Quantifying Support Practice Sub-Factor Values for Erosion-Control and Sediment Retention Devices

Research Final Report from (the University of Tennessee, Knoxville) | (Chris Wilson, Karen Abercrombie, John Schwartz, and Jon Hathaway) | February 28, 2023

Sponsored by Tennessee Department of Transportation Long Range Planning Research Office & Federal Highway Administration

(University Logo(s) in Footer. Mark as Decorative.)

DISCLAIMER

This research was funded through the State Planning and Research (SPR) Program by the Tennessee Department of Transportation and the Federal Highway Administration under ***RES #2020-24:*** **Quantifying Support Practice Sub-Factor Values for Erosion-Control and Sediment Retention Devices*.***

This document is disseminated under the sponsorship of the Tennessee Department of Transportation and the United States Department of Transportation in the interest of information exchange. The State of Tennessee and the United States Government assume no liability of its contents or use thereof.

The contents of this report reflect the views of the author(s) who are solely responsible for the facts and accuracy of the material presented. The contents do not necessarily reflect the official views of the Tennessee Department of Transportation or the United States Department of Transportation.

Technical Report Documentation Page

1. Report No. RES 2020-24	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle *Quantifying Support Practice Sub-Factor Values for Erosion-Control and Sediment Retention Devices*		5. Report Date February 2023 6. Performing Organization Code R01-3601-680
7. Author(s) Chris Wilson, Karen Abercrombie, John Schwartz, and Jon Hathaway		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Tennessee Dept. of Civil & Environmental Engineering Knoxville, Tennessee 37996		10. Work Unit No. (TRAIS) 11. Contract or Grant No. RES 2020-24
12. Sponsoring Agency Name and Address Tennessee Department of Transportation 505 Deaderick Street, Suite 900 Nashville, TN 37243		13. Type of Report and Period Covered Final Report December 2020 - February 2023 14. Sponsoring Agency Code
15. Supplementary Notes Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.		

Roadway construction sites can be substantial contributors to sediment pollution; however, erosion can be mitigated by utilizing erosion prevention and sediment control devices. An estimation of the erosion can be determined empirically through the revised universal soil loss equation (RUSLE) or deterministically with the water erosion prevention project (WEPP) to design sediment control measures. Due to RUSLE's empirical structure, limitations occur in determining accurate erosion yields per use of empirical factors. WEPP can simulate erosion yields based on physical site conditions. In this study, WEPP was used to estimate the RUSLE erosion control practices factor (P-factor). A variety of different parameters influence the efficiency of these sediment control devices, including drainage area, climate, soil types, topography, and land use/cover. This study focused on a combination of five common soil types (clay loam, silt clay loam, silt clay, silt loam, and loam) and four climate regions (Knoxville, Nashville, Chattanooga, and Memphis) in Tennessee to generate P-factors for silt fences and straw-filled sediment tubes. The study was performed by generating and calibrating a hillslope model, performing numerical simulations for a generated watershed, and determining and analyzing the P-factor. While no significant fluctuations of the P-factor for the different climate regions were found, there were significant differences for the soil type. The soil type had the greatest influence on the efficiency of these sediment control devices due to variations in soil composition and hydraulic conductivity. The soil type with the greatest efficiency was silt clay loam (P= 0.34 for silt fences), while silt loam produced the least level of reduction (P= 0.55 for straw-filled sediment tubes). Both tables and regression equations were created to model the P-factor for each combination of climate and soil type

17. Key Words **Soil erosion, Silt fences, Straw-filled sediment tubes, WEPP model, USLE practice management (P) factor, Erosion calculator**	18. Distribution Statement No restriction. This document is available to the public from the sponsoring agency at the website http://www.tn.gov/.		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages xxx	22. Price

Acknowledgement

This research was sponsored by the Tennessee Department of Transportation. The author is indebted to Ryan Sweeney and Ali Hangul for serving as the Technical Advisor and providing productive input to improve this project. The author would also like to thank Dr. Thanos Papanicolaou and Dr. Ben Abban for their help with the development of this project.

Executive Summary

Recent reviews of Best Management Practices have highlighted wide ranges of efficiency values for many commonly used stormwater and sediment control practices (e.g., Hangul, 2017; Schwartz and Hathaway, 2018). Despite the broadness of the ranges, the pools of studies from which these values were derived were actually quite small. The studies may not have considered a sufficient number of *soil – climate – topography – surface cover – practice* permutations for a diverse region like Tennessee. Although concerning, this shortcoming should be expected if one considers the constraints in funding, the time it takes to collect ample data, and the availability of researchers.

In a precursor study (RES#2016-20; Wilson, 2021) conducted for the Tennessee Department of Transportation (TDOT) at the University of Tennessee – Knoxville, the practice efficiencies (i.e., RUSLE's P-factor) of silt fences and sediment tubes were quantified for rainfall intensities and soils found in Tennessee. The study developed and used a systematic approach involving an intermediate-sized, physical model of a roadcut. The physical model was scaled to fit inside a laboratory so that controlled conditions and repeatable methods would provide consistent and reasonable erosion estimates.

Three rainfall intensities were applied for 20 minutes to the predominant soil textures of east and west Tennessee. These events occurred over bare soil without any sediment control devices to determine a baseline soil loss rate and over bare soil with the silt fences and sediment tubes installed. The sediment-laden export was collected to determine the total amount of runoff and soil loss from the physical model during the applied events. The P-factors for both sediment control devices were determined by comparing the baseline erosion to the soil loss measured with the different sediment control devices installed. The P-factor values ranged from 0.03 to 0.76.

These P-factor values are a valuable addition for TDOT engineers and roadway construction project managers who use the Revised Universal Soil Loss Equation (RUSLE) to estimate erosion rates. However, because of the high variability in P-factor values observed from a limited number of "site conditions", RUSLE users must be cautious.

RUSLE is empirical in nature and requires an abundance of measured data from physical experiments and field observations to estimate its coefficients. For P-factors, data sources are especially limited. In fact, most P-factor values used at roadway and construction sites are often borrowed from agricultural applications. Conducting more studies like RES#2016-20 is an ideal, but impractical solution. As an alternative, this present study (RES#2020-24) used a

different type of model, the Water Erosion Prediction Project (or WEPP model) to explore more site conditions in Tennessee and augment the data collected during RES#2016-20.

