff Function	Equation	
Exponential Washoff	$W=K_W q^{NW} B$	W= Rate of washoff (mg/hour) N_W=Washoff exponent, K_W=Washoff coefficient $(in/hr)^{-NW}hr^{-1}$ q=Runoff rate per unit area of subcatchment (in/hr), B=Pollutant buildup (mg)
Rating Curve Washoff	$W=K_W Q^{NW}$	W=Rate of washoff (mg/s); N_W=Washoff exponent, K_W=Sediment loading rate $(mg/s)(l/s)^{-Nw}$, Q=Volumetric runoff rate (l/s)
EMC Washoff	$W=K_W Q$	W=Rate of washoff (mg/s) K_W= Pollutant Event Mean Concentration (EMC) (mg/l) Q= Volumetric Runoff (l/s)

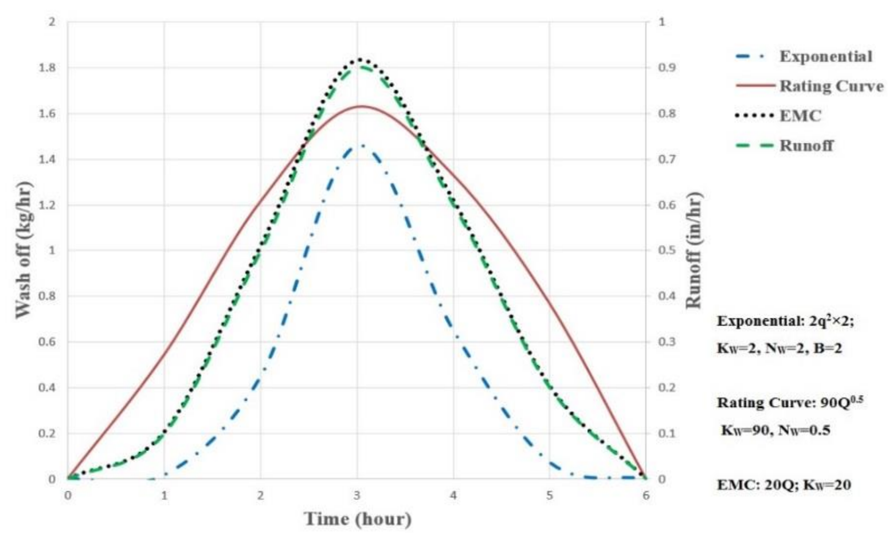


Figure 2.2. Comparison between washoff equations for a hypothetical example

For example, if one assumes that K_W and N_W are equal to 1 in the exponential function, the runoff rate is equal to 0.2 in/hr, and the initial building load for TN (i.e. B) is 20 lbs, the associated washoff rate can be calculated as follows.

N Wash of Rate=0.2 (in/hr)×20 (lb)×454000 (mg/lb)×(1/3600)(hr/sec)= 504 mg/s

2.4 Regression Equations

Another technique to estimate nonpoint source pollutant loads is by using a regression- curve approach. Several researchers have developed regression equations for such purposes including Driver and Tasker (1988), Evaldi and Moore (1994), Crain and Martin (2009).

2.4.1 Driver and Tasker Equations

In 1988, Driver and Tasker developed 31 regression equations for use in estimating stormwater runoff loads based on different combinations of physical, land-use, and climatic characteristics of urban watersheds throughout the United States on a regional basis. The United States was divided into three regions on the basis of mean annual rainfall. The regression equations were derived using data from the 1983 National Urban Runoff Program (NURP), which collected runoff and water quality data from over 100 sites in the United States. The regression equations were developed for 11 storm-runoff loads plus storm-runoff volume. The storm-runoff loads (expressed in pounds) collected as part of the study included: chemical oxygen demand (COD), suspended solids (SS), dissolved solids (DS), total nitrogen (TN), total ammonia plus organic nitrogen as nitrogen (TKN), total phosphorus (TP), dissolved phosphorus (DP), total recoverable cadmium (CD), total recoverable copper (CU), total recoverable lead (PB), and total recoverable zinc (ZN). Storm-runoff volumes (RUN) are expressed in inches. The general regression model developed as part of the study is given by the following equation (Driver and Tasker, 1988).

$$Y = \beta_0 \times X_1^{(\beta 1)} \times X_1^{(\beta 2)} \times ....Xn^{(\beta n)} \times BCF \qquad \text{(Eq. 2.1)}$$

Where $\hat{Y}$ =Estimated stormwater-runoff load or volume (The response variable) β_0, β_1, β_2, β_n =Regression coefficients; X_0, X_1,X_2,X_3= physical, landuse, or characteristics (The explanatory variables); and where BCF is a bias-correction factor.

The explanatory variables used in the regression models included the following:

(DA)= Total contributing drainage area of the watershed in square mile; (IA)= Impervious area as a percent of DA; (LUI)= Industrial landuse as a percent of DA; (LUC)= Commercial landuse as a percent of DA; (LUR)= Residential landuse as a percent of DA; (LUN)= Nonurban landuse as a percent of DA; (PD)= Population density in people per square mile; (TRN)= Total storm rainfall in inches; (DRN)= duration of each storm in minutes; (ITN)= Maximum 24-hour precipitation intensity that has a 2-year recurrence interval (INT), in inches; (MAR)= Mean annual rainfall in inches; (MNL)= Mean annual nitrogen load in precipitation, in pounds per acre; (MIT)= Mean minimum January temperature (MIT), in Fahrenheit (Driver and Tasker, 1988).

Driver and Tasker, (1988) also developed a set of simplified regression models which were based on only three explanatory variables. The explanatory variables of the simplified model include total storm rainfall (TRN), drainage area (DA), and impervious area (IA). The values of regression coefficients for each explanatory variable can be found in Driver and Tasker (1988). Note that for each storm-runoff load, the values of regression coefficients are not available for all explanatory variables. In these cases, the value of regression coefficients should assumed to be equal to zero.

2.4.2 Elvadi and Moore Equations

In 1994, Elavdi and Moore, used Driver and Taskers' regression equations to estimate storm-runoff volumes, mean concentrations and loads of selected constituents in storm runoff from urban watersheds of Jefferson County, Ky. The equations were developed based on water quality data measured in 26 stations in Jefferson County Kentucky (Elavdi and Moore, 1994). They estimated stormwater runoff and constituent loads for the 26 stations using Driver and Taskers' regression equations. The plots of measured and estimated runoff and constituent loads in their study showed that adjustments were needed in the estimation models in order to best fit the Louisville data. The adjustments were determined by simple linear regression between the estimated runoff quantity and constituent loads in the runoff and the Jefferson County measurements (Elavdi and Moore, 1994). Examples of the developed adjusted regression equations are shown in Table 2.5.

Table 2.5. The regression equations for single storm runoff loads for Jefferson County, KY (Elavdi and Moore, 1994)

The adjusted regional regression models that can be used to compute loads in stormwater runoff and quantity of runoff for single storms from urban watersheds of Jefferson County	
$TN=0.3455\times(TRN^{0.776})\times(DA^{0.474})\times(IA^{0.611})\times(MNL^{0.863})$	(Eq. 2.2)
$TP=55.86\times(TRN^{1.019})\times(DA^{0.846})\times(LUC^{0.189})\times(LUR^{0.103})\times(LUN^{-0.160})\times(MJT^{-0.754})$	(Eq. 2.3)
The adjusted regional three-variable regional regression models that can be used to compute constituent loads in single storms from urban watersheds of Jefferson County	
$TN=3.063\times(TRN\times0.703)\times(DA\times0.465)\times(IA\times0.521)$	(Eq. 2.4)
$TP=2.799\times(TRN\times0.954)\times(DA\times0.789)\times(IA\times0.289)$	(Eq. 2.5)

Example 2.2:

Assume that there is a watershed in Jefferson County with drainage area (DA) equal to 0.2 sq. miles including 20 percent residential landuse (LUR); 15 percent commercial landuse (LUC) and 10 percent nonurban landuse (LUN), and where 40 percent of the watershed is impervious (IA). If the average rainfall associated with the storm event is 0.75 inches (TRN), and the Mean Minimum January Temperature is 20 F (MJT), then the TP load for the storm event can be estimated using the regression equations of Driver and Tasker (1988) and Elvadi and Moore (1994) as follows. Note: Kentucky is located in region III with mean annual rainfall equal to or greater than 40 inches.

1. Driver and Tasker, 1988 (For region III, using Equation 2.1):

$$TP(III)=\beta_0\times(TRN)^{(\beta1)}\times(DA)^{(\beta2)}\times(LUR+1)^{(\beta3)}\times(LUC+1)^{(\beta4)}\times(LUN+2)^{(\beta5)}\times(MJT)^{(\beta6)}\times BCF$$

TP (III)= $53.2\times(0.75)^{1.019}\times(0.2)^{0.846}\times(21)^{0.103}\times(16)^{0.189}\times(12)^{-0.16}\times(20)^{-0.754}\times2.059=3.4$ lbs

2. Elavdi and Moore, Six parameter model, 1994 (Using Equation 2.3):

$TP=55.86\times(TRN^{1.019})\times(DA^{0.846})\times(LUR^{0.103})\times(LUC^{0.189})\times(LUN^{-0.160})\times(MJT^{-0.754})$

$TP=55.86\times(0.75^{1.019})\times(0.2^{0.846})\times(15^{0.189})\times(20^{0.103})\times(10^{-0.160})\times(20^{-0.754})=$ 3.2 lbs

3. Elavdi and Moore, Three parameter model, 1994 (Using Equation 2.5):

$TP=2.799\times(TRN\times0.954)\times(DA\times0.789)\times(IA\times0.289)$

$TP=2.799\times(0.75\times0.954)\times(0.2\times0.789)\times(40\times0.289)=$ 3.65 lbs

2.4.3 Crain and Martin Equations

In 2009, Crain and Martin, presented the results of a study conducted by the U.S. Geological Survey to provide estimates of TN and TP annual loads and yields from 55 stream stations that were part of Kentucky's ambient stream water-quality monitoring network from 1979 through 2004. As part of the study, they developed regression equations for each monitoring station which could be used to estimate the mean annual TN and TP load. An example of one of the regression equations for the Kentucky River at Frankfort (USGS station number: 03287500) are provided below.

$$TN=1.97 + 1.16\ln(Q) + 0.01\ln(Q)^2 - .017\sin(2\pi dtime) + 0.16\cos(2\pi dtime) - 0.01(dtime) + 0.02(dtime)^2 \quad \text{(Eq. 2.6)}$$

$$TP=-0.8 + 1.40\ln(Q) + 0.08\ln(Q)^2 - 0.5\sin(2\pi dtime) - 0.09\cos(2\pi dtime) - 0.03(dtime) \quad \text{(Eq. 2.7)}$$

Where Q=centered streamflow (in cubic feet per second); sin, sine; cos, cosine; π, pi; dtime, centered decimal time.

2.5 EMC Approach

Event mean concentrations (EMCs) represent the average concentration (mg/l) of a specific pollutant associated with stormwater runoff (Lin, 2004). Over the last several decades, researchers have developed average or median EMCs for different landuses using the results of detailed filed studies. EMCs can be used to predict the daily TN and

TP loads coming off of a land surface by multiplying the value of the EMC for a given landuse by the volume of runoff from that landuse. Then, the total annual or daily load coming from various nonpoint sources within the watershed can be obtained by summing the nutrient loads from all landuses.

Example 2.3:

A city planner is trying to estimate total TP load of a single storm from a watershed that contains several different landuses as shown in Table 2.6.

Table 2.6. Information of the hypothetical watershed for applying the EMC approach

Landuse	Area (Acre)	Runoff (inch)	Mean TP EMC* (mg/l)
Residential	100	0.7	0.59
Industrial	50	0.9	0.27
Golf Course	30	0.4	1.07
Pasture	150	0.5	2.14
Forest	200	0.3	0.35

*The EMC values have been adapted from Line *et al.* (2002)

The total TP load coming from one/all landuse(s) into the streams can be calculated using the EMC approach as follow:

$$\text{Total TP Load (lbs)}= \sum_{i=1}^{n} EMC_i \times R_i \times A_i \times CF \quad , i=1,2,\ldots n \qquad \text{(Eq. 2.8)}$$

Where n= Total number of landuses; i= Landuse number, R= Stromwater runoff from i^{th} landuse (inch); A= Area of i^{th} landuse (Acre); CF= Conversion factor, which is 0.226.

So, the total TP load is:

[(100×0.7×0.59)+ (50×0.9×0.27)+ (30×0.4×1.07)+ (150×0.5×2.14)+ (200×0.3×0.35)]×0.226= 56 lbs

2.5.1 Development of EMCs

EMCs are normally calculated using one of three different methods: 1) flow weighted composite method, 2) flow weighted discrete sample method, and 3) time-weighted discrete sample method. The method employed will depend on several factors including the available type of sampling equipment and water quality analysis costs.

2.5.1.1 Flow Weighted Composite Sample Method

Flow weighted composite samples are collected every time a prescribed stream volume passes the sampling point. Each time a sample is collected, a constant volume of water is extracted from the stream (either manually or automatically using an automatic sampler with a pump) and then deposited in a single container (which also contains the cumulative volume from previous samples). This type of sampling requires a stream flow gage that can determine the total volume of water that passes the sampling point at a given time. Once the sampling is completed, a single sample from the container is analyzed. Because each of the previously collected individual samples are assumed to represent the concentration of the volume of runoff preceding its capture and because each of these total volumes are equal, the EMC for the total storm event will simply be the concentration of the final composite sample.

$$EMC = Cc \qquad \text{(Eq. 2.9)}$$

Where: EMC = The event mean concentration of the storm event (mg/l) and Cc = The pollutant concentration of the composite sample (mg/l).

2.5.1.2 Flow Weighted Discrete Samples

Similar to flow weighted composite samples, flow weighted discrete samples are collected every time a prescribed stream volume passes the sampling point. However, in this case, each time a sample is collected, a constant volume of water is extracted from the stream (either manually or automatically using an automatic sampler with a pump) and then deposited in a separate container. This type of sampling is normally done when a temporal distribution of the pollutant loading is desired as opposed to only the storm average. The concentration in each sample container I is then determined separately (C_I). Each sample is thus assumed to represent the average pollutant concentration for the preceding volume of water that has passed the sampling point. As with flow weighted composite sampling, this type of sampling requires a stream flow gage that can determine the total volume of water that passes the sampling point at a given time. The EMC for the storm event can then be determined using the following equation:

$$EMC = \Sigma\ (Ci)/n \qquad \text{(Eq. 2.10)}$$

Where: EMC = The event mean concentration of the storm event (mg/l), n= Total number of samples, i=Sample number, Ci= The pollutant concentration of the i^{th} sample (in each container) (mg/l),

2.5.1.3 Time Weighted Discrete Samples

Time weighted discrete samples are collected using a user defined constant time interval (e.g. 10 minutes) and then deposited in a separate sample bottle. In each case, the same sample volume is collected from the stream and a different pollutant concentration is determined for each sample (i.e. Ct). However, unlike with flow weighted sampling, the incremental stream volume (i.e. Vt) will now be different and must be measured. This requires a stream flow gage that is capable of measuring and reporting these incremental stream volumes. Once sample concentrations Ct and the incremental stream flow volumes Vt have been determined, the EMC can be estimated as follows:

$$EMC = (\Sigma\ Ct \times Vt)/\Sigma Vt \qquad \text{(Eq. 2.11)}$$

Where: EMC = The event mean concentration of the storm event (mg/l), t= Number of time intervals; Ct= The pollutant concentration of sample taken in time t (mg/l), Vt= The incremental stream flow volume in time t (L).

In those cases where the streamflow gage may not integrate the instantaneous discharges in order to determine the Vts, the EMC can be determined directly from the individual sample concentrations Ct and the instantaneous discharges q_t using the following equation:

$$EMC = \frac{\sum_{t=1}^{N}\left(\frac{C_t - C_{t-1}}{2} + C_{t-1}\right)\times\left(\frac{q_t - q_{t-1}}{2} + q_{t-1}\right)\times \Delta\,\mathrm{t}}{\sum_{t=1}^{N}\left(\frac{q_t - q_{t-1}}{2} + q_{t-1}\right)\times \Delta\,\mathrm{t}} \qquad \text{(Eq. 2.12)}$$

Where EMC =The event mean concentration of the storm event (mg/l), t= Number of time intervals, Ct = The event mean concentration of n^{th} sample in time t (mg/l), N=Number of samples, Δ t =Time interval, q= Discharge rate (L/s).

Example 2.4

Assume that a research team has collected water quality samples from a test watershed and that all of the samples were taken at using a flow-weighted discrete sample approach and tabulated as follows:

Table 2.7. The information of samples for calculating EMC using flow-weighted discrete sample approach

No of Samples	Flow Discharge (l/s)	Flow Volume (L)	Concentration (mg/l)
1	5	5000	12
2	12	5010	11
3	29	4995	10
4	15	5000	13
5	3	5005	15

The average event mean concentration can be calculated using equation 2.10, so the EMC can be determined as follows:

$$\text{EMC}=\frac{12+11+10+13+15}{5}=12.2 mg/l$$

Now assume that a research team has collected water quality samples from a test watershed and that all of the samples were taken at using a time-weighted (i.e. 15-minutes interval) discrete sample approach and tabulated as follows:

Table 2.8. The information of samples for calculating EMC using Time-weighted discrete sample approach

No of Samples	Flow Discharge (l/s)	Flow Volume (L)	Concentration (mg/l)
1	5	4500	12
2	10	9000	11
3	25	22500	10
4	20	18000	13
5	4	3600	15

Assuming the incremental flow volumes have been measured (i.e. column 3 in Table 2. 8), then the EMC for the storm can be determined using equation 2.11 as follows:

$$EMC = \frac{(12\times 4500)+(11\times 9000)+(10\times 22500)+(13\times 18000)+(15\times 3600)}{4500+9000+22500+18000+3600} = 11.56 mg/l$$

If the incremental flow volumes are not available, then the EMC for the storm can be determined using the instantaneous stream discharges (i.e. column 2 of Table 2.8) and equation 2.12 as follows:

$$\text{EMC}= \frac{[(11.5\times 7.5)+(10.5\times 17.5)+(11.5\times 22.5)+(14\times 12)]\times 15\times 60}{[7.5+17.5+22.5+12)]\times 15\times 60} = 11.7\text{mg/l}$$

2.5.2 Literature Review of EMCs

In order to develop a more reliable dataset from which to construct average EMCs for total nitrogen and total phosphorus for a wide range of both urban and agricultural landues, an extensive literature review was performed. The literature examined as part of this study is summarized in Figure 2.3 and then discussed in detail in the following paragraphs.

	Urban	Residential	Commercial	Industrial	Open Spaces	Roadway	Forest	Golf Course	Mixed Landuse	Undeveloped	Barren	Agriculture	Row Crop	Non-Row Crop	Corn	Soybean	Cotton	Alfalfa	Oat/Wheat	Grassland	Silviculture	Pastureland	Mixed Ag	Rotational Graze	Continuous Graze
Reckhow *et al.* 1980 (9)							●					●	●	●	●	●	●	●	●		●	●	●	●	●
EPA ,1983 (3)	●	●	●		●																				
Elvadi and Moore, 1994 (6)		●	●	●								●										●			
Scueter. J. *et al.* 1997, (8)						●																			
EPA, 1999 (12)												●								●					
Dennis A., *et al.* 1999 (2)	●								●	●	●														
Line *et al.* 2002 (11)								●														●			
Pitt *et al.* 2004 (5)		●	●	●	●	●																			
Crain and Martin, 2009 (10)							●													●	●				
Dubrovsky *et al.* 2010 (1)	●								●	●	●														
K. W. King and Balogh, 2011 (4)		●					●	●			●										●	●			
NSQD KY/TN data, 2014 (7)		●	●	●	●																				

Figure 2.3. The reviewed literatures from which EMC values for different landuses were obtained.

In 1980, Reckhow *et al.* conducted a comprehensive literature review of total nitrogen and total phosphorus loads for a range of agricultural landuses. The report not only summarized the loads in terms of load export coefficients but also provided total annual runoff estimates for each data set. These data sets were used to estimate the associated event mean concentration (EMC) for each landuse using the the following equation:

$$EMC(mg/l) = \frac{ExportLoad\,(kg/ha/year) \times \text{Area(ha)}}{K \times VolumetricRunoff\,(cm^3/\text{year})} \qquad \text{(Eq. 2.13)}$$

Where K is conversion factor and equal to 10^9. Because the Reckhow *et al.* (1980) report included several different datasets for the same type of landuse, a range of EMCs were obtained. These results were then used to synthesize several statistics for each landuse, including the median, maximum and minimum of the calculated values. There statistics were then used to help develop the tables and figures discussed in section 2.5.3.

One of the first attempts to compile EMCs for nutrient loads (i.e. total nitrogen [TN] and total phosphorus [TP]) from urban watersheds was the National Urban Runoff Program (EPA, 1983). This program was conducted between 1978 and 1983 and examined stormwater quality from separate storm sewers in watersheds containing a range of different landuses. Ultimately, the NURP project studied 81 outfalls in 28 communities throughout the U.S. and included the monitoring of approximately 2,300 storm events. The data was compiled for several land-use categories, although most of the information was obtained from residential lands (US-EPA, 1983). Table 2.9 shows summary of the median pollutant EMC values for all sites categorized by landuse.

Table 2.9. Median pollutant EMCs for different landuses (US-EPA, 1983)

Pollutant	**Unit**	**Residential**	**Mixed**	**Commercial**	**Open/Nonurban**
BOD	mg/l	10	7.8	9.3	-
COD		73	65	57	40
TSS		101	67	69	70
Total Lead	(μg/l)	144	114	104	30
Total Copper		33	27	29	-
Total Zinc		125	154	226	195
Total Kjeldahl Nitrogen		1900	1288	1179	965
NO2-N+NO3-N		736	558	572	543
Total P		383	263	201	121
Soluble P		143	56	80	26

In 1991, the U.S. Congress appropriated funds for the U.S. Geological Survey (USGS) to begin the National Water-Quality Assessment (NAWQA) Program. As a part of the NAWQA Program, the USGS works with other federal, state, and local agencies to understand the spatial extent of water quality, how water quality changes with time, and how human activities and natural factors affect water quality across the nation. The NAWQA Program focuses on water quality in more than 50 major river basins and aquifer systems. Together, these include water resources available to more than 60 percent of the population in watersheds that cover about one-half of the land area of the conterminous United States. NAWQA began investigations in 20 of these areas in 1991 and phased in work in more than 30 additional basins by 1997 (Dennis *et al.* 1999).

Dennis *et al.* published the first report of the NAWQA Program and describe the major findings on water-quality issues of regional and national concern. The report presented insights on nutrients and pesticides in water and on pesticides in bed sediment and fish tissue. The major finding of this report regarding nutrient concentrations was that the highest nitrogen and phosphorus concentrations generally were found in agricultural and urban streams. Nutrient concentrations in areas of mixed landuse were lower than in agricultural or urban areas but were higher than in undeveloped areas (Dennis *et al.* 1999).

In 2002, Line *et al.* published a report on pollutant export values from various landuses in the Upper Neuse river basin in North Carolina. The researchers derived several EMCs for seven landuses using data obtained from monitoring six small drainage areas within the Upper Neuse River Basin, which is located in east central North Carolina (Line *et al.* 2004).

In 2004, Jeff P. Lin, provided an additional literature review of several publications that contained reported values of both LECs and EMCs. Results from this study were also synthesized and used in developing average EMC values for a range of landuses.

In 2004, Pitt *et al.* analyzed data from the National Stormwater Quality Database (NSQD). The database was originally constructed to serve as a basis for performing an assessment of water quality in the United States. At the time of the analysis, the database contained over 10 years of monitoring data collected from more than 200 municipalities throughout the country in this report, a basic analysis was conducted on the data in the

NSQD dataset to provide median EMC values of various pollutants for different landuses. Then, additional comparisons were made between the EMC values reported in the NURP (1983) and the NSQD database (EPA, 1983). The results revealed that the nutrient EMCs have been remained relatively unchanged between the two datasets. However, sediment and heavy metal concentrations have been reduced across all the landuses, and lead concentrations, have dropped by an order of magnitude over the last 20 years (Pitt *et al.* 2004). Table 2.10 shows median EMC values of selected pollutants for standard landuse categories in the NSQD database.

Table 2.10. Median Value of EMCs for selected pollutant for standard landuse categories (Pitt *et al.* 2004)

Parameter	Overall	Residential	Commercial	Industrial	Freeways	Open Space
Area (acres)	56	57.3	38.8	39	1.6	73.5
% Impervious	54.3	37	83	75	80	2
Precipitation Depth (in)	0.47	0.46	0.39	0.49	0.54	0.48
TSS (mg/l)	58	48	43	77	99	51
BOD5 (mg/l)	8.6	9	11.9	9	8	4.2
COD (mg/l)	53	55	63	60	100	21
NH3 (mg/l)	0.44	0.31	0.5	0.5	1.07	0.3
NO2+NO3 (mg/l)	0.6	0.6	0.6	0.7	0.3	0.6
Total Kjeldahl Nitrogen (mg/l)	1.4	1.4	1.6	1.4	2	0.6
Filtered Phosphorus (mg/l)	0.12	0.17	0.11	0.11	0.2	0.08
Total Phosphorus (mg/l)	0.27	0.3	0.22	0.26	0.25	0.25

In 2010, Dubrovsky N. M. *et al.*, summarized the results of a series of USGS publications that was published as: *The Quality of Our Nation's Waters*. In the report, they presented an assessment of the occurrence and distribution of nutrients in the nation's streams and groundwater based on water-quality data from about 500 streams and over 5,000 wells collected from 1992 through 2001. The report provided estimates of five water quality constituents (i.e. total nitrogen, total phosphorus, nitrate, ammonia and orthophosphate) in 51 major hydrologic systems across nation that were collected as part of the USGS National Water Quality Assessment (NAWQA) program. The report summarizes the result of their analyses using a range of statistics and box and whisker plots for both TN and TP and for both streams and groundwater for four different landuses: agricultural, urban, mixed and undeveloped lands (Dubrovsky N. M. *et al.* 2010).

In 2011, King and Balogh conducted a study to quantify the surface runoff losses of nitrate-nitrogen (NO3-N), total nitrogen (TN), dissolved reactive phosphorus (DRP), and total phosphorus (TP) resulting from prevailing practices on a managed golf course. Inflow and outflow discharge waters on a sub-area of the Northland Country Club (NCC) located in Duluth, Minnesota were measured for both quantity and quality from April through November from 2003 to 2008. Then, the measured EMC and LEC values from different landuses were compared against a range of literature values, which were presented as box and whiskers plots (See Figure 2.5). The range of nutrient values were obtained from multiple studies documented in their report. The findings of their study highlight the need for adopting conservation practices aimed at reducing offsite nutrient transport (King and Balogh, 2011).

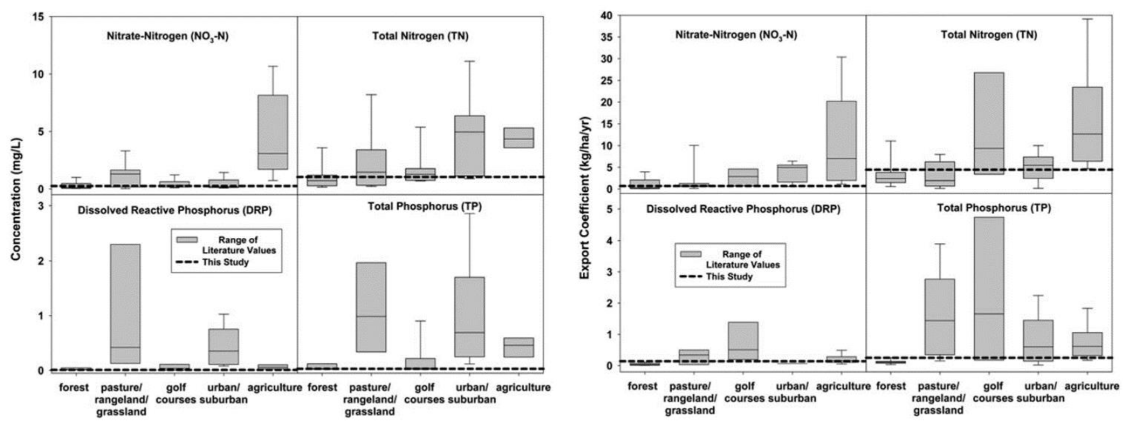


Figure 2.4. Comparison between the measured EMC and LEC values against literature values presented in King and Balogh, 2011.

2.5.3 Summary of EMCs

The data from the literature review were compiled and analyzed in order to develop summary statistics and realistic ranges of values of total nitrogen and total phosphorus for both urban and agricultural landuses. In most cases, the EMCs are reported as mean or median values depending on the type of summary statistics reported in the reviewed studies. In other cases, box and whisker plots of the underlying data series have been reported. The additional statistics associated with such plots typically included (10-percentile, 25-percentile, 50-percentile (median), 75-percentile, 90-percentile, minimum and maximum values) for each landuse.

Once all the statistical values (median, mean, percentiles, minimum and maximum) of the EMCs for both urban and agricultural landuses were collected, they were entered into a database. A review of the magnitude and range of the resulting values was conducted to examine the variability in the values of the nutrient data each specific landuse. Since the number of samples from which the mean and median values were obtained were not reported in all the studies, it was not possible to calculate a weighted value of all medians or means. Hence, four tables were created in which statistical values for TN and TP EMCs were categorized for each landuse. The resulting tables are provided in appendix A. Because most of the literature reported the median values of the EMCs rather than the means, the median values were used. This likely provides a more realistic estimate of the typical EMCs since the use of a mean value can sometimes be significantly skewed by data points that appear to be outliers based on a comparison with other reported values.

Different types of statistic plots were generated for each landuse based on the types of values available from the database. For instance, for some landuses, there was only one single median value available in a study, while in other cases, all of the summary statistics were available for the same landuses in other studies. The different types of whisker plots used in reporting the EMCs for the different landuses are shown in Figure 2.5.

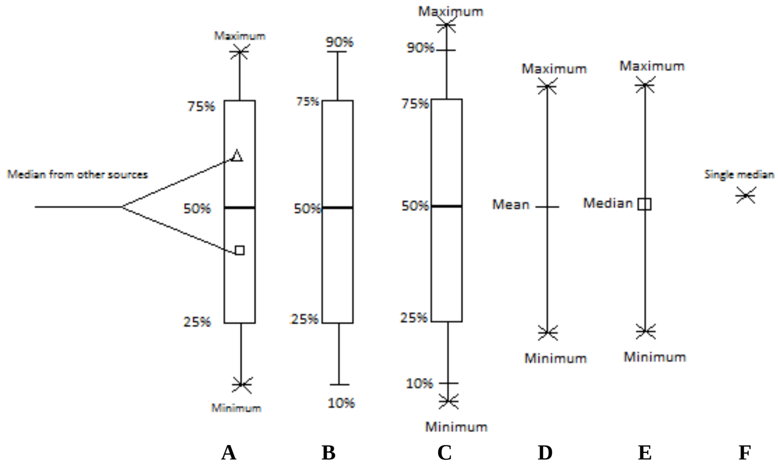


Figure 2.5. Different types of statistic plots used to report EMC statistics

Type A plots were created for those cases where a box and whisker plot (including minimum, maximum, 25-percentile, 75-percentile, 50-percentile) were provided in one study, and two single median values from obtained from two other studies. Type B plots were created for those cases in which a box and whisker plot (including 10-percentile, 90-percentile, 25-percentile, 75-percentile, 50-percentile) was available, but only from one study. Type C plots were created for the cases in which one box and whisker plot (including 10-percentile, 90-percentile, 25-percentile, 75-percentile, 50-percentile) were provided in one study, and two single median values were available from two other studies. In this case, the two single median values were used to determine the minimum and maximum values of the plot. Type D plots were created for the cases in which only two single median values were available from two separate studies. In this case, the average of the two medians was determined and also drawn on the plot as a dashed line in the middle). Type E plots were created for those datasets in which three single median values were reported from three separate studies and where the values were then treated as a minimum, median and maximum of the plot. Finally, the Type F plot was used to report the results where_there was only one single median value available (from that landuse) from the literature reviewed.

Figures 2.6 and 2.7 provide wisker plots of TN and TP EMCs for both urban and agricultural landues respectively. The numbers associated with each landuse as listed in the abscissa of the plots corresponds to the reference(s) from which the data for the plot was obtained. As can be seen from the figures, the EMCs associated with the urban landuse exhibits a relatively wide range of values which reflects a mixture of various types of urban activities (e.g. residential, commercial, and industrial). In those cases where one may need an EMC value for a mixed urban landuse, and the division of landuse into different categories is not of importance, the singular “urban landuse” (see Figures 2.6 and 2.7) can be used. For both TN and TP plots, roadway and golf course landuses exhibit the highest median EMC value. On the other hand, undeveloped urban landuses, had the lowest TN and TP median EMC values. Among the plots that represent EMCs for urban landuses, the mixed landuse represents the EMC value for a combination of agricultural and urban landuses. Among agricultural landuses, continuous planting of corn exhibits the widest range of TN and TP EMC with the maximum value equal to 92.5 (mg/l) and 24.5 (mg/l), respectively. On the other hand, silviculture had the lowest TN and TP median EMC values equal to 0.64 (mg/l) and 0.06 (mg/l), respectively.

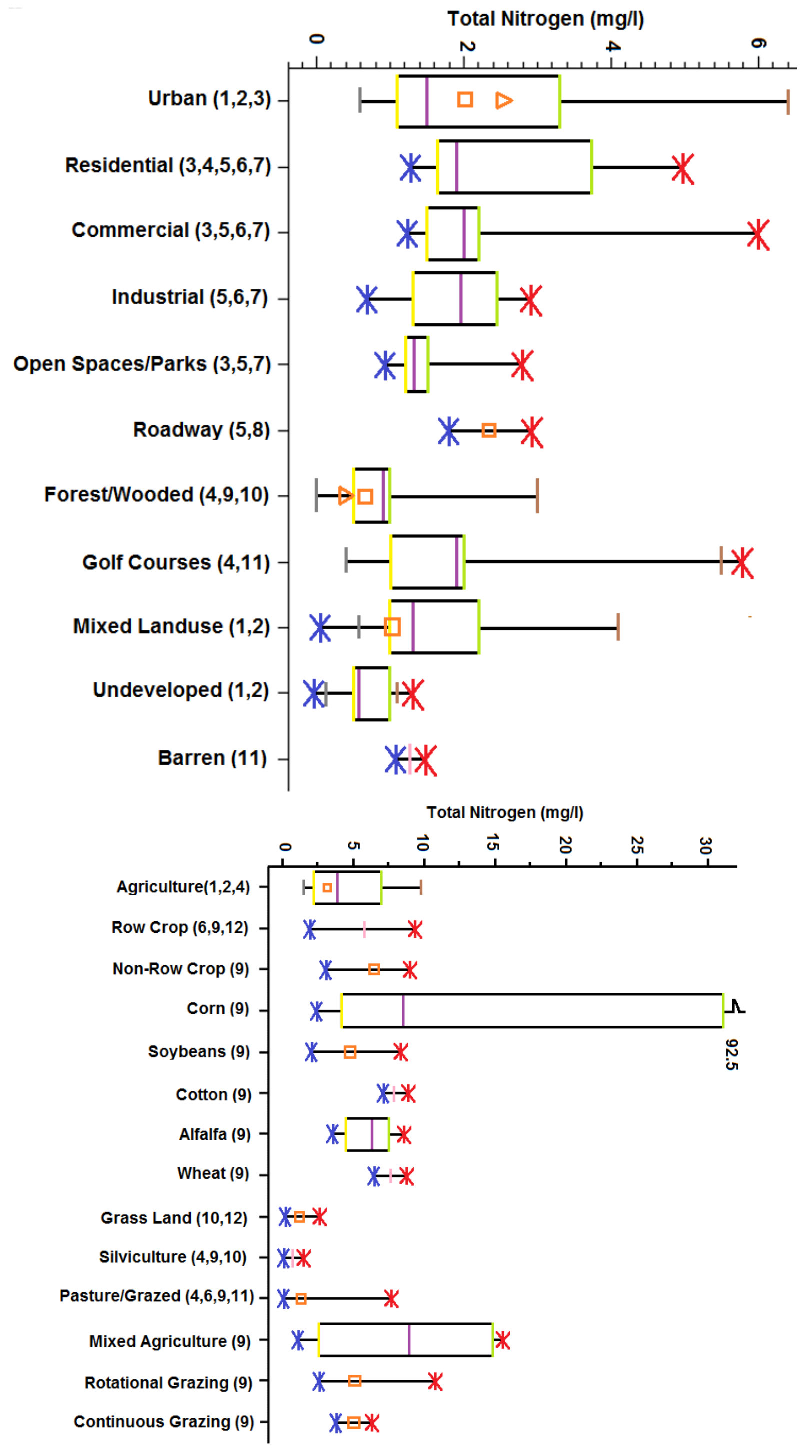


Figure 2.6. Total Nitrogen EMC for Urban and Agricultural Landuses

---

References for figure 2.6 1- Dubrovsky*et al.* 2010, 2- Dennis *et al.* 1999, 3- United States Environmental Protection Agency (US-EPA), 1983, 4- King and Balogh, 2011, 5- Pitt, *et al.* 2004, 6-KY USGS report, 1994, 7-NSQD, 2014, 8-Scueter*et al.* 1997, 9- Reckhow *et al.* 1980, 10-KY USGS report, 2009, 11-Line *et al.* 2002, 12-EPA, 1999.

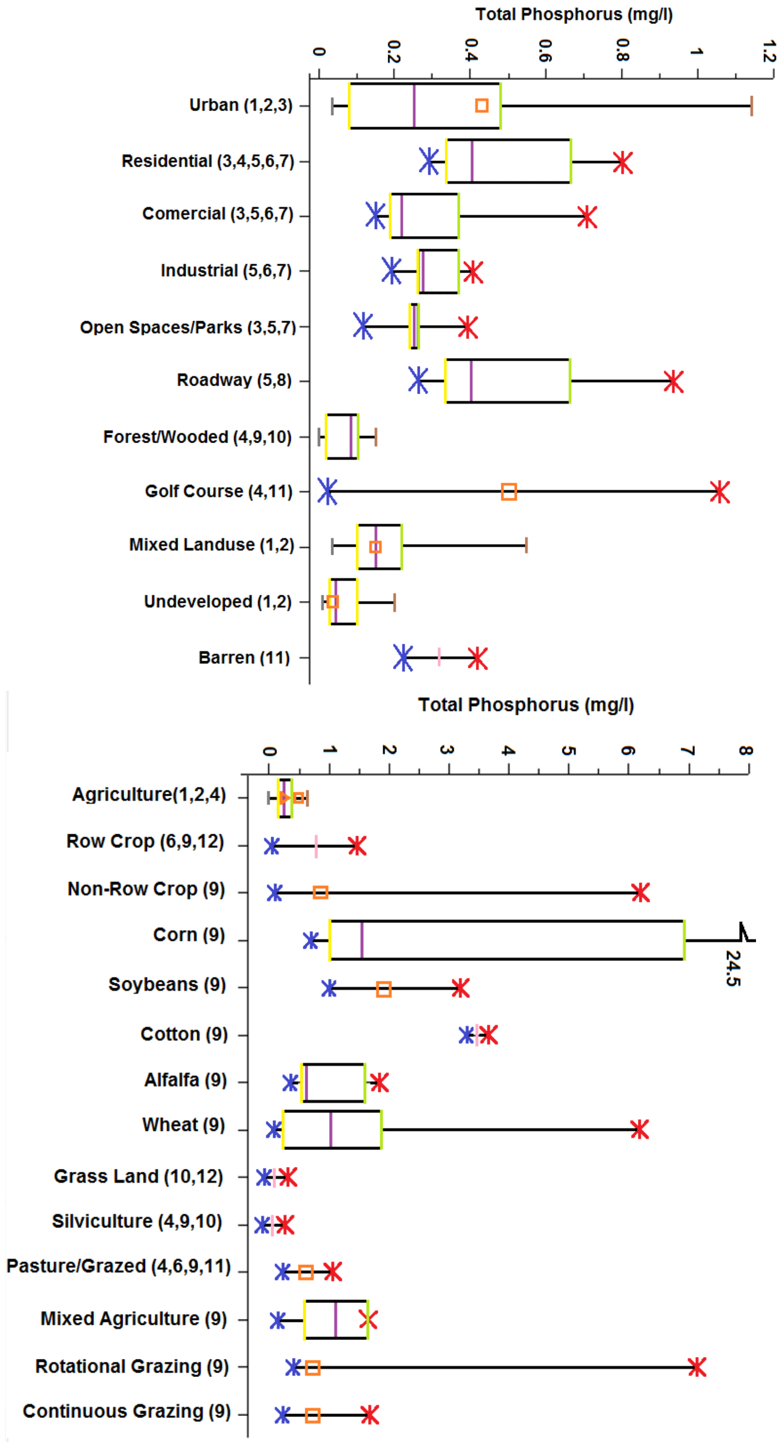


Figure 2.7. Total Phosphorus EMC for Urban and Agricultural Landuses

References for figure 2.7 1- Dubrovsky *et al.* 2010, 2- Dennis *et al.* 1999, 3- United States Environmental Protection Agency (US-EPA), 1983, 4- King and Balogh, 2011, 5- Pitt *et al.* 2004, 6-KY USGS report, 1994, 7-NSQD, 2014, 8- Scueter*et al.* 1997, 9- Reckhow *et al.* 1980, 10-KY USGS report, 2009, 11-Line *et al.* 2002, 12-EPA, 1999.

In addition to the wisker plots of EMCs for different urban and agricultural landuses, tables of median, maximum and minimum values were also synthesized from the literature review. These values are provided in Table 2.11 below. These values have been recommended for use in the Kentucky Nutrient Model.

Table 2.11. Summary statistics of TN and TP EMCs for different landuses

Landuse	TN (mg/l)			TP (mg/l)		
	Median	Max	Min	Median	Max	Min
Urban						
Barren	1.32	1.35	1.29	0.32	0.43	0.21
Roadway	2.35	3	1.7	0.36	0.95	0.25
Residential	2.32	5	1.25	0.405	0.81	0.3
Commercial	2	6.08	1.3	0.22	0.71	0.16
Industrial	1.95	2.9	0.66	0.27	0.41	0.2
Recreational						
Parks	1.33	2.8	0.93	0.25	0.4	0.12
Golf Course	4	6.12	1.9	0.55	1.07	0.03
Natural						
Forest	0.64	0.9	0.45	0.094	0.15	0.02
Grassland	0.61	2.8	0.45	0.06	0.15	0.02
Agricultural						
Pasture	3.54	4.11	2	0.46	1	0.25
Row Crops	2.6	8.5	2.2	0.26	1.54	0.06
Silviculture	0.64	0.9	0.45	0.06	0.12	0.02

2.6 Load Export Coefficient (LEC) Approach

Load export coefficients (LECs) represent the average total amount of a pollutant discharged from a given landuse area over a year time period (e.g. kg/ha/year) (Lin, 2004). If the areas of the different landuses (A_i) within a watershed are known, then an estimate of the annual total load of that pollutant from that watershed can be obtained from the following equation

$$L_W = \sum_{i=1}^{n} LEC_i \times A_i \quad , \qquad i=1,2,\ldots n \qquad \text{(Eq. 2.14)}$$

Where: Lw=The total annual load from a watershed (kg); n= Total number of landuses; i= Landuse number; LECi= Load export coefficient of the i^{th} landuse (kg/ha/year), Ai= Area of the i^{th} landuse (ha);

Example 2.5

A watershed planner is trying to estimate the total annual TN load from a watershed that has the following distribution of LECs.

Table 2.12. Information of the hypothetical watershed for applying the LEC approach

Landuse	Area (ha)	Mean TN LEC* (kg/ha/year)
Forested	300	2.45
Rowcrops	100	9
Non Row Crop	120	6
Pasture	150	4.63

*The LEC values have been adapted from Beaulac and Reckhow, 1982

The annual TN load coming from all landuse(s) within the watershed into the discharging stream can be calculated using the LEC approach as follow:

Total annual TN load= [(300×2.45)+ (100×9)+ (120×6)+ (150×4.63)] =3049 kg/year or 2714 lbs/year

2.6.1 Development of LECs

The process of calculating LECs will vary depending on the sampling method employed. For example, if the water quality samples are taken using a discrete sampler using a flow-weighted approach, the total load for a single storm j can be calculated using following equation:

$$\text{Total Load} = \sum_{j=1}^{M} Vtotal_j \frac{\sum_{i=1}^{N} Ci}{N} \qquad i=1,\ldots N \quad, j=1,\ldots M \qquad \text{(Eq. 2.15)}$$

where M = Total number of storms in a year, j=Strom number, i=Sample number N = Total number of samples in the j^{th} storm, V_{totalj} = Total runoff volume of the j^{th} storm (L), C_i= Pollutant concentration in sample i (mg/l).,

However, if the samples are collected using a composite sampler using a flow weighted approach, then the total mass of load can be calculated as below:

$$\text{Total Load} = V_T C_T \qquad \text{(Eq. 2.16)}$$

Where: V_T=Total runoff volume of the storm (L), C_T=Composite sample pollutant concentration (mg/l)

2.6.2 Literature Review of LECs

In order to develop a more reliable dataset from which to construct average LECs for total nitrogen and total phosphorus for a wide range of both urban and agricultural landues, an extensive literature review was performed. The literature examined as part of this study is summarized in Figure 2.8 and then discussed in detail in the following paragraphs.

	Urban	Residential	Commercial	Industrial	Roadway	Forest	Golf Course	Row Crop	Non-Row Crop	Fallow Cultivated	Various Rotation	Corn	Cotton	Sorghum	Soybean	Oat/Wheat	Agriculture	Pastureland	Grassland	Mixed Ag
Michael and Reckhow, 1982 (1)	●		●	●		●	●	●	●									●		●
Horner, R.R., et al. 1990 (2)		●			●	●												●	●	
Dodd, R. C., et al. 1992 (5)						●											●			
Burton, G.A. and R.E. Pitt, 2002 (3)		●	●	●	●															
Daren Harmel, et al. 2006 (6)										●	●	●	●	●	●	●		●		
K. W. King and J. C. Balogh, 2011 (4)		●				●	●										●	●		

Figure 2.8. The reviewed literatures from which load values for different landuses were obtained.

In 1980, Reckhow *et al.* proposed an uncertainty analysis methodology that used an input-output phosphorus lake model to quantify the relationship between landuse and lake trophic quality. One of the significant parameters for employing the methodology was the total phosphorus and total nitrogen LECs from different landuses. Part of the study included a comprehensive literature review of total nitrogen and total phosphorus loads for a large range of forest, urban and agricultural landuses. They also discussed several criteria that should be considered in selection of appropriate LECs (Reckhow et al. 1980). Subsequently in 1982, Beaulac and Reckhow published a paper that summarized the results of the 1980 Reckhow *et al.* report. They also discussed some of the major physiographic and climatic characteristics which control the magnitude of the nutrient flux. The characteristics include landuse description, soil texture, precipitation, water runoff and other site specific features that might have an effect on nutrient runoff

(Beaulac and Reckhow, 1982). The paper also included a series of box plots that summarized the ranges of the LECs for TN and TP for the different landuses evaluated in their (See Figure 2.9).

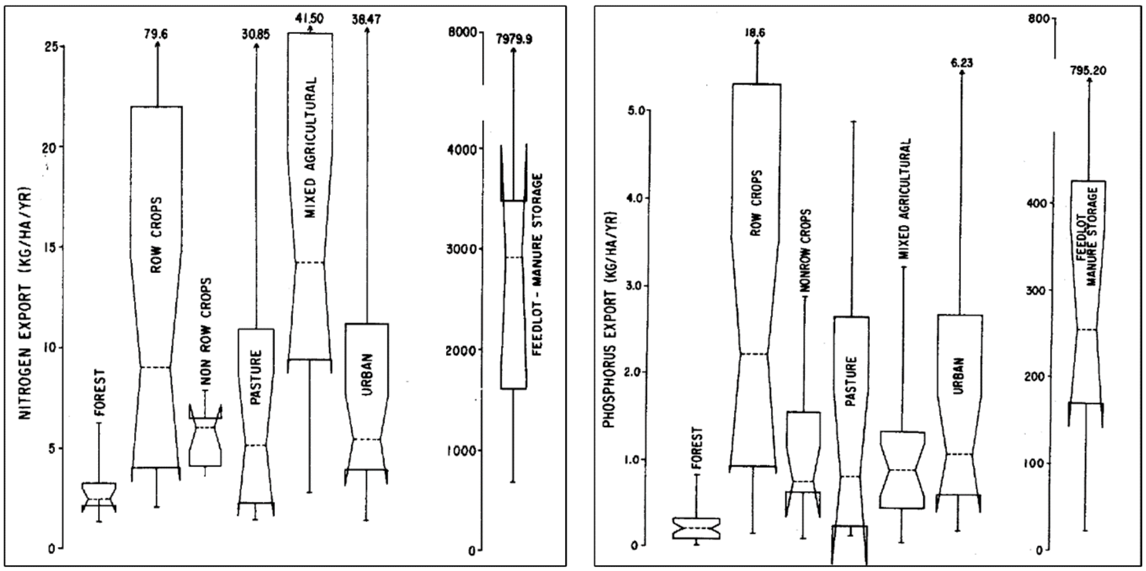


Figure 2.9. Box Plots of TN and TP LECs from various landuses
(Beaulac and Reckhow, 1982)

In 1992, Dodd *et al.* published the results from a study that examined median export coefficients based on literature review of at least 78 studies (not documented in the report), which were then used to estimate nutrient loading in watersheds in the Albermarle-Pamlico estuarine system, located on the North Carolina-Virginia coastal areas (Dodd *et al*. 2002). They found that among all point and nonpoint source pollutants, agricultural landuse was the largest contributor of both phosphorus and nitrogen inputs. Table 2.13 shows a summary of median and 25%-75% of TN and TP LECs for different landuses used the Dodd *et al.* 2002 study.

Table 2.13. Median and range of TN and TP LECs (lbs/acre/year) used in Dodd *et al.* 2002

	Agriculture	**Forest/Wetland**	**Developed**
Total Nitrogen			
Low (25%)	4.45	0.61	4.45
Median	8.72	2.07	6.68
High (75%)	12.73	3.38	8.65
Total Phosphorus			
Low (25%)	0.49	0.08	0.40
Median	0.88	0.12	0.94
High (75%)	1.81	0.19	1.34

In 2002, Burton and Pitt, published a handbook entitled *Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists and Engineers* for use by scientists and watershed planners in estimating the water quality impacts of stormwater runoff from different landuses (Burton and Pitt, 2002). The handbook provides a logical approach for an experimental design that can be tailored to address a wide range of environmental concerns. The handbook also contains several chapters which discuss impairment and sources of stormwater pollutants, effects of stressor categories on human and ecosystem, overview of watershed assessment tools and problem formulation, sampling collection methods, ecosystem component characterization, statistical analyses of receiving water data, and data interpretation. They also present an estimate of typical urban area pollutant yields from different landuses, including commercial, residential, highway, industrial, which were synthesized from several separate studies (Burton and Pitt, 2002). Table 2.14 shows a summary of pollutant LECs for various urban landuses reported in Burton and Pitt, 2002.

Table 2.14. Typical pollutant LECs (lbs/acre/year) reported in Burton and Pitt, (2002)

	TSS	TP	TKN	NH3-N	NO2-N and NO3-N
Commercial	1000	1.5	6.7	1.9	3.1
Parking lot	400	0.7	5.1	2	2.9
High-Density Residential	420	1	4.2	0.8	2
Medium-Density Residential	250	0.3	2.5	0.5	1.4
Low-Density Residential	65	0.04	0.3	0.02	0.1
Highway	1700	0.9	7.9	1.5	4.2
Industrial	670	1.3	3.4	0.2	1.3
Shopping Center	440	0.5	3.1	0.5	1.7

In 2006, Harmel *et al*. conducted a study to compile measured annual total nitrogen (TN) and total phosphorus (PP) loads resulting from field scale transport from agricultural land uses. They relied heavily on the previous extensive survey of Reckhow *et al*. 1980 and then added additional data from more recent published studies that reported measured annual TN and TP data from agricultural land uses. In this study, annual TN and TP load data were obtained from 40 publications, resulting in a 163-record database with more than 1,100 watershed years of data (Harmel *et al*. 2006). A summary of the results is provided in Table 2.15 below.

Table 2.15. Median annual pollutant values (kg/ha/year) for various landuses treatments (Harmel *et al*. 2006).

Landuse	Total N	Dissolved N	Particulate N	Total P	Dissolved P	Particulate P
Tillage						
Conventional	7.88	2.41	7.04	1.05	0.19	0.64
Conservation	7.7	2.3	3.4	1.18	0.65	1
No-Till	1.32	4.2	1.8	0.63	1	0.8
Pasture/Range	0.97	0.32	0.62	0.22	0.15	0
Conservation Practice						
None	2.19	1.6	1.7	0.41	0.26	0.64
One Practice	6.73	1.33	14.8	0.61	0.14	0.37
2+Practice	8.72	2.61	3.3	1.22	0.5	0.75
Corn	18.7	3.02	7.27	1.29	0.22	0.85
Cotton	7.88	2.47	9.13	5.01	0.68	5.6
Sorghum	3.02	0.3	-	1.18	-	-
Peanuts	-	-	-	-	0.05	-
Soybeans	-	2.7	21.9	0.45	0.6	9.6
Oats/Wheat	6.61	1.31	5.9	2.2	0.3	3.45
Fallow Cultivated	3	0.9	2.7	1.08	0.48	0.45
Various Rotation	3.68	3.12	1.36	0.59	0.8	0.6

2.6.3 Summary of LECs

Wisker plots of the LECs for the different landuses for urban and agricultural watersheds are provided in Figures 2.7 and 2.8. The numbers associated with each landuse as listed in the abscissa of the plots corresponds to the reference(s) which serve as the basis of the plot. In comparing the two figures, it is apparent that urban landuses exhibit a relatively wide range of values. This variability reflects the diversity of urban activities from low density residential housing to industrial developments (Beaulac and Reckhow, 1982). For the purpose of this study, the residential landuses were divided into five categories (e.g. single family low density, single family medium density, single family high density, multi-family and urban residential; see Appendix A), however, the median values from all categories were used to create one single box plot for residential landuses. In general, industrial and commercial watersheds have relatively higher impervious surfaces as compared to residential areas. This may be one reason for the occurrence of higher export loads for industrial and commercial landuses in Figure 2.10 and 2.11.

From the results shown in Figure 2.10, one can observed that the mixed urban landuses have the widest range of TN and TP LEC with the maximum value equal to 36.47 (kg/ha/year) and 6.2 (kg/ha/year) respectively. Similarly, Figure 2.11 shows that the row crop landuse has the widest range of TN and TP LEC with the maximum value equal to 79.6 (kg/ha/year) and 18.6 (kg/ha/year) respectively. Forest landuses were observed to have the lowest median LECs for both TN and TP.

The mixed agriculture landuse contains a number of various urban and agricultural activities. In many cases, one activity such as a continuous corn or grazing land dominates. In others, a small percentage of the watershed is urbanized (Beaulac and Reckhow, 1982). However, the agricultural landuse represents the combination of different agricultural activities and does not contain any mixture of urban areas. In general, industrial landuses export a high rate of TP load as compared to other areas. In addition, the load coming from row cropped watersheds is notably higher than loads from non-row cropped watersheds. This may be due to the fact that row cropped watersheds usually undergo more disturbance of the soil surface as compared to non-row cropped watersheds (Beaulac and Reckhow, 1982).

In addition to the wisker plots of LECs, tables of median, maximum and minimum values were also synthesized from the literature review. These values are provided in Table 2.16 below. These values have also been recommended for use in the Kentucky Nutrient Model.

Table 2.16. Summary statistics of TN and TP LECs for different landuses

Landuse	TN (kg/ha/year)			TP (kg/ha/year)		
	Median	Max	Min	Median	Max	Min
Urban						
Roadway	2.4	3.5	1.3	1	1.5	0.8
Residential	4.2	7	0.45	0.55	1.13	0.05
Commercial	5.2	11.1	1.6	1.25	1.7	0.8
Industrial	6.6	7.95	5.3	1.86	2.25	1.47
Recreational						
Golf Course	3.76	6	1.52	0.84	1.5	0.19
Natural						
Forest	2.45	6	1.5	0.2	0.9	0.01
Grassland	4.2	7.1	1.2	0.9	4.9	0.2
Agricultural						
Pasture	4.63	30.85	1	0.9	4.9	0.2
Row Crops	9	79.6	2	2.4	18.6	0.2

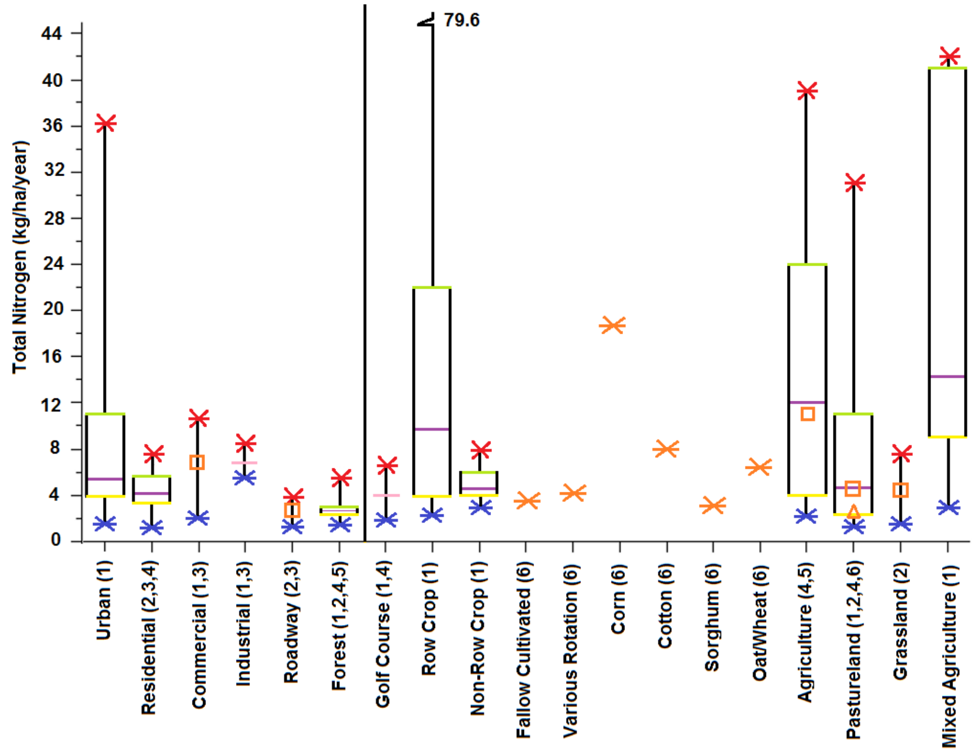


Figure 2.10. Total Nitrogen LECs for Urban and agricultural Landuses

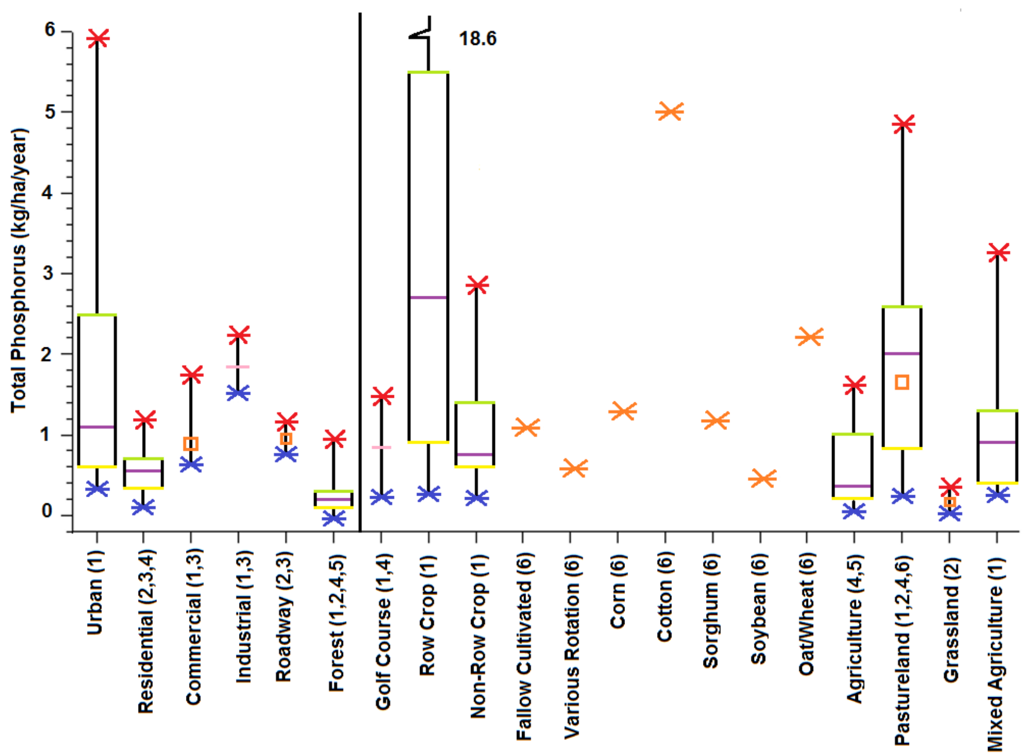


Figure 2.11. Total Phosphorus LECs for Urban and Agricultural Landuses

References for figures 2.10 and 2.11: 1-Michael and Reckhow, 1982, 2-Horner, R.R., et al. 1990, 3-Burton, G.A. and R.E. Pitt, 2002, 4-K. W. King and J. C. Balogh, 2011, 5- Dodd, R. C., et al. 1992, 6-Daren Harmel, et al. 2006

2.7 Summary and Conclusions

The goal of this study was to compile LEC and EMC data for urban and agricultural landuses by conducting an extensive literature review and building a dataset which provides summary statistics of the values reported in each reviewed study (see appendix A). The dataset was then used to generate several summary statistical plots for each landuse. Generally, in some cases the values of the LECs varied significantly for one single landuse. The reason is that these values are not only a function of the landuse, but are also dependent on the climatological and physical characteristics of the watersheds. The results of export loads in the urban areas showed that the values of TN and TP tend to vary proportionally for different landuses. For example, a landuse that exports a high TN load also tends to export a high TP load. However, for both the LECs and EMCs, TN values were significantly higher than the TP values for all urban and agricultural landuses. In addition, agricultural landuses typically had higher EMCs and LECs as compared to urban landuses.

The results have been provided for use by stormwater professionals in predicting total nitrogen and total phosphorus loads from both urban and agricultural watersheds. The LECs can be used to provide rough estimates of annual loads while the EMCs can be used to predict the loads associated with single storm events or used with watershed models like the Kentucky Nutrient Model to predict annual loads. Theoretically, the use of a watershed model will provide a way to model the temporal distribution of loads over an extended time period as well as to test the impacts of different best management practices (BMP) on nutrient reductions.

3 Chapter 3: Review of Cost and Performance of Urban and Agricultural Best Management Practices (BMPs)

3.1 Introduction and Purpose

Nutrients are absolutely necessary for the health of aquatic systems. However, excessive nutrients can cause water pollution and public health issues throughout the country. While nutrients occur naturally in the environment, human activities are a common cause of excessive nutrient loading to water bodies. Human activities associated with nutrient over-enrichment in water bodies include agricultural and urban/residential fertilization, treated sewage effluent, detergents, septic systems, combined sewer overflows, sediment mobilization, and animal waste (International stormwater BMP database, 2012).

The increase of impervious surface areas resulting from land development can increase the amount of runoff after a rainfall event and disturb natural hydrological processes. The increased water volume can degrade water quality and damage properties and habitats. In addition, an increase in runoff can cause erosion of barren land surfaces and the transport of sediment into water bodies. The sediment coming from agricultural lands or farms typically contains nutrients such as particulate nitrogen and phosphorus, which exist in fertilizers and pesticides.

When these substances get into the water, they create stormwater quality impacts which can lead to the degradation of water bodies. Degradation of lakes, streams, and wetlands by urban stormwater runoff reduces property values, raises bills from public water utilities, and reduces tourism and related business income (North Carolina Division of Water Quality (NCDWQ), 2007).

Best Management Practices (BMPs) include structural or non-structural practices that can be used to help to reduce runoff, erosion, solids, metals, bacteria and nutrient load into water bodies. The runoff coming from urban watersheds can be controlled by implementing various urban BMPs, which reduce the runoff and decrease the peak flow of storm events. Sediment erosion and nutrients coming from agricultural watersheds can be controlled or reduced by using various agricultural practices that control erosion and trap sediment.

Depending on the type of BMP, several treatment processes can result in the reduction of nutrient concentrations in stormwater BMPs. First, the load exported from a BMP can be reduced by incorporating some type of infiltration mechanism of the practice. As the runoff reduces, the amount of dissolved nutrient in the outlet of watershed also decreases. Secondly, nutrients can be removed by settling/sedimentation processes.

There are many criteria that can be used in the selection of a particular BMP for a specific region. First of all, the decision makers need to know the source of pollution in the watershed of interest. Then, they need to have information about the cost and performance of each BMP. Several researches have compiled a range of data related to the cost and efficiency of different types of BMPs. Most of these data sets tend to be for a small set of BMPs for a localized or regional area. The performance of the different BMPs has been found to be a function of several parameters, including: watershed physical characteristics, the runoff volume and amount of sediment and nutrients entering the BMP, the physical dimensions of the BMPs (i.e. slope, dimensions, outlet structure, native soil type, infiltration rate, sediment settling rates, etc.).

This chapter contains a summary of the results of an extensive literature review of both urban and agricultural BMPs. Reported information includes: a brief description of each BMP, a list of advantages and disadvantages of each BMP, feasibility considerations, potential applications, costs, and the relative efficiency or effectiveness of the BMP. In this study, BMP performance (or effectiveness) is defined as the percent reduction of sediment or nutrients as they pass through the BMP. Reported cost data include land costs, construction costs, and maintenance and operations costs. The data have been summarized in such a way as to allow modelers or designers to perform preliminary siting and cost analyses for a wide range of possible BMPs.

3.2 Background

In 1972, the National Pollutant Discharge Elimination System (NPDES) program was established under the Clean Water Act. NPDES Phase I and Phase II require communities to develop, implement, and enforce a program to reduce pollutants in runoff from new development and redevelopment projects (The Kansas City Mid-America Regional Council (MARC) and the Kansas City Metro Chapter of the American Public Works Association (APWA), 2012).

Under the Clean Water Act (CWA) Section 401(a) (1), the United States Environmental Protection Agency (US-EPA) is required to develop criteria for water quality based on the latest scientific knowledge. The US-EPA is currently encouraging all states, territories and authorized tribes to accelerate efforts related to the development of water quality standards for nutrients. The water quality standards developed by States serve as the basis for a biennial assessment of water body use attainment. As a result of biennial assessments, States develop "303(d)" lists of waters not attaining water quality standards. States are then required to initiate the TMDL process to address these impairments. (International stormwater BMP database technical report, 2012). While a developed TMDL has no direct regulatory force related to non-point source reductions, they can provide a load analysis that may provide guidance for the design and possible BMPs. Such BMPs may be implemented as part of a watershed management plan or facilitated through 319 grants or as part of some type of mandated flow or nutrient reduction requirement associated with a court order consent decree.

Several researchers, federal and state agencies, local governments, and professional organizations have attempted to assemble information on urban and agricultural BMPs for use in assistance or guidance documents related to the management of stormwater or agricultural runoff. One of the most comprehensive databases of BMPs is the International Stormwater Best Management Practices (BMP) Database. This database began in 1996 under a cooperative agreement between the American Society of Civil Engineers (ASCE) and the U.S. Environmental Protection Agency (US-EPA). In 2004, the project transitioned to a more broadly supported coalition of partners led by the Water Environment Research Foundation (WERF), including the Federal Highway Administration (FHWA), American Public Works Association (APWA), and the Environmental and Water Resources Institute (EWRI) of ASCE. The Project features a database of over 500 BMP studies, performance analysis results, tools for use in BMP performance studies, monitoring guidance and other study-related publications. The overall purpose of the project is to provide scientifically sound information to improve the design, selection and performance of BMPs. Continued population of the database and assessment of its data will ultimately lead to a better understanding of factors influencing BMP performance and help to promote improvements in BMP design, selection and implementation (International Stormwater Best Management Practices (BMP) Database project website). In 2010-2011, the sponsors solicited a series of comprehensive (BMP) performance analysis technical papers based on data contained in the database. The most recent technical paper related to the database was released in 2014 and provides a statistical summary for various category of pollutants including solids, bacteria, nutrients and metals. The report contains box plots which show the influent and effluent concentrations for different pollutants and different BMPs, which have been generated using the observations from documented numerous field studies. The report also provides tables which include various influent/effluent statistics, including the median values as well as 25th and 75th percentiles.

In 1992, Rodulfo Camacho conducted a study to evaluate the financial cost-effectiveness of point and non-point source nutrient reduction technologies in the Chesapeake Bay Basin. They suggested that unit costs and nutrient reduction efficiencies presented in their report can also be used in optimization models to identify cost-effective nutrient reduction strategies. The study utilized BMP information from the Chesapeake Bay Program BMP tracking database and BMP longevity studies conducted by (Rosenthal and Urban, 1990. BMP unit cost data were obtained from several states. In their report, cost-effectiveness is defined as the ratio of the cost per pound of pollutant per year (Rodulfo Camacho, 1992).

In 1997, Brown and Schueler conducted a study to develop cost prediction equations and assess the cost-effectiveness of the most commonly used urban stormwater BMPs in the Mid-Atlantic region using 1996 - 1997 cost data. The BMPs included 38 pond systems, 12 bioretention areas, nine sand filters, and five infiltration trenches. In general, they found that the total construction costs of the examined BMPs have a significant correlation with the storage volume of the practices Table 3.1 shows a summary of the cost prediction equations for different urban BMPs (Brown and Schueler, 1997).

Table 3.1. Cost prediction equations for different urban BMPs (Brown and Schueler, 1997)

Total Construction Costs ($)		Total Number of Practices
All Ponds and Wetlands[1]	$23.07V^{0.705}$	41
Dry Extended Detention Pond[1]	$11.72V^{0.76}$	18
Wet Extended Detention Pond[1]	$12.87V^{0.729}$	11
Wet Ponds[1]	$106.07V^{0.615}$	9
Sand Filters[2]	$156.67WQV^{0.571}$	9
Bioretention Practices[2]	$6.88WQV^{0.991}$	11

1-V=Total basin volume (cfs); 2-WQV= Water quality volume (cfs)

In 1999, the United States Environmental Protection Agency (US-EPA) conducted a study entitled “A Preliminary Data Summary of Urban Stormwater BMPs” to summarize information regarding the effectiveness, the expected cost and environmental benefits of urban BMPs (US-EPA, 1999). The report also provides detailed information on the design of various structural and nonstructural urban BMPs. Table 3.2 shows a summary of expected pollutant removal efficiency range of different urban BMPs used in their study.

Table 3.2. Typical pollutant removal efficiency of different urban BMPs (US-EPA, 1999)

BMPs	Typical Removal Efficiency (%)		
	Suspended Solid	Nitrogen	Phosphorus
Dry Detention Basins	30-65	15 - 45	15 - 45
Retention Basins	50 - 80	30 - 65	30 - 65
Constructed Wetlands	50 - 80	< 30	15 - 45
Infiltration Basins	50 - 80	50 - 80	50 - 80
Infiltration Trenches/Dry Wells	50 - 80	50 - 80	15 - 45
Porous Pavement	65 - 100	65 - 100	30 - 65
Grassed Swales	30 -65	15 - 45	15 - 45
Vegetated Filter Strips	50-80	50 - 80	50 - 80
Surface Sand Filters	50-80	< 30	50 - 80
Other Media Filters	65 - 100	15 - 45	< 30

In 2003, the United States Environmental Protection Agency (US-EPA) released a guidance document entitled "National Management Measures for Control of Non-Point Pollution from Agriculture" to provide technical information to state program managers and others on the best available and economically achievable means of reducing Nonpoint Source (NPS) pollution of surface and groundwater from agriculture. The guidance provides background information on agricultural NPS pollutions, how they enter water bodies, and how such problems can be assessed and then addressed (US-EPA, 2003). As part of the guidance, basic definitions, costs and effectiveness of different agricultural BMPs have been provided, which have been adapted for the current study (US-EPA, 2003).

In 2003, Wossink and Hunt conducted a study on urban structural BMPs in North Carolina to determine the cost efficiency of different urban BMPs for the purpose of identifying the unit reduction costs associated with each BMP. As part of the study, they developed several curves, which correlate construction and maintenance costs to the size of four different types of BMPs. The BMPs included wet ponds, stormwater wetlands, sand filter, and bioretention. Associated removal rates for each BMP were synthesized from 60 BMPs in the Southeast and Mid-Atlantic states (Wossink and Hunt, 2003). Table 3.3 shows the cost curves and required surface area for the examined urban BMPs.

Table 3.3. Construction and maintenance cost curves and required surface area for urban BMPs (Wossink and Hunt, 2003).