WEPP is a process-driven, deterministic, distributed-parameter model that incorporates soil, land use, and topographic heterogeneity along a hillslope. WEPP, being physically based, considers the mechanics of hydrology, hydraulics, erosion, and sediment transport and is thus less dependent on masses of measured runoff and erosion data to build regression equations. Conversely, it is computationally more complex, lacking the simplicity and ease-of-use that makes RUSLE appealing.

WEPP calculates runoff by first determining infiltration with the Green-Ampt Mein-Larson equation and then solving the continuity equation for overland routing. For erosion, WEPP examines a sequence of processes starting with interrill erosion. Detachment, transport, and deposition of sediment in the rills are then calculated using a steady state solution to the 1-D sediment continuity equation.

In addition, WEPP has an impoundment component that can simulate the hydraulic and sedimentation processes related to silt fences, terraces, culverts, and check dams. The hydraulics of the impoundment are determined through direct integration of the continuity equation. The sedimentation component determines the amount of sediment deposited and the outflow concentration using the conservation of mass and overflow rates, while considering the impoundment geometry and its hydraulic response.

In this study, the runoff and soil loss from a hillslope were simulated using five prevalent soil textures (i.e., loam; silt loam; silty clay loam; clay loam; silty clay) and rainfall data from four climate regions in Tennessee surrounding the largest cities in the state (i.e., Knoxville, Nashville, Chattanooga, and Memphis). The **first objective** was to develop a WEPP model using the measured runoff, soil loss, and P-factor data from RES#2016-20 for calibration of the saturated hydraulic conductivity, the critical shear stress, and the rill/interrill erodibilities. The **second objective** was to determine P-factor values for silt fences and sediment tubes for each combination of soil type and climate region mentioned above using the calibrated models. The generated P-factors for this study are compiled in a reference table to be used in RUSLE by TDOT.

A first set of simulations for calibration was performed using WEPP's hillslope module. The simulated hillslope had the same dimensions as the physical model used in the RES#2016-20 experiments. These simulations contained 15 scenarios based on the experiments having bare soil but no sediment control device. The second set of simulations was performed using the watershed module in WEPP. The watershed was composed of the calibrated hillslopes, scaled up, with a short channel. This set contained 20 scenarios that were run without any sediment control device at the end of the channel, as well as another 20 scenarios that were run with silt fence at the end of the channel and 20 scenarios that were run with straw-filled sediment tubes at the end of the channel. The sediment control devices were represented in WEPP as a form of impoundment. The comparison between the simulations with no control practice and those with a practice were used to determine the P-factor.

For a second set of simulations, the WEPP watershed module was used so that an impoundment (i.e., silt fence; sediment tube) could be implemented into the simulations. The hillslopes had the original length of 6 ft; however, the width was scaled up to 10,000 ft so that the minimum required watershed area for WEPP of 0.1 acre was reached. The scaling of only the width was chosen to avoid the formation of large rills after a critical source length is reached, which would produce inflated sediment yields and prevent us from using the measured values of soil loss in kg/m^2 from the experiments in RES#2016-20 to validate the model.

The results of the first set of simulations were similar to the findings of RES#2016-20. There were positive linear relationships between runoff and the runoff coefficient for each soil texture and there were strong, exponential relationships between the sediment yield and runoff coefficient. No correlation was observed between rainfall and the sediment yield.

For the second set of simulations, runoff and sediment yield values exhibited large ranges when considering all combinations of soil texture and climate region. Comparatively, the simulations using the silt fence and those using the sediment tubes saw similar trends, but the values for the silt fence simulations had smaller ranges. The simulations with silt loam soils had the largest range for sediment yield from 0.47 to 0.96 kg/m^2, while the simulations with clay loam and silt clay had the largest ranges for runoff coefficients from 0.32 to 0.45 and 0.26 to 0.39, respectively.

The P-factor values for the silt fence simulations changed slightly across soil textures, but the P-factor values for the sediment tube simulations were uniform. Analyses of Variance (ANOVAs) showed significant differences between the P-factor values for the silt fences and straw-filled sediment tubes (ANOVA; $p<0.05$). Between soil types, the ANOVAs saw no significant differences for the P-factor values (ANOVA; $p>0.05$). The simulations with silt clay loam soils saw the most efficient P-factor values of 0.34. The silt loam simulations, though, had the least efficient values of 0.54.

For this study, the simulations showed that the practices were able to retain a significant amount of sand but were unable to provide any considerable retention for silt and clay particles. Although loam had the greatest sediment yield in the simulations performed without impoundments, the amount of soil export was dramatically decreased by the sediment control devices due to high levels of sand. However, clay loam and silt loam were less efficient despite the high levels of sand present in both because they had also high silt contents. The silt form less stable aggregates than clay particles. The silt particles can pass through the practices, while the larger aggregates cannot pass. would suggest that these devices could successfully capture a significant amount of the eroded soil; however, these soils have the highest P-factor which indicates a lower efficiency. Although silty clay and silt clay loam also had high levels of silt, they also have high levels of clay to aid in aggregate formation.

Another component that may help explain the differences in the practices' efficiency was the hydraulic conductivity of the soil. The simulations showed that the hydraulic conductivity decreased as the runoff coefficient increased. A soil that has a higher hydraulic conductivity can infiltrate more water, resulting in a decrease in runoff. A decrease in runoff is crucial to reducing erosion as the corresponding decrease in the entrainment force translates to less detachment.

The determination of these P-factors is crucial for entities in industry or academia to estimate erosion from a site. A GIS map of the P-factors for RUSLE accompanies this study.

Key Findings

- Despite the broadness of the ranges for practice efficiency values (i.e., P-factor), the pools of studies from which these values were derived were actually quite small.
- There were positive linear relationships between runoff and the runoff coefficient for each examined soil texture and there were strong, exponential relationships between the sediment yield and runoff coefficient. No correlation was observed between rainfall and the sediment yield.
- simulations with silt loam soils had the largest range for sediment yield from 0.47 to 0.96 kg/m^2, while the simulations with clay loam and silt clay had the largest ranges for runoff coefficients from 0.32 to 0.45 and 0.26 to 0.39, respectively.
- The P-factor values for the silt fence simulations changed slightly across soil textures, but the P-factor values for the sediment tube simulations were uniform. The simulations with silt clay loam soils saw the most efficient P-factor values of 0.34. The silt loam simulations, though, had the least efficient values of 0.54.
- A major component that was observed to have more influence in the numerical simulations is soil composition. The simulations showed that the practices were able to retain a significant amount of sand but were unable to provide any considerable retention for silt and clay particles.