BMP	Construction Cost ($)	20-year maintenance cost ($)	Required surface area of BMP (acres)			
			Residential development		Highly impervious area (CN=80)	100% impervious areas (CN=100)
			Piedmont (CN 80-90)	Coastal Plain (CN 65-75)		
Wet ponds	$C=13,909X^{0.672}$	$C=9,202X^{0.269}$	SA=0.015X	SA=0.0075X	SA=0.02X	SA=0.05X
Wetlands	$C=3,852X^{0.484}$	$C=4,502X^{0.153}$	SA=0.02X	SA=0.01X	SA=0.03X	SA=0.065X
Sand filters	$C=47,888X^{0.882}$	$C=10,556X^{0.534}$	-	-	-	SA=0.017X
Bio-retention in clay soil	$C=10,162X^{1.088}$	$C=3,437X^{0.152}$	SA=0.025X	SA=0.015X	SA=0.03X	SA=0.07X
Bio-retention in sandy soil	$C=2,861X^{0.438}$	$C=3,437X^{0.152}$	SA=0.025X	SA=0.015X	SA= 0.03X	SA=0.07X

X= size of watershed (acres), SA= surface area of BMP (acres)

In 2006, the Pennsylvania Department of Environmental Protection (PADEP) published a BMP Stormwater Manual for the state of Pennsylvania (PADEP, 2006)). The manual provides an overview of planning concepts and provides design standards for use by local authorities, planners, land developers, engineers, contractors, and others involved with the planning, designing, reviewing, approving, and constructing land development projects (PADEP 2006). The manual contains several chapters which cover BMP description, design criteria, key design elements, potential applications, stormwater function (i.e. percent runoff volume reduction), TP/TSS pollutant removal, costs and maintenance issues. The appendix of this manual contains an extensive literature review of nutrient (TSS, TN, TP, TKN, NO_3) removal efficiencies for various urban and agricultural BMPs.

In 2007, the North Carolina Division of Water Quality (NCDWQ), also published a stromwater BMP manual. The manual provides information on BMP purposes along with a detailed description, pollutant removal efficiencies, feasibility considerations, advantages, disadvantages, major design elements, general characteristics, regulatory and requirements, design steps and maintenance issues. The manual provides average values for TSS, TN and TP removal efficiencies for various BMPs which are incorporated into the design criteria associated with the manual. Unfortunately, the manual does not provide any construction or maintenance costs.

In 2008, the Center for Watershed Protection (CWP) and the Chesapeake Stromwater Network (CSN) published the results from a study entitled "Technical memorandum: The runoff reduction method" for the Virginia Department of Conservation & Recreation (DCR) as a technical assistance for the Virginia Stormwater Management Regulations & Handbook. As part of the study, an extensive literature review was performed to derive EMCs for TN and TP and removal rates for various urban BMPs. Table 3.4 shows an estimated range of pollutant removal efficiencies for different urban BMPs (CWP and CSN, 2008).

Table 3.4. Estimated range of pollutant removal efficiency for different BMPs (CWP and CSN, 2008)

BMP	Pollutant Removal Efficiency (%)	
	TN	TP
Grass Channel	20	15
Bio-retention	40 to 60	25 to 50
Water Quality Swales	25 to 35	20 to 40
Extended Detention Ponds	10	15
Infiltration Practices	30 to 45	60 to 65
Wetlands	25 to 55	50 to 75
Wet Detention Ponds	30 to 40	50 to 75

In 2008, the CH2M Hill Company evaluated the efficiencies of several BMPs as part of a nutrient trading project involving the Jordan Lake Watershed in North Carolina. Researchers also sought to estimate the cost and cost-effectiveness of several selected urban and agricultural BMPs in North Carolina. They estimated unit costs of agricultural BMPs by dividing the total cost of installing and maintaining a BMP, for a specified period of time, by the amount of pollutant removed or otherwise prevented from reaching the relevant water body (CH2M Hill Company, 2008). Utilizing collected cost data, pollutant loading rates and removal efficiency of various BMPs, they developed TN and

TP reduction estimates (Pounds/Acre/Year removed by BMP) and cost-effectiveness estimates ($/Pounds removed/Year) for each examined BMP.

In 2009, National Association of Clean Water Agencies (NACWA) published a paper which presents a technical discussion of nutrient removal, and provides examples in regard to the challenges associated with establishing appropriate nutrient removal requirements. One of the sections of the study is allocated to providing a summary of the nutrient removal effectiveness and costs of different nonpoint source urban and agricultural BMPs. The results of this study revealed that the costs for nonpoint source controls can be quite variable in comparison to those associated with point source controls depending upon site specific applications (NACWA, 2009).

Also, in 2009, the National Research Council (NRC) established a Committee on the Evaluation of Chesapeake Bay Program (CBP) Implementation for Nutrient Reduction to Improve Water Quality in response to a request from the US-EPA with funding provided by Virginia, Maryland, Pennsylvania, and the District of Columbia. After two years, the committee released a report to assess the framework used by the states and the CBP for tracking nutrient and sediment control practices, which are implemented in the Chesapeake Bay watershed (CBP Committee, 2011). The information provided in the CBP report in regard to the TN, TP and TSS removal effectiveness of the different urban and agricultural BMPs was adapted for the current study.

In 2010, Rephann *et al.* published a report to estimate the costs of different agricultural BMPs (from 2005 to 2010) that were supposed to be implemented in Virginia to reduce the pollution entering the Chesapeake Bay in an effort to remove the Bay from the federal list of “impaired” waters. This work was conducted as of an ongoing “Tributary Strategy”, which is a plan to reduce nitrogen, phosphorus, and sediment reductions necessary to achieve Virginia’s portion of Chesapeake Bay restoration goals by 2010 (Rephann *et al.* 2010). The estimated cost information for agricultural BMPs that was developed as part of this study was adapted for the current research.

As part of the Chesapeake Bay Nutrient Reduction Program, scientists and engineers have employed various water quality model in efforts to identify potential reductions across the region. In 2010, the US-EPA published a document entitled “Estimates of

County-Level Nitrogen and Phosphorus Data for Use in Modeling Pollutant Reduction" for use in the Chesapeake Bay Nutrient and Sediment Scenario Builder Model (SBM). The SBM is a free and online decision support tool which is designed to assist planners in achieving the nutrient load caps that where developed as part of the Chesapeake Bay Nutrient TMDL (US-EPA, 2010). The tool allows users to develop several scenarios in order to understand the impacts of implementing land use changes and BMPs by comparing nutrient and sediment management scenarios (US-EPA, 2010). The document contains several chapters that cover BMP descriptions as well as the TN and TP removal efficiencies of various types of urban and agricultural BMPs.

In 2012, the Kansas City Mid-America Regional Council (MARC) and the Kansas City Metro Chapter of the American Public Works Association (APWA) published a manual entitled "The Manual of BMPs for Stormwater Quality". Their goal was to prepare a guidance document for applying urban BMPs within the Kansas City Area. The manual addresses the need to control the volume and quality of stormwater discharges from developed sites. The manual includes chapters that provide basic BMP definitions, removal effectiveness for several different pollutants (e.g. sediment, nitrogen, phosphorus, metals and bacteria), general applications, advantages, disadvantages, design requirements and considerations, maintenance and inspection issues and a design example for each urban BMP (MARC and APWA, 2012). Also, in 2012, the Maryland's Department of Environment, published the Maryland's phase II Watershed Implementation Plan (WIP) for the Chesapeake Bay TMDL. The Maryland's Phase I WIP mostly focused on assigning the allowable loads of nitrogen, phosphorus, and sediment to different point and nonpoint pollutant sources, and identifying the statewide strategies for reducing the levels of the pollutants that were impairing the Chesapeake Bay. The US-EPA guidance for Phase II placed a strong emphasis on working with key local partners to ensure that they are aware of their roles and responsibilities in contributing to the planning and implementation processes (Maryland's Department of Environment, WIP, 2012). The cost analysis of different types of urban BMPs, provided in the phase II plan, was adapted for the current study.

In 2013, the Center for Watershed Protection of Maryland, conducted a study on the cost-effectiveness of urban stromwater BMPs in the James River Watershed in Virginia.

The goal of this study was to provide identify the cost effectiveness of several urban BMPs for potential use in management activities in the Chesapeake Bay watershed. As part of their analysis, they evaluated which urban stormwater practices provided the greatest nutrient and sediment reductions for the lowest investment. These results were then used to help localities in the James River watershed more cost-effectively achieve the pollutant load reductions recommended by the Chesapeake Bay TMDL (the Center for Watershed Protection of Maryland, 2013). The cost effectiveness for TN and TP were obtained by dividing the average annual total cost of the BMPs by the total annual TP or TN reduction.

In 2013, Houle *et al*., conducted a study to make a comparison between maintenance costs, labor demands, and system performance for Low Impact Development (LID) and conventional stormwater management. Seven types of stormwater control measures (SCMs) were observed for the first 2–4 years of operations. The results of this study indicated that when compared to conventional systems, LID systems have lower marginal maintenance burdens (as measured by cost and personnel hours) and higher water quality treatment capabilities as a function of pollutant removal performance (James J. Houle *et al*. 2013).

Also in 2013, Houtven *et al.* estimated cost and nutrient reductions for 13 agricultural BMPs in the Chesapeake Bay. These estimates were obtained using several data sources including modeling results from the Chesapeake Bay Watershed Model (CBWM) (USPEA, 2010). In order to estimate BMP cost and nutrient load reduction, they estimated a cost per acre for each BMP, the delivered per-acre nutrient loads (TMDL Scenario of the Chesapeake Bay Watershed Model), and the delivered per-acre nutrient load reduction accomplished by each BMP (Houtven *et al.* 2013).

Mason *et al.* also conducted a study in 2013 to examine the costs associated with Green Stormwater Controls. They collected data from 18 projects in Greater Cincinnati area including 260,000 square feet of bioinfiltration practices, 165,000 square feet of vegetative (green roofs), 169,000 square feet of porous/pervious paving, 55,000 gallons of rainwater harvesting, 2,040 linear feet of storm sewer separation/redirection and 5 large capacity dry wells. They reported construction cost benefits (per liter runoff captured) for various stromwater controls from Green Infrastructure Projects.

In 2014, the Kentucky Water Resources Research Institute (KWRRI) conducted a study for the Kentucky Division of Water (KDOW) to determine stakeholder preferences of 20 separate nutrient management strategies that were identified by the stakeholders through a 1-year process that included interviews and focus groups. The published study includes quantitative assessment scores as well as qualitative perspectives by the stakeholders on each of the examined management strategies. A comprehensive description of various nutrient management strategies has been provided in the study (KWRRI, 2014). All in all, 22 separate studies were examined for use in developing summary descriptions, design criteria, removal efficiencies and cost data. A summary of the associated studies is provided in Figure 3.1.

Sources of BMP Data (22 Studies)		Type of BMP		BMP Definition	Removal Efficiency (%)			Unit Removal (Slb/acre)			Cost Effectiveness ($/lb/year)			Costs
	Year	Urban	Agricultural		TN	TP	TSS	TN	TP	TSS	TN	TP	TSS	
Camacho	1992	●	●		●	●	●							●
Brown and Schueler	1997	●												●
US-EPA	1999	●	●		●	●	●							
Wossink and Hunt	2003	●												●
US-EPA	2003	●												●
Pensylvannia Stormwater BMP Manual	2006	●		●	●	●	●	●	●					
North Carolina Stormwater BMP Manual	2007	●		●	●	●	●			●	●	●	●	●
Jordan Lake Watershed Trading Project , CH2M Hill	2008	●	●		●	●	●	●	●					
CWP and CSN	2008	●			●	●	●							
National Association of Clean Water Agencies (NACWA)	2009		●											●
Rephann et al.	2010		●	●										
US-EPA	2010	●	●		●	●	●							
CBP Committee	2011	●	●		●	●	●							
International Stormwater BMP Database	2012	●												
MARC and APWA	2012	●												
MD, WIP	2012	●	●											●
Houle et al.	2013	●												●
Houtven et al.	2013	●	●	●	●	●	●							●
Mason	2013	●												●
James River Basin Project (MD CWP)	2013	●			●	●	●				●	●	●	
(KWRRI)	2014		●	●										
International Stormwater BMP Database	2014	●			●	●								

Figure 3.1. A summary of literature examined in this study

3.3 Urban and Agricultural BMP Data Compilation: Organization Method

Results from the previous literature review were used to construct a BMP database which includes a description, advantages, disadvantages, feasibility consideration, potential application, TSS, TN and TP removal efficiency, cost efficiency, construction, operational and maintenance costs for a range of BMPs. Note that for BMP performance data obtained from the International Stormwater BMP technical report (2014), the median

TN/TP influent and effluent were obtained from the report to calculate nutrient percent removal of the associated BMP. An example of the types of data provided for each BMP (e.g. stormwater wetland) are shown in Tables 3.5 to 3.7 and Figure 3.2.

Figure 3.2. Typical of a Stormwater Wetland

Table 3.5. Characteristics of Stormwater Wetland

Stormwater Wetlands		
Descriptions	Stormwater wetlands are constructed systems that mimic the functions of natural wetlands and use physical, chemical, and biological processes to treat stormwater pollution (NC Stromwater BMP Manual, 2007)	
Advantages	• Creates a shallow matrix of sediment, plants, water, and detritus that collectively removes multiple pollutants through a series of complementary physical, chemical, and biological processes. • Best BMP design for maximum TSS, nitrogen, and phosphorus removal while also providing stormwater volume control. • Aesthetically pleasing when properly maintained and can be sited in both low and high-visibility areas. • Can provide an excellent habitat for wildlife and waterfowl (NC Stormwater BMP Manual, 2007)	
Disadvantages	• Occupies more land than other stormwater BMPs such as detention basins. • Needs to meet critical water balance requirements to stay healthy and properly functioning. • Poorly maintained stormwater wetlands can be colonized by invasive species that out-compete native wetlands plants. • Removal of invasive plants is difficult and labor intensive and may need to be done repeatedly (NC Stormwater BMP Manual, 2007)	
Feasibility Consideration (NC Stormwater BMP Manual, 2007)	Land Requirement Cost of Construction Maintenance Burden Treatable Basin Size Possible Site Constraints Community Acceptance	High Med Med Med-High Med Med
Potential Applications (PA Stormwater BMP Manual, 2006)	Residential Commercial Ultra urban Industrial Retrofit Highway/Road	Yes Yes Limited Yes Yes Yes

Table 3.6. Removal efficiency of a stormwater wetland

BMP type	***Percent Removal (%)***			***Reference***
	TN	***TP***	***TSS***	
Stormwater wetland	22	32.5	61	Woskin and Hunt, 2003
	40	35	-	CH2M Hill, 2008
	40	40	85	NC BMP Manual, 2007
	75	58	96	Houle *et al.* 2013
	25	40	51	MD CWP, 2013
	10	28	-	CWP AND CSN, 2008
	13	48	-	
	-	33	-	
	-	57	-	
	-	69	-	
	-	15	-	
Submerged gravel wetland	Negative	46	-	
Stormwater wetland	35 to 45	45	-	
Wetland Basin	-5	28	62	International BMP Database, 2014
	-4	38	-	International BMP Database, 2012
Wetland Channel	16	7	-	

Table 3.7. Cost and cost effectiveness of a stormwater wetland

Costs ($)		Reference
Construction cost	$C=3,852X^{0.484}$	Wossink and Hunt, 2003
20-year maintenance cost	$C=4502X^{0.153}$	
Required Surface Area of BMP (acres)		
Residential Piedmont (CN 80-90)	SA=0.02X	
Residential Coastal Plain (CN 65-75)	SA=0.01X	
Highly Impervious Area (CN 80)	SA=0.03X	
100% Impervious Area (CN 100)	SA=0.065X	
Where X=size of watershed (acres); SA=surface area of BMP (acres)		

Capital Cost Equation ($)	
$23.07V^{0.705}$	Brown and Schueler, 1997
Where V=Total basin volume (ft^3)	

Costs		Unit	Reference
Capital Costs	0.6 to 1.25	$/ft.[3] of BMP	C2HM Hill, 2008
O&M costs as percent of Capital costs	3 to 6	$	

Inflated 2012 Capital Costs	67,800	$	Houle *et al.* 2013[2]
Maintenance-Capital Cost Comparison (year)[1]	12.2	$	
Personnel	53.6	(hours/year)	
Personnel	5,280	($/year)	
Material	272	($/year)	
Subcontractor Cost	0	($/year)	
Annual O&M costs	5,550	($/year)	
Annual maintenance/capital costs	8	(%)	

1-Number years at which amortized maintenance costs equal capital construction costs
2-Filter Length (m)=15.8, Width (m)=11.3, Area (m^2)=179, Depth=0.6 ft, Ponding depth (ft)=0.4, Catchment area (ha)=0.4, Water quality volume (m3)=97.7, Water quality flow (m3/s)=0.2, Watershed area/filter =22.6

Cost Effectiveness			Unit	Reference
TN	TP	TSS	$/lb	MD CWP, 2013
1,160.28	6,670.36	10.99		

Table 3.7. Cost and cost effectiveness of a stormwater wetland (Continued)

Wetlands and Wet Ponds Costs Per Acre Impervious Area Treated (New)		**Reference**
Pre-Construction Costs[1]	5,565	MD, WIP II, 2012
Construction Costs[2]	18,550	
Land Costs[3]	2,000	
Total Initial Costs	26,115	
Total Post-construction costs[4]	763	
Annual Costs over 20 years	41,368	
Average Annual Costs over 20 years	2,068	
Wetlands and Wet Ponds Costs Per Acre Impervious Area Treated (Retrofit)		
Pre-Construction Costs[1]	21,333	
Construction Costs[2]	42,665	
Land Costs[3]	2,000	
Total Initial Costs	65,998	
Total Post-construction costs[4]	763	
Annual Costs over 20 years	81,251	
Average Annual Costs over 20 years	4,063	

1-Includes cost of site discovery, surveying, design, planning, permitting, etc. 2- Includes capital, labor, material and overhead costs, but not land costs, associated implementation; 3- It is assumed that: 1) the opportunity cost of developable land is $100,000 per acre and 2) 50% of projects that require land take place on developable land with the rest taking place on land that is not developable. This brings the opportunity cost of land for stormwater BMPs that require land to $50,000 per acre. Actual county-specific land cost and percent developable land values can be filled in. 4- Combined annual operating, implementation, and maintenance costs.

3.4 Summary of the Performance Data

As discussed previously, the goal of this study was to review recent publications on nutrient and sediment BMP cost and performance data in order to develop summary information for use by engineers in the design and implementation of BMPs for impaired watersheds. A summary of the observed performance data for TN, TP, and TSS for the examined BMPs is provided in Table 3.8 and Figures 3.3 to 3.5

Table 3.8. The Minimum, Maximum and Mean removal efficiencies (%) for different BMPs

BMP	TN			TP			TSS		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Bioretetion	46	80	21	53.5	87	8	77	92	55
Stormwater Wetalnds	30	75	10	39	69	7	71	96	51
Sand Filter	32.5	47	15	47	88	20	72	85	51
Grass Swale	42.5	99	10	32.5	83	4.5	65	98	22
Riparian Buffer	50	94	27	55	91	34	60	-	-
Infiltration Basins	60	80	45	63	80	50	81.5	99	50
Infiltration Practices	82	85	80	81	85	65	95	-	-
Infiltration Trenches	56	80	42	53	100	4.5	73	90	50
Filtering Practices	40	-	-	60	-	-	80	-	-
Dry Extension Detention Pond	22	45	10	29	81	7	62.4	96	30
Dry Pond	21	45	5	27	45	10	51.5	65	30
Wet Extended Detention Basin	36.5	55	16	63.45	90	37	76	98	54
Wet Pond	31.5	65	6	44	87	5	66	93	7
Porous Pavement	82.5	100	65	47.5	65	30	82.5	100	65
Permeable Pavement	48	88	10	47	80	10	71	85	55
Street Sweeping	3	-	-	3	-	-	-	-	-
Riparian Forest Buffer	39.5	65	19	39	45	30	50	60	40
Urban Nutrient Management	13	17	9	13	22	4.5	50	-	-
Continuous No-Till	12.5	15	10	30	40	20	50	-	-
Riparian Grass Buffer	27.5	46	13	39	45	30	50	60	40
Wetland Restoration	11	15	7	18.5	26	12	9.5	15	4
Conservation Tillage	6	8	3	13	22	5	21	30	8
Land Conversion	56	88	10	53	94	7	-	-	-
Cover Crop	21	45	5	7	15	0	7.5	20	0
Cattle Exclusion (no buffer)	32	-	-	28	-	-	-	-	-
50 Ft. Excluded Riparian Buffer	66	-	-	82	-	-	-	-	-
Off-Stream Watering	15	25	5	20	30	22	35	40	30
Filter Strip	51	80	30	54	80	34	72	90	50
Terraces	37.5	55	20	70	-	-	85	-	-
Diversion System	27.5	45	10	50	70	30	35	-	-
Grassed Water Ways	40	-	-	45	-	-	-	-	-

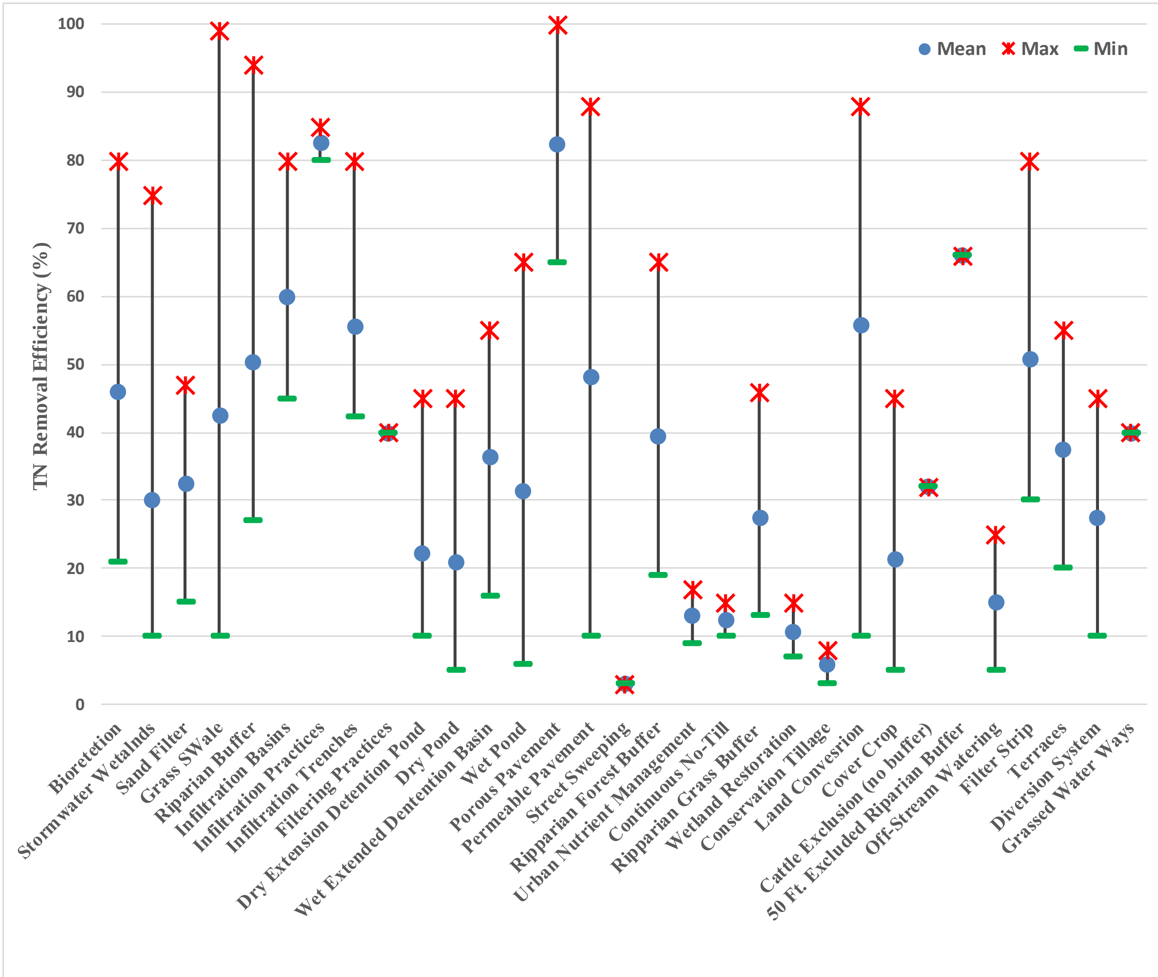


Figure 3.3. TN Removal Efficiency for different BMPs

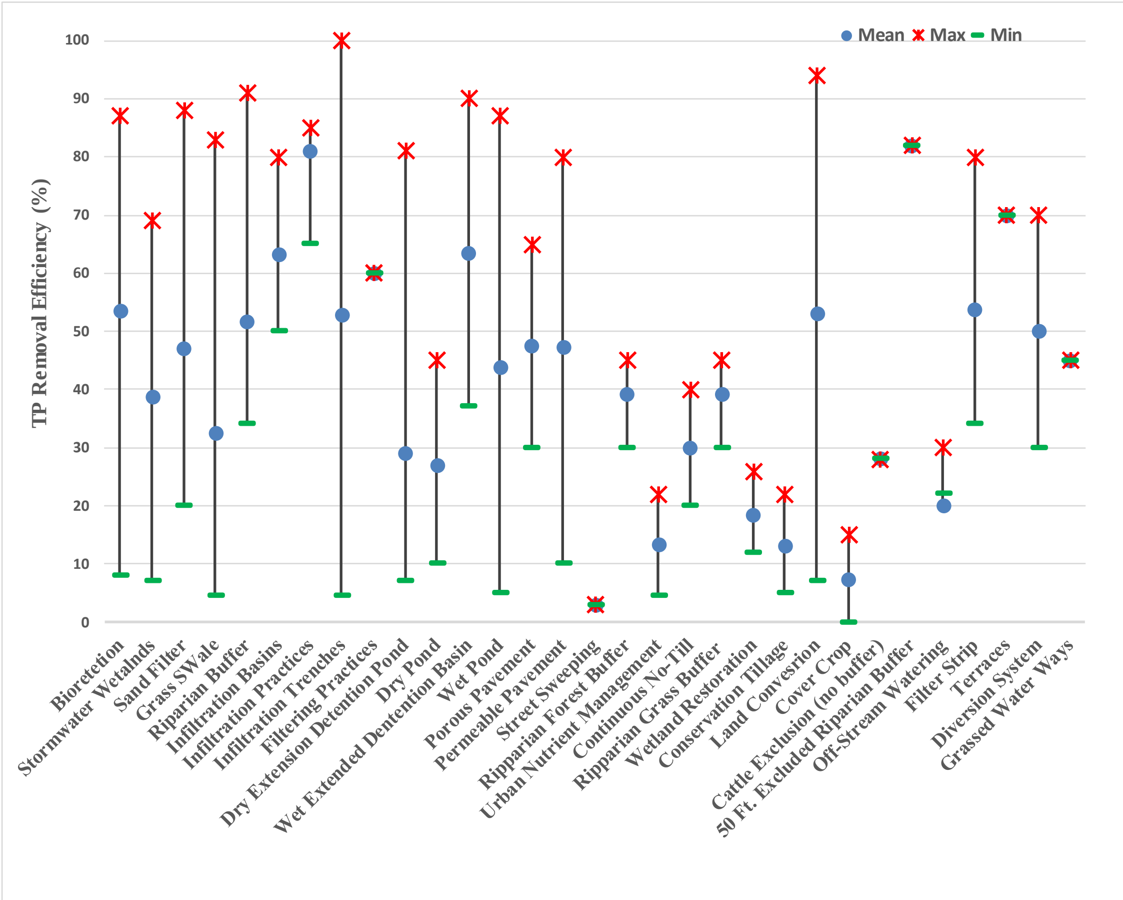


Figure 3.4. TP Removal Efficiency for different BMPs

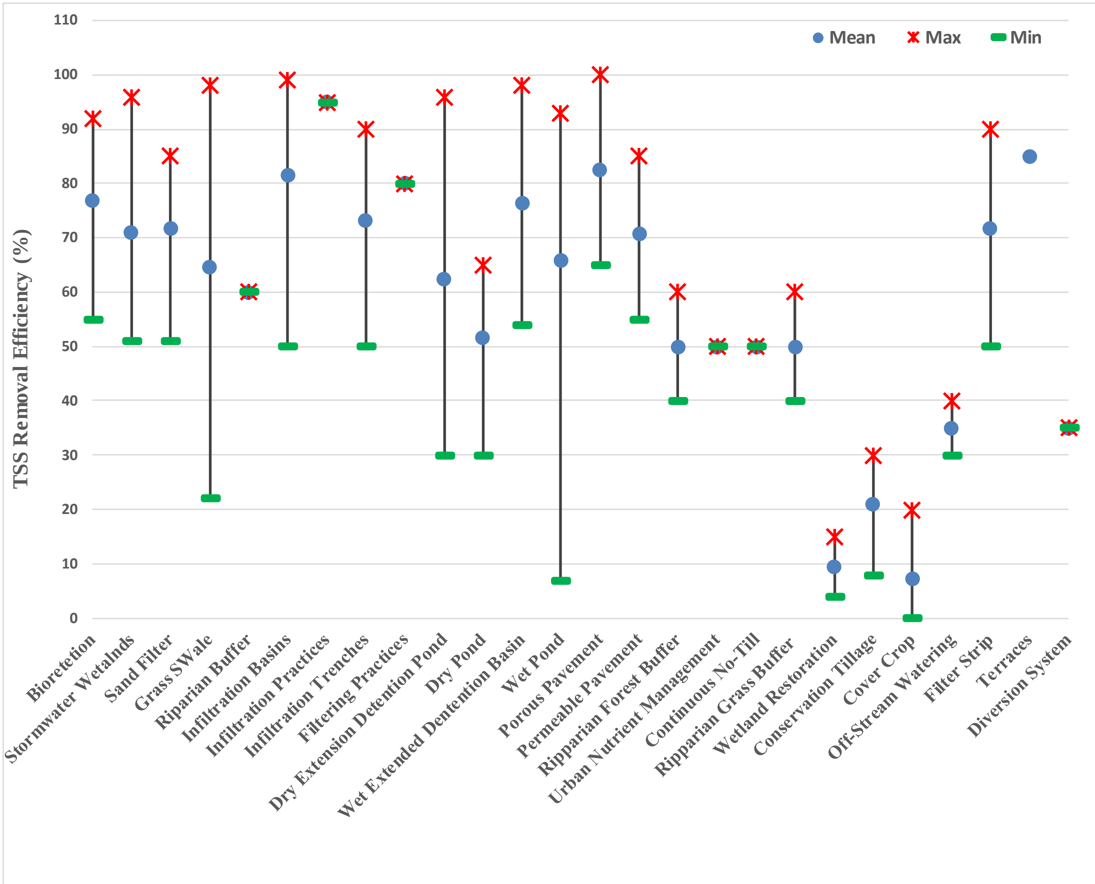


Figure 3.5. TSS Removal Efficiency for different BMPs

3.5 Summary of the Results

Figure 3.3 shows that the grass swale and the land conversion have the widest range of TN removal efficiency among urban and agricultural BMPs. However, among urban BMPs, the infiltration practices and the street sweeping have the highest and the lowest mean TN removal efficiency, respectively. In addition, among agricultural BMPs, the 50 feet excluded riparian buffer and the conservational tillage have the highest and the lowest mean TN removal values, respectively.

Figure 3.4 shows that the infiltration trenches, the grass swale, and the land conversion have the widest range of TP removal efficiency among urban and agricultural BMPs. However, among urban BMPs, the infiltration practices and the street sweeping have the highest and the lowest mean TP removal efficiency, respectively. In addition, among agricultural BMPs, the 50 feet excluded riparian buffer and the cover cropping have the highest and the lowest mean TP removal values, respectively.

Figure 3.5 shows that the wet ponds, the grass swales, and the filter strips have the widest range of TSS removal efficiency among urban and agricultural BMPs. However, among urban BMPs, the infiltration practices and the dry ponds have the highest and the lowest mean TSS removal efficiency, respectively. In addition, among agricultural BMPs, the terraces and the cover cropping have the highest and the lowest mean TN removal values, respectively.

3.6 Summary and Conclusion

The summary tables reveal high variability among the reported percent removal efficiencies. There are several possible reasons for such variability. One reason may be due to differences in data collection and analysis protocols. Another reason is that in some cases, the BMPs actually increased the effluent loadings as opposed to decreasing the loadings. This could be due to several reasons, such as poor design, improper installation, applications to inappropriate sites (e.g. soils), release of nutrients from treatment media (e.g. bio-retention basins), etc.

For example, although the primary purpose of implementing bio-retentions is reducing the runoff volume, the media used in the practice may cause the exportation of nutrient load out of the BMP. Also, the swales and strips may export nutrients due to stream bank erosion and/or poor vegetative condition. The design of these kinds of BMPs can be modified to mitigate such adverse effects. For instance, modifying the media specifications of bio-retentions may assist the BMP to perform better.

The authors of the International BMP Database Project recommend that one not assume a negative BMP efficiency if hypothesis testing of the actual raw data results indicate that there is no statistically significant difference between the influent and effluent data sets. Instead, they recommend that "statistically significant reduction was not provided based on the data set" can be claimed in such cases. As a result, they generally recommend focusing on the effluent concentrations achieved, instead of percent removal. Additional information about the use of the International Database results for such applications can be found in the International Database website (http://www.bmpdatabase.org/Docs/FAQPercentRemoval.pdf).

The authors of the International BMP Database have discussed the reasons that the percent removals have been omitted as a measure of the BMP performance from their technical reports. One of the reasons for such an omission is due to the recognition that results associated with an application with a low influent concentration and a low effluent concentration may not be significant because the influent water may not be extremely polluted. In such cases, one can't necessarily conclude that a certain BMP is not effective. Thus, the inclusion of results from such cases could potentially bias the conclusion drawn from observations. Moreover, the influent/effluent concentrations may not reflect actual influent/effluent loads, especially for urban BMPs. The reason is that in urban areas the developed impervious areas increase the runoff volume. So, the BMPs are typically implemented to reduce the runoff rather than decreasing the nutrient or sediment. Hence, those studies which solely report influent/effluent reduction for the BMPs which significantly reduce the runoff (e.g. infiltration practices and permeable pavement), would not accurately reflect the performance of BMPs since a significant load reduction may take place even when a significant concentration reduction does not occur.

Attempts to develop general cost equations from the reviewed literature were difficult due to the variability and formats of the different equations, variabilities in how operation and maintenance costs were determined, differences in amortization periods, etc. In addition, costs tended to be based on local or regional design criteria that varied considerable across the country. Instead, more detailed costs functions were provided in Appendix B which tried to incorporate these factors for the particular region were the BMP were actually applied. The decision maker is then left with judging their particular applicability for their own area of application.

Unfortunately, few researchers have correlated optimal BMP size and performance to the actual runoff and nutrient loads associated with specific storm events. One possible way to address this issue would be to use existing field data to calibrate to appropriate watershed models which could then be used to evaluate the performance of different BMPs against the resulting runoff volumes and influent loads. Alternatively, when such data is not available and a more detailed modeling analysis is not practical, the information provided in this chapter can be used to provide a relative comparison of different BMPs for general planning purposes on the basis of general load reduction predictions and their associated relative costs.

4 Chapter 4: Assessment of Cost and Performance of Urban BMPs Using WinSLAMM Model

4.1 Introduction and Purpose

One of the ways to reduce the pollutant loads entering into streams is by implementing different Best Management Practices (BMPs) within the watershed. BMPs can be classified as either structural or non-structural. Non-structural BMPs may involve the use of different landuse strategies (e.g. conservation tillage) or the use of different behavioral strategies (e.g. reduction of fertilizer use). Structural BMPs may involve the construction of different types of stormwater or water quality facilities such as retention ponds or bioswales. One of the challenges facing watershed managers is in selecting the most appropriate BMPs to use in a given watershed. Some of the factors affecting these decisions include pollutant removal effectiveness, cost, aesthetics, maintenance and social acceptance.

In recent decades, various watershed models have incorporated options for modeling different types of BMPs. For example, the Hydrological Simulation Program-Fortran (HSPF) developed by Johnson *et al*. (1980), the Storm Water Management Model (SWMM) developed by Metcalf and Eddy, (1971), the Soil and Water Assessment Tool (SWAT) developed by Arnold *et al.* (1998) and the System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) developed by US-EPA (2003) have all been modified to accommodate options for modeling BMPs. The models can then be used to simulate and evaluate the impact of implementing BMPs on the stormwater runoff and water quality. Many of these models are very complicated and require extensive amounts of data which may limit their use to modeling specialists. In addition, few of these models relate the required size and dimensions of the BMP to the magnitude of the pollutant load being treated or the actual efficiencies of the BMPs. Instead, many of these models provide a constant percent load reduction based on the type of BMP, without considering the magnitude of the loads being treated or the size of the BMP. As a result, there exists a need for BMP models that can correlate BMP performance to these important independent variables.

One approach to developing such models is to develop mathematical relationships or regression equations that relate these variables. This requires a significant amount of field observations from actual BMPs. An initial step towards the development of such a database was the creation of the International Stormwater Database (1969). The database was begun in 1996 under a cooperative agreement between the American Society of Civil Engineers (ASCE) and the Unites States Environmental Protection Agency (US-EPA). The Project features a database of over 500 BMP studies, performance analysis results, tools for use in BMP performance studies, monitoring guidance and other study-related publications. The overall purpose of the database is to provide scientifically sound information to improve the design, selection and performance of BMPs. As the database continues to be updated, systematic assessments of the data should ultimately lead to a better understanding of factors influencing BMP performance. This knowledge can be then used to help promote improvements in BMP design, selection and implementation (US-EPA and ASCE, 2017). Unfortunately, the current database does not include enough detailed information on BMP characteristics to allow for the construction such detailed mathematical relationships.

An alternative to the use of the International BMP Database is to develop and calibrate a mathematical model of a particular type of BMP and then simulate the performance of the BMP under different loading conditions. Once multiple results have been generated, regression equations can then be developed that reflect BMP performance as a function of a range of independent variables (e.g. runoff volume, pollutant load, BMP dimensions, etc.). Once developed, these relationships can then be imbedded into larger watershed models for use in locating and siting BMPs so as to maximize the pollutant reduction at a minimum cost.

In the current study, the Source Loading and Management Model (WinSLAMM) developed by Pitt *et al.* 1979, is used to develop mathematical relationships for three urban BMPs: 1) a filter strip, 2) a grass swale, 3) a biofiltration. The developed relationships provide a way to predict the pollutant load reduction of each BMP as a function of the input pollutant load and the design parameters associated with the facility. These relationships can then be embedded in a larger planning model like the Kentucky Watershed Nutrient Model for the purpose of selecting and siting the most cost effective BMPs for the purpose of meeting a specific water quality target.

4.2 Background

Selecting an appropriate model to address project objectives is one of the most significant steps in watershed planning and management. Decision makers and watershed planners need to have an initial knowledge about the performance and purpose of the developed models before using them for their projects. This section contains a review of most commonly used models that contain BMP modules.

In mid 1970's, Pitt *et al.* began the development of the Source Loading and Management Model (WinSLAMM), primarily as a data reduction tool for use in early street cleaning and pollutant source identification projects sponsored by the US-EPA's Storm and Combined Sewer Pollution Control Program. Additional information contained in the WinSLAMM was obtained during the US-EPA's Nationwide Urban Runoff Program (NURP) (US-EPA, 1983). The WinSLAMM model is a continuous and long-term model for daily rainfall-runoff simulation of small scale watersheds. The model predicts sediment and nutrient load coming from urban landuses, and evaluates the performance of different urban management practices in reducing runoff volume and pollutant loads.

In 1980, The US-EPA developed the Hydrologic Simulation Program Fortran (HSPF) which is a continuous model for simulation of hydrology and water quality processes within large-scale and small-scale watershed systems. The model can perform simulation for a long period (e.g. several years) with multiple time steps from a few minutes to a day. The model contains a large number of sub-models developed from physically-based theory, laboratory and empirical equations to predict surface runoff, baseflow, groundwater recharge, dissolved oxygen (DO), biochemical oxygen demand (BOD, pesticides, fecal coliforms, sediment routing and transport, and organic and inorganic nutrients. The model can simulate the performance of urban and agricultural BMPs (see Table 4.1). The HSPF is highly complex and needs a large amount of input data which limit its use to modeling specialists (Johnsen *et al.* 1980).

In 1988, Huber and Dickinson developed the Storm Water Management Model (SWMM). The model as funded by the US-EPA to perform rainfall-runoff simulation for urban catchments. The SWMM can be used to model single runoff events or to model the response of a watershed over a longer period (e.g. one year) with multiple time steps from one minute to a day. This enables the model to be used to assess the effectiveness of urban management practices for both short term and long-term performance. The water quality simulation component of the model uses a build-up and washoff equation, rating curve, constant pollutant concentrations, and the Modified Universal Soil Loss Equation (MUSLE) method for predicting pollution. The quantity simulation component uses a nonlinear reservoir model for simulating watershed runoff and either a kinematic wave or dynamic wave formulation for simulating the transport of flows through open channels and pipe systems (Novotny and Olem, 1994).

In 1990, W. Walker *et al.* developed the first version of the P8 Urban Catchment Model (P8-UCM) for the US-EPA to predict stormwater runoff pollutants in urban catchments. The model performs hourly and daily continuous simulation and uses the SCS curve number equation to predict runoff from pervious areas. The model obtains particle build-up and wash-off processes using equations derived primarily from the SWMM program. The P8-UCM predicts suspended solid, TP and total Kjeldahl nitrogen, copper, lead, zinc, and total hydrocarbons. The program is capable of simulating pollutant transport and removal through various urban structural BMPs. The Rhode Island Department of Environmental Management (1988) recommended the first application of a BMP design to achieve TSS efficacy by 70% or 85% (William Walker and Jeffery Walker, 1990).

In 1998, Arnold *et al.* developed the Soil and Water Assessment Tool (SWAT). SWAT was funded by the USDA's Agricultural Research Service (ARS). The SWAT is a continuous and long-term yield model which is developed to model the hydrological and water quality processes within large scale watersheds. The model is able to estimate the effect of implementing urban and agricultural practices on water, sediment, and agricultural chemical yields in watersheds with varying soils, land use, and management conditions over long periods of time (Texas A&M Agrilife Research & Extension Center, 2017). In recent years, various extensions including the, Swat-MODFLOW (Bailey *et al.* 2016), Qswat (Dile *et al.* 2017), Swat-cup (Abbaspour *et al.* 2007) have been developed for the model.

In 2001, the US-EPA developed a simplified Spreadsheet Tool for Estimating Pollutant Loads (STEPL). The model employs the Natural Resources Conservation Service (NRCS) Curve Number (CN) method for predicting runoff volume. The sediment load is determined by using the Universal Soil Loss Equation (USLE). The predicted values of TN, TP and Biochemical Oxygen Demand (BOD) are generated using an EMC approach. The model calculates annual nutrient and sediment loads for each landuse type and aggregates them for the entire watershed. The model has the capability to estimate load reductions resulting from the implementation of urban and agricultural BMPs. Users are required to enter a pollutant removal efficacy for each BMP, and the tool calculates the combined efficiency of BMPs and estimates annual load reduction within watershed.

In 2002, Lowrance *et al.* developed the Riparian Ecosystem Management Model (REMM) at the USDA-ARS Southeast Watershed Research Laboratory in Tifton, GA. The REMM simulates water quality, hydrology, nutrient dynamics, and soil movement within riparian zones between agricultural field and water bodies. The USLE method is used to simulate rill and inter-rill erosion within riparian buffer zones. The model also contains a pesticide transport component which simulates plant intake, movement in soil profile, adsorption/ desorption and degradation (Lowrance *et al.* 2002).

In 2003, the US-EPA funded a project to develop a model called the System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN). The model was developed to provide stormwater managers with a decision support system to assist them to evaluate and select optimal (based on cost and effectiveness of BMPs) urban BMP combination at various watershed scales. An ArcView interface (US-EPA, 2009) has also been developed for the model. The runoff and pollutant load simulation algorithms used in the model were adapted from the SWMM5 and the sediment load prediction algorithm was adapted from the HSPF. The model simulates flow and pollutant transport through different urban structural BMPs along with a library for estimating unit cost of implementation of BMPs. An optimization module has been developed which uses an initial scatter search and subsequent evolutionary optimization techniques (i.e. scatter search and non-dominated sorting genetic algorithm-II (NSGA-II)) to suggest an optimal strategy for selection and placement of BMPs Due to complexity of the model, users need to be trained and become familiar with watershed modeling processes, calibration and validation techniques (US-EPA, 2009).

In 2013, the Center for Watershed Protection was funded by US-EPA to develop the Watershed Treatment Model (WTM). The model is a spreadsheet-based tool which estimates annual runoff and load from different point and nonpoint pollutant sources. The model contains a BMP module which enables users to select between various types of management practices and then examine the effects of annual pollutant load within the modeled watershed. The model uses the Simple Method (Schueler, 1987) to calculate annual runoff and pollutant load. Users need to have information about the effectiveness and implementation level of each modeled BMP (Deb Caraco, 2013).

A total of 10 different simulation models were ultimately examined for possible use in this study. These are summarized in Table 4.1. As can be seen from the table, each model has its own set of unique features and capabilities. Ultimately, WinSLAMM was chosen due to its relative simplicity and its ability to relate the dimensions and characteristics of each BMP and watershed load to an associated performance and cost.

Table 4.1. Summary of the most commonly used watershed and BMP simulation models

Model	BMPs/Management Programs
WinSLAMM	Filter Strip, Grass swale, Wet detention pond, Bio-filtration, Porous pavement, Street sweeping
SWMM	Detention basins, Infiltration practices, Wetlands, Ponds, Stormwater, Rain barrels, Rain gardens, Green roofs, Permeable pavement, Street planters, Infiltration trenches, Vegetated swales.
P8-UCM	Detention basin (wet, dry, extended), Infiltration practices, Swale/buffer strip, Manhole/splitter
SWAT	Agricultural conservation practices, Detention basins, Infiltration practices, Ponds, Vegetative practices, Irrigation, Tile drains, Street sweeping, Wetlands, Vegetated filter strips, Grassed waterways, Controlled grazing, Grade stabilization, Field terraces, Modified fertilizer and Pesticide application rates.
STEPL	Contour farming, Filter strips, Reduced-tillage, systems, Streambank stabilization and fencing, Terracing, Forest road practices, Forest site preparation practices, Animal feedlot practices, Various urban and low-impact development, (LID) practices (e.g., detention basin, Infiltration practices, swale/buffer strips
HSPF	Nutrient management, Contouring, Terracing, Ponds, Wetlands,
SUSTAIN	Rain barrels, Rain gardens, Constructed wetlands, Wet and dry ponds, Grass swales, Vegetated filter strip, Sand filters, Green roofs, Permeable pavement
WTM	Terraces, Street sweeping, Riparian buffer, Detention ponds, Wetlands, Filters, Green roofs, Rooftop disconnection, Permeable pavement, Grass channel, Dry and wet swale, Rain tanks and cisterns, Soil amendment, Bioretention, Infiltration practices, Filter Strips

4.3 The WinSLAMM Model

The WinSLAMM uses the concept of small storm hydrology (Pitt 1987, 1999) to calculate runoff volumes and pollutant loadings for urban drainage basins for multiple rainfall events over a defined time period (e.g. 1 year). While more extreme rainfall events are typically controlled because of the potential for surcharge and flooding, it has been recognized that the more frequent events should also be managed as it has been demonstrated that they have a significant impact on groundwater recharge, water quality and watercourse erosion (Rivard, 2010). In the WinSLAMM, all rainfall events are used because although large events contribute significant amounts of pollutants to urban runoff, many smaller events contribute more runoff volume and total pollutant load over the course of a year (PV & Associates LLC, 2015). The users need to select rainfall time series and source load information including type of landuse and soil type. The model also requires users to select the type and values of parameters for selected BMPs. The parameters include the size of BMPs, the average infiltration rate, and the runoff retardance factor. In the current study, the WinSLAMM model was used to assess the performance of three urban BMPs including a grass swale, a filter strip, and a biofiltration system. The goal of the analysis was to develop performance curves for each selected BMP.

4.3.1 Rainfall and Runoff

The WinSLAMM contains a library that provides historical rainfall time series from a database of actual rainfall stations and annual rainfall time series. For this study, the Lexington Bluegrass Airport rainfall station was selected, which contains rainfall time series from 1953 to 1999. This dataset was then examined to determine an average rainfall year from the total time series. The average annual rainfall depth from 1953 to 1999 was equal to 47.64 inches. It was determined that 1970 had approximately 47.64 inches of rain. Thus, 1970 was considered as the rainfall year for the rest of analysis. Figure 4.1 shows the annual rainfall depth for 1953 to 1999 for the Lexington Bluegrass Airport rainfall station.

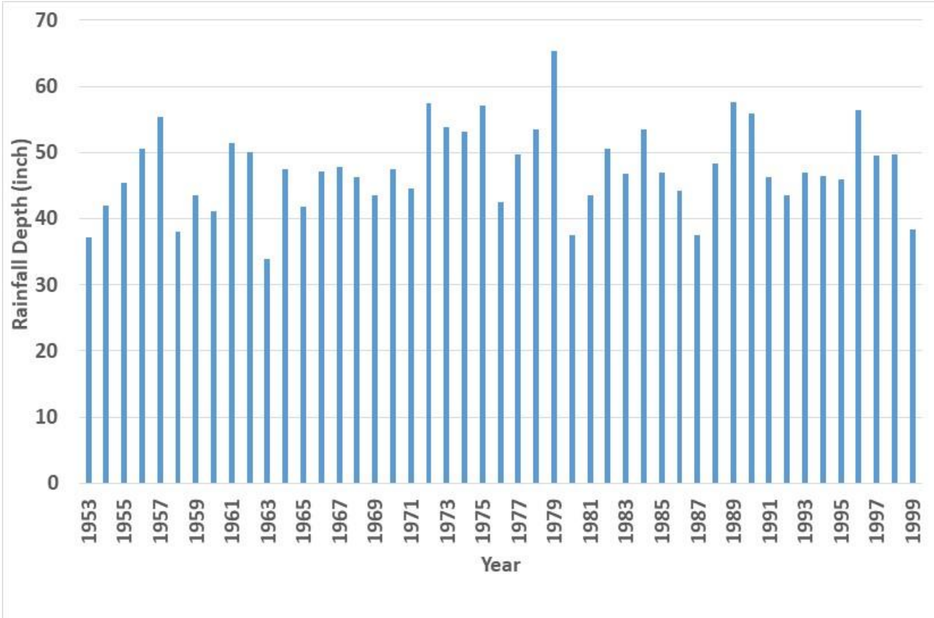


Figure 4.1. The annual rainfall depth for the Lexington Bluegrass Airport Station.

The WinSLAMM model calculates the runoff volume by multiplying a runoff coefficient C by rainfall depth and area of landuse (See Equation 4.1). The landuses include commercial, industrial, residential, freeways and institutional areas. Each landuse contains different source load areas, and users can assign the percentage area of the load sources within each landuse. The load source areas include rooftops, driveways, streets, parking areas, etc. The runoff coefficients (the ratio of runoff to rainfall as a function of rainfall depth) have been determined through field monitoring. Figure 4.2 shows an example of the runoff coefficients for different source load areas. For the current study, the runoff was generated assuming an urban medium density residential landuse. The fractional areas of each source load area within a one-acre medium residential landuse are shown in Table 4.2 (PV & Associates LLC, 2015).

$$\textbf{Runoff Volume (ft}^3\textbf{)= 3,630×Runoff Coefficient ×Rainfall Depth (inch)×Landuse Area (acre)} \qquad \text{(Eq. 4.1)}$$

Area Types (AT):

AT 1: Connected flat roofs
AT 2: Connected Pitched Roofs
AT 3: Directly connected impervious areas
AT 4: Directly connected unpaved areas
AT 5: Pervious areas - Sandy soils
AT 6: Pervious areas - Silty soils
AT 7: Pervious areas - Clayey soils
AT 8: Smooth textured streets
AT 9: Intermediate textured streets
AT 10: Rough textured streets
AT 11: High Traffic Urban Paved Areas
AT 12: High Traffic Urban Pervious Areas

(•) **Runoff Coefficient Data**

( ) **Drainage Efficiency Coefficient Data**

Volumetric Runoff Coefficients for Rains (in. and mm.)

Rain (in)	0.01	0.08	0.12	0.20	0.39	0.59	0.79	0.98	1.2	1.6	2.0	2.4	2.8	3.2	3.5	3.9	4.9
Rain (mm)	1	2	3	5	10	15	20	25	30	40	50	60	70	80	90	100	125
AT 1	0.00	0.00	0.30	0.54	0.72	0.79	0.83	0.84	0.86	0.88	0.90	0.91	0.93	0.94	0.94	0.95	0.96
AT 2	0.25	0.63	0.75	0.85	0.93	0.95	0.96	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99
AT 3	0.93	0.96	0.96	0.97	0.97	0.97	0.97	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99
AT 4	0.00	0.00	0.00	0.00	0.47	0.64	0.72	0.77	0.81	0.86	0.89	0.91	0.92	0.93	0.94	0.94	0.95
AT 5	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.03	0.04	0.07	0.10	0.13	0.15	0.20	0.22	0.25
AT 6	0.00	0.00	0.00	0.05	0.08	0.10	0.11	0.12	0.13	0.14	0.16	0.19	0.22	0.24	0.28	0.30	0.35
AT 7	0.00	0.00	0.00	0.10	0.15	0.19	0.20	0.21	0.22	0.23	0.26	0.29	0.32	0.33	0.36	0.39	0.45
AT 8	0.35	0.49	0.54	0.59	0.65	0.69	0.72	0.76	0.80	0.85	0.88	0.90	0.91	0.93	0.93	0.94	0.95
AT 9	0.26	0.43	0.49	0.55	0.60	0.64	0.67	0.67	0.73	0.80	0.84	0.86	0.88	0.90	0.91	0.92	0.93
AT 10	0.18	0.39	0.47	0.53	0.60	0.64	0.67	0.70	0.73	0.80	0.84	0.86	0.88	0.90	0.91	0.92	0.93
AT 11	0.55	0.73	0.77	0.83	0.87	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	1.00
AT 12	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.33	0.40	0.50	0.55	0.60	0.62	0.65	0.65	0.65	0.65

Figure 4.2. Runoff coefficients for different source loads (PV & Associates LLC, 2015)

Table 4.2. Source load areas within one-acre medium residential landuse

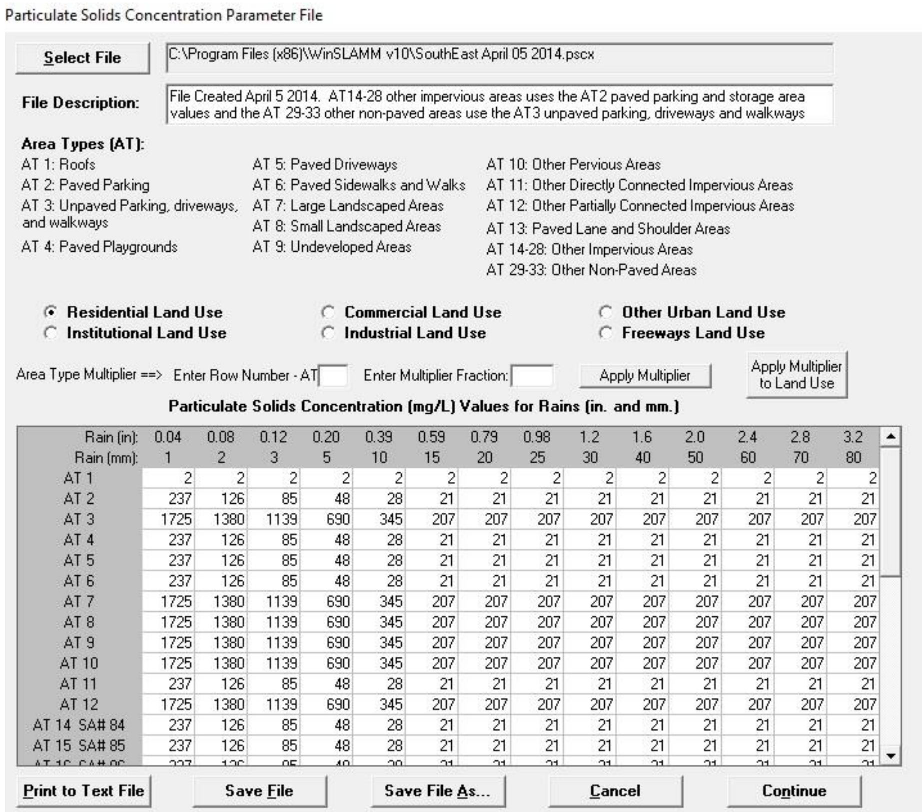
Source Load	Area (acres)
Roofs	0.168
Parking	0.007
Driveways/Sidewalks	0.08
Streets	0.157
Landscape Areas	0.526
Isolated Areas	0.001
Pervious Areas	0.064

4.3.2 Sediment Load Calculations

Total suspended solid loadings are calculated by multiplying runoff volume by particulate solid concentration (See Equation 4.2). The particulate solid concentrations used in the model have been calibrated from monitored data from Birmingham, Alabama. The runoff concentrations are a function of the rainfall depth and the landuse. Figure 4.3

shows a screen capture of the particulate solid concentrations for a different load source area of residential landuse obtained from the WinSLAMM library (PV & Associates LLC, 2015).

Particulate Solid Loading (lbs)= 6.2×10^{-5} ×Runoff Volume (ft^3) ×Particulate Solid Concentration (mg/l) (Eq. 4.2)



Rain (in):	0.04	0.08	0.12	0.20	0.39	0.59	0.79	0.98	1.2	1.6	2.0	2.4	2.8	3.2
Rain (mm):	1	2	3	5	10	15	20	25	30	40	50	60	70	80
AT 1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
AT 2	237	126	85	48	28	21	21	21	21	21	21	21	21	21
AT 3	1725	1380	1139	690	345	207	207	207	207	207	207	207	207	207
AT 4	237	126	85	48	28	21	21	21	21	21	21	21	21	21
AT 5	237	126	85	48	28	21	21	21	21	21	21	21	21	21
AT 6	237	126	85	48	28	21	21	21	21	21	21	21	21	21
AT 7	1725	1380	1139	690	345	207	207	207	207	207	207	207	207	207
AT 8	1725	1380	1139	690	345	207	207	207	207	207	207	207	207	207
AT 9	1725	1380	1139	690	345	207	207	207	207	207	207	207	207	207
AT 10	1725	1380	1139	690	345	207	207	207	207	207	207	207	207	207
AT 11	237	126	85	48	28	21	21	21	21	21	21	21	21	21
AT 12	1725	1380	1139	690	345	207	207	207	207	207	207	207	207	207
AT 14 SA# 84	237	126	85	48	28	21	21	21	21	21	21	21	21	21
AT 15 SA# 85	237	126	85	48	28	21	21	21	21	21	21	21	21	21

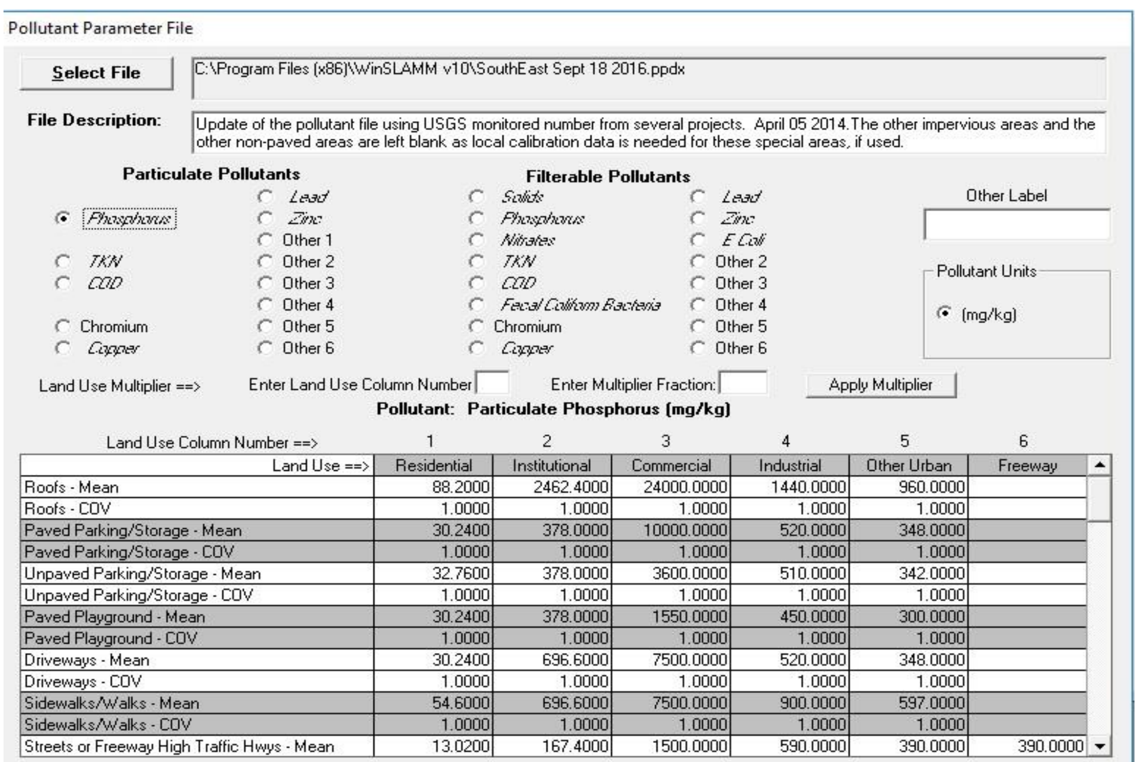
Figure 4.3. Particulate solid concentrations for different load source areas of residential landuse.

4.3.3 Nutrient Load Calculations

The WinSLAMM model can be used to assess several pollutants, including: particulate and suspended solid, total and dissolved nitrogen, total and dissolved phosphorus, COD, TKN, Chromium, Copper, Lead, Zinc, Cadmium and Pyrene. In this study, the performance of the BMPs in removing total nitrogen (TN) and total phosphorus (TP) is examined. The particulate pollutant loading for each landuse area is calculated by multiplying the particulate solid loading by particulate pollutant strength (mg/kg) (See Equation 4.3). Also, the filterable pollutant loading is calculated by multiplying the runoff volume by filterable pollutant concentrations (See Equation 4.4). The particulate pollutant strengths and the filterable pollutant concentrations have been determined from monitored data for different areas of the country (PV & Associates LLC, 2015). Once the incremental loads have been determined, the program adds up the particulate and filterable pollutant loads to generate the total pollutant load coming from different landuses. Figures 4.4 and 4.5 respectively show screen captures of the phosphorus particulate pollutant strength and the filterable pollutant concentrations for different landuses.

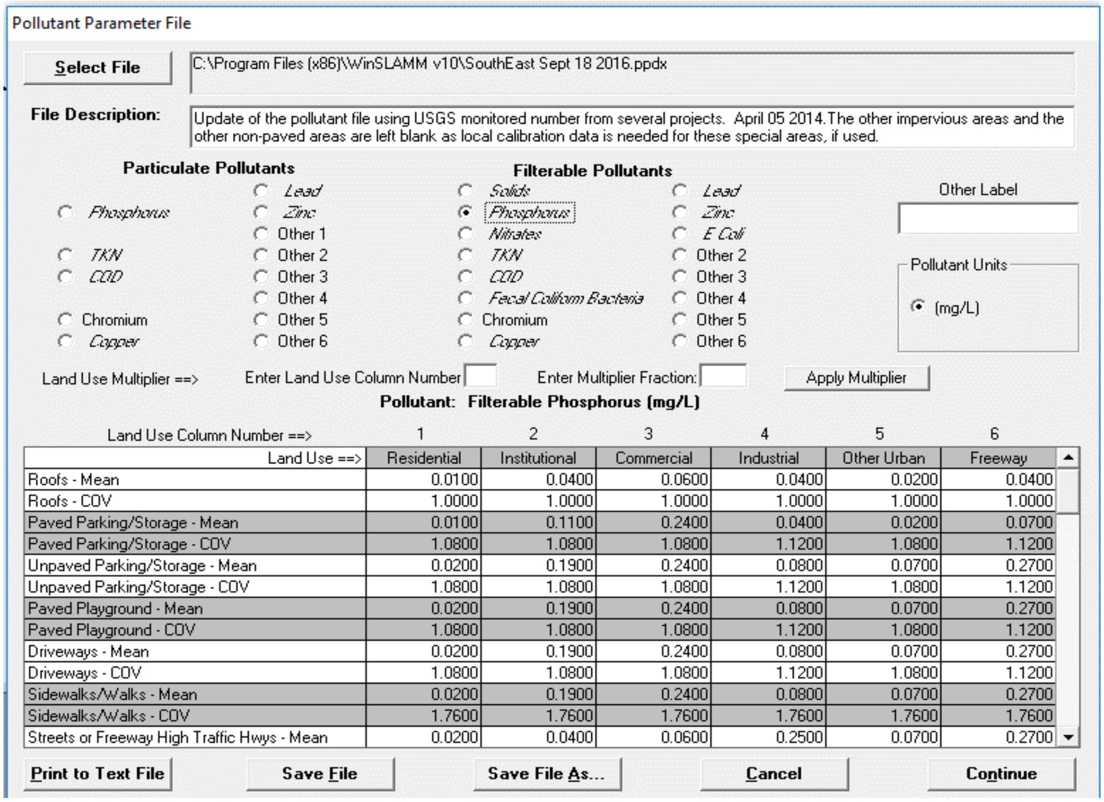
Particulate Pollutant Load (lbs) =0.453×10^{-6}×Particulate Solids Loading (lbs)×Particulate Pollutant strength (mg/kg) (Eq. 4.3)

Filterable Pollutant Load (lbs)= 6.2×10^{-5}×Runoff Volume(ft^3)×Filterable Pollutant Concentration (mg/l) (Eq. 4.4)



Land Use ==>	1 Residential	2 Institutional	3 Commercial	4 Industrial	5 Other Urban	6 Freeway
Roofs - Mean	88.2000	2462.4000	24000.0000	1440.0000	960.0000	
Roofs - COV	1.0000	1.0000	1.0000	1.0000	1.0000	
Paved Parking/Storage - Mean	30.2400	378.0000	10000.0000	520.0000	348.0000	
Paved Parking/Storage - COV	1.0000	1.0000	1.0000	1.0000	1.0000	
Unpaved Parking/Storage - Mean	32.7600	378.0000	3600.0000	510.0000	342.0000	
Unpaved Parking/Storage - COV	1.0000	1.0000	1.0000	1.0000	1.0000	
Paved Playground - Mean	30.2400	378.0000	1550.0000	450.0000	300.0000	
Paved Playground - COV	1.0000	1.0000	1.0000	1.0000	1.0000	
Driveways - Mean	30.2400	696.6000	7500.0000	520.0000	348.0000	
Driveways - COV	1.0000	1.0000	1.0000	1.0000	1.0000	
Sidewalks/Walks - Mean	54.6000	696.6000	7500.0000	900.0000	597.0000	
Sidewalks/Walks - COV	1.0000	1.0000	1.0000	1.0000	1.0000	
Streets or Freeway High Traffic Hwys - Mean	13.0200	167.4000	1500.0000	590.0000	390.0000	390.0000

Figure 4.4. Particulate strength for phosphorus (mg/kg)



Land Use ==>	1 Residential	2 Institutional	3 Commercial	4 Industrial	5 Other Urban	6 Freeway
Roofs - Mean	0.0100	0.0400	0.0600	0.0400	0.0200	0.0400
Roofs - COV	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Paved Parking/Storage - Mean	0.0100	0.1100	0.2400	0.0400	0.0200	0.0700
Paved Parking/Storage - COV	1.0800	1.0800	1.0800	1.1200	1.0800	1.1200
Unpaved Parking/Storage - Mean	0.0200	0.1900	0.2400	0.0800	0.0700	0.2700
Unpaved Parking/Storage - COV	1.0800	1.0800	1.0800	1.1200	1.0800	1.1200
Paved Playground - Mean	0.0200	0.1900	0.2400	0.0800	0.0700	0.2700
Paved Playground - COV	1.0800	1.0800	1.0800	1.1200	1.0800	1.1200
Driveways - Mean	0.0200	0.1900	0.2400	0.0800	0.0700	0.2700
Driveways - COV	1.0800	1.0800	1.0800	1.1200	1.0800	1.1200
Sidewalks/Walks - Mean	0.0200	0.1900	0.2400	0.0800	0.0700	0.2700
Sidewalks/Walks - COV	1.7600	1.7600	1.7600	1.7600	1.7600	1.7600
Streets or Freeway High Traffic Hwys - Mean	0.0200	0.0400	0.0600	0.2500	0.0700	0.2700

Figure 4.5. Filterable concentration of phosphorus (mg/l)

4.3.4 Infiltration Rate of BMPs

Infiltration rate of soils used in the design of BMPs needs to be selected by users. Table 4.3 shows the soil types and corresponding infiltration rates in the WinSLAMM. For this study, the performance analysis of BMPs was conducted for sandy loam, loam, and sandy clay loam soils since this covers the spectrum of soils typically used in infiltration BMPs in urban areas.

Table 4.3. The soil types and corresponding infiltration rates (PV & Associates LLC, 2015).

Soil Type	Infiltration Rate (in/hr)
Sand	4
Loamy Sand	1.25
Sandy Loam	**0.5**
Loam	**0.25**
Silt Loam	0.15
Sandy Clay Loam	**0.1**
Clay Loam	0.05
Silty Clay Loam	0.025
Sandy Clay	0.025
Silty Clay	0.02
Clay	0.01

4.3.5 Vegetative Retardance Factor

The retardance factor of vegetative covers is considered in the design of some BMPs (such as grass swale and filter strips) and needs to be provided as an input. Assumed available grass species are categorized into five classes of retardance according to their condition and cover type (see Table 4.4). Generally, Kentucky Bluegrass is best adapted to Central and Eastern Kentucky and bermudagrass and zoysiagrass to Western Kentucky. However, Tall Fescue adapts well throughout the state (Powell, 2000). Kentucky bluegrass tends to struggle during the hot summers and requires more work and money to keep it looking good. On the other hand, Tall fescue, is the best adapted grass for Kentucky as it has a good heat and cold tolerance (Gregg, 2016). For this study, the Tall Fescue was selected in design of BMPs as it has good tolerance and is adaptable throughout Kentucky the Tall Fescue is associated with retardance class B.

Table 4.4. The retardance classification of vegetal covers (USDA, 2007)

Retardance	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall (average 30 in)
	Reed canarygrass or Yellow bluestem ischaemum	Excellent stand, tall (average 36 in)
B	Smooth bromegrass	Good stand, mowed (average 12 to 15 in)
	Bermudagrass	Good stand, tall (average 12 in)
	Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses	Good stand, unmowed
	Tall fescue	Good stand, unmowed (average 18 in)
	Sericea lespedeza	Good stand, not woody, tall (average 19 in)
	Grass-legume mixture—Timothy, smooth bromegrass, or orchardgrass	Good stand, uncut (average 20 in)
	Reed canarygrass	Good stand, uncut (average 12 to 15 in)
	Tall fescue, with birdsfoot trefoil or ladino clover	Good stand, uncut (average 18 in)
	Blue grama	Good stand, uncut (average 13 in)
C	Bahiagrass	Good stand, uncut (6 to 8 in)
	Bermudagrass	Good stand, mowed (average 6 in)
	Redtop	Good stand, headed (15 to 20 in)
	Grass-legume mixture—summer (orchardgrass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (6 to 8 in)
	Centipedegrass	Very dense cover (average 6 in)
	Kentucky bluegrass	Good stand, headed (6 to 12 in)
D	Bermudagrass	Good stand, cut to 2.5-in height
	Red fescue	Good stand, headed (12 to 18 in)
	Buffalograss	Good stand, uncut (3 to 6 in)
	Grass-legume mixture—fall, spring (orchardgrass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (4 to 5 in)
	Sericea lespedeza or Kentucky bluegrass	Good stand, cut to 2-in height. Very good stand before cutting
E	Bermudagrass	Good stand, cut to 1.5-in height
	Bermudagrass	Burned stubble

4.3.6 Particle Size Distribution

WinSLAMM contains a library of particle size distributions that is applied for each source load area within each landuse. For example, the particle size distribution for sidewalk runoff will be different than particles that are flushed off from a paved area. The WinSLAMM database contains different distributions constructed from 31 particle sizes (See Table 4.5). Each of these particle sizes are characterized by a “Percent Greater Than” value, which is associated with the percent of the particles that are greater than a particle with a specific size. For instance, 100% of particles in a distribution are greater than 0 microns. The combined particle size distribution coming from different landuses is calculated by a mass-weighting approach for each rainfall event. In applying the mass-weighting approach, each percent greater than a particle size value for a rainfall event is multiplied by the total suspended solids mass calculated (See section 4.3.2). Then, the resulting products are summed and divided by the total mass from the land use for each rainfall event for each particle size increment. The resulting values represent the combined mass-weighted particle size distribution (PV & Associates LLC, 2015).

Table 4.5. The 31 distinct particle sizes in WinSLAMM (PV & Associates LLC, 2015).

No of particle	Particle Size (microns)
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	20
17	25
18	30
19	35
20	40
21	50
22	60
23	80
24	100
25	150
26	200
27	300
28	500
29	800
30	1000
31	2000

WinSLAMM provides three types of soils for each landuse. The soils include: Sand, Silt and Clays. The user can determine the percentage of each of these three soils within the soil of the landuses. The different classes of soils are composed of a specific percentage of sand, silt and clay. Table 4.6 shows the USDA textural classes of soils (USDA, 2004).

Table 4.6. USDA textural classes of soils

Soil Class	Percentage		
	Sand	Silt	Clay
Sand	86-100	0-14	0-10
Loamy Sand	70-86	0-30	0-15
Sandy Loam	50-70	0-50	0-20
Loam	23-52	28-50	7-27
Silty Loam	20-50	74-88	0-27
Sandy Silt Loam	0-20	88-100	0-12
Clay Loam	20-45	15-52	27-40
Sandy Clay Loam	45-80	0-28	20-35
Silty Clay Loam	0-20	40-73	27-40
Sandy Clay	45-65	0-20	35-55
Silty Clay	0-20	40-60	40-60
Clay	0-45	0-40	40-100

4.3.7 BMPs

WinSLAMM allows the user to simulate the performance of several BMPs. In the current study, sensitivity analyses were conducted on three different BMPs for the purpose of generating a set of results which could then be used to develop functional relationships for each of the BMPs. The selected BMPs include: 1) a grass swale, 2) a filter strip, and 3) a biofiltration basin. Each of these BMPs are discussed in detail in the following sections.