Key Recommendations

- Conducting more physicals experiments is an ideal, but impractical solution for examining more state-specific conditions. As an alternative, the Water Erosion Prediction Project (or WEPP model) can explore more site conditions in Tennessee with less effort and cost.
- Future studies could conduct numerical simulations for various climate lengths, incorporate more soil types and climate regions, as well as more practices.
- More complete understanding could be developed for how the composition of these soil types fluctuates over time and the corresponding influence this fluctuation has on the generated P-factors.

Table of Contents

DISCLAIMER i

Technical Report Documentation Page ii

Quantifying Support Practice Sub-Factor Values for Erosion-Control and Sediment Retention Devices ii

Acknowledgement iii

Executive Summary iv

- Key Findings vii
- Key Recommendations viii

List of Tables x

List of Figures xi

Chapter 1 Introduction 1

- 1.1 Problem Statement 1
- 1.2 Knowledge Gaps and Objectives 1

Chapter 2 Literature Review 4

- 2.1 Overview 4
- 2.2 Revised Universal Soil Overview 5
- 2.3 Water Erosion Prevention Project 6
- 2.4 Previous Competed Research 7

Chapter 3 Methodology 10

- 3.1 WEPP Generation of Hillslope Model 10
- 3.2 WEPP Generation of Watershed Model 13
- 3.3 WEPP Watershed Model Generation of P-Values 15

Chapter 4 Results and Discussion 16

- 4.1 Baseline Soil Erosion 16
- 4.2 Soil Erosion Control Practice Factor 21
- 4.3 GIS Maps of P-Factor for Tennessee 33

Chapter 5 Conclusion 35

References 37

Appendices 42

List of Tables

Table 2-1. Overview of Physical Lab Scale Model Experimental Set-up. 8
Table 2-2. Corresponding Recurrence Intervals to the NTPEP Testing 9
Table 2-3. Soil Composition and Properties for the Study. 9
Table 3-1. Summary of Input Values to the WEPP Hillslope Module. 11
Table 3-2. Predefined Tolerances for WEPP Hillslope Simulations. 13
Table 3-3. WEPP Hillslope Module Output Ranges from Literature. 14
Table 3-4. WEPP Watershed Module Averaged Output Parameters for Each Soil Type 15
Table 3-5. WEPP Watershed Dimensions of Impoundments. 15
Table 4-1. Summary of Numerical Simulations Without Sediment Control Devices. 17
Table 4-2. Summary of Event Averages. 18
Table 4-3. Summary of WEPP Numerical Simulations with Silt Fences. 21
Table 4-4. Summary of WEPP Numerical Simulations with Straw-filled Sediment Tubes. 22
Table 4-5. Statistical Results of Simulation Events for Silt Fences. 22
Table 4-6. Statistical Results of Simulation Events for Straw-filled Sediment Tubes. 23
Table 4-7. Summary of Soil Composition Breakdown of the P-Factor for Silt Fences 28
Table 4-8. Summary Table of RUSLE P-Factors for Silt Fences and Straw-filled Sediment Tubes. 31

.

List of Figures

Figure 2-1. Photo: Physical Lab Model Experimental Set-up. From Wilson (2021). 8
Figure-3-1. Hillslope Module in WEPP Model. 11
Figure 3-2. Slope in WEPP Hillslope Module. 12
Figure 4-1. Relationships of Gross Soil Erosion and Runoff in Comparison to Runoff Coefficients. 18
Figure 4-2. Sediment Yield per Runoff Coefficients without WEPP Impoundments for Clay Loam 19
Figure 4-3. Sediment Yield per Runoff Coefficients without WEPP Impoundments for Loam. 19
Figure 4-4. Sediment Yield per Runoff Coefficients without WEPP Impoundments for Silt Clay. 19
Figure 4-5. Sediment Yield per Runoff Coefficients without WEPP Impoundments for Silt Clay Loam. 20
Figure 4-6. Sediment Yield per Runoff Coefficients without WEPP Impoundments for Silt Loam. 20
Figure 4-7.WEPP Simulations: Runoff Coefficient Distribution for Clay Loam. 24
Figure 4-8. WEPP Simulations: Runoff Coefficient Distribution for Loam. 24
Figure 4-9. WEPP Simulations: Runoff Coefficient Distribution for Silt Clay. 24
Figure 4-10. WEPP Simulations: Runoff Coefficient Distribution for Silt Clay Loam. 25
Figure 4-11. WEPP Simulations: Runoff Coefficient Distribution for Silt Loam. 25
Figure 4-12. WEPP Simulations: P-Factor Distribution for Clay Loam. 25
Figure 4-13. WEPP Simulations: P-Factor Distribution for Loam. 26
Figure 4-14. WEPP Simulations: P-Factor Distribution for Silt Clay. 26
Figure 4-15. WEPP Simulations: P-Factor Distribution for Silt Clay Loam. 26
Figure 4-16. WEPP Simulations: P-Factor Distribution for Silt Loam. 27
Figure 4-17. Silt Fence Effectiveness for Sediment Yields. 28
Figure 4-18. Hydraulic Conductivity Compared to Runoff Coefficients for Silt Fences. 30
Figure 4-19. Simulation Results: P-Factor Regression for Clay Loam. 31
Figure 4-20. Simulation Results: P-Factor Regression for Loam. 32
Figure 4-21. Simulation Results: P-Factor Regression for Silt Clay. 32
Figure 4-22. Simulation Results: P-Factor Regression for Silt Clay Loam. 33
Figure 4-23. Simulation Results: P-Factor Regression for Silt Loam. 33
Figure 4-24. GIS map of P-Factors for silt fences within Tennessee. 34
Figure 4-25. GIS map of P-Factors for straw-filled sediment tubes within Tennessee. 34

Click or tap here to enter text.

Chapter 1 Introduction

1.1 Problem Statement

Soil erosion rates at roadway and other construction sites can exceed those in agricultural areas by a hundred-fold (e.g., Faucette et al., 2006). If control measures are not implemented, these excess loads can lead to higher construction costs for replacing lost soil or cleaning up the exported sediment (Ledermann et al., 2010).

Several literature and web-based sources detail multitudes of Best Management Practices, or BMPs, for limiting the loss of sediment with new practices continually being developed (e.g., Muste et al., 2002; Sprague et al., 2014). Recent reviews of these sources (e.g., Hangul, 2017; Schwartz and Hathaway, 2018) discuss deficiencies including the lack of long-term efficiency data (Liu et al., 2017). Moreover, the practices exhibit wide ranges of efficiency values (e.g., Theisen and Spittle, 2006; Faucette et al., 2008; Garcia et al., 2015), which may seem discerning. Nonetheless, the wide ranges should be expected if one considers all possible combinations of soil, slope, rainfall, practice design, and implementation, especially for a diverse state like Tennessee.

Certain studies have attempted to account for some of this diversity (e.g., Tyner et al., 2011; Chapman et al., 2014) but they can only do so much with the available funding. Alternatively, efforts such as the National Transportation Product Evaluation Program (NTPEP) by the American Association of State Highway and Transportation Officials (AASHTO) have pushed standardized testing methods of different practices to provide a common ground for comparison. Soil, slope, and rainfall are set on large-scale platforms (Sprague and Sprague, 2012; AASHTO, 2014), and all practices are tested under a singular condition.

The underlying assumption that practices will respond similarly regardless of the site-specific conditions remains unverified. The study, herein, combined measurements from controlled experiments with physical and empirical modeling to examine the response of silt fences and sediment tubes under different soils and climates found in Tennessee. The end products are more applicable efficiency values for roadway and other construction sites in the state.

1.2 Knowledge Gaps and Objectives

From the problem statement, it is apparent that practice efficiency values, despite their broad ranges, do not consider the diverse range of conditions within a region. In many cases, the available efficiency values were determined for only a single permutation of site parameters.

This limitation becomes apparent when empirical models like the Revised Universal Soil Loss Equation (RUSLE) are used to quantify erosion rates at a site. RUSLE has been widely adopted across industry and academia due to its simplicity and its ability to estimate soil loss with relative accuracy. Its empirical nature, though, requires an abundance of data from physical experimentation and field observations to estimate its coefficients (Renard et al., 1994).

Some of RUSLE's parameters are well defined, especially those for soil, slope, and rainfall (the K-, LS-, and R- factors, respectively). However, its other factors for surface cover (the C-factor) and especially for erosion control practices (the P-factor) are limited. In fact, most C- and P-factor values used at roadway and construction sites were borrowed from agricultural applications (Toy et al., 1999; TDOT, 2012). Despite the relatively few conditions under which these factors have been developed, they have a disproportionately large range (Faucette et al., 2008).

A previous study (RES#2016-20; Wilson, 2021) was conducted to quantify the efficiency of silt fences and sediment tubes for rainfall intensities and soils found in Tennessee using controlled experiments. Similar to other studies (e.g., Zech et al., 2008), RES#2016-20 could only explore a handful of conditions. It was only able to determine the P-factors for three sediment control devices under three different rainfall intensities. These limitations are a direct example of the inability to cover fully the complete array of different parameters that go into RUSLE through physical experiments, which ultimately affects the predictive ability of the empirical model.

To circumvent the inability to cover the complete array of site parameters, this present study utilized a different type of model to explore more conditions found in Tennessee. The Water Erosion Prediction Project (WEPP) is a physically based, numerical model that has been observed to achieve even more accurate estimates of runoff and soil loss than RUSLE (Stolpe, 2005; Wilson et al., 2016).

WEPP, being a physically based simulation model, considers the mechanics of hydrology, hydraulics, erosion, and sediment transport and is thus less dependent on masses of measured runoff and erosion data to build regression equations (Laflen et al., 1991). Conversely, it is computationally more complex, lacking the simplicity and ease-of-use that makes RUSLE so appealing.

This present study used WEPP to augment the data collected during the physical experiments of RES#2016-20 by considering a broader range of values for the parameters that have been shown to influence the efficiency of best management practices. In particular, soil composition has a high correlation to the efficiency of sediment control devices (e.g., Barrett et al., 1998; Wishowski et al., 1998; Faucette et al., 2008; Wilson, 2021). This study focused on five different soil compositions that are prevalent in Tennessee (i.e., loam; silt loam; silty clay loam; clay loam; silty clay). In addition, this study considered the climate for four different regions of Tennessee. These regions include the four highest populated cities in Tennessee (Knoxville, Nashville, Chattanooga, and Memphis).

The **first objective** of this study was to develop a WEPP model using the measured runoff, erosion, and P-factor data from RES#2016-20 to calibrate and validate it. The **second objective** was to determine P-factor values for silt fences and sediment tubes for each combination of soil type and climate region mentioned above using the developed WEPP. The generated P-factors for this study are compiled for the Tennessee Department of Transportation (TDOT) in a reference table to be utilized in RUSLE.

Chapter 2 Literature Review

2.1 Overview

Best management practices include a variety of different structures and methods that can treat, prevent, or reduce the amount of eroded soil entering surrounding waterways (Kaufman, 2006). Due to the significant erosion rates that are often observed on construction sites and the vast array of negative impacts that sediment pollution has on the environment (e.g., Faucette et al., 2006), the United States government mandated the containment of soil eroded from any site. The National Pollutant Discharge Elimination System (NPDES) Phase II, enforced by the United States government, specifically dictates these sites achieve a reduction in erosion by implementing various sediment control structures, such as silt fences and straw-filled sediment tubes (Faucette et al., 2009).

Installers of sediment control devices at construction sites must have an awareness of the gross soil erosion at their site and the overall efficiency of these control devices. RUSLE is currently the most widely accepted tool for organizations, such as TDOT (TDOT, 2012), to determine the gross soil erosion of an area (Theisen and Spittle, 2006; Faucette et al., 2008; Tyner et al., 2011; Gogo-Abite and Chopra, 2013). Through an analysis of these various studies, it is apparent that the efficiency of these sediment control devices can vary greatly from experiment to experiment. The irregularities of these efficiencies can be correlated to the differences in the experimental set-up and a lack of previously established factors to appropriately model a given area (Faucette et al., 2008). For example, there is a lack of defined reduction efficiencies of these erosion prevention and sediment control devices for the state of Tennessee (Schwartz and Hathaway, 2018). This absence of data resulted in TDOT funding the University of Tennessee to analyze the efficiency of different practices in a controlled and uniform experimental set-up (RES#2016-20; Wilson, 2021).