4.4 Grass Swale

4.4.1 Definition

A grassed swale is a shallow open-channel drainage ditch which has been stabilized with grass or other herbaceous vegetation for the purpose of filtering pollutants (North

Carolina Stromwater BMP Manual, 2007). A figure of a typical grass swale is shown in Figure 4.6.

Figure 4.6. A typical figure of a Grass Swale

4.4.2 Theoretical Equations for Modeling a Grass Swale

WinSLAMM determines the pollutant reduction efficiency of a grass swale by routing a hydrologic time series and load series through a set of submodels that simulate the sediment trapping efficiency of the grass lining along with the infiltration rate of the swale. The runoff volume reduction of the swale is a function of swale infiltration rate and the wetted perimeter of the channel. The swale length, width and infiltration rate must be specified as part of the model input. Using these values, the program determines the depth of flow in the swale and then calculates the velocity times the hydraulic radius (VR) for each time step. The Manning's roughness coefficient (i.e. n) of the channel is obtained using VR-n curves which are expressed as a function of the type of channel lining. An example of such a curve is provided in Figure 4.7 for a channel with a bluegrass lining (Kirby *et al*. 2005). The model then uses the Manning's equation to calculate the flow rate for each time step. This process is repeated until the initial and final flow values converge to a constant value. Once the flowrate is determined, Manning's equation is then used to determine the average depth in the channel, which will be used to calculate the wetted perimeter. The wetted parameter will then be used to determine the volume of water loss through infiltration.

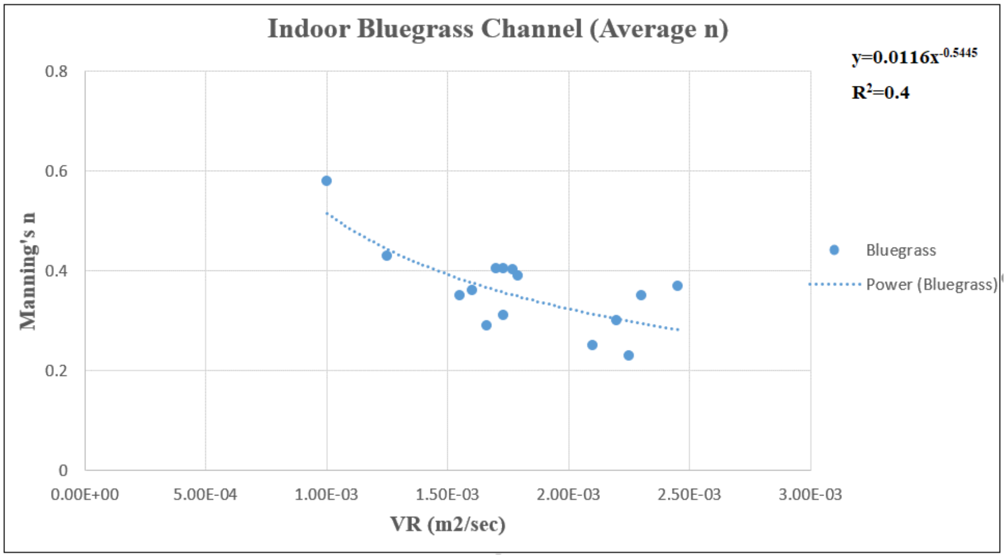


Figure 4.7. Relationship between VR and Manning's n for a Bluegrass lined channel (Kirby *et al.* 2005).

Nara *et al*. 2008, conducted several field experiments in order to develop relationships for use in predicting the sediment load reduction in the grass swales. They found that the relationship between the flow depth and the grass height is significant in determining the sediment trapping efficiency of the swales. A series of curves, which display the percent sediment load reduction versus particle settling frequency were developed for different combinations of the flow depth/grass height ratio. The following equation shows the relationship between the particle percent reduction and the settling frequency for flow depth/grass height ratios between 0 and 1 (Nara *et al*. 2008).

$$Y=2.101\times\log(X)^2+6.498\times\log(X)+76.82 \qquad \text{(Eq. 4.5)}$$

where: Y= Particle percent reduction and X=Settling frequency.

The settling frequency represents the probability that a single particulate will settle while flowing through a swale with length L. The frequency is a function of flow velocity, settling velocity, channel length and flow depth can be calculated as shown in the following equation (Nara *et al.* 2008).

$$Settling\ Frequency = \frac{Traveling\ Time}{Settling\ Time} \qquad \text{(Eq. 4.6)}$$

where the particle traveling time is the average time that it takes for a given particle to travel from the beginning to the end of a swale and where the average settling time is the average time that it takes for a given particle to settle out of the water column as the particle travels through a swale. The average traveling time can be calculated using the following equation (Nara *et al*. 2008).

$$Traveling\ Time = \frac{Swale\ Length}{Flow\ Velocity} \qquad \text{(Eq. 4.7)}$$

While the average settling time can be calculated using the following equation (Nara *et al*. 2008).

$$Settling\ Time = \frac{Flow\ Depth}{Settling\ Velocity} \qquad \text{(Eq. 4.8)}$$

The settling velocity (Vs), in water with 20.2 Celsius, can be estimated using the Stokes' Law which is shown in the following equation (Nara *et al*. 2008).

$$Vs = 21{,}778 \times (P_p - 1) \times R^2 \qquad \text{(Eq. 4.9)}$$

Where:

Vs = Settling velocity of a particle (cm/s)
R = Radius of a particle (cm)
P_p = Density of a particle (g/cm^3)

For example, the settling velocity of sand, silt, and clay are provided in Table 4.7.

Table 4.7. The settling velocity of sandy, silty and clayey soils (USDA, 1987).

Soil Type	**Density (g/cm^3)**	**Diameter range (mm)**	**Settling Velocity Range (cm/s)**
Sand	1.71	0.05-2	0.096-154.6
Silt	1.52	0.002-0.05	0.00011-.0707
Clay	1.62	<0.002	0-0.000135

4.4.3 WinSLAMM Input parameters for a Grass Swale

WinSLAMM requires several input parameters for use in modeling a grass swale. These include:

- Fraction Drainage Area served by Swale (0-1)
- Swale Side Slope (ft H: ft V)
- Typical Swale Depth (ft)
- Average Swale Length to outlet (ft)
- Channel Retardance Factor
- Bottom Width (ft)
- Typical Grass Height (inch)
- Period of rainfall
- Longitudinal Slope (%) (ft/ft)
- Swale Length (ft)
- Watershed Area (Acres)
- Swale Dynamic Infiltration Rate (in/hr)

A screen capture of the input screen for the grass swale data is shown in Figure 4.8. Typical ranges for each of the values are given below.

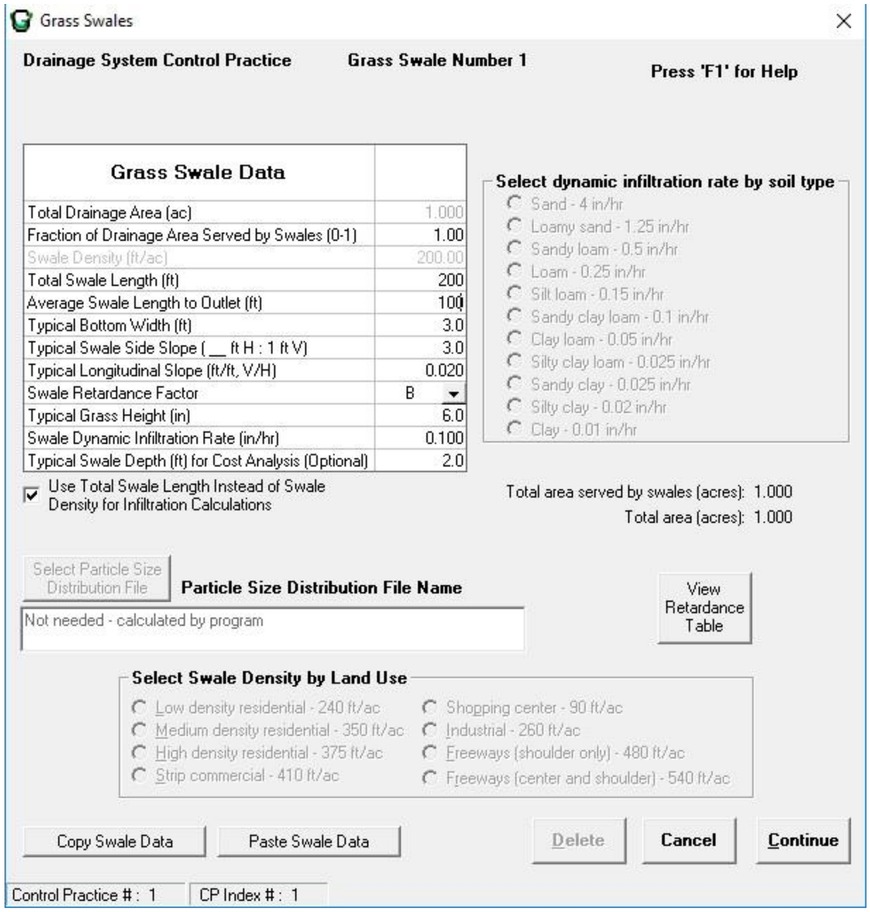


Figure 4.8. The grass swale parameters window in the WinSLAMM

4.4.3.1 Total Drainage Area:

The Pennsylvania Stormwater BMP Manual (2006) recommends that the contributing area draining to the swale not exceed to 1 to 2 acres. Alternatively, the West Virginia Stormwater Management and Design Guidance Manual (2012), recommends that the contributing drainage area to the grass swale shall be less than or equal to 5 acres. For this study, the drainage area was assumed to be restricted to 1 acre.

4.4.3.2 Fraction of Drainage Area served by Swale (0-1):

It was assumed that the total drainage area is served by the swale. Thus, this parameter was set equal to 1.

4.4.3.3 Total Swale Length:

The North Carolina Division of Water Quality Stormwater BMP Manual (2007) recommends a swale length of approximately 150 ft/acre of contributing drainage. Similarly, the Pennsylvania Stormwater BMP Manual (2006) states that the optimal swale length will be between 100 to 200 ft. For this study, it was assumed that the swale serves a one-acre square medium density residential lot and the length of swale is equal to one side of the lot, which is almost 200 ft. Figure 4.9 shows a hypothetical one-acre square lot served by a grass swale with the total length equal to 200 ft.

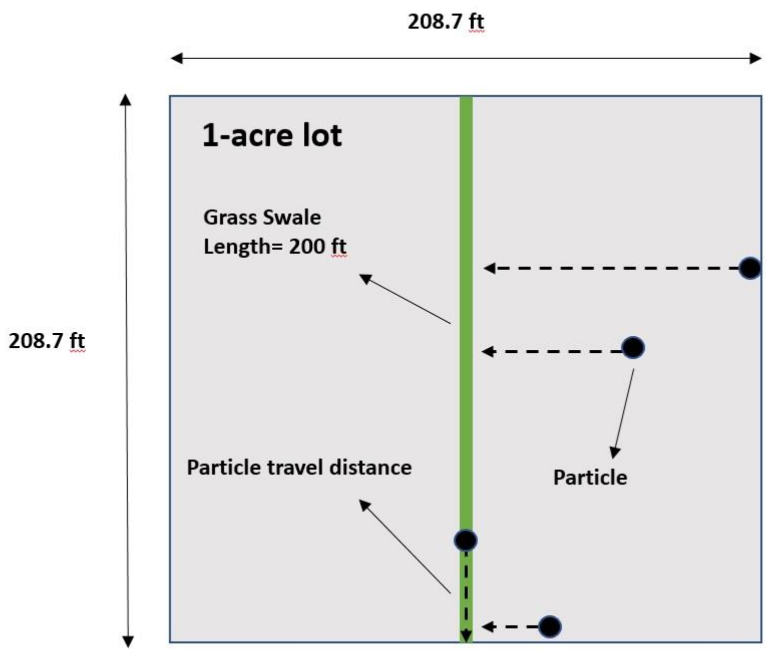


Figure 4.9. A hypothetical one-acre square lot served by a grass swale

4.4.3.4 Average Swale length to outlet:

This parameter is the average distance that the particles travel along the lot and in the swale to arrive at the drainage system (See Figure 4.9). This value is used to help determine the particulate filtering capability of the swale drainage system (PV & Associates LLC, 2015). A sensitivity analysis revealed that the performance of the BMP was slightly affected by this parameter. For this study, this parameter assumed to be equal to 100 ft.

4.4.3.5 Swale Side Slope:

The wetted perimeter of the swale is a function of side slope. By increasing the wetted perimeter, additional water can be infiltrated into the swale. According to the New Jersey Stromwater BMP Manual (2016), the maximum allowable side slope should be 3:1. Similarly, the North Carolina Division of Water Quality Stormwater BMP Manual (2007) recommends that the grass swale side slope should not be greater than 3:1. As before, a sensitivity analysis of this parameter was conducted to examine the effect of the side slope on the performance of the BMP. This analysis revealed that the optimal side slope was 3:1. As a consequence, a slide slope of 3:1 was used in this study.

4.4.3.6 Bottom Width:

A review of several drainage manuals revealed recommended bottom widths ranging from 2 to 6 feet. After performing several sensitivity analyses, optimal removal efficiencies were found to be associated with a bottom width of 3 feet. As a result, this value was used for the subsequent functional analysis.

4.4.3.7 Swale Depth:

The Pennsylvania and the North Carolina Stormwater BMP Manuals require that the swales should be designed to not exceed a depth of 18 inches with 0.5-foot freeboard. In this study, a maximum depth of 2 ft was assumed for the swale depth.

4.4.3.8 Typical Grass Height:

The New Jersey Stormwater manual recommends that the height of grass shall be between 3 to 6 inches. In addition, the North Carolina Stormwater BMP manual recommends that the grass swale vegetation shall be maintained at a height of approximately six inches. In this study, the height of grass was considered as 6 inches. However, the sensitivity analysis of this parameter revealed that the performance of the practice was not noticeably changed when the grass height was varied from 3 to 6 inches. Thus, for this study the Tall Fescue with height of 6 inches was selected.

4.4.3.9 Swale Longitudinal Slope:

According to the North Carolina Division of Water Quality Stormwater BMP Manual (2007), grass swales are not practical in areas of steep terrain, although terracing a series of grass swale cells may work on slopes from 5% to 10%. In addition, the Pennsylvania Stormwater Management BMP Manual (2007) recommends that the maximum longitudinal slope should not exceed 5%. As before, a sensitivity analysis was performed for this variable, while holding the other variables constant. This analysis revealed that the optimal removal efficiency was associated with a longitudinal slope of 2%. As a result, this value was assumed as constant in the subsequent functional analysis.

4.4.3.10 Dynamic swale infiltration rate:

This parameter is a function of the soil type underneath the swale. A sensitivity analysis of this parameter revealed that the performance of the swale is highly effected by the soil infiltration rate. As a result, this parameter was left as an independent variable in the subsequent functional analysis.

4.4.4 Grass Swale Performance Curves

Following a review of the literature and after a series of sensitivity runs, the swale was assumed to be designed using the default parameter values shown in Table 4.8. The runoff and sediment loads (and thus the associated nutrient loads) were generated assuming an urban medium density residential landuse. The only parameter that was not fixed was the swale infiltration rate (as expressed as a function of the soil type). A series of simulations were then performed using WinSLAMM for the average response year (i.e. 1970) while varying the swale infiltration rate. The results from these simulations were then used to develop a series of curves that can be used to predict nutrient load reductions as a function of the input load to the grass swale (see Figures 4.10 and 4.11).

Table 4.8. The assigned values for each parameter of the grass swale

Fraction Drainage Area served by Swale (0-1)=1	Bottom Width= 3 ft
Side Slope= 3:1	Typical Grass Height= 6 inches
Typical Swale Depth= 2 ft	Period of rainfall= 1970
Average Swale Length to outlet= 100 ft	Watershed Area= 1 acres
Retardance Factor: B	Swale Dynamic Infiltration Rate: Variable
Longitudinal slope= 2 %	Length of the swale: 200 ft

As one varies the soil type, the performance of the BMP changes because the infiltration rate is different for each soil type. As the infiltration rate increases, the swale absorbs more runoff coming from the lot. Different swale length leads to different average annual load reductions. The swale length was varied from 100 to 200 to obtain an average annual load reduction for different soil types. Then the load reduction values were used to develop a series of curves (Figures 4.12 and 4.13) that can be used to predict average annual load reduction as a function of the swale length and soil type. Note that in these two figures the average daily influent load (over one year) coming into the swale is constant for each soil type.

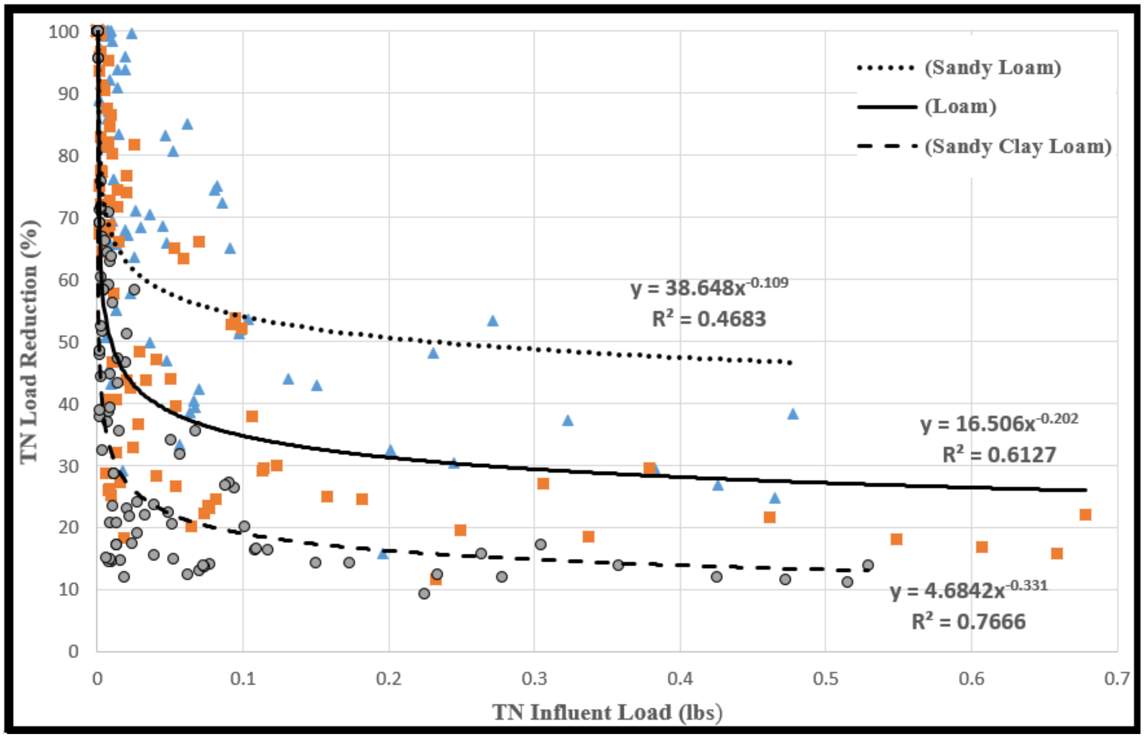


Figure 4.10. The grass swale TN performance curves for length of 200 ft

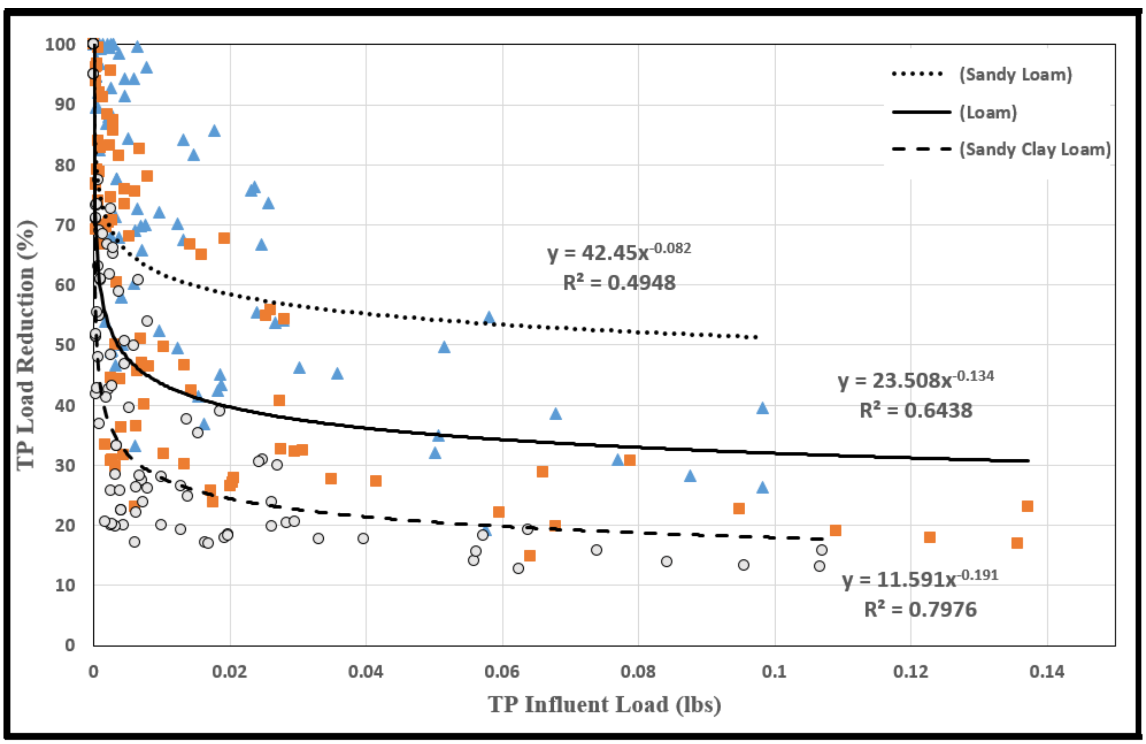


Figure 4.11. The grass swale TP performance curves for length of 200 ft

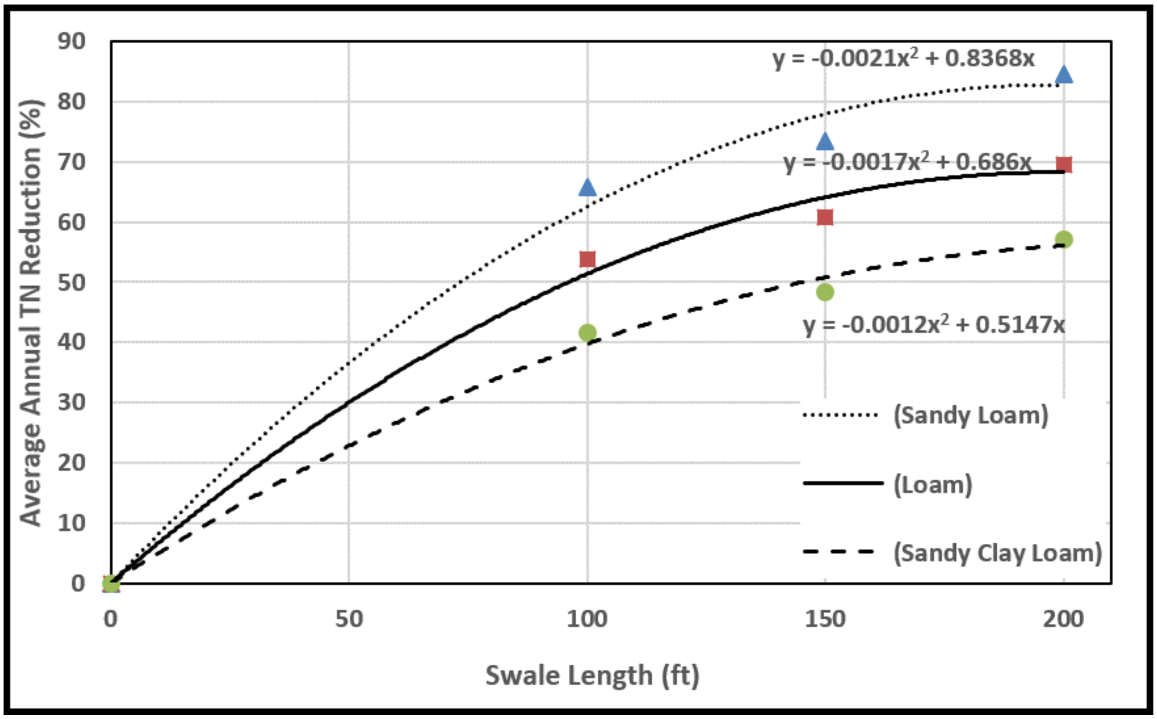


Figure 4.12. The grass swale TN performance curves for different lengths

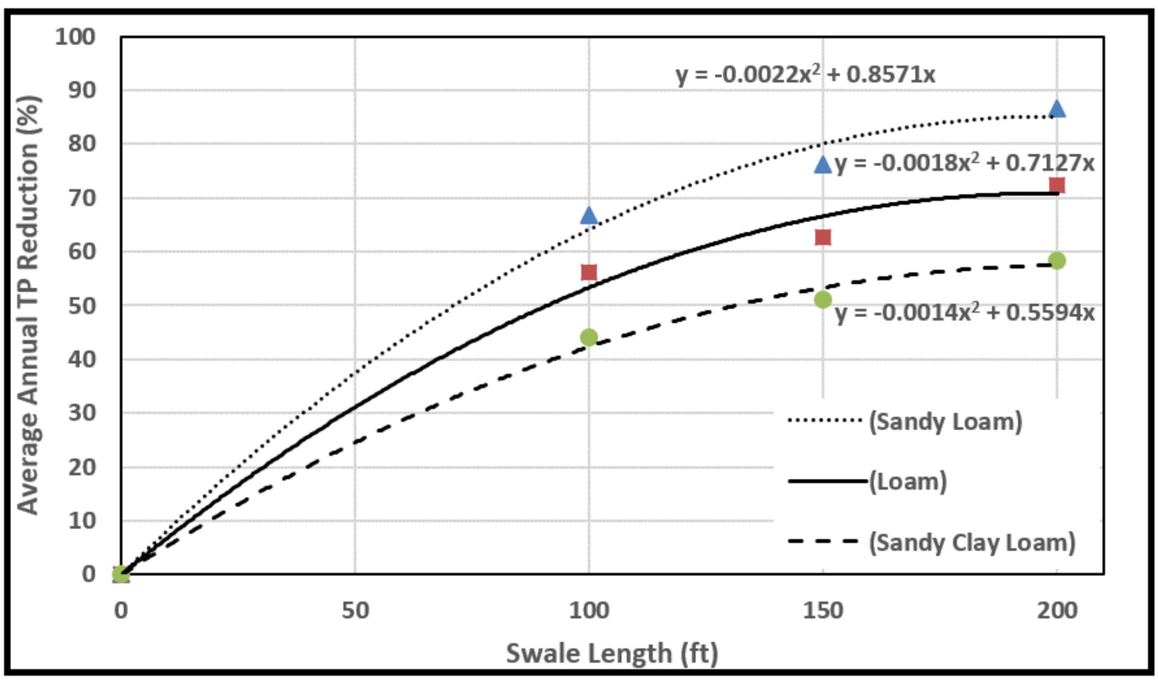


Figure 4.13. The grass swale TP performance curves for different lengths

4.5 Filter Strip

4.5.1 Definition

A filter strip is a section of land capable of sustaining sheet flow, either forested or vegetated with turf grasses or other plants, which provides pollutant removal as the stormwater passes through it (North Carolina Stromwater BMP Manual, 2007). A figure of a typical filter strip is shown in Figure 4.14.

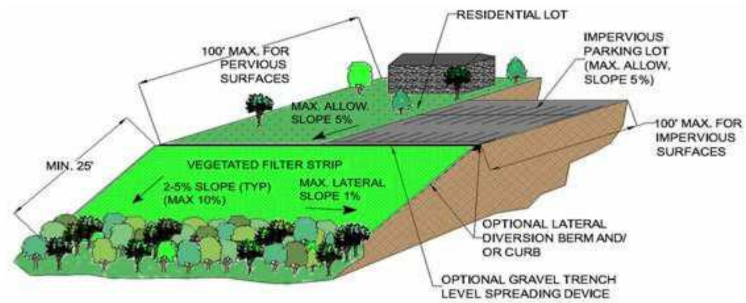


Figure 4.14. The typical figure of a Filter Strip (Pennsylvania Stromwater BMP Manual, 2006)

4.5.2 Simulation process of filter strip

The WinSLAMM determines the pollutant reduction efficiency of a filter strip by routing a specified hydrologic and load time series through a series of submodels that simulate the sediment trapping efficiency and infiltration associated with the filter strip. The filter strip runoff volume reduction is a function of infiltration rate and the wetted perimeter of strip. The runoff is assumed to be evenly distributed across the width of the filter strip (such as through the use of a level spreader) and does not form concentrated flow channels or rills as it flows across the strip (WinSLAMM User's Manual, 2016). The wetted perimeter is modeled as the width of the filter strip. The length of filter strip is the dimension that water flows along the practice. Figure 4.15 shows the width and length of a filter strip (PV & Associates LLC, 2015).

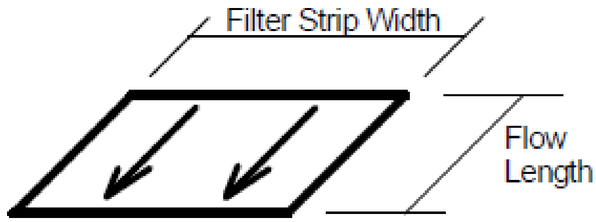


Figure 4.15. The width and length of a filter strip (PV & Associates LLC, 2015).

The WinSLAMM simulates a filter strip very similar to the way it models a grass swale (i.e. removal efficiencies are determined as a function of the trapping efficiency and the infiltration rate). However, unlike for a grass swale, the full benefits (as calculated by the model) are assumed to occur only for grass filters that are at least 20 percent, or 1/5th, of the contributing area (PV & Associates LLC, 2015).

4.5.3 WinSLAMM Input Parameters for a Filter Strip

WinSLAMM requires several input parameters for use in modeling a filter strip. These include:

- Total Area in Source Area (ac)
- Area Fraction served by Filter Strip (0-1)
- Total Filter Strip Width
- Flow Length
- Dynamic Infiltration Rate (in/hr)
- Typical Longitudinal Slope (%) (ft/ft)
- Typical Grass Height (inch)
- Grass Retardance Factor
- Surface Clogging Load
- Period of rainfall

A screen capture of the WinSLAMM input menu for these parameters is provided in Figure 4.16. The individual parameters as discussed in more detail below.

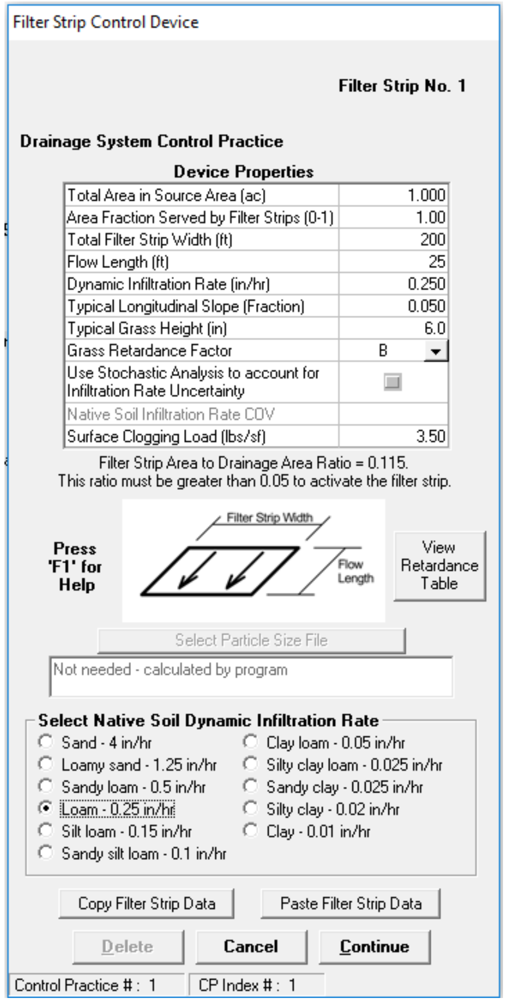


Figure 4.16. The Filter Strip Parameters window in the WinSLAMM.

4.5.3.1 Total Area in Source Area (acre):

Similar to the grass swale, the drainage area was assumed to be restricted to 1 acre.

4.5.3.2 Fraction of drainage area served by Filter Strip (0-1):

It was assumed that this value is equal to 1, which means that the filter strip serves the total drainage area.

4.5.3.3 Dynamic Infiltration Rate (in/hr):

This parameter is a function of soil type underneath the BMP. A sensitivity analysis of this parameter revealed that the performance of the filter strip is highly affected by the soil infiltration rate. As a result, this parameter was considered as an independent variable in the subsequent functional analysis.

4.5.3.4 Surface Clogging Load:

This parameter presents the mass of sediment per square foot that will clog the filter strip. In this study, the surface clogging load was assumed to be 3.5 lbs/sf.

4.5.3.5 Typical Grass Height (inch):

The Pennsylvania Stormwater manual recommends that the height of grass shall be between 4 to 6 inches. In this study, the height of grass was considered as 6 inches. However, the sensitivity analysis of this parameter revealed that the performance of the practice was not noticeably changed when the grass height was varied from 4 to 6 inches. Thus, for this study the Tall Fescue with height of 6 inches was selected.

4.5.3.6 Typical Longitudinal Slope (%) (ft/ft):

According to the North Carolina Stomwater BMP Manual (2007), slopes must be in the appropriate range: less than 5 percent slope is preferable; in no cases, may slope exceed 15 percent. On the other hand, the Pennsylvania stormwater manual (2006), recommends that the maximum filter strip slope should be determined based on soil type and vegetated cover. Also, filter strip slope should never exceed 8% and the slopes less than 5% are generally preferred. In addition, the maximum contributing drainage area slope is generally less than 5% unless energy dissipation is provided. As before, a sensitivity analysis was performed in order to find the optimum slope. For this analysis, the slope varied from 1 to 15 percent while all other parameters remained constant. This analysis revealed that the optimal removal efficiency was associated with a longitudinal slope of 5%. As a result, this value was assumed as constant in the subsequent functional analysis.

4.5.3.7 Total Filter Strip Width:

According to the North Carolina Stormwater BMP Manual (2007), the width of the filter strip must be between a minimum of 30 ft and a maximum of 130 ft. However, the Pennsylvania Stormwater BMP Manual (2006) and the Lexington Fayette County

Stormwater Manual (2009) recommends that the minimum filter strip width should be equal to the width of the contributing drainage area. As the drainage area considered to be a one-acre square lot the width of the filter strip was assumed to be equal to the width of the drainage area, which is approximately 200 ft.

4.5.3.8 Flow Length:

According to the North Carolina Stormwater BMP Manual (2007), the length (parallel to flow) of a filter strip shall in all cases be a minimum of 50 ft. On the other hand, according to the Pennsylvania Stomwater Manual (2006), the minimum recommended length of the filter strip should be 25 ft; however, shorter lengths provide some water quality benefits as well. Also, the New Jersey Stormwater BMP Manual (2016) recommends that in order to maintain the sheet flow throughout the filter strip, the length of the structure must be between: the minimum length of 25 feet and the maximum length of 100 feet. For this study, the flow length of the filter strip assumed to be equal to 25 ft.

4.5.4 The filter strip performance curves

Following a review of the literature and after a series of sensitivity runs, the filter strip was assumed to be designed using the default parameter values shown in Table 4.9. The only parameter that was not fixed is the filter strip infiltration rate (as expressed as a function of the soil type). A series of simulations were then performed using the WinSLAMM for the average response year (i.e. 1970) while varying the filter strip infiltration rate. The results from these simulations were then used to develop a series of curves that can be used to predict nutrient load reductions as a function of the input load to the filter strip (See Figures 4.17 and 4.18).

Table 4.9. The assigned values to the parameters of filter strip

Area Fraction Served by Filter Strip	1	Watershed Area (acres)	1 acres
Surface Clogging Load	3.5 lbs/sf	Flow Length	25 ft
Grass Height	6 inches	Infiltration Rate	Variable
Grass Retardance Factor	B	Filter Strip Width	200 ft
Longitudinal Slope	5%		

As one varies the soil type, the performance of the BMP changes because the infiltration rate is different for each soil type. As the infiltration rate increases, the filter strip absorbs more runoff coming from the lot. Different filter strip widths leads to different average annual load reductions. The filter width was varied from 100 to 200 to obtain an average annual load reduction for different soil types. Then the load reduction values were used to develop a series of curves (Figures 4.21 and 4.22) that can be used to predict average annual load reduction as a function of the filter length and soil type, for a constant average annual influent load coming from a one-acre medium density residential lot. Note that in these two figures the average daily influent load (over one year) coming into the filter strip is constant for each soil type.