Although RES#2016-20 determined the efficiency for three specific sediment control devices, it also observed the influence of different parameters on the total efficiency of the sediment control devices, namely climate and soil composition, in support of other previous studies (e.g., Sonnevald and Nearing, 2003). Because of the strong influence of specific site parameters on erosion, one must be cautious when using empirical models like RUSLE. Due to constraints with funding, the time it takes to collect ample data, and the availability of researchers, the data available for quantifying the various empirical parameters that drive RUSLE may be limited and may not consider all possible permutations of soil, slope, climate, and cover. Another method for accurately simulating the net soil lost from construction sites is the Water

Erosion Prediction Project, or WEPP (Laflen and Flanagan, 2013). The utilization of WEPP to determine these reduction efficiencies through numerical simulations can expand upon the data available for these various parameters. The key differences between these two models for estimating sediment erosion are described below in Section 2.2 and 2.3.

2.2 Revised Universal Soil Overview

The Revised Universal Soil Loss Equation, more commonly called RUSLE, is a widely adopted method that empirically determines gross soil erosion rates for a hillslope. RUSLE can be seen in Equation 2.1 where A is the computed soil loss, R is the rainfall-runoff erosivity factor, K is the soil erodibility factor, LS is the slope length and steepness factor, C is the cover management factor, and P is the erosion control practices (e.g., Tyner et al., 2011). Due to its empirical nature, these factors are quantified through observations from the field or through conducted experiments.

$$A = R \cdot K \cdot LS \cdot C \cdot P \tag{2.1}$$

RUSLE is an essential planning tool used by several state Departments of Transportation to ensure the conservation of soil (Renard et al., 1997). Due to its widespread usage, the replicability of the estimated soil erosion is critical; however, a debated component of RUSLE is the P-factor due to the large variability observed in the literature (Stolpe, 2005; Faucette et al., 2008; Tyner et al., 2011; Gogo-Abite and Chopra 2013; Wilson, 2021). The P-factor ranges between 0 and 1, where a lower number indicates a greater efficiency for erosion control. The method for calculating the P-factor can be seen in Equation 2.2.

$$P = \frac{A_{with\ practice}}{A_{without\ practice}} \tag{2.2}$$

The P-factors found in literature vary greatly across the different erosion prevention and sediment control devices. For silt fences, the study that achieved the most substantial and consistent reduction in soil loss was by Faucette et al. (2008), which measured P-factors from 0.11 to 0.29. Theisen and Spittle (2006) were also able to achieve a P-factor as low as 0.12; however, unlike Faucette et al. (2008), the study observed a wider range of P-factors from 0.12

to 0.58. The same holds true for the precursor of the present study. RES#2016-20 measured P-factor values between 0.03 and 0.57. Finally, the studies conducted by Fifield (2005) and Gogo-Abite and Chopra (2013) found similar soil loss ratios of 0.6 and 0.44 to 0.77, respectively.

Although the range of P-factors is large for silt fences, the range for straw-filled sediment tubes is even greater. One study by García et al. (2015) observed a range of P-factors from 0.03 to 0.81. Other studies achieved more uniform results. Those studies by Kelsey et al. (2006), Theisen and Spittle (2006), Faucette et al. (2008), and Wilson (2021) observed P-factor ranges of 0.29 to 0.45, 0.14 to 0.51, 0.10 to 0.32, and 0.32 to 0.76, respectively. Through the lack of a consensus on the ideal value for the P-factor, a large amount of variability can occur for the soil loss estimated by RUSLE.

One explanation for the variability in measured P-factor values across studies is the different experimental parameters underlying each study. The P-factor can be influenced by a variety of different land utilizations and ecological conditions (Sonneveld and Nearing, 2003). The specific parameters that directly impact the efficiency of these control devices are climate, drainage area, topography, soil type, and land cover (Wilson, 2021). These parameters can influence the partitioning of rainfall between infiltration and runoff, the total runoff volume, peak runoff rate, and the frequency/ duration for which runoff will occur. Furthermore, several studies have found that the amount of runoff a site experiences is directly correlated to the amount of soil that will be eroded (e.g., Williams, 1991; Parsons et al., 2006; Zheng and Chen, 2015; Wilson, 2021). Understanding the connections between different site parameters with runoff and erosion can improve the accuracy and precision of P-factor values used in RUSLE.

2.3 Water Erosion Prevention Project

Both WEPP and RUSLE were created to address shortcomings of the Universal Soil Loss Equation (Laflen and Flanagan, 2013). Although WEPP and RUSLE both estimate the amount of soil loss for a defined area, the two models determine these rates through differing means. As described in Section 2.2, RUSLE is an empirical model that relies on physically determined correction factors. In contrast, WEPP is a process-driven, deterministic, distributed-parameter model that can incorporate heterogeneity in soil, land use, and topographic parameters along a hillslope (Flanagan and Nearing, 1995). Climate data can be measured values but can also be generated via a climate generator (e.g., CLImate GENerator, or CLIGEN).

WEPP calculates rainfall excess, or runoff, by first determining infiltration with the Green-Ampt Mein-Larson equation. It then performs the continuity equation to estimate runoff rates in overland routing. Thus, WEPP is more accurate than approaches utilizing the Rational method and curve numbers (Stone et al., 1995). Regarding hillslope erosion in WEPP, the sequence of processes starts with interrill erosion, where soil particles detach through raindrop impact and are delivered to the rills by shallow runoff, or sheet flow. Detachment, transport, and deposition of sediment in the rills are then calculated using a steady state solution to the 1-D sediment continuity equation (Foster et al., 1995).

In addition, WEPP comes with a complete management practice database and an impoundment component that can simulate the hydraulic and sedimentation processes related to silt fences, terraces, culverts, and check dams (Lindley et al., 1995). The hydraulics of the impoundment are determined through direct integration of the continuity equation. The sedimentation component determines the amount of sediment deposited and the outflow concentration using the conservation of mass and overflow rates, while considering the impoundment geometry and its hydraulic response.