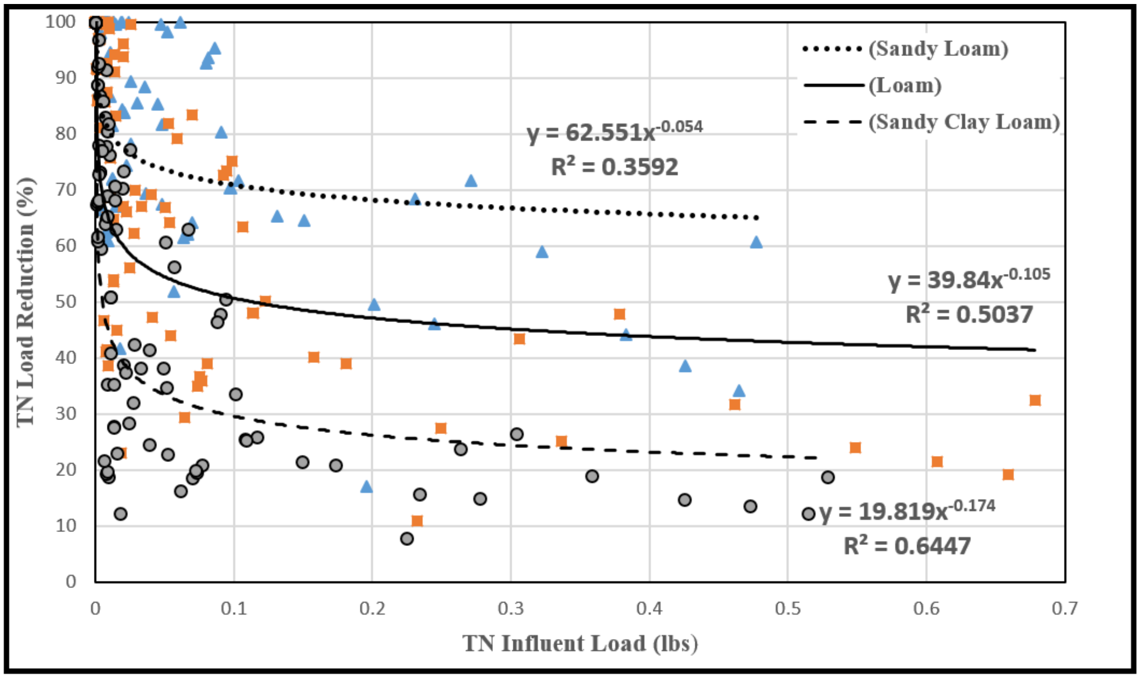


Figure 4.17. The filter strip TN performance curves for width of 200 ft

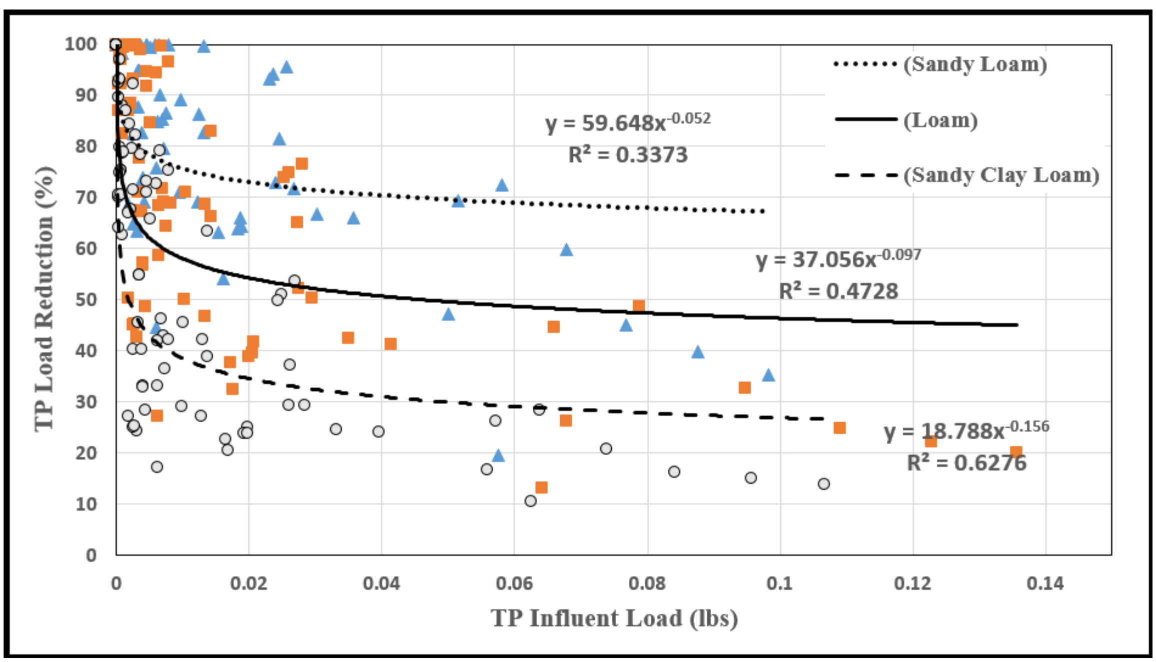


Figure 4.18. The filter strip TP performance curves for width of 200 ft

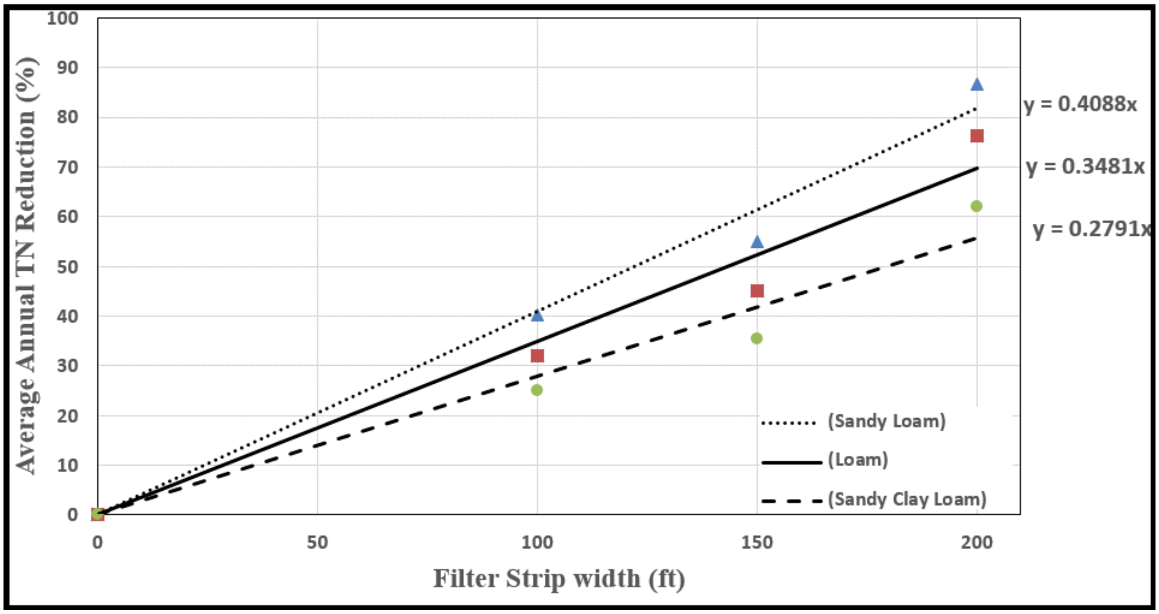


Figure 4.19. The filter strip TN performance curves for different width

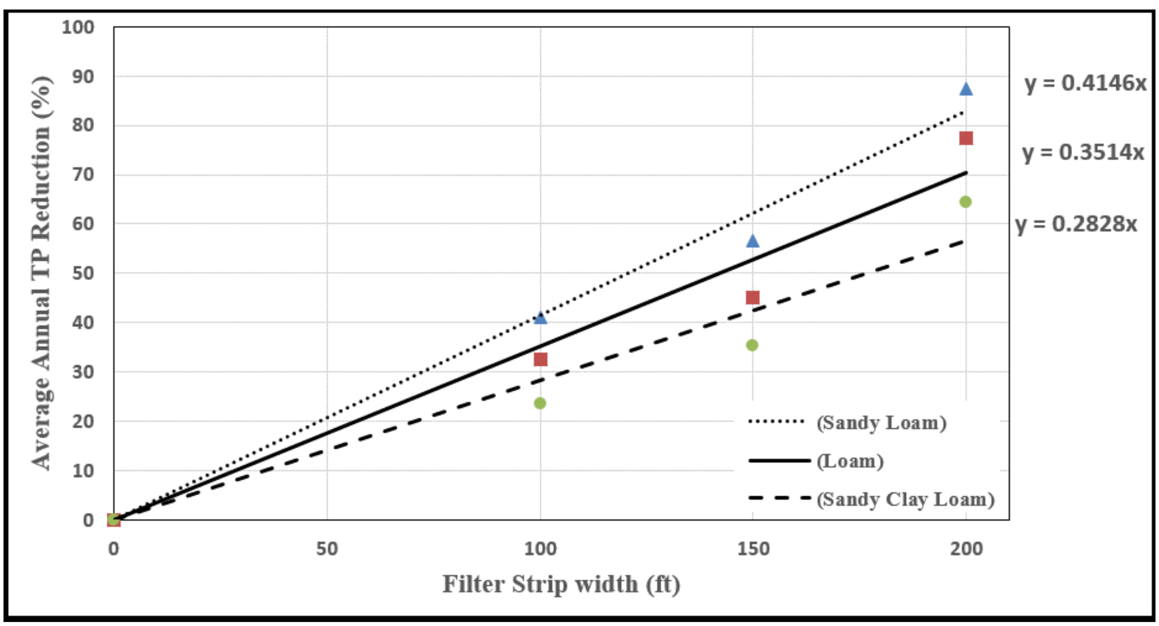


Figure 4.20. The filter strip TP performance curves for different widths

4.6 Biofiltration/Raingarden

4.6.1 Definition

Biofiltration is a practice to treat stormwater runoff using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression (Lexington-Fayette Urban County Government Stormwater Manual, 2009). A figure of a typical biofiltration is shown in Figure 4.21.

Figure 4.21. The typical figure of a biofiltration

4.6.2 The simulation process of biofiltration

Biofiltration is a type of bio-filter device. The program simulates the performance of biofiltration by conducting routing calculation for pond storage volume along with soil treatment options. The model contains some outlet options for the device including natural soil infiltration, evaporation, overflows (e.g. weirs or stand pipes) and subsurface discharge via infiltration into native soil underneath the device.

The program uses the Modified-Puls Storage-Indication algorithm (The U.S. Bureau of Reclamation, 1949) to model the hydraulic operation of biofiltration and routes the flow into the device starting from surface layer through subsurface layers including engineered soil and/or rock fill. The amount of water infiltrating into the device depends on the storage capacity of the layers, size of the device, surface, and subsurface outlet structures. When the soil layers are fully saturated and the rate of water flowing into the device is higher than infiltration rate of native soil underneath the device and the extra water overflows from the surface outlet structure.

The percent pollutant removal of the device is a function of amount of water flowing into the device, the infiltration rate of native soil, the filtering capacity of each subsurface layer, and size of the device. The amount of pollutants filtered by the subsurface layers depends on particulate size distribution of the sediment that the runoff introduce to the device and soil type of the layers. The program assumes the water that infiltrates into the subsurface media and drains into the native soil underneath the device receive complete treatment. On the other hand, the water that bypass over the surface outlet structure receives no treatment. For more information about the fractional removal of the particulates and biofiltration outlet device operation criteria please refer to PV & Associates LLC, 2015.

4.6.3 WinSLAMM Input Parameters for a Biofiltration

WinSLAMM requires several input parameters for use in modeling a biofiltration. These include:

- Top Area (square feet)
- Bottom Area (square feet)
- Total Depth (feet)
- Typical Width (ft)
- Native Soil Infiltration Rate (inches per hour)
- Native Soil Infiltration Rate COV (Coefficient of Variation)
- Infiltration Rate Fraction - Bottom (0.001-1)
- Infiltration Rate Fraction - Side (0.001-1)
- Rock Filled Depth (ft)
- Rock Fill Porosity
- Engineered Media Type
- Engineered Media Infiltration Rate (in/hr)
- Engineered Media Depth (ft).
- Engineered Media Porosity (0-1)
- Percent Solids Reduction Due to Engineered Media
- Inflow Hydrograph Peak Flow to Average Flow Ratio
- Number of Devices in the Source Area or Upstream Drainage System
- Particle Size Distribution File
- Characteristics of the outlets
- Evaporation and Evapotranspiration
- Plant type and root depth

A screen capture of the input screen for the biofiltration data is shown in Figure 4.22. A brief description of the major parameters of the model is provide in the following sections.

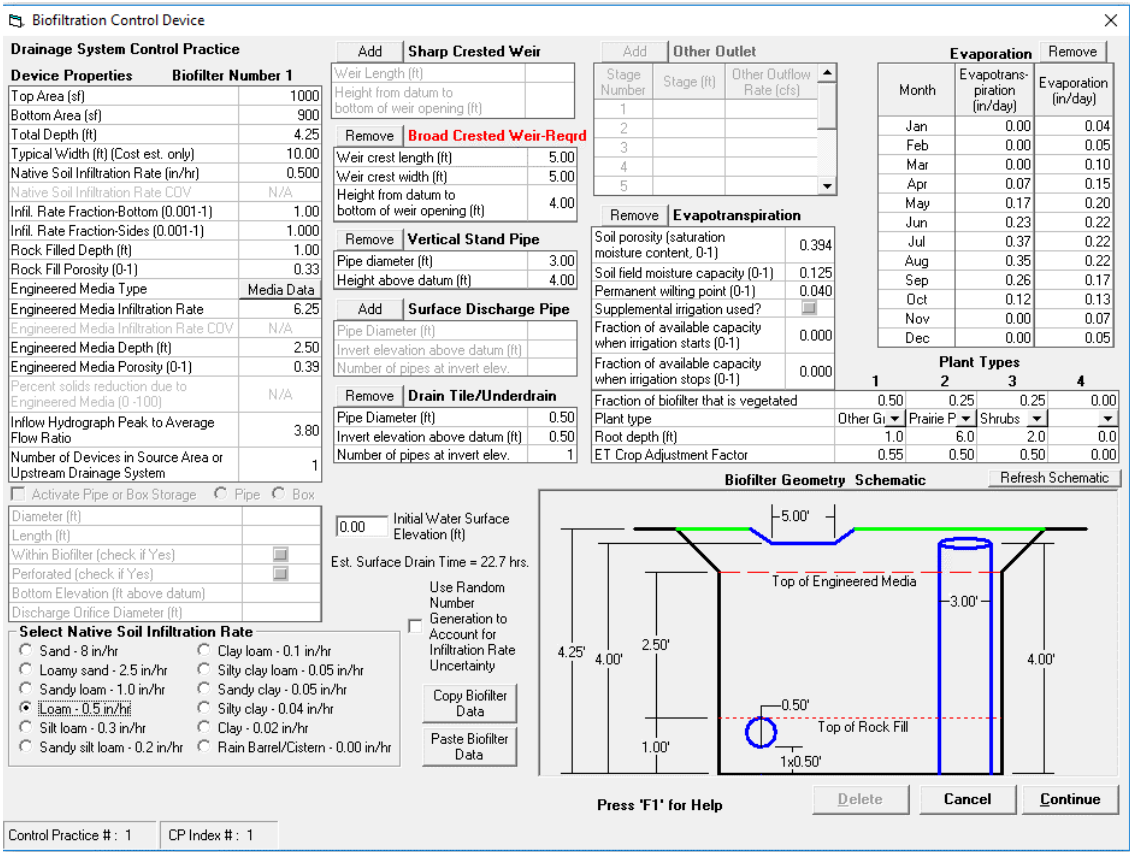


Figure 4.22. The biofiltration parameters window in the WinSLAMM.

4.6.3.1 Total Drainage Area:

The West Virginia Stormwater Management and Design Guidance Manual (2012), recommends that the contributing drainage area to a biofiltration shall between 0.25 to 1 acres. For this study, the drainage area was assumed to be restricted to 1 acre.

4.6.3.2 Top Area (square feet):

The performance of the BMP is highly affected by the top surface area of biofiltration. The North Carolina Stormwater BMP Manual (2007) recommends that the contributing drainage area to an individual biofiltration cell shall typically be equal to or less than 5 acres. The West Virginia Stormwater Management and Design Guidance Manual (2012), recommends that the surface area shall be between 2% (0.02 acres) to 3% (0.03 acres) of drainage area. For this study, the drainage area of the biofiltration assumed to be 900 ft^2 (0.02 acres).

4.6.3.3 Bottom Area (square feet):

This parameter represents the top area of the engineered soil (See Figure 4.23), and can be adjusted based on the top area and embankment side slope of the device. The Pennsylvania and the North Carolina Stormwater BMP Manuals recommend a maximum side slope of 3:1. Hence, the bottom area would be adjusted based on the top area and side slope, which was assumed to be 3:1.

4.6.3.4 Total Depth (feet):

The total depth and top area determine the storage capacity of the device. The reviewed manuals recommend different criteria for ponding depth and volume of BMP. The North Carolina Stormwater BMP Manual (2007), states that the sizing shall take into account all runoff at ultimate build-out including off-site drainage. In addition, an individual biofiltration cell is intended to treat the first flush. Moreover, the cell can be designed to hold the first inch of rainfall from the entire drainage area and ponding depth shall be 12 inches or less (Nine inches is preferred). The Lexington-Fayette Urban County Government Stormwater Manual (2009) suggests that the size of filter bed area should be in accordance with the design WQV corresponding to the area draining to it. The Pennsylvania Stormwater BMP Manual (2006) suggests that the ponding depths should be generally limited to 12 inches or less and surface ponding depth should not exceed 6 inches in most cases and should empty within 72 hours. A sensitivity analysis of this parameter revealed that the performance of BMPs is not highly affected by the depth of BMP. The performance is highly affected by surface area and infiltration rate of native soil underneath the BMP. Hence the total depth and ponding depth of the device were assumed to be equal to 4.25 ft and 9 inches, respectively.

4.6.3.5 Typical Width (ft):

The model allows users to determine width of the device if they want the program to provide a cost analysis. The North Carolina Stormwater BMP Manual (2007) suggest that all the biofiltration widths should not be less 10 feet. Moreover, according to Lexington-Fayette County Urban Government Stromwater Manual (2009), at least a 2:1 length to width ratio should be maintained for width greater than 10 feet. Thus, for this study, a 10 feet width was assumed for the biofiltration.

4.6.3.6 Native Soil Infiltration Rate (inches per hour):

Similar to the other two BMPs, the performance of the BMP was highly affected by the native soil infiltration rate underneath the BMP. In this study, the native soil infiltration rate was considered to be a variable parameter which will be varied for each soil group.

4.6.3.7 Rock Filled Depth (ft):

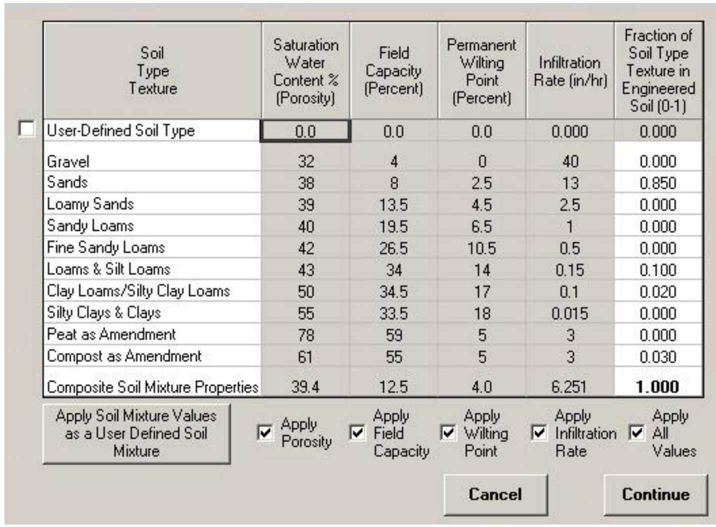
This parameter must be equal to or less than biofiltration depth. The model assumes that water flows through this layer very quickly. This parameter was assumed to be 1 ft.

4.6.3.8 Engineered Media Depth (ft).

This parameter must be equal to or less than the biofiltration depth. The Pennsylvania Stormwater BMP Manual (2006) states that the planting soil depth should generally be at least 18 inches where only herbaceous plant species is utilized. However, the North Carolina stormwater Manual (2007) suggests that media depth in a biofiltration should be between 2 and 4 feet because most of the pollutant removal occurs within the first 2 feet of soil and that excavations deeper than 4 feet become more expensive. Moreover, the New Jersey Stormwater BMP Manual (2016) asserts that the soil bed must be a minimum of 18 – 24 inches in depth. For this study, the engineered soil was considered to be 2.5ft.

4.6.3.9 Engineered Media Type:

The program determines the engineered media infiltration rate depending upon the type of engineered soil layer. The manuals suggest different mixtures of soil type. After reviewing different stormwater manuals the following mixture of soil was selected for the engineered media layer.



Soil Type Texture	Saturation Water Content % (Porosity)	Field Capacity (Percent)	Permanent Wilting Point (Percent)	Infiltration Rate (in/hr)	Fraction of Soil Type Texture in Engineered Soil (0-1)
User-Defined Soil Type	0.0	0.0	0.0	0.000	0.000
Gravel	32	4	0	40	0.000
Sands	38	8	2.5	13	0.850
Loamy Sands	39	13.5	4.5	2.5	0.000
Sandy Loams	40	19.5	6.5	1	0.000
Fine Sandy Loams	42	26.5	10.5	0.5	0.000
Loams & Silt Loams	43	34	14	0.15	0.100
Clay Loams/Silty Clay Loams	50	34.5	17	0.1	0.020
Silty Clays & Clays	55	33.5	18	0.015	0.000
Peat as Amendment	78	59	5	3	0.000
Compost as Amendment	61	55	5	3	0.030
Composite Soil Mixture Properties	39.4	12.5	4.0	6.251	**1.000**

Figure 4.23. The detailed media characteristics for biofiltration

4.6.3.10 Evaporation:

The average biofiltration surface evaporation rate (in/day), for each month of the year, should be determined by users. The data were retrieved from the Unites States National and Oceanic and Atmospheric Administration (NOAA) technical report entitled "The mean monthly, seasonal, and annual Pan Evaporation for the United States", (1981). Table 4.10 shows monthly means of estimated "pan evaporation" computed from meteorological measurements using a form of the Penman equation (Kohler *et al.* 1955) for the Lexington Airport Station.

Table 4.10. Monthly means of estimated pan evaporation (inches/month) for the Lexington Airport Station

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.31	1.51	2.97	4.64	5.9	6.58	6.67	6.46	5.16	3.84	2.15	1.39

All other variables were assumed to be the default of the model because the performance of the BMP was slightly sensitive to them. Figure 4.23 shows the values of all biofiltration parameters assumed for this study.

4.6.4 The biofiltration performance curves

A series of simulations were performed using the WinSLAMM for the average response year (i.e. 1970) while varying the biofiltration infiltration rate. The results from these simulations were then used to develop a series of curves that can be used to predict nutrient load reductions as a function of the input load to the biofiltration (See Figures 4.24 and 4.25).

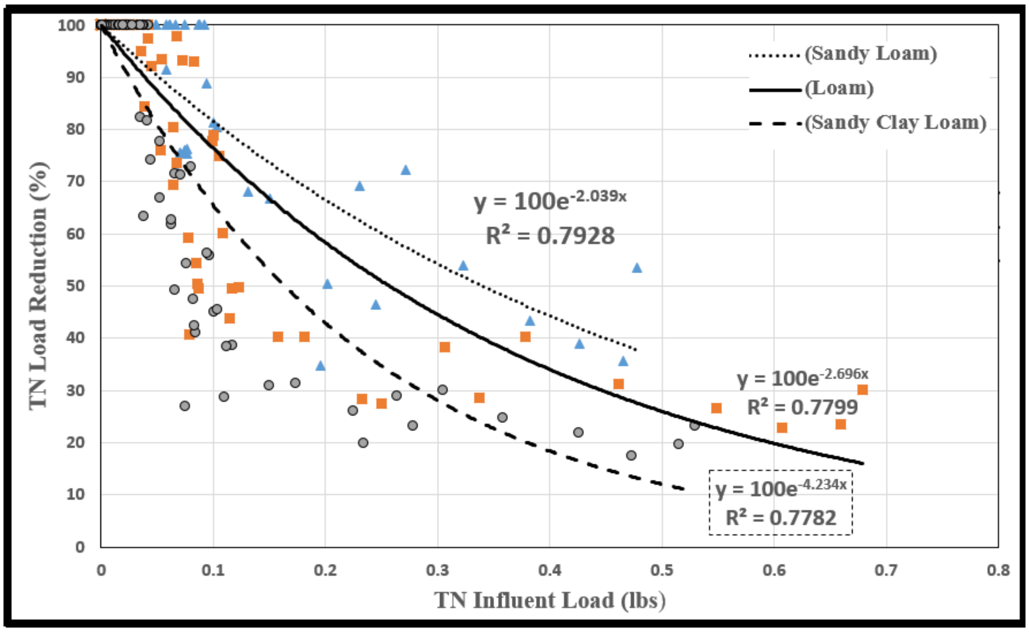


Figure 4.24. The biofiltration TN performance curves

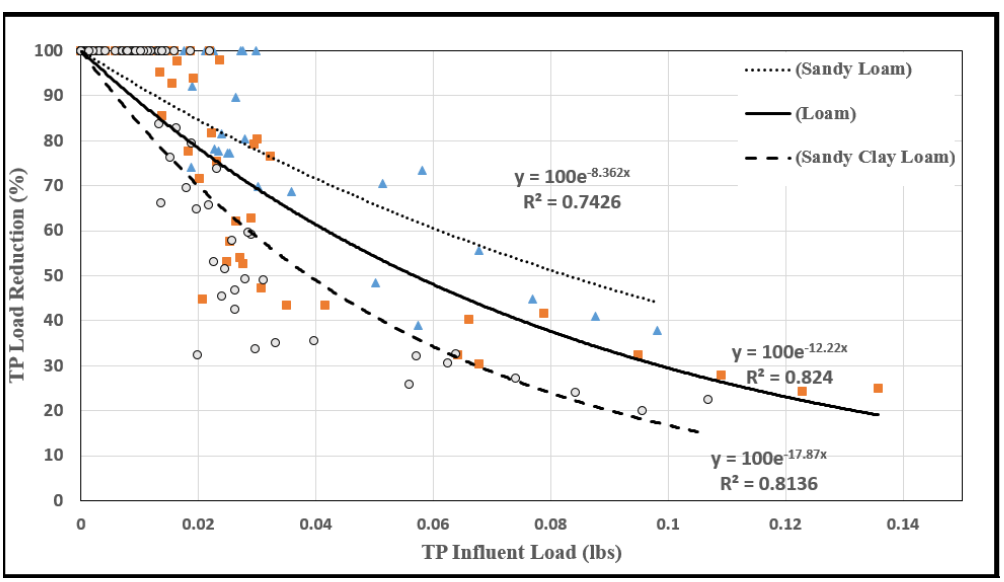


Figure 4.25. The biofiltration TP performance curves

4.7 Cost Estimation

In addition to development of performance curves, the cost data were obtained from the WinSLAMM cost estimation for the three selected urban BMPs. The base year for cost estimation was variable in the reviewed reports. As a result, the costs were all adjusted to a present day basis (i.e. 2016) using the following equation.

$$Pn=P(1+i)^n \quad \text{(Eq. 4.10)}$$

Where Pn = Present worth of the costs; P = Base estimated cost; i = average inflation rate over the periods of adjustment, which is rate of increase/decrease of prices over time; n = Difference between selected year and base year. The average annual inflation rate of the United States from 2000 to 2016 is equal to 2.1%, (Coin News Family, 2017)

In addition, each of the reviewed literature estimates cost of BMPs for a particular region. The costs of BMPs vary from city to city and region to region. In this study, the estimated costs of BMPs were adjusted for Kentucky (i.e. Lexington) using the weighted average RSMeans City Cost Indexes (CCIs) as follows:

$$\text{Cost in Lexington} = \frac{\text{CCI for Lexington}}{\text{CCI for City A}} \times \text{Cost in City A} \quad \text{(Eq. 4.11)}$$

The CCI number is a percentage ratio of a specific city's cost to the national average cost of the same item at the stated time (RSmeans, 2017). The CCIs can be found online through the RSmeans website. Table 4.11 shows typical weighted average CCIs for selected cities in the Unites States. The costs of the three practices were obtained from the WinSLAMM model. As the costs were associated with Birmingham, Alabama, 2011, they were inflated to 2016 dollars using an average annual inflation rate in the United States. Then the costs were adjusted for Kentucky (Lexington) using the CCIs, by multiplying them by 90 and then dividing by 87 (See Table 4.12).

Table 4.11. Typical average weighted CCIs for selected cities in the U.S (RSmeans, 2017)

State	City	Average Weighted CCI
Virginia	Norfolk	87
Maryland	Baltimore	93
Pennsylvania	Philadelphia	113.7
North Carolina	Charlotte	80.1
Kentucky	Lexington	90
	Louisville	91.3
Alabama	Birmingham	87

*Table 4.12. Cost estimation of the selected urban BMPs (Inflated to 2016 for Lexington, Kentucky)

Grass Swale							
Capital Cost Equation ($/ft)	Bottom Width (ft)	Coefficients			O&M Cost Equation ($/ft/year)	Coefficients	
		A	B	C		D	E
[1] $Y=AX^2+BX+C$	1	0.80	4.04	4.98	[1] $Y=DX+E$	0.11	0.49
	3	0.81	4.50	5.77		0.11	0.54
	5	0.65	5.48	6.57		0.11	0.57
	8	0.58	6.06	8.37		0.10	0.64
	10	0.94	4.33	12.05		0.11	0.67

Filter Strip					
Capital Cost Equation ($/ft)	Coefficients		O&M Cost Equation ($/ft/year)	Coefficients	
	A	B		C	D
[2] $Y=A\times Ln(X)+B$	21.34	49.32	[2] $Y=CX+D$	0.02	0.13

Biofiltration						
Capital Cost Equation ($/ft)	Biofilter Depth (ft)	Coefficients		O&M Cost Equation ($/ft/year)	Coefficients	
		A	B		C	D
[3] $Y=AX+B$	3	5.22	35.25	[3] $Y=CX+D$	0.37	1.58
	4	6.51	39.62		0.41	1.62
	5	7.54	43.96		0.46	1.80
	6	9.03	47.09		0.53	1.69
	8	11.48	51.66		0.63	1.77
	10	14.20	56.57		0.72	2.11
	12	16.74	66.60		0.83	2.27

*Retrieved from WinSLAMM model (PV & Associates LLC, 2015). 1-X=Swale Depth (ft) 2-X=Filter Strip Width (ft), 3- X=Biofiltration Width

4.8 Summary and Conclusion

This chapter reviewed the most commonly used watershed models that incorporate options for modeling different types of BMPs. A few of the models correlate the performance of the BMPs to the size and influent loads of the nutrients. The models that use governing water quality and quantity equations or relationships for simulating the performance of BMPs are typically complicated and their use is limited to specialists. Among all the reviewed models the WinSLAMM model was selected to develop performance curves for three urban BMPs including grass swales, filter strips, and biofiltration facilities. The model was set up to perform water quality and quantity analysis for a one-year (1970) period with daily time steps. The model results (including the influent TN/TP load into and the effluent TN/TP load out of the BMPs) were then used to develop performance curves for three soil types and a specific size of BMP. Different stormwater BMP manuals and published reports along with model simulations were used to determine the values of BMP parameters including size, slope, soil type, and vegetation type. Table 4.14 summarizes the performance curves developed for each BMP.

Table 4.13. The performance curves for selected urban BMPs[1]

BMPs		Grass Swale	Filter Strip	Biofiltration
TN Curve				
Soil Type	Sandy Loam	$Y=38.6X^{-0.109}$	$Y = 52.5X^{-0.054}$	$Y = 100e^{-2.039X}$
	Loam	$Y=16.5X^{-0.202}$	$Y = 39.8X^{-0.105}$	$Y = 100e^{-2.7x}$
	Sandy Clay Loam	$Y=4.6X^{-0.34}$	$Y = 19.8X^{-0.174}$	$Y = 100e^{-4.2x}$
TP Curve				
Soil Type	Sandy Loam	$Y=42.5X^{-0.09}$	$Y = 59.6X^{-0.052}$	$Y=100e^{-8.36X}$
	Loam	$Y=23.5X^{-0.134}$	$Y = 37X^{-0.097}$	$Y=100e^{-12.22X}$
	Sandy Clay Loam	$Y=11.59X^{-0.191}$	$Y = 18.7X^{-0.156}$	$Y=100e^{-7.87X}$

1: X=TN/TP influent load (lbs) Y=TN/TP load reduction (%)

The information provided in this chapter can be used in larger watershed models such as the Kentucky Nutrient Model (KYNM) to assist planners and modelers in predicting the efficiency of these three BMPs for urban landuses.

5 Chapter 5: Assessment of Agricultural Best Management Practices (BMPs)

5.1 Introduction and Purpose

The United States has millions of acres of agricultural, graze, and pasture lands for the production of food and raising animals. These activities are major causes of water pollution throughout the country. Grazing, plowing, and cultivation can cause the disturbance of the soil surface and discharge of sediment into water bodies during rainfall events. In addition, fertilizer application can result in the introduction of pollutants including pesticides, nitrogen, and phosphorus into the streams. In recent decades, watershed planners and decision makers have tried to alleviate water impairment by employing different practical approaches. One of the most commonly used approaches for reduction of sediment and nutrient loads into the streams is by implementing different agricultural Best Management Practices (BMPs) within agricultural watersheds. The agricultural BMPs may involve the implementation of different landuse strategies (e.g. conservation tillage and cover cropping), the employment of different behavioral strategies (e.g. reduction of the fertilizer use), or the construction of water quality facilities and structural practices (e.g. grassed waterways, cattle exclusion, and stream crossing).

Selecting the most appropriate agricultural BMPs, which can mitigate impairment of streams within a watershed, is a very challenging task for watershed managers and planners. They typically examine and consider various criteria in order to choose the most practical and advantageous strategy. The criteria may include: construction and operational costs, pollutant removal efficiency of BMPs, topographic/geologic constraints, land area development limitations, environmental impacts, social/stakeholder acceptance, and recreational benefits. One of the primary tasks in the planning level is to perform a cost-effectiveness analysis for choosing the *best* BMP or the combination of different BMPs for a specific area. Watershed models that incorporate options for simulating of the performance of BMPs can be useful in determining the cost-effectiveness of such options.

There exist several models that exclusively focus on the agricultural watersheds, farms, and performance modeling of agricultural BMPs. These include the Agricultural Policy/Environmental Extender model (APEX) developed by Williams *et al.* in 1990, the

Annualized Agricultural Non-Point Source Pollution Model (AnnAGNPS) developed by Cronshey and Theurer in 1998, and the Water Erosion Prediction Project (WEPP) model developed by Flanagan and Nearing in 1995. Most of these models are very complicated and require extensive amounts of data, which may limit their use to modeling specialists. These models typically employ different approaches for the simulating the BMPs which can sometimes make direct comparisons difficult and subsequent applications challenging.

Different approaches exist for predicting the performance of agricultural BMPs. One of the conventional approaches for estimating the performance of BMPs is in using empirical equations which have been developed using field measured data or published literature. An alternative approach is using conceptual models that are derived from applying simplifying assumptions to basic equations of conservation of mass, energy, and momentum. Reduction of nutrient loads can also be simulated by evaluating the impacts of changes in landuses. For example, several models (e.g. SWAT, APEX) allow users to modify the hydrologic curve numbers (CNs) and/or the Universal Soil Loss Equation (USLE) parameters to simulate the effect of implementing different landuse strategies (e.g. contour farming or strip cropping) within a watershed. Such models can be applied for specific locations, or used to generate general response functions (e.g. nonlinear regression models) from multiple applications of the model to a range of data sets. Alternatively, BMP performance can also be estimated by employing constant runoff coefficients (as a function of landuse) along with an average pollutant removal efficiency (as a function of the type of BMP).

5.2 Agricultural BMP Models

Several different computer models have been proposed for use in designing and evaluating the performance of BMPs for agricultural lands. These are summarized in Table 5.1 and discussed in more detail in the following paragraphs.

Table 5.1. Summary of the most commonly used agricultural BMP simulation models

Model	BMPs/Management Programs
WEPP	Conservation tillage, Modified crop rotations, Buffer strips, Planting and harvest date, Compaction row arrangement, Terraces, Field borders, Windbreaks
VFSMOD	Filter Strip
AnnAGNPS	Riparian Buffers, Vegetated buffer strips, Wetlands, Fertilizer application rates, Conservation tillage, Controlled grazing, Grade stabilization.
APEX	Permeable Surfaces–Lawns, parks, Auto mowing, Wetlands–Simulated as a shallow reservoir, Nutrient management practices, Tillage operations, Conservation practices, Alternative cropping systems, Grazing systems, Buffer strips, Manure applications and other management scenarios
SWAT	Agricultural conservation practices, Detention basins, Infiltration practices, Ponds, Vegetative practices, Irrigation, Tile drains, Street sweeping, Wetlands, Vegetated filter strips, Grassed waterways, Controlled grazing, Grade stabilization, Field terraces, Modified fertilizer and Pesticide application rates.

In 1997, Munoz-Carpena and E. Parsons developed the Vegetative Filter Strip Modeling System (VFSMOD) to simulate hydrology, sediment and pollutant transport processes through vegetative filter strips. The model uses a finite element solution for the overland flow equations and the Green-Ampt equation for modeling time-dependent infitration (Winchell and Tammara, 2009). The model can be used to estimate the performance of filter strips in reducing runoff and trapping sediment and pesticides.

In 1995, Flanagan and Nearing developed the Water Erosion Prediction Project (WEPP) model for the United States Department of Agriculture (USDA). The model was developed for the simulation of stormwater runoff and erosion processes (sheet and rill erosion) and sediment delivery in small watersheds. The model is process-oriented and is able to perform daily, monthly, and annual continuous simulations. The WEPP model includes components for rainfall generation, frozen soils, snow accumulation and melt, irrigation, infiltration, overland flow hydraulics, water balance, plant growth, and residue decomposition. The WEPP is also able to estimate the impact of agricultural management practices on sediment delivery within watershed. The model is not suitable for large watersheds, and is only appropriate for hillslope profiles of tens of meters and small watersheds up to hundreds of meters (Shoemaker *et al.* 2005).

In 1998, Cronshey and Theurer developed the Annualized Agricultural NonPoint Source Pollution Model (AnnAGNPS) for the USDA's Agricultural Research Service. The model can be used to simulate the hydrology of surface water and estimate the sediment, nutrients and pesticide load within large scale watersheds. The model employs the Natural Resources Conservation Service (NRCS) Curve Number (CN) method for hydrological processes, the Revised Universal Soil Loss Equation (RUSLE) for predicting sediment yield, and observed site-specific data for estimating dissolved N, P and organic carbon. The model is able to evaluate the effect of implementing agricultural practices on watershed systems (Cronshey and Theurer, 1998).

In 2008, Williams *et al.* developed the Agricultural Policy/Environmental Extender model (APEX) at the Texas Blackland Research and Extension Center. The APEX is a physical-based, continuous and distributed parameter model that is designed for field scale. It can be used to evaluate the effect of implementation of agricultural BMPs on water quality. The model contains sub-models for routing water, sediment, nutrients, and pesticides across complex landscapes and channel systems to the watershed outlet as well as groundwater and reservoir components (Texas A&M Agrilife Research & Extension Center, 2008). The model contains various components including climate inputs, hydrologic balance, livestock grazing inputs, manure management and erosion, reservoir, economics components and etc. The model is data intensive which can limit its use to modeling specialists. Updated versions of the model have been modified to estimate the performance of different BMPs and landuse strategies.

Among the reviewed models the SWAT model documentation was reviewed to obtain a set of empirical equations that predict performance of the vegetative filter strips in agricultural landuses. Then, various studies were reviewed to obtain the different methodologies that the models use to predict the performance of agricultural landuse strategies as discussed in the following sections.

5.3 Performance Assessment of Vegetated Filter Strips for Agricultural Watersheds

The Soil and Water Assessment Tool (SWAT) uses empirical models to estimate the performance of filter strips. The empirical model has been developed using a combination of measured data and filter strip simulations derived from using the VFSMOD model. The VSMOD model was used to generate 1650 simulations. The simulations were conducted on a cultivated field with curve number of 85 and C factor of 0.1 for 3-hour rainfall events ranging from 10 mm to 100 mm (Neitsch *et al.* 2011). For developing the empirical model, the dimension of the drainage area was fixed at 100 meters by 10 meters, and the width of the filter strip was fixed at 10 m. The length of the filter strip was ranged from 1 m to 20 m. In addition, the simulations were conducted for 2%, 5% and 10% slopes on 11 soil textural classes. Then a regression equation (See Equation 5.1) was developed using the simulation database to correlate filter strip runoff reduction to runoff loading into the filter strip and saturated hydraulic conductivity of soil (Neitsch *et al.* 2011).

$$\text{Runoff Reduction (\%)} = 75.8 - 10.8\text{Ln}(RL) + 25.9\text{Ln}(K_{sat}) \qquad \text{(Eq. 5.1)}$$

Where RL is runoff loading (mm) and K_{sat} is the saturated hydraulic conductivity of soil (mm/hr)

A similar regression equation (See Equation 5.2) is employed by SWAT to predict sediment reduction as a function of sediment loading and runoff reduction.

$$\text{Sediment Reduction (\%)} = 79-1.04SL+0.213RR \qquad \text{(Eq. 5.2)}$$

Where SL is sediment loading (kg/m^2) and RR is runoff reduction (%).

Alternatively, Neitsch *et al.* 2011 developed their own regression equation (see Figure 5.1) for estimating the amount of sediment reduction in filter strips as a function of the sediment loading.

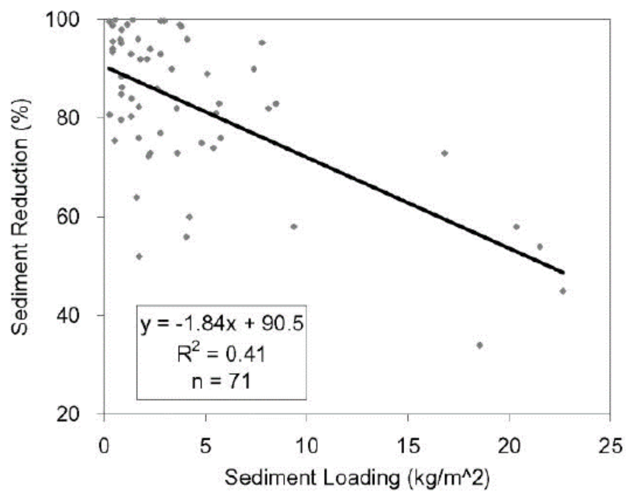


Figure 5.1. Sediment reduction as a function of sediment loading (Neitsch *et al.* 2011).

Once the sediment load reduction is determined, the associated nutrient reduction percentage can then be estimated using the following figures. The TN and TP reduction models were developed using the measured data reported in literature.

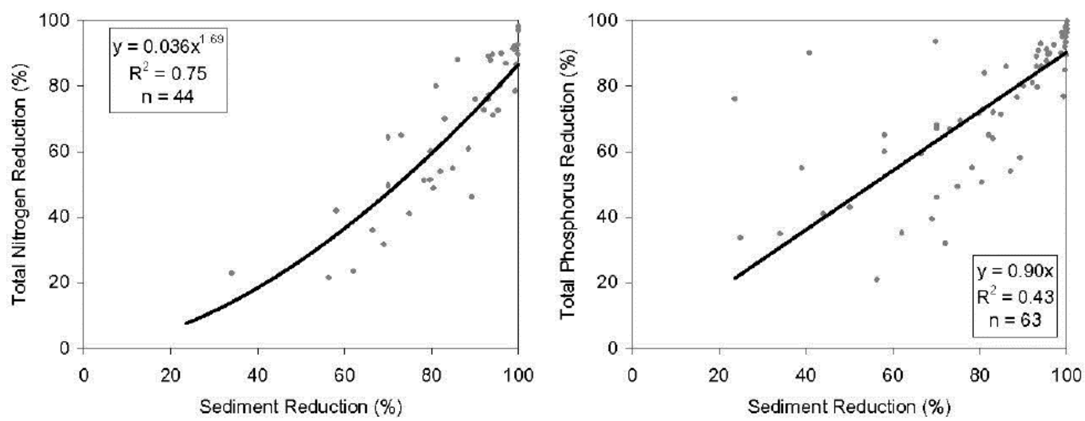


Figure 5.2. Filter strip TN and TP load reduction models used in the SWAT (Neitsch *et al.* 2011).

5.4 Predicting Sediment Load from an Agricultural Watersheds

The traditional way to predict sediment load from an agricultural watershed is using the Universal Soil Loss Equation (USLE) equation. The USLE predicts the annual rate of erosion that results from sheet and gully erosion on a single slope based on soil type, pattern of rainfall, land topography, crop system, and management practices (Wischmeier and Smith, 1965, 1978). The USLE contains five major factors which are presented in the following equation. Then in 1997 Renard *et al.* developed the Revised Universal Soil Loss Equation (RUSLE), which has the same formula as the USLE but has several improvements in determining factors. These include some new and revised isoerodent maps, a time-varying approach for soil erodibility factor, a subfactor approach for evaluating the cover-management factor, a new equation to reflect slope length and steepness, and new conservation-practice values (Renard *et al*. 1997).

$$A = R \times K \times LS \times C \times P \qquad \text{(Eq. 5.4)}$$

Where A = Long-term average annual soil loss (tons/acre/year); R = Rainfall and runoff factor, which is varied based on geographic location; K= Soil erodibility factor, which shows the susceptibility of soil particles to detachment and transport by rainfall and runoff; LS=Slope length-gradient factor (i.e. soils with longer profiles and steeper slopes expose to the higher risk of erosion); C = Crop/vegetation and management factor which shows the effectiveness of crop management systems in reducing soil loss, and P = Support practice factor, which shows the effects of implementing the practices that reduce rate of runoff volume. The value of USLE factors can be found in the Wischmeier and Smith, 1978.

One of the disadvantages of the USLE is that the annual sediment yield is not correlated with the storm runoff volumes. Williams (1975), developed the Modified Universal Soil Loss Equation (MUSLE) which uses the storm-based runoff volumes and runoff peak flows to simulate erosion and sediment yield (Williams 1975). The MUSLE replaces the USLE's rainfall erosivity factor with a runoff energy factor as presented in the following equation.

$$Y=11.8\times(Q\times q_p)^{0.56}\times K\times LS\times C\times P \qquad \text{(Eq. 5.5)}$$

Where Y= Sediment yield (tons), Q=Storm runoff volume (m^3), q_p= Peak runoff rate (m^3/s), and K, C, SL and P are the standard USLE factors, which have been discussed before. The MUSLE can be used to estimate the daily sediment yield resulting from rill and sheet erosion. Then the daily sediment yield values can be summed up to calculate the total tons of sediment yield per year.

An alternative to the more popular USLE or MUSLE is to estimate of the sediment load using the EMC approach (Huber, 1992) as presented in the following equation.

$$\text{Sediment Load (lbs)} = 0.226 \times SC \times R \times A \qquad \text{(Eq. 5.6)}$$

Where: SC= Total Suspended Solid (TSS) EMC (mg/l), R= Stromwater runoff from the watershed (inch); A= Area of watershed (Acre).

The TSS EMC for different agricultural landuses were adapted from the field studies reported in literature. The median TSS EMCs for various agricultural landuses are shown in Table 5.2.

Table 5.2. TSS EMC for different agricultural landuses.

Landuse	**TSS EMC (mg/l)**
Cropland[3]	107
Pastureland[2,3]	89
General Agriculture[3]	55.3
Forested/Wooded[2]	19
Wetland[3]	10.2
Open Water/Lake[3]	3.1

1- Raird *et al.* 1996, 2-Line *et al.* 2002, 3- Harper, H. H., 1998

5.5 Nutrient Reduction for Agricultural Lands

Implementation of landuse strategies can change the characteristics of soil surface and topography of lands. The characteristics that may change include: the curve number (CN), the USLE factors, the Manning's roughness coefficient, and land slope. For example, implementation of contour farming can reduce surface runoff by impounding water in small depressions. Contour faming can also decrease sheet and rill erosion by reducing erosive power of surface runoff and preventing or minimizing development of rills (Arabi *et al.* 2007). The impact of employing agricultural landsuse strategies on water quality and quantity can be examined by using physically based models that allow users to modify these parameters. For example, the effect of using conservation systems (e.g. conservation tillage) can be estimated by modifying CN or P and C factors of the USLE equation which can be found in the Wischmeier and Smith (1978).

General recommendations for modification of the soil characteristics and land topography to accommodate the effects of land use strategies can be found in literature. For instance, Arabi *et al.* (2007) present some techniques for modifying landuse characteristics in SWAT to examine the effect of implementing ten agricultural BMPs. The ten conservation practices included contour farming, strip-cropping, parallel terraces, cover crops, residue management, field borders, filter strips, grassed waterways, lined waterways, and grade stabilization structures. Then, they employed the model to examine the effect of the practices on water quality constituents, including sediment, TN, TP and pesticide yields in the Smith Fry watershed in Indiana. As part of the study, the impacts of changes in the hydrologic curve numbers were examined after implementing three conservation practices: contour farming, terraces, and residue management. In order to develop the relationships, they used a table provided by Netitsch *et al.* (2005), which contains recommendations for modification of curve number values in different fields. The fields involve different landuses and soil characteristics under various hydrologic conditions which were adapted from Wischmeier and Smith, 1978 (Arabi *et al.* 2007). Figure 5.3 shows how the curve numbers vary before and after implementing the three different landuse management strategies.

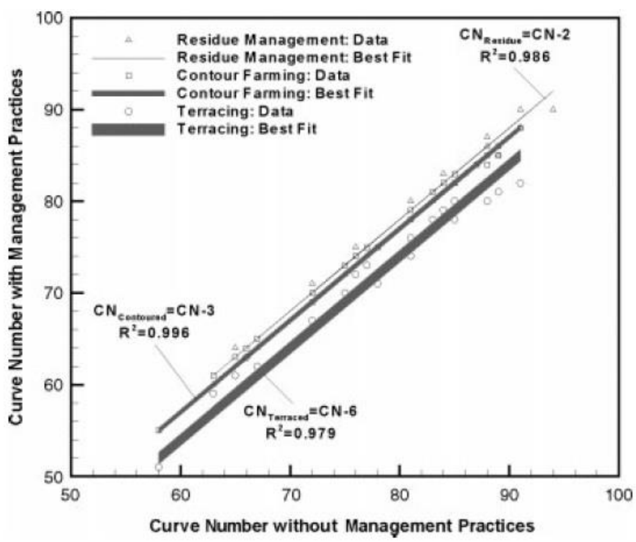


Figure 5.3. Effect of implementing three conservation practices on curve number (Arabi *et al.* 2007).

This approach is only practical for those cases when both the hydrologic runoff and the soil erosion are being predicted on a daily basis. However, in using models like the Kentucky Nutrient Model which predict nutrient loads using an EMC approach, an alternative approach is needed. For cases like this, the effectiveness of the landuse strategies in reducing nutrients can be approximated by using constant percent nutrient removal efficiencies as reported in literature. Several such studies are summarized in the following paragraphs.

One of the comprehensive studies for evaluating cost-effectiveness of agricultural landuse strategies has been conducted by the CH2M Hill Company for Mid-Carolina Council of Governments Cape Fear River Assembly in 2008. Engineers from CH2M Hill conducted a review coordinated with representatives from several agricultural agencies to determine the TN and TP load removal efficiency for different landuse strategies. In order to perform cost-effectiveness analysis of the BMPs placed on the cropland and pastureland areas, a TN and TP loading rate for one acre of each landuse was assumed. The assumed pollutant loading rates for pastureland and cropland are shown in Table 5.3.

Table 5.3. The assumed loadings for one acre of landuse (CH2M Hill, 2008)

Lanuse	TN Loading (lbs/acre-year)	TP Loading (lbs/acre-year)
Cropland	13.37	5.32
Pastureland	6.76	1.48

5.6 Nutrient Reduction for Additional Agricultural BMPs

In addition to estimates of loading data, engineers from CH2MHill also collected annualized installation and maintenance cost of the BMPs. In order to compare the costs on the basis of the acre treated, the BMP area was multiplied by its land consumption percentage. Then, the unit costs were estimated by dividing the total cost of each BMP by the amount of TN and TP removed. Table 5.4 shows the calculated TN and TP load percent removed as well as the calculated effectiveness and cost-effectiveness for different agricultural BMPs (CH2M Hill, 2008). Included in the table is a category of nutrient scavenger crops. A nutrient scavenger crop is a crop of small grain that is grown primarily to scavenge and cycle plant nutrients. Some of the benefits of nutrient scavenger crops include reduction of soil erosion, sedimentation and pollution from dissolved and sediment attached substances. In order for such crops to be effective, they must grow quickly and accumulate significant biomass in the early fall before nutrients are leached to the root zone (NC Department of Agriculture, 2017).

Table 5.4. Percent removal, effectiveness and cost-effectiveness of agricultural BMPs (CH2M Hill, 2008)

Agricultural BMPs	Assumed Percent Removal		Effectiveness (lb removed/acre)		Cost Effectiveness ($/lb/yr)		Total Costs per Acre Treated	BMP Land Consumption (ac BMP/ 1 ac treated)
	TN	TP	TN	TP	TN	TP	$	
Nutrient Scavenger Crop			1.3-0.7	0.6-0.2	21-42	48-174	283	0
Rye and Triticale	15	7-15	-	-	-	-		
Oats and Barley	10	7-15	-	-	-	-		
Wheat	5	7-15	-	-	-	-		
Grassed Waterway	40	45	5.4-0.7	2.4-0.7	20-40	45-161	156	0.05
Land Conversion								1
Cropland to Pasture	49	80	6.6-na	3.8-na	303-na	534-na	507	
Cropland to Forest	88	94	11.8-na	5-na	173-na	409-na	396	
Pastureland to Forest	76	69	na-5.17	na-1.2	na-397	na-1787	549	
Cattle Exclusion (No Buffer)	32	28	na-2.16	na-0.4	na-26	na-134	555	0

In 2009, Simpson and Weammert published a separate report to provide estimates of the effectiveness of BMPs that participating states were implementing as part of the US-EPA Chesapeake Bay's Tributary Strategies Program. The Tributary Strategies are the Chesapeake Bay nutrient and sediment reduction strategies outlined by jurisdictions within the Chesapeake Bay watershed to achieve water quality standards (Simpson and Weammert, 2009). Table 5.5 shows a summary of TN, TP and TSS removal efficiency estimates for selected BMPs reported by Simpson and Weammert, 2009.

Table 5.5. TN and TP Removal Effectiveness of agricultural BMPs (Simpson and Weammert, 2009)

	Pollutant Removal Effectiveness (%)		
BMPs	TN	TP	TSS
Animal waste management livestock	80	80	-
Barnyard Runoff Control	20	20	40
Loafing Lot Management	20	20	40
Mortality Composters	40	10	-
Dairy Precision Feeding and Forage Management	24	25	-
conventional till	8	15	25
Conservation Tillage	3	5	8
Continuous No-Till	10 to 15	20 to 40	70
hay	3	5	8
pasture	5	10	14
Agricultural Water Control Structure	33	-	-
Alternative Watering Facilities	5	8	10
Stream Access Control with Fencing	13 to 46	30 to 45	40-60
Enhanced Nutrient Management	7	-	-
Decision Agriculture	4	-	-
Horse Pasture Management	-	20	40
Prescribed Grazing	9 to 11	24	30
Precision Intensive Rotational Grazing	9 to 11	24	30
Forest Harvesting Practices	50	60	60

Finally, in 2010, the US-EPA published a report entitled "Guidance for Federal Land Management in the Chesapeake Bay Watershed" which presented an overview of agricultural BMPs and information resources available to achieve water quality goals in the most cost-effective and potentially successful manner within the Chesapeake Bay watershed (US-EPA, 2010). The study provided a summary of agricultural BMP performance, costs, and additional actions that can be employed to reduce N, P and sediment loading from agricultural activities within the Chesapeake Bay Watershed. It also discussed nutrient management of cropland, the prevention of soil erosion from cropland, and nutrient management associated with animal feeding operations (AFOs). A summary of the data developed as part of the study is provided in Tables 5.6 and 5.7.

Table 5.6. Capital cost data provided by US-EPA (2010) for different agricultural BMPs[1]

BMP	Unit	Range of capital Costs[1]
Diversions	ft	\$2.63–\$7.36
Terraces	ft	\$4.43–\$19.75
Waterways	ft	\$7.85–\$11.84
	acre	\$151–\$5,684
Permanent Vegetative Cover	acre	\$92–\$360
Conservation Tillage	acre	\$12.68–\$84.58

1-2010 US dollars

Table 5.7. Annualized Cost estimates provided by US-EPA (2010) for different agricultural BMPs[1]

Practice	Life span	Median annual costs[2] (Years)(EAC[3]) (\$/acre/yr)
Nutrient Management	3	4.00
Strip Cropping	5	19.32
Terraces	10	140.75
Diversions	10	86.74
Sediment Retention Water Control Structure	10	148.56
Grassed Filter Strips	5	12.17
Cover Crops	1	16.65
Permanent Vegetative Cover on Critical Areas	5	117.72
Conservation Tillage[4]	1	28.87
Reforestation of crop and pastured	10	77.69
Grassed Waterways[5]	10	1.67/LF/year
Animal Waste systems[6]	10	6.26/ton/year

Source: Camacho 1991

Notes:

1. Median costs (1990 dollars) obtained from the Chesapeake Bay Program Office (CBPO) BMP tracking database and Chesapeake Bay Agreement Jurisdictions' unit data cost. Costs per acre are for acres benefited by the practice. 1990 dollars converted to 2010 dollars.
2. Annualized BMP total cost including O&M, planning, and technical assistance costs.
3. EAC = equivalent annual cost: annualized total; costs for the life span. Interest rate = 10%.
4. Government incentive costs.
5. Annualized unit cost per linear foot of constructed waterway.
6. Units for animal waste are given as \$/ton of manure treated.

5.7 Summary and Conclusion

This chapter contains the summaries of a review of the literature on the efficiencies and costs of various agricultural BMPs. Some of the estimates can be expressed in terms of functional relationships between load reduction and sediment load, while others have been characterized as average mean efficiencies. These estimates can be used in support of general planning purposes or used in more sophisticated computer models for the purposes of examining trade-offs between performance and costs. In support of future applications of the Kentucky Nutrient Model, the following efficiencies and costs are proposed:

Table 5.8. The pollutant removal efficiencies and costs of agricultural BMPs proposed for KYNM

BMP	**Percent Load Reduction (%)**			**Costs**
Nutrient Scavenger Practices	**TN[3]**	**TP[3]**	**TSS**	**Total Costs[6] ($/acre)**
Rye and Triticale	15	7 to 15	-	85
Oats and Barley	10	7 to 15	-	61.2
Wheat	5	7 to 15	-	57.2
Land Conversion	**TN[3]**	**TP[3]**	**TSS**	**Total Costs[3] ($/acre)**
Cropland to Pasture	49	80	-	672
Cropland to Forest	88	94	-	525
Pastureland to Forest	76	69	-	728
Tillage Practices	**TN[6]**	**TP[6]**	**TSS[6]**	**Total Costs ($/Acre/Year)**
Conservation Tillage	3	5	8	47[2]
Conventional Tillage	8	15	25	-
No-Till Seeding	10 to 15	20 to 40	70	15.47[4]

**Y= TN/TP load reduction (%) X=Sediment reduction (%); ***Y=Sediment Reduction (%) X=Sediment Loading (kg/m^2); 1- Neitsch *et al.* 2011, 2-Camacho 1992, 3-CH2MHILL, 2008 4-KY NRCS, 5- Simpson and Weammert, 2010. 6-USDA, 2016 for southeastern area

6 Chapter 6: Summary and Conclusion

6.1 Summary and Conclusion

In this research, four pollutant modeling approaches were discussed. The approaches include: 1) pollutant buildup washoff equations, 2) national and regional regression models, 3) the Load Export Coefficient (LEC) method, and 4) the Event Mean Concentration (EMC) method. The employment of the two later approaches requires the typical values of LECs and EMCs for urban and agricultural landuses. A literature review was conducted to compile TN and TP LEC and EMC data and to generate several summary statistical plots for different urban and agricultural landuses. The results can be used by stormwater professionals in selecting appropriate values of these parameters for use in predicting TN and TP loads from both urban and agricultural watersheds.

Following this work, an extensive literature review was conducted to compile removal efficiency and cost data for both urban and agricultural best management practices (BMPs). The resulting dataset was then reviewed and examined in order to determine ranges of TN, TP, and total suspended solid (TSS) removal efficiencies for selected BMPs. This work revealed that few researchers have correlated optimal BMP size and performance to the actual runoff and nutrient loads associated with specific storm events. Thus, the performance of most BMPs have been summarized with average or mean values, which do not provide sufficient information for making actual design decisions. As a result, several urban BMP simulation models were reviewed for the possible use in establishing such relationships. Ultimately, the Source Loading and Management Model (WinSLAMM) was selected to develop mathematical relationships for three urban BMPs: 1) a filter strip, 2) a grass swale, 3) a biofiltration. Potentially, these relationships could be used in planning models (e.g. Kentucky Nutrient Model) to predict the pollutant load reduction of each BMP as a function of the input pollutant load and selected design parameters associated with the facility. Finally, an attempt was made to develop some general cost data for each of the reviewed urban BMPs.

Following an analysis of urban BMPs, the performance of agricultural BMPs were examined. This included an evaluation of the utility of using BMP performance relationships utilized by the Soil and Water Assessment Tool (SWAT) model to BMP performance. For this examination, the focus was limited to the use of vegetative filter strips. It was discovered that the individual model for filter strips relied on published literature of filter efficiencies and the compiled results of filter strip simulations using the Vegetative Filter Strip Modeling System (VFSMOD) model. These results were then used to develop a general performance curve for agricultural filter strips. Finally, general removal efficiencies for TN and TP for different tillage and landuse conversion practices were synthesized from the literature for additional BMP applications. As with the urban BMPs, a limited set of cost data was also synthesized for the selected BMPs.

Several conclusions can be drawn from this research:

- It is unclear whether traditional buildup/washoff water quality modeling is superior to simply using EMCs for prediction of daily nutrient loads
- Simpler models (e.g. EMCs) may be sufficient to identify proportional loads (from different sources) to receiving water bodies.
- The compilation of the EMC and LEC values showed that many of the published EMC's vary significantly.
- The BMP summary tables revealed high variability among the reported percent removal efficiencies. One of the reason for such variability may be due to differences in data collection and analysis protocols. Another reason is that in some cases, the BMPs increase the effluent loadings as opposed to decreasing the loadings. This could be due to several reasons, such as poor design, improper installation, applications to inappropriate sites (e.g. soils), release of nutrients from treatment media (e.g. bio-retention basins), etc.
- The development of performance curves for urban BMPs showed that the performance of the practices is highly affected by the size of practice, the influent load and the soil infiltration rate.

6.2 Recommendations

- This study has tried to examine some of the variability of reported EMC's with an objective to identifying either typical median values for a static applications or pdf parameters for possible stochastic applications.
- As a compromise, a variable EMC approach based on antecedent rainfall is suggested.
- There remains a need for better characterization of the actual pdfs
- Another possible way to assess the performance of BMPs is using existing field data to calibrate to appropriate watershed models which could then be used to evaluate the performance of different BMPs against the resulting runoff volumes and influent loads.
- The agricultural field scale models such as the Agricultural policy/Environmental Extender model (APEX) model might be an option to be used for developing better performance curves for agricultural BMPs
- The information provided in this research can be imbedded into larger watershed models such as the Kentucky Nutrient Model (KYNM) for use in locating and siting BMPs so as to maximize the pollutant reduction at a minimum cost.

Appendix A: Compilation of EMC and LEC Values

Table A.1. Total Nitrogen EMCs for Urban and Agricultural Landuses (mg/l)

Land Use		Median	10%	25%	75%	90%	Min	Max	Source
Urban		1.5	0.6	1.1	3.3	6.4	-	-	1
		2	-	-	-	-	0.3	4.5	2
		2.76	-	-	-	-	-	-	3
Residential (Urban/Suburban)		5	0.5	1.5	6	11	-	-	4
		1.75	-	-	-	-	-	-	3
	National	2	-	-	-	-	-	-	5
	Zone2	1.8	-	-	-	-	-	-	
	Louisville	3.76	-	-	-	-	0.93	18	6
	Louisville	1.25	-	-	-	-	0.44	90.1	7
	Lexington	3.7	-	-	-	-	2.9	3.7	
	Knoxville	1.5	-	-	-	-	0.3	7.5	
Commercial	National	2.2	-	-	-	-	-	-	5
	Zone 2	2	-	-	-	-	-	-	
		1.75	-	-	-	-	-	-	3
	Louisville	2.1	-	-	-	-	1.73	2.64	6
	Louisville	1.3	-	-	-	-	0.44	90.1	7
	Lexington	6.08	-	-	-	-	1.75	18.1	
	Knoxville	1.5	-	-	-	-	0.5	20.2	
Industrial	National	2.1	-	-	-	-	-	-	5
	Zone 2	1.8	-	-	-	-	-	-	
	Louisville	2.45	-	-	-	-	0.98	5.38	6
	Louisville	0.66	-	-	-	-	0.3	1	7
	Lexington	2.9	-	-	-	-	1.9	3.3	
	Knoxville	1.3	-	-	-	-	0.28	16.7	
Open spaces/Parks		1.51	-	-	-	-	-	-	3
	National	1.2	-	-	-	-	-	-	5
	Zone 2	1.2	-	-	-	-	-	-	
	Louisville	0.93	-	-	-	-	0.3	1.3	7
	Lexington	2.8	-	-	-	-	2.4	3.2	
	Knoxville	1.45	-	-	-	-	0.28	16.7	
Roadway	Zone 2	2.4	-	-	-	-	-	-	5
	National	2.3	-	-	-	-	-	-	
	Low Traffic/Res. Streets	1.7	-	-	-	-	-	-	8
	Urban Highway	3	-	-	-	-	-	-	
Forest/Wooded		0.9	0	0.5	1	3	-	-	4
		0.68	-	-	-	-	0.21	1.58	9

Table A.1. Total Nitrogen EMCs for Urban and Agricultural Landuses (mg/l) (Continued)

Land Use		Median	10%	25%	75%	90%	Min	Max	Source
Forested/Wooded		0.61	-	-	-	-	0.15	2.37	10
		0.45	-	-	-	-	0.15	1.42	
Golf Course/Green		1.9	0.4	1	2	5.5	-	-	4
		6.12	-	-	-	-	-	-	11
Mixed land use		1.3	0.58	1	2.2	4.1	-	-	1
		0.75	-	-	-	-	0	3	2
Undeveloped		0.58	0.1	0.5	1	1.1	-	-	1
		0.1	-	-	-	-	0.05	1.4	2
Barren		1.35	-	-	-	-	-	-	11
Agriculture		3.9	1.5	2.2	7	9.8	-	-	1
		3	-	2.5	4	-	-	-	4
		3	-	-	-	-	0.3	7.5	2
Row Crop		8.5	-	-	-	-	2.3	92.55	9
		2.6	-	-	-	-	1.8	2.9	12
		2.2	-	-	-	-	0	5.5	6
Non Row Crop		6.63	-	-	-	-	2.8	8.82	9
Corn		8.5	-	-	-	-	2.31	92.5	
Soybean		5.1	-	-	-	-	1.82	8.34	
Cotton		7.94	-	-	-	-	7.1	8.8	
Alfalfa		6.36	-	-	-	-	3.6	8.5	
Wheat		6.45	-	-	-	-	6.7	8.8	
Grass land		2.8	-	-	-	-	-	-	12
	Region XI	0.61	-	-	-	-	0.15	2.37	10
	Region IX	0.45	-	-	-	-	0.15	1.42	
Silviculture		0.9	-	-	-	-	0	3	4
		0.68	-	-	-	-	0.211	1.58	9
	Region XI	0.61	-	-	-	-	0.15	2.37	10
	Region IX	0.45	-	-	-	-	0.15	1.42	
Grazed and Pasture		2	0	0.5	3	7.5	-	-	4
		4.63	-	-	-	-	1.62	74.8	9
		3	-	-	-	-	-	-	11
		4.08	-	-	-	-	0.55	13.16	6
Animal feedlot +manure storage		1047.28	-	-	-	-	393.36	2382	9
Rotational Grazing		5	-	-	-	-	2.49	11	
Continuous Grazing		5.1	-	-	-	-	4	6.26	
Mixed Ag.		9	-	-	-	-	1.04	15.31	

Table A.2. Total Phosphorus EMCs for Urban and Agricultural Landuses (mg/l)

Land Use		Median	10%	25%	75%	90%	Min	Max	Source
Urban		0.25	0.034	0.08	0.48	1.14	-	-	1
		0.25	-	-	-	-	0	0.6	2
		0.42	-	-	-	-	-	-	3
Residential (Urban/Suburban)		0.7	0.1	0.2	1.7	2.8	-	-	4
		0.38	-	-	-	-	-	-	3
	National	0.3	-	-	-	-	-	-	5
	Zone2	0.43	-	-	-	-	-	-	
	Louisville	0.81	-	-	-	-	0.163	12.89	6
	Louisville	0.33	-	-	-	-	0.08	1.3	7
	Lexington	0.63	-	-	-	-	0.07	6.9	
	Knoxville	0.34	-	-	-	-	0.03	1.78	
Commercial		0.2	-	-	-	-	-	-	3
		0.22	-	-	-	-	-	-	5
	Zone 2	0.37	-	-	-	-	-	-	
	Louisville	0.19	-	-	-	-	0.14	0.38	6
	Louisville	0.28	-	-	-	-	0.09	10.2	7
	Lexington	0.71	-	-	-	-	0.1	2.3	
	Knoxville	0.16	-	-	-	-	0.01	1.83	
Industrial	National	0.26	-	-	-	-	-	-	5
	Zone 2	0.26	-	-	-	-	-	-	
	Louisville	0.41	-	-	-	-	0.15	1.82	6
	Louisville	0.27	-	-	-	-	0.07	0.81	7
	Lexington	0.37	-	-	-	-	0.13	2.5	
	Knoxville	0.2	-	-	-	-	0.02	0.97	
Open space		0.12	-	-	-	-	-	-	3
		0.25	-	-	-	-	-	-	5
	Zone 2	0.26	-	-	-	-	-	-	
	Louisville	0.24	-	-	-	-	0.07	0.26	7
	Lexington	0.4	-	-	-	-	0.26	0.45	
	Knoxville	0.25	-	-	-	-	0.02	0.02	
Roadway	Zone 2	0.95	-	-	-	-	-	-	5
	National	0.25	-	-	-	-	-	-	
	Low Traffic/Res. Streets	0.55	-	-	-	-	-	-	8
	Urban Highway	0.32	-	-	-	-	-	-	
	High Traffic/Highway	0.4	-	-	-	-	-	-	13
	Low Traffic/Res. Streets	0.36	-	-	-	-	-	-	
	Med Traffic/ Streets	0.33	-	-	-	-	-	-	
Forest/Wooded		0.1	-	0	0.12	-	-	-	4
		0.094	-	-	-	0.022	0.29	-	9

Table A.2. Total Phosphorus EMCs for Urban and Agricultural Landuses (mg/l) (Continued)

Land Use		Median	10%	25%	75%	90%	Min	Max	Source
		0.02	-	-	-	0.01	0.37	-	10
		0.02	-	-	-	0.01	0.15	-	
		0.15	-	-	-	-	-	-	
Golf Course/Green		0.03	-	0.01	0.9	-	-	-	4
		1.07	-	-	-	-	-	-	11
Mixed land use		0.15	0.034	0.1	0.22	0.55	-	-	1
		0.1	-	-		-	0	0.4	2
Undeveloped		0.045	0.01	0.03	0.1	0.2	-	-	1
		0.05	-	-	-	-	0	0.1	2
Barren		0.21	-	-	-	-	-	-	11
		0.25	0.07	0.15	0.38	0.6	-	-	1
Agriculture		0.5	-	0.3	0.6	-	-	-	4
		0.2	-	-	-	-	0	0.7	2
		1.54	-	-	-	-	0.65	24.5	9
		0.26	-	-	-	-	0.1	0.3	12
Row Crop		0.06	-	-	-	-	0	0.61	6
Non Row Crop		0.78	-	-	-	-	0.1	6.16	9
Corn		1.54	-	-	-	-	0.65	24.5	
Soybean		2	-	-	-	-	0.93	3.16	
Cotton		3.4	-	-	-	-	3.6	3.2	
Alfalfa		0.62	-	-	-	-	0.37	1.79	
Wheat		1	-	-	-	-	0.1	6.16	
		0.15	-	-	-	-	-	-	12
	Region XI	0.02	-	-	-	-	0.01	0.37	10
Grass land	Region IX	0.02	-	-	-	-	0.01	0.15	
		0.12	-	-	-	-	0	0.1	4
		0.094	-	-	-	-	0.022	0.29	9
	Region XI	0.02	-	-	-	-	0.01	0.37	10
Silviculture	Region IX	0.02	-	-	-	-	0.01	0.15	
		1	-	0.4	1.9	-	-	-	4
		0.65	-	-	-	-	0.06	7.19	9
Grazed/Pasture		0.25	-	-	-	-	-	-	12
		0.37	-	-	-	-	0.01	3.57	10
Animal feedlot +manure storage		132	-	-	-	-	68.64	501	9
Mixed Ag.		1.11	-	-	-	-	0.15	1.66	
Rotational Grazing		0.56	-	-	-	-	0.42	7.19	
Continuous Grazing		0.97	-	-	-	-	0.75	3.33	

1- Dubrovsky, N. M., et al, 2010, 2- Dennis A., et al 1999, 3- United States Environmental Protection Agency (US-EPA), 1983, 4- K. W. King and J. C., 2011, 5- Pitt, R., A. Maestre, and R. Morquecho 2004, 6-KY USGS 94, 7-NSQD 2014, 8-Scueter 1997, 9- K. H. Reckhow, et al, 1980, 10-KY Statewide 2009, 11-Line 2002, 12-EPA 99, 13-Penn state manual 2006.