In previous studies, WEPP has been used to simulate the net soil lost from construction sites (e.g., Tiwari et al., 2000; Stolpe, 2005; Moore et al., 2007). Moreover, similar studies have found that WEPP is able to estimate soil loss more accurately than RUSLE (Stolpe, 2005; Wilson et al., 2016). For example, Stolpe (2005) found a correlation coefficient of 0.93 between the measured data and WEPP-simulated results, while the correlation coefficient was 0.71 between the measured data and the RUSLE-simulated results. The accuracy displayed by WEPP in studies such as these enables it to be utilized to estimate the amount of erosion when physical data is not available.

2.4 Previous Competed Research

RES#2016-20 was conducted for TDOT at the University of Tennessee - Knoxville (UTK) to determine P-factor values for three sediment control devices (i.e., silt fences; straw-filled sediment tubes; mulch-filled sediment tubes) under different soil and climate conditions found in Tennessee. The study developed and used a systematic approach involving an intermediate-sized, physical model of a roadcut that followed NTPEP guidelines and the standard practice, TM11340 (Sprague and Sprague, 2014). The physical model was scaled down to fit inside a laboratory so that controlled conditions and repeatable methods would provide consistent and reasonable erosion estimates (Zech et al., 2008). The scaled-down model was designed to the specifications illustrated in Figure 2-1 and stated in Table 2-1.

Four sets of experiments were performed. During each set of experiments, soil from different regions in Tennessee was placed in the physical model and compacted to 95% of the Proctor density. Rainfall with three different intensities was applied to the soil for 20 minutes. The sediment-laden runoff was collected in its entirety for determining the total amount of runoff and eroded soil generated during the applied event. The first set of experiments consisted of bare soil without any sediment control devices to determine a baseline erosion rate. The three remaining sets of experiments used the same bare soil, but each incorporated a different sediment control device. The P-factors for each of the sediment control devices were then determined by comparing the baseline erosion to the erosion found for each of the different sediment control devices. The P-factor values ranged from 0.03 to 0.76 (Wilson, 2021).

The different rainfall intensities were produced using Norton Ladder Multiple Intensity Rainfall Simulators (Figure 2-1). Three varying intensities were based on the rainfall intensity-duration-frequency curves for regions of Tennessee regions to ensure they represented climates experienced throughout the state. The corresponding recurrence intervals are in Table 2-2.

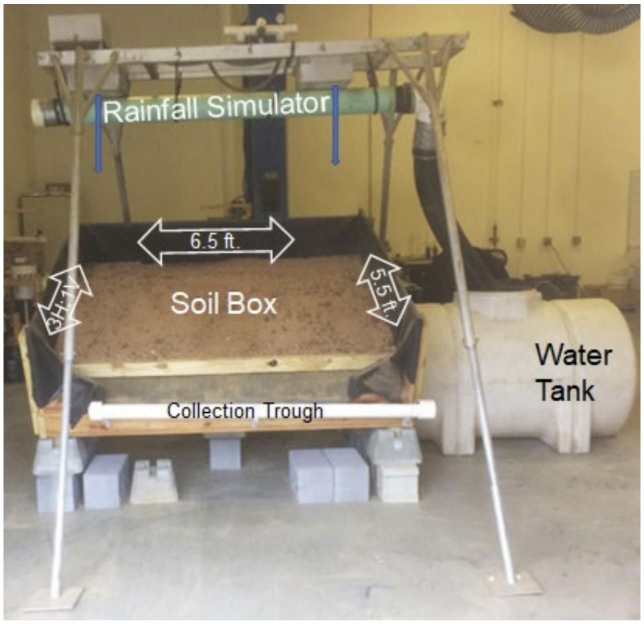

Figure 2-1. Photo: Physical Lab Model Experimental Set-up (Wilson, 2021).

Table 2-1. Overview of Physical Lab Scale Model Experimental Set-up.

Experimental Setup	
Hillslope	6 ft x 6 ft
Uniform Slope	3H:1V

Management	Bare
Climate	Single Storm
Duration (min)	20
	2.31
Intensity (in/hr)	3.29
	4.1

Regarding the different soils used in the physical model, they were representative of the main soil textures found in Tennessee. These textures were determined by conducting a survey of the state's soil survey maps developed by the Natural Resources Conservation Service. The selected soil textures along with the corresponding composition and properties are in Table 2-3.

Table 2-2. Corresponding Recurrence Intervals to the NTPEP Testing

Region	2 in/ hr	4 in / hr	6 in/hr
Knoxville	10 yr - 60 min	50 yr - 30 min	100 yr - 15 min
Chattanooga	5 yr - 60 min	25 yr - 30 min	100 yr - 15 min
Nashville	7 yr - 60 min	40 yr - 30 min	100 yr - 15 min
Memphis	5 yr - 60 min	25 yr - 30 min	100 yr - 15 min

Table 2-3. Soil Composition and Properties for the Study.

Soil	Sand	Silt	Clay	K_s (mm/h)
Clay loam	30.24	40.25	29.51	1.68
Silty Clay	12.44	40.74	46.82	1.57
Silty Clay Loam	20.30	43.06	36.64	13.32
Silty Loam	29.40	49.79	20.81	16.06
Loam	41.62	33.85	24.53	133.20

Chapter 3 Methodology

Meeting the objectives set forth in Chapter 1 required generating two sets of simulations using WEPP. The first set of simulations was performed using the hillslope module of WEPP (Ascough et al., 1995). The simulated hillslope had the same dimensions as the physical model used in the experiments of RES#2016-20. This set of simulations contained 15 scenarios based on the experiments having bare soil but no sediment control device. The measured runoff and soil loss from these experimental runs were used to calibrate key input parameters of WEPP, namely the saturated hydraulic conductivity, the critical shear stress, and the rill/interrill erodibilities. The second set of simulations was performed using the watershed module in WEPP (Ascough et al., 1995). The watershed was composed of the calibrated hillslopes, scaled up, with a short channel. This set contained 20 scenarios that were run without any sediment control device at the end of the channel. In addition, there were another 20 scenarios that were run with silt fence at the end of the channel and 20 scenarios that were run with straw-filled tubes at the end of the channel. The sediment control devices were represented in WEPP as a form of impoundment. The comparison between the simulations with no control practice and those with a practice were used to determine the P-factor with Equation 2.2.