Table A.3. Total Nitrogen LECs for Urban and Agricultural Landuses (kg/ha/year)

Land Use			Median	10%	25%	75%	90%	Min	Max	Source
Urban			5.4	-	3.90	11	-	1	36.47	1
Residential	Single family low density		4	-	-	-	-	3.3	4.7	2
			0.45	-	-	-	-	-	-	3
	Single family medium density		2.7	-	-	-	-	-	-	2
			4.43	-	-	-	-	-	-	3
	Single family high density		5.6	-	-	-	-	4	5.8	2
			7	-	-	-	-	-	-	3
	Multi family residence		5.6	-	-	-	-	4.7	6.6	2
	Urban/Suburban		4	0	2	5	9	-	-	4
Commercial			5.2	-	-	-	-	1.6	8.8	1
			11.13	-	-	-	-	-	-	3
Industrial			5.3	-	-	-	-	-	-	3
			7.95	-	-	-	-	-	-	1
Roadway	Unspecified		2.4	-	-	-	-	1.3	3.5	2
	Parking lot		9.09	-	-	-	-	-	-	3
	Highway		13.75	-	-	-	-	-	-	
Forest/Wooded			2	0	1	2.6	10	-	-	4
			2.45	-	2.3	3	-	1.5	6	1
			2	-	-	-	-	1.1	2.8	2
			2.33	-	-	-	-	-	-	5
Golf Courses			6	-	2.5	27	-	-	-	4
			1.52	-	-	-	-	-	-	1
Developed			7.5	-	-	-		-	-	5
Cropland	Row Crops		9	-	3.8	22	-	2	79.6	1
	Non Row Crops		6.07	-	4.00	6.00	-	3.00	7.50	
	Fallow Cultivated		3	-	-	-	-	-	-	6
	Various Rotations		3.67	-	-	-	-	-	-	
Crop type	Corn	Unspecified	18.7	-	-	-		-	-	
	Cotton		7.78	-	-	-	-	-	-	
	Sorghum		3	-	-	-	-	-	-	
	Oats/Wheat		6.6	-	-	-	-	-	-	
Agriculture			9.8	-	-	-	-	-	-	5
			12	2.2	4	24	39	-	-	4
Pastureland/rangeland			1	0	0.2	5	7	-	-	4
			0.97	-	-	-	-	-	-	6
			4.63	-	2.3	11	-	1	30.85	1

Table A.3. Total Nitrogen LECs for Urban and Agricultural Landuses (kg/ha/year) (Continued)

Land Use	Median	10%	25%	75%	90%	Min	Max	Source
	4.2	-	-	-	-	1.2	7.1	2
Grassland	4.2	-	-	-	-	1.2	7.1	
Animal feedlot +manure	2920.91	-	1600	3500	-	700	7980	1
Mixed Ag.	14.28	-	9.00	41	-	2.5	41.5	

Table A.4. Total Phosphorus LECsfor Urban and Agricultural Landuses (kg/ha/year)

Land Use		Median	10%	25%	75%	90%	Min	Max	Source
Urban		1.1	-	0.6	2.5	-	0.3	6.23	1
Residential	Single family low density	0.55	-	-	-	-	0.46	0.64	2
		0.045	-	-	-	-	-	-	3
	Single family medium density	0.34	-	-	-	-	-	-	3
	Single family high density	0.66	-	-	-	-	0.54	0.76	2
		1.13	-	-	-	-	-	-	3
	Multi family residence	0.7	-	-	-	-	0.59	0.81	2
	Urban/Suburban	0.5	0	0.1	1.3	2	-	-	4
Commercial		0.8	-	-	-	-	0.69	0.91	2
		1.7	-	-	-	-	-	-	3
Industrial		1.47	-	-	-	-	-	-	3
		2.25	-	-	-	-	-	-	1
Roadway	Unspecified	1.1	-	-	-	-	0.59	1.5	2
	Parking lot	0.8	-	-	-	-	-	-	3
	Highway	1	-	-	-	-	-	-	
Forest/Wooded		0.1	--	-	-	-	-	-	4
		0.2	-	0.1	0.3	-	0	0.9	1
		0.11	-	-	-	-	0.1	0.13	2
		0.13	-	-	-	-	-	-	5
Golf Courses		1.5	-	0.1	4.7	-	-	-	4
		0.19	-	-	-	-	-	-	1
Developed		1.06	-	-	-	-	-	-	5

Table A.4. Total Phosphorus LECs for Urban and Agricultural Landuses (kg/ha/year) (Continued)

Land Use	Median	10%	25%	75%	90%	Min	Max	Source	Land Use
Cropland	Row Crops	2.24	-	0.9	5.5	-	0.2	18.6	1
	Non Row Crops	0.76	-	0.6	1.4	-	0.2	2.9	
	Fallow Cultivated	1.08	-	-	-	-	-	-	6
	Various Rotations	0.59	-	-	-	-	-	-	
	Cotton	5	-	-	-	-	-	-	
	Sorghum	1.18	-	-	-	-	-	-	
	Soybeans	0.45	-	-	-	-	-	-	
Agriculture		0.5	0.1	0.15	0.9	1.6	-	-	4
		1.4	0.2	0.15	2.8	4	-	-	4
		0.24	-	-		-	-	-	6
		0.9	0.82	2	2.6	-	0.2	4.9	1
Pastureland/rangeland		0.13	-	-	-	-	0.01	0.25	2
Grassland		0.13	-	-	-	-	0.01	0.25	2
Animal feedlot +manure		223.8	-	160	420	-	800	795.20	1
Mixed Ag.		0.91	-	0.40	1.30	-	0.20	3.30	

1-Michael and Reckhow 1982, 2-Horner, R.R., et al 1990, 3- Burton, G.A. and R.E. Pitt. 2002, 4-K. W. King and J. C. Balogh, 2011, 5- Dodd, R. C., et al, 1992, 6-Daren Harmel, et al 2006, 7-Earl Shaver, et al, 2007, 8-Jeff P. Lin, 2004.

References

Abbaspour, K.C., J. Yang, I. Maximov., R. Siber, K. Bogner, J. Mieleitner, J. Zobrist, R.Srinivasan. (2007). "Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT". Journal of Hydrology. 333:413-430.

American Public Works Association. (1969). "Water Pollution Aspects of Urban Runoff" Federal Water Pollution Control Administration. Contract WP-20-15. Washington, DC.

Andre´ F.J., Romero C. (2008). "Computing compromise solutions: On the connections between compromise programming and composite programming". *Applied Mathematics and Computation*. Vol. 195, No. 1. pp 1–10.

Arabi Mazdak., Frankenberger Jane R., Engel Bernie A., Arnold Jeff G. (2007). "Representation of agricultural conservation practices with SWAT". Hydrological Process. Vol 22, P: 3042–3055.

Arabi Mazdak. (2017). "Nutrient Modelling Overview". Colorado States University. Available at: www.epadatadump.com/pdf-files/day2_arabi.pdf

Arnold JG, Srinivasan R, Muttiah RS, Williams JR. (1998). "Large area hydrologic modelling and assessment part I: model development". Journal of American Water Resources Association 34(1): 73–89.

AVCO Economic Systems Corporation. (1970). "Storm Water Pollution from Urban Land Activity". EPA 111034FKL07/70 (NTIS PB-19528l). Washington, DC.

Bailey Ryan T., Wible Tyler C., Arabi Mazdak, Records Rosemary M., Ditty Jeffrey. (2016). "Assessing regional-scale spatio-temporal patterns of groundwater-surface water interactions using coupled SWAT-MODFLOW model". Hydrological Processes. Vol 30. 4420-4433.

Brown, W. and T. Schueler. (1997). "The Economics of Storm Water BMPs in the Mid-Atlantic Region". Center for Watershed Protection. Ellicott City, MD.

Burton, G.A. and R.E. Pitt. (2002). "Stormwater Effects Handbook". Lewis Publishers. CRC Press. Boca Raton. FL.

Camacho, R. (1992). "Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation: Financial cost effectiveness of point and nonpoint source nutrient reduction technologies in the Chesapeake Bay basin". Interstate Commission on the Potomac River Basin.

Caraco deb. (2013). "Watershed Treatment Model (WTM) 2013 Documentations". Center for Watershed Protection.

Center for Watershed Protection (CWP) and Chesapeake Stromwater Network (CSN). (2008). “Technical Memorandum: The Runoff Reduction Method”. Ellicott City. MD 21043. Available at: http://www.vwrrc.vt.edu/swc/documents/pdf/CWP%20Technical%20Memo%20RRMethod_041808%20w_Apps.pdf

Chesapeake Bay Committee. (2011). “Achieving nutrient and sediment reduction goals in the Chesapeake Bay: An evaluation of program strategies and implementation”. National Academies Press.

CH2M Hill. (2008). “Jordan Lake Watershed Trading Project-BMP Cost Estimates and Cost-Effectiveness” Mid-Carolina Council of Governments Cape Fear River Assembly.

CH2M Hill. (2000). “Technical Memorandum 1. Urban Stormwater Pollution Assessment”. prepared for North Carolina Department of Environment and Natural Resources. Division of Water Quality.

CH2M Hill. (2008). “Jordan Lake Watershed Trading Project-BMP Cost Estimates and Cost-Effectiveness”. Mid-Carolina Council of Governments Cape Fear River Assembly.

City of Duluth Storm Water Office. (2017). “City of Duluth Streams to Lake Superior Streams”, University of Minnesota, retrieved from: http://www.lakesuperiorstreams.org/stormwater/toolkit/swales.html

Coin News Family. (2017). “US Inflation Calculator”. Available at: http://www.usinflationcalculator.com/

Cronshey, R.G., and F.D. Theurer. (1998). “AnnAGNPS Nonpoint Pollutant Loading Model”. In Proceedings of First Federal Interagency Hydrologic Modeling Conference. April 19-23. Las Vegas. NV.

Crain Angela S., Martin Gray R. (2009). “Concentrations, and Estimated Loads and Yields of Total Nitrogen and Total Phosphorus at Selected Water-Quality Monitoring Network Stations in Kentucky. 1979–2004”. USGS (Unites States Geological Survey).

Cronshey, R.G., and F.D. Theurer. (1998). “AnnAGNPS—Nonpoint Pollutant Loading Model”. In Proceedings of First Federal Interagency Hydrologic Modeling Conference. Las Vegas. NV.

Dodd, R. C., McMahon, G., and Stichter, S. (1992). “Watershed planning in the Albemarle-Pamlico estuarine system: Report 1- annual average nutrient budgets”. US-EPA. Center for Environmental Analysis. Report 92-10. Raleigh. NC.

Dubrovsky, N. M., Burow, K. R., Clark, G. M., Gronberg, J. M., Hamilton, P. A., Hitt, K. J.,Wilber, W. G. (2010). “The Quality of Our Nation's Water: Nutrients in the Nation's

Streams and Groundwater. 1992-2004". US Geological Survey Circular vol 135. Washington, DC: US Department of the Interior

Dennis A. Went, Kevin D. Richard, Lan R. Waite, Jeffrey d. Martin. (1999). "The Quality of Our Nation's Waters Nutrients and Pesticide". US Geological Survey Circular. Reston, Virginia. Available at: https://pubs.usgs.gov/circ/circ1225/pdf/front.pdf

Evaldi Ronald D. and Moore Brian L. (1994). "Techniques for Estimating the Quantity and Quality of Storm Runoff from Urban Watersheds of Jefferson County, Kentucky". US Geological Survey. Water Resources Investigation Report 94-4023.

Erikson.J. Andrew, Weiss T Peter, Gulliver S John. (2013). "Optimizing stormwater treatment practices: a handbook of assessment and maintenance". Springer. New York.

Flanagan, D.C., and M.A. Nearing, eds. (1995). "USDA-Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation NSERL". Report no. 10. West Lafayette. IN.

Haith, D. A., Shoemaker, L. (1987). "Generalized watershed loading functions for stream flow nutrients". Water Resources Bulletin 23(3):471-478.

Harmel Daren, Potter Steve, Casebolt Pamela, Reckhow Ken, Green Collen, and Haney Rick. (2006). "Compliation of Measured Nutrient Load Data for Agricultural Land Uses in the United States". Journal of the American Water Resources Association. vol. 42, issue 5, pp. 1163-1178.

Hershfield D. M. (1961). "Rainfall Frequency atlas of Unites States". Cooperative Studies Section. Hydrologic Services Division for Engineering Division. Soil Conservation Service U.S. Department of Agriculture.

Hogan Michael, (2010) Water pollution. Encyclopedia of Earth. Topic ed. Mark McGinley, ed. in chief C. Cleveland, National Council on Science and the Environment, Washington DC.

Horner, Richard R., Joseph J. Skupien, Eric H. Livingston, and H. Earl Shaver. (1990). "Fundamentals of Urban Runoff Management: Technical and Institutional Issues". Prepared by the Terrene Institute. In cooperation with the U.S. Environmental Protection Agency. Washington, DC.

Houle, J.J. and Roseen, R.M. (2013). "Comparison of maintenance cost, labor demands, and system performance for LID and conventional stormwater management". Journal of environmental engineering, 2013. 139(7): p. 932-938.

Huber, W.C., and R.E. Dickinson. (1988). “Storm Water Management Model Version 4, User’s manual”, EPA 600/3 88/ 001a (NTIS PB88-236641/AS). U.S. Environmental Protection Agency, Athens, GA.

Huber, W.C., J.P. Heaney, S.J. Nix, R.E. Dickinson, and D.J. Polmann. (1981). “Storm Water Management Model User’s Manual. Version III”. EPA-600/2-84-109a (NTIS PB84-198423). U.S. Environmental Protection Agency, Cincinnati, OH.

Huber, W. C, (1992). “Prediction of Urban Nonpoint Source Water Quality: Methods and Models.” International Symposium on Urban Stormwater Management, Sydney.

Johanson, R.C., J.C. Imhoff and H.H. Davis, (1980). “User's Manual for the Hydrologic 516 Simulation Program - FORTRAN (HSPF). Version No. 5.0.” EPA-600/9-80-105., U.S. 517 EPA Environmental Research Laboratory, Athens, GA.

James River Association (JRA). (2013). “Cost-Effectiveness Study of Urban Stormwater BMPs in the James River Basin”. Marylands’ Center for Watershed Protection.

International Stormwater Best Management Practices (BMP) Database .(2014). “Pollutant Category Statistical Summary Report: Solids, Bacteria, Nutrients, and Metals” Geosyntec Consultants. Inc. Wright Water Engineers. Inc.

International Stormwater Best Management Practices (BMP) Database (2012). “Pollutant Category Summary Statistical Addendum: TSS, Bacteria, Nutrients, and Metals”. Geosyntec Consultants, Inc. Wright Water Engineers, Inc.

International Stormwater Best Management Practices (BMP) Database Project (2017). Available at: http://www.bmpdatabase.org/history.html

International Stormwater BMP Database Project .(2017). “Frequently Asked Questions”. Available at: http://www.bmpdatabase.org/Docs/FAQPercentRemoval.pdf.

Kentucky Water Resources Research Institute (KWRRI) .(2014). "Community Visions for Nurient Management for the Floyds Fork Watershed".

King K. W. and Balogh J. C. (2011). “Stream water nutrient enrichment in a mixed-use watershed.” Journal of environmental Monitoring. pp. 721-731. 10.1039/C0EM00584C.

Kirby, J.T., S.R. Durrans, R. Pitt, and P.D. Johnson. (2005). “Hydraulic resistance in grass swales designed for small flow conveyance”. Journal of Hydraulic Engineering. Vol. 131.

Kohler, M.A., Nordenson, T.J., and Fox, W.E. (1955). Evaporation from Pans and Lakes. Research Paper 38, u.s. Weather _Bureau, Washington, D.C.

Kohler E. A., Poole V. L., Reicher Z. J. and Turco R. F. (2004). “Nutrient, metal, and pesticide removal during storm and nonstorm events by a constructed wetland on an urban golf course.” Ecol. Eng. 23, 285–298.

Lee, J. H., Bang, K.W., Ketchum, L.H., Choe, J.S., and Yu, M.J. (2002). “First flush analysis of urban storm runoff”. The science of the total environment, 293(1-3). 163-175.

Lexington-Fayette Urban County Government (LFUCG). (2009). “Stormwater Manual”. Available at: https://next.lexingtonky.gov/sites/default/files/2016-07/Stormwater%20Manual%202009%20%28updated%29.pdf

Lin. Jeff P. (2004). “Review of Published Export Coefficient and Event Mean Concentration (EMC) Data”. Engineer Research and Development Center, Vicksburg Ms.

Line, D. E., White, N. M., Osmond, D. L., Jennings, G. D., and Mojonnier, C. B. (2002). "Pollutant export from various land uses in the Upper Neuse River Basin," *Water Environment Research* 74(1). pp. 100-108.

Lowrance, R. R., L. S. Altier, R. G. Williams, S. P. Inamdar, D. D. Bosch, J. M. Sheridan, D. L. Thomas, and R. K. Hubbard. (2002). “The Riparian Ecosystem Management Model: simulator for ecological processes in riparian zones”. USDA-ARS Conservation Research Report 46.

Maryland’s Department of Environment. (2012). “Cost Analyses and Funding Studies for Maryland’s Phase II Watershed Implentation Plan (WIP)”. Available at: http://msa.maryland.gov/megafile/msa/speccol/sc5300/sc5339/000113/014000/014606/unrestricted/20120442e-005.pdf

Mason, D., A, (2013). “Detailed Look at Costs Associated with Green Stormwater Controls”. Southeastern Stormwater Association. Available at: http://www.seswa.org/assets/Services/Annual-Conference/2013/09%20-%20mason.pdf

Metcalf and Eddy Inc. (1971). “Storm Water Management Model Volume I – Final Report, I”. 524 11024DOC07/71. Water Quality Office. Environmental Protection Agency. Washington DC.

Mid-America Regional Council (MARC) and American Public Work Association (APWA). (2012). “BMP Manual of Best Management Practices For Stormwater Quality”. Available at: http://www.jeffersoncitymo.gov/BMPManual_Oct2012.pdf

Munshaw, Gregg. (2016). "Lawn Establishment in Kentucky [2016]". Agriculture and Natural Resources Publication. Available at: http://uknowledge.uky.edu/anr_reports/91/?utm_source=uknowledge.uky.edu%2Fanr_reports%2F91&utm_medium=PDF&utm_campaign=PDFCoverPages

Munoz-Carpena R., Parsons JE., Wendell GJ. (1999). “Modeling hydrology and sediment transport in vegetative filter strips”. Journal of Hydrology 214: 111-129.

Nara, Y., R. Pitt, S.R. Durrans, and J. Kirby. (2006). “Sediment transport in grass swales.” In: Stormwater and Urban Water Systems Modeling. Monograph 14, edited by W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt. CHI. Guelph, Ontario, pp. 379 - 402.). Available from: (https://engineering.purdue.edu/mapserve/LTHIA7/documentation/hsg.html)

Neitsch S.L., Arnold J.G., Kiniry J.R., Williams J.R. (2011) “Soil and Water Assessment Tool Theoretical Documentation Version 2009”. Texas A&M Agrilife Research & Extension Center.

Neitsch SL, Arnold JG, Kiniry JR, Williams JR. (2005). Section 2 Chapter 1-Equations: surface runoff. In Soil and Water Assessment Tool Theoretical Documentation, Grassland, Soil and Water Research Laboratory. Agricultural Research Service. Temple, TX 76502.

Nietch T, Borst M, Schubauer-Berigan JP. (2005). “Risk management of sediment stress: A framework for sediment risk management research”. Environmental Management 36(2): 175–194.

New Jersey Department of Environmental Protection. (2010). “New Jersey Stormwater BMP Manual”. Chapter 9.12. Available from: http://www.nj.gov/dep/stormwater/bmp_manual/NJ_SWBMP_9.12.pdf

Novotny, V., and H. Olem. (1994). “Water Quality: Prevention, Identification, and Management of Diffuse Pollution”. Van Nostrand Reinhold, New York.

Novotny, V. (2003). “Water Quality: Diffuse Pollution and Watershed Management”. New York, NY: John Wiley & Sons.

North Carolina Department of Environment and Natural Resources (NCDENR), (2007), “Stormwater BMP Mannual”, North Carolina Division of Water Quality. Available from: https://www.ncsu.edu/ehs/environ/DWQ_StormwaterBMPmanual_001%5B1%5D.pdf

NSQD (National Storm Water Quality Datebase). (2014). Data Retrieved from: http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml

Ouyang Da. (2017). “RUSLE: Online Soil Erosion Assessment Tool”. Institute of water research. Michigan State University. Available at: http://www.iwr.msu.edu/rusle/about.htm

Olivia Harcourt Devereux. (2010). “Estimates of County Level Nitrogen and Phosphorus Data for Use in Modeling Pollutant Reductions”. US-EPA, University of Maryland and the Chesapeake Bay Program.

Omernik, J.M. (1976). “The Influence of Land Use on Stream Nutrient Levels”. US-EPA Ecological Research Series EPA-60013-76-014. US Environmental Protection Agency. Corvallis, OR.

Ormsbee, L., Albritton, B., White, E. (2017). “Disaggregated Streamflow Approach for Improving Water-Quality Modeling”, Journal of Hydrologic Engineering, Vol 22 (4).

Pennsylvania Department of Environmetal Protection. (2006). “Pennsylvania Stormwater Best Management Practices Manual”. Available from: http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-68851/363-0300-002.pdf

Pitt, R. (1979). “Demonstration of Non-point Pollution Abatement through Improved Street Cleaning Practices”. US-EPA-600/279-161 (NTIS PB80-108988). Cincinnati, OH.

Pitt, R.E. (1987). “Small Storm Flow and Particulate Washoff Contributions to Outfall Discharges”. Ph.D. dissertation. Department of Civil and Environmental Engineering. the University of Wisconsin – Madison.

Pitt, R., (1997). “SLAMM Stormwater Quality Model”. Alabama’s Water Environment Association and Air & Waste Management Association Alabama Chapter Joint Conference. Orange Beach, Alabama.

Pitt, R.E. (1999). "Small Storm Hydrology and Why it is Important for the Design of Stormwater Control Practices." Journal of Water Management Modeling R204-04. doi:10.14796/JWMM.R204-04.

Pitt, R. E. and Voorhes, J. (2000). “The Source Loading and Management Model (SLAMM), a Water Quality Management Planning Model for Urban Stormwater Runoff”. University of Alabama, Department of Civil and Environmental Engineering, Tuscaloosa, AL.

Pitt, R., A. Maestre, and R. Morquecho. (2004). “The National Stormwater Quality Database (NSQD) Version 1.1 Report.” University of Alabama, Department of Civil and Environmental Engineering, Tuscaloosa, AL.

Powell, A. J. Jr. (2000). "Lawn Establishment in Kentucky". Agriculture and Natural Resources Publications. Paper 4. Available at: http://uknowledge.uky.edu/anr_reports/4/?utm_source=uknowledge.uky.edu%2Fanr_reports%2F4&utm_medium=PDF&utm_campaign=PDFCoverPages

PV & Associates, LLC. (2015). “WinSLAMM Model Algorithms”. Available at: http://www.winslamm.com/docs/WinSLAMM%20Model%20Algorithms%20v6.pdf

PV & Associates, LLC. (2016). “WinSLAMM Model Help Menu”. Available at: http://www.winslamm.com/

Puckett, L.l. (1995). “Identifying the major sources of nutrient water pollution”. Environmental Scieince Technology, 29: 408-414.

Raird, C., Jennings, M., Ockerman, D., Dybale, T. (1996). Characterization of nonpoint sources and loadings to Corpus Christi Bay National Estuary Program study Area, Corpus Christi Bay National Estuary Program/USGS/NRCS; CCBNEP-05.

Rephann, T.J. (2010). “Economic impacts of implementing agricultural best management practices to achieve goals outlined in Virginia’s tributary strategy”. Center for Economic and Policy Studies.

Reckhow K. H., Beaulac M. N., Simpson J. T. (1980). “Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficient.” Volume 11; Volume 80 of EPA / Office of Water Planning and Standards. US Environmental Protection Agency.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder coordinators. (1997). “Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)”. U.S. Department of Agriculture, Agricultural Handbook 703, 404 pp.

Rivard, G. (2010). "Small Storm Hydrology and BMP Modeling with SWMM5." Journal of Water Management Modeling R236-10. doi: 10.14796/JWMM.R236-10.

Rosenthal A., and Urban D. (1990). “BMP Longevity: A Pilot Study”, report to the Chesapeake Bay Program, CBP/TRS 50-90.

RSmeans. (2013). “City cost indexes”. Rockland, MA 02370. Available at: https://www.rsmeansonline.com/References/CCI/1-Unit%20Cost%20(MasterFormat%202010)/3-Year%202013%20Base.PDF

RSmeans. (2017). “How to use the city cost indexes”. Rockland. MA 02370. Available at: https://www.rsmeansonline.com/References/HowToUsePages/How-to-Use-CCI-2014.pdf

Sartor, J.D. and Boyd, G.B. (1972). “Water Pollution Aspects of Street Surface Contaminants”. EPA-R2-72-081 (NTIS PB-214408). U.S. Environmental Protection Agency, Washington, DC.

Schueler, T. (1987). "Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices". MWCOG. Washington. D.C.

Shaheen, D.G. (1975). "Contributions of Urban Roadway Usage to Water Pollution" EPA-600/2-75-004 (NTIS PB-245854). US-EPA, Washington, DC.

Shapiro, M. H. (2013). "EPA Testimony Statement on Nutrient Trading and Water Quality". Retrieved from http://www.epa.gov/ocir/hearings/pdf/nutrient_trading_and_water_quality.pdf

Shaver Earl, Horner Richard, Skupien Joseph, May Chris, Ridley Graeme. (2007). "Fundamentals of urban runoff management". US-EPA. North American Lake Management Society.

Shoemaker Leslie, Dai Ting, and KoenigTetra Jessica. (2005). (TMDL Model Evaluation and Research Needs). US-EPA. Tetra Tech Virginia.

Shoemaker Leslie, Riverson Jr John, Alvi Khalid, X. Zhen Jenny, Paul Sabu, Rafi Teresa. (2009). "SUSTAIN- A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality". US-EPA.

Shuman L. M., Smith A. E. and Bridges D. C., (2000). "Potential Movement of Nutrients and Pesticides Following Application to Golf Courses, in Fate and Management of Turfgrass Chemicals". American Chemical Society, Washington, DC, pp. 78–93.

Simpson, Thomas, Weammert Sarah. (2009). "Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus and Sediment in the Chesapeake Bay Watershed". Chesapeake Bay Program, University of Maryland, Available at: http://www.chesapeakebay.net/about/programs/watershed_implementation_plan_tools/

Steuer J, Selbig W, Hornewer N.J, Prey J. (1997). "Sources of contamination in an urban basin in Marquette, Michigan and analysis of concentrations, loads, and data quality." U.S. Geological survey, Water Resources Investigations Report: 97-4242.

Strecker, E.W.; Quigley, M.M. Urbonas, B.; and Jones, J., (2004). "Analyses of the Expanded US-EPA/ASCE International BMP Database and Potential Implications for BMP Design". Proceedings of the World Water and Environmental Resources Congress. Salt Lake City, Utah.

Tasker G D, Driver N E, (1988). "Nationwide regression models for predicting urban runoff water quality at unmonitored sites". Water Resources Bulletin, 24(5): 1091–1101

Tetra Tech. (2009). "Loading Simulation Program in C++ (LSPC) Version 3.1 User's Manual". 542 Fairfax, VA.

Texas A&M Agrilife Research & Extension Center. (2008). "Agricultural Policy/Environmental Extender (APEX) model". Available: http://blackland.tamu.edu/models/

United States Department of Agriculture (USDA) Soil Conservation Service. (1987). "Soil Mechanics Level I, Module 3: USDA Textural Classification Study Guide". Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044818.pdf

United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (2007). "Engineering Field Handbook: Chapter 7: Grassed Waterways". H_210_NEH_650 - Part 650. Available at: https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17766.wba

USDA, NRCS. (2004). Soil Survey Staff, "Soil Survey Laboratory Method Manual", Soil Survey Investigation Report No. 42. Version 4.0 U.S. Gov. Print Office. Washington D.C.

Unites States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (2016). "KY 2016 Kentucky EQIP Payment Schedule". Kentucky Environmental Quality Incentives Program (EQIP). Available at: https://www.nrcs.usda.gov/wps/portal/nrcs/main/ky/programs/financial/eqip/

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. (1981). "Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States". NOAA Technical Report NWS 34. Washington DC.

U.S. Army Corps of Engineers. (1976). "Storage, Treatment, Overflow, Runoff model 550 'STORM': User's Manual" Hydrologic Engineering Center, Davis, CA.

U.S-EPA (United States Environmental Protection Agency). (1972). Clean Water Act. 33 U.S.C. 1251.

US-EPA. (1983). "Results of Nationwide Urban Runoff Program". US-EPA-PB/84-185552.

US-EPA. (1999). "Preliminary Data Summary of Urban Stormwater BMPs". EPA-821-R-99-012. Washington DC.

US-EPA. (1999). "Protocol for developing nutrient TMDLs". EPA 841-B-99-007. Office of Water (4503F). Washington D.C., 58.

US-EPA. (2003). “National Management Measures for Control of Non-Point Pollution from Agriculture”. EPA-841-B-03-004. Washington DC.

US-EPA. (2003). “System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN)”. Available: https://www.epa.gov/water-research/system-urban-stormwater-treatment-and-analysis-integration-sustain

US-EPA. (2008). “Handbook for Developing Watershed Plans to Restore and Protect Our Waters”. Nonpoint Source Control Branch. Washington DC 20460.

U.S-EPA. (2009). “*SUSTAIN*--A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality”. (Publication No. EPA/600/R-09/095).

U.S-EPA. (2009). “National water quality inventory: Report to congress. 2004 reporting cycle”-. No. EPA 841-R-08-001. Available at: https://www.epa.gov/waterdata/national-water-quality-inventory-report-congress.

US-EPA. (2010). “Guideline for Federal Land Management in the Chesapeake Bay Watershed”. Nonpoint Source Pollution Office of Wetlands. US-EPA 841-R-10-002

US- EPA. (2016). “Storm Water Management Model Reference Manual Volume III – Water Quality”. Office of Research and Development National Risk Management Laboratory Cincinnati, OH 45268.

US-EPA, ASCE. (2017). “The History of International Stormwater Best Management Practices (BMP) Database Project”. Available from: http://www.bmpdatabase.org/history.html

Van Houtven, G. and C.B. Commission. (2013). “Nutrient credit trading for the Chesapeake Bay: An economic study”. Chesapeake Bay Commission.

White E, Albritton B, Ormsbee L. (2015). “The Kentucky Nutrient Model”. Proceedings of the World Environmental and Water Resources Congress 2015. 2667-2676.

William W. Walker, Jeffrey D. Walker. (2017). “P8 Urban Catchment Model”. Available at: http://www.wwwalker.net/p8/#Model_Reviews_&_Reports

Williams, J.R. (1975). “Sediment-yield prediction with Universal Equation using runoff energy factor. In: Present and Prospective Technology for Predicting Sediment Yield and Sources”. U.S. Dept. Agric. ARS-S-40. pp 244-252.

Williams, J. R., R. C. Izaurralde, and E. M. Steglich. (2008). “Agricultural policy/environmental extender model theoretical documentation”. BREC Report #2008-17. Blackland Research and Extension Center. 130 p.

Winchell Michael and Estes Tammara. (2009). “Review of Simulation Models for Evaluating the Effectiveness of Buffers in Reducing Pesticide Exposure”. Vol 1. Stone Environmental Inc.

Wischmeier WH, Smith DD. (1978). Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. US Department of Agriculture, Agricultural Handbook No.537, US Government Printing Office: Washington, DC 20402–9328.

Wossink A and Hunt WF. (2003). “An Evaluation of Cost and Benefits of Structural Stormwater BMPS in North Calorina”. NC Cooperative Extension Service.

Yihun Dile, R. Srinivasan and Chris George. (2017). “QGIS Interface for SWAT (QSWAT)”. USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research. Available at: http://swat.tamu.edu/software/qswat/

Vita

Education:

1. M. Sc.

Master of Science in Water Resources Engineering at University of Kentucky, Lexington, Kentucky (August 2015 to August 2017).

Thesis Title: I am currently working under supervision of Dr. Lindell Ormsbee to model (Simulation-Optimization Approach) urban and agricultural best management practices to reduce nutrient loads in watershed outlet.

2. M. Sc.

Master of Science in Water Engineering at Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran (September 2012 to February 2015).

Thesis Title: "Urban Water Systems Management Considering Technical, Economical and Environmental Criteria: Simulation-Optimization Approach".

3. B. Sc.

Bachelor of Science in Civil Engineering at Shahid Bahonar University of Kerman, Kerman, Iran (September 2008 to October 2012).

Major Areas of Interest

- Watershed Management
- Sustainable Urban Water Management
- Integrated Urban Water Modeling & Management
- Stormwater Systems Modeling
- Stream Restoration
- Watershed Sedimentation
- Groundwater Modeling &Management
- Energy-Water Nexus
- Water Distribution Network Modeling
- Genetic and PSO Algorithms

Computer Skills:

- Matlab, Excel Macros
- HEC-HMS, EPANET, MODFLOW, SWMM, WaterMet, SDSM
- Autocad, ArcGIS (Basic)
- Microsoft Office
- Etabs, SAFE

Conference and Journal Papers:

- **Nazari S.,** Mousavi S.J., Behzadian K., Kapelan Z., "Sustainable urban water management: a simulation optimization approach", 11th International Conference on Hydroinformatics, New York, USA, 2014.

- **Nazari S.,** Mousavi S.J., Behzadian K., Kapelan Z., "Compromise programming based scenario analysis of urban water systems management options: Case study of Kerman city", 11th International Conference on Hydroinformatics, New York, USA, 2014.

- **Nazari S.,** Ebadi T., Khaleghi T., "Assessment of the nexus between groundwater extraction and greenhouse gas emissions employing aquifer modeling", Procedia Environmental Sciences, 25, 183-190, 2015.

- Shojaee S., Iazadpanah E., **Nazari S.,** "Imposition of the essential boundary conditions in transient heat conduction problem based on Isogeometric analysis", Scientia Iranica journal (International Journal of Science and Technology), Volume 21, Number 6, 2014.

- **Nazari S.,** Rahmani F., Kheyrandish F., "Risk management of urban stormwater systems using NSGA-II algorithm", 10th International Conference on Civil Engineering, Water Resources and Environmental Engineering, Tabriz, Iran, 2015.

- **Nazari S.,** Mousavi S.J., Behzadian K., "Prioritization of simulated operating and intervention options in urban water systems using compromise programming ", 10th International Conference on Civil Engineering, Water Resources and Environmental Engineering, Tabriz, Iran, 2015.

- Behzadian K., Kapelan Z., **Nazari S.,** Venkatesh G., Brattebø H., Sægrov S., Mousavi S.J., "Quantitative assessment of future sustainability performance in urban water services using WaterMet2", TRUST conference, Mulheim, Germany, 2015.

- **Nazari S.,** Ormsbee L., "Urban and Agricultural Nutrient Event Mean Concentration and Load Data for Watershed Quality Assessment Models", submitted to World Environmental and Water Resources Congress, Sacramento, California, 2017.

Honors:

- Ranked 650th among nearly 35000 participants in Iranian graduate nationwide entrance exam in 2012.

- Ranked in top 3% in Iranian undergraduate nationalwide entrance exam in 2008

Work Experiences:

1-Environmental Research Center of Amirkabir University of Technology (Tehran Polytechnic), as research assistant, (2013-2014).

Project: Preparing a manual for environmental impact assessment of civil engineering projects for Tehran Municipal.

2-Kerman Water and Wastewater Engineering Company, as research assistant, (2014)
Project: Preparing an integrated urban water model for five cities of Kerman province

3-Kerman Jahad Nasr Consulting Engineering Company, as project manager, (2011-2012).