3.1 WEPP Generation of Hillslope Model

As stated previously, the first set of simulations were designed to calibrate key parameters affecting runoff and erosion process modeled in WEPP. The key parameters were the saturated hydraulic conductivity, the critical shear stress, and the rill/interrill erodibilities. The calibrated values for these parameters were then transferred to the second set of experiments where the P-factors values were determined.

To calibrate the parameters accurately, the simulated hillslope (Figure 3-1) was designed using the exact dimensions of the physical model used in RES#2016-20 (Figure 2-1). The descriptions of the management, slope, rainfall intensities/ duration, and soil classifications are described in the following sections. The base values of the input values for these different components are presented in Table 3-1. The 15 simulation scenarios were derived by the different combinations of the three rainfall intensities (Table 2-1) and five soil types (Table 2-2).

3.1.1. Management in WEPP Hillslope Module

The management of the hillslope was set as *continuously fallow*, as all the box experiments were conducted with the soil being bare (Wilson, 2021). The bare hillslope was established in the

WEPP Hillslope module by setting the initial plant as *nothing grows* and the initial residue cropping system as *fallow*.

3.1.2. Slope in WEPP Hillslope Module

The experiments of RES#2016-20 were conducted in a 6' by 6' box with a uniform slope of 3H:1V (Wilson, 2021). To match these constraints, the slope in WEPP was set as *uniform* with a 33% slope. The hillslope generated in WEPP can be observed in Figure 3-2.

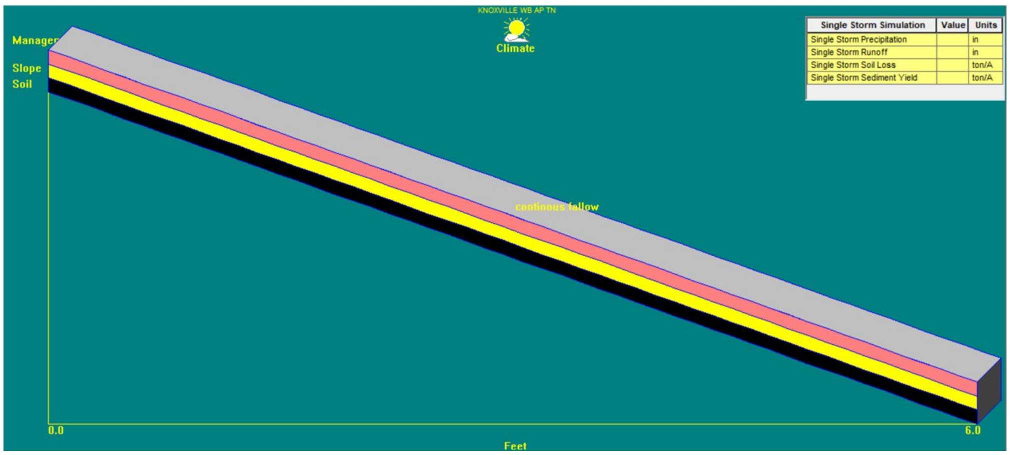

Figure-3-1. Hillslope Module in WEPP Model.

Table 3-1. Summary of Input Values to the WEPP Hillslope Module.

Management					
Initial	Fallow				
Initial Plant Growth	Nothing Grows				
Initial Residue Cropping System	Fallow				
Slope					
Distance (ft)	0	6			
Slope (%)	33.33	33.33			
Climate					
Intensity (in/hr)	2.31	3.29	4.1		
Storm Amount (in)	0.77	1.097	1.366		
Duration (hr)	0.33	0.33	0.33		
Soil					
Soil Type	**Clay Loam**	**Silt Clay**	**Silt Loam**	**Loam**	**Silt Clay Loam**
Albedo	0.23	0.23	0.23	0.23	0.23
Initial Saturation Level (%) *	0	0	0	0	0
Interrill Erodibility (kg·s/m^4) *	4000000	4000000	4000000	4000000	4000000
Rill Erodibility (s/m) *	0.005	0.005	0.005	0.005	0.005
Critical Shear (Pa) *	5.6	5.6	5.6	5.6	5.6
Effective Hydraulic Conductivity (mm/h) *	0.15	0.15	0.15	0.15	0.15
Sand (%)	30.24	12.44	29.4	41.62	20.3
Clay (%)	29.51	46.82	20.81	24.53	36.64

3.1.3. Climate in WEPP Hillslope Modules

The previous experiments in RES#16-20 use three different rainfall intensities of 2.31, 3.29, and 4.10 in/hr that were run for a duration of 20 minutes (Wilson, 2021). The intensities were uniform through the entire 20 minutes.

These rainfall patterns were replicated in the first simulation set using single storm event climate files for each rainfall intensities with the storm duration being set to 0.33 hr. The storm amount generated for each single storm event was calculated utilizing the rainfall intensity and set accordingly. The rainfall amounts were set to 0.770 in, 1.097 in, and 1.366 in for the 2.31, 3.29, and 4.10 in/hr rainfall intensities.

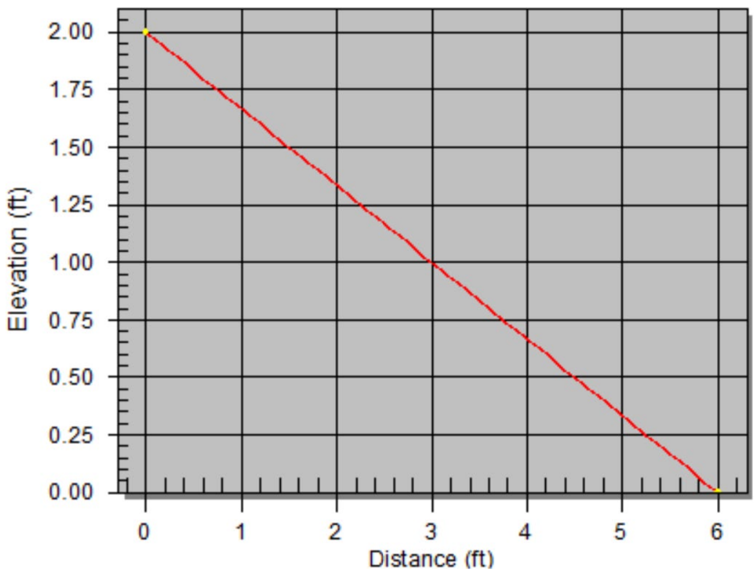

Figure 3-2. Slope in WEPP Hillslope Module.

3.1.4. Soil in WEPP Hillslope Module

An analysis of the various soil textures in the state of Tennessee found that certain classifications are more predominant, which aided in selecting the specific soil textures to include in the study (Wilson, 2021). Though this analysis, it was determined that silt loam, clay loam, silty clay, silty clay loam, and loam were to be evaluated. The composition of these soils are in Table 2.3.

These soil textures were integrated into the hillslope model by generating new soil files in the soil database in WEPP. For each of the five soil textures, the percents of sand and clay were set to the corresponding value shown in Table 2.3, while the albedo was set to the default of 0.23. The interrill erodibility, rill erodibility, critical shear, effective hydraulic conductivity, and initial saturation levels were initially set to the default values but were later adjusted during the calibration phase.

3.1.5. WEPP Hillslope Model Calibration

The goal of this first set of simulations was to develop calibrated values for critical shear strength, effective hydraulic conductivity, and the rill/interrill erodibility for each soil type. These calibrated values would then translate to the second set of simulations for calculating the P-factor values.

Initially, default values were used for the calibrated parameters. The values were individually and systematically adjusted within defined limits from the literature (e.g., Elliot, 1990; Gilley et al., 1993; Abaci and Papanicolaou, 2009; Elhakeem et al., 2018). The values were adjusted until the runoff volumes and sediment yields fell within the ranges of measured values from the bare soil – no practice experiments of RES#16-20 which can be observed in Table 3.2. The final calibrated values for each of the different soil textures can be found in Appendix A. The known values from the box experiments that were implemented into WEPP, along with starting parameter values were based upon literature and are found in Table 3.3. Throughout the calibration process, it was observed that all these parameters will have an impact on the amount of soil loss, but only the moisture level and effective hydraulic conductivity influence the amount of storm runoff.

Table 3-2. Predefined Tolerances for WEPP Hillslope Simulations.

	Target Values					
Intensity	2.31	2.31	3.29	3.29	4.1	4.1
	Runoff (L)	Sediment (kg)	Runoff (L)	Sediment (kg)	Runoff (L)	Sediment (kg)
Clay loam	23.68 ± 12%	0.393 ± 85%	33.72 ± 12%	0.560 ± 85%	42.03 ± 12%	0.698 ± 85%
Silty clay	21.58 ± 12%	0.4 ± 85%	33.53 ± 12%	0.502 ± 85%	43.37 ± 12%	0.725 ± 85%
Silty clay loam	14.72 ± 34%	0.119 ± 57%	20.96 ± 34%	0.170 ± 57%	26.13 ± 34%	0.211 ± 57%
Silt loam	11.15 ± 40%	0.134 ± 74%	11.87 ± 27%	0.191 ± 74%	12.46 ± 18%	0.238 ± 74%
Loam	11.2 ± 40%	0.081 ± 74%	11.7 ± 27%	0.220 ± 74%	12.6 ± 18%	0.251 ± 74%

3.2 WEPP Generation of Watershed Model

For the second set of simulations, the WEPP watershed module was used so that an impoundment (i.e., silt fence; sediment tube) could be implemented into the simulations. The watersheds were developed by importing the previously generated hillslopes with the properly calibrated parameters for each of the different combinations of soil textures and rainfall intensities.

The hillslopes had the original length of 6 ft; however, the width was scaled up to 10,000 ft so that the minimum required watershed area for WEPP of 0.1 acre was reached. The scaling of only the width was chosen to avoid the formation of large rills after a critical source length is reached. The production of rills would produce inflated sediment yields and prevent us from using the measured values of soil loss in kg/m^2 from the soil box experiments in RES#16-20 to validate the model.

The calibrated parameters for each of the different soils were averaged across the different intensities (Table 3.4) due to model limitations that require at least one year of climate data for the impoundments to be properly simulated. The climate data were expanded with a climate generator, CLIGEN. For each of the four climate regions (i.e., Knoxville, Nashville, Chattanooga, and Memphis), 50 years of climate data were generated to ensure stabilization of the runoff and soil loss values (Papanicolaou and Abaci, 2008).

The 20 scenarios for the no practice, silt fence, and straw sediment tubes sub-sets include simulating each of the five soil types in the four different climate regimes. Each simulation was run for a single year and the runoff was calculated using the kinematic wave approach. Through a comparison between these simulations, an efficiency of the erosion control device can be determined.

Table 3-3. WEPP Hillslope Module Output Ranges from Literature.

Ranges from Literature			
Overall Ranges from Literature			
Parameters	**Ranges**	**Units**	**Reference**
Interrill Erodibility (K_i)	1e5 to 1e7	$kg \cdot s/m^4$	[1, 2]
Rill Erodibility (K_r)	0.002 to 0.013	s/m	[1,3]
Critical Shear Stress (τ_c)	3 to 8	Pa	[4, 5, 6]
Effective Hydraulic Conductivity (K_{be})	0.15 to 1.13	mm/hr	[1, 3, 7]
Baseline Parameters			
K_i	4,000,000	$kg \cdot s/m^4$	[8]
K_r	0.005	s/m	
τ_c	5.6	Pa	
K_e	0.15	mm/hr	

(1) Elliot, 1987; (2) Papanicolaou et al., 2007; (3) Gilley et al., 1993; (4) Barrett et al., 1995; (5) Chow, 1988; (6) Risse et al., 1994; (7) Julien and Torres, 2006; and (8) TDOT, 2021.

Table 3-4. WEPP Watershed Module Averaged Output Parameters for Each Soil Type

Soil Type	Clay Loam	Silty Clay	Silty Clay Loam	Silty Loam	Loam
Components	Output				
Moisture Level	25.00	25.00	69.62	57.99	75.00
K_i (kg·s/m^4)	629960.5	542883.5	736806.3	1000000.0	1000000.0
K_r (s/m)	0.005	0.004	0.004	0.005	0.005
τ_c (Pa)	5.500	5.500	5.810	5.500	5.500
K_e (mm/h)	3.634	4.182	11.238	14.157	23.588

3.3 WEPP Watershed Model Generation of P-Values

Initially, the generated watershed models were run to simulate each of the different combinations of soil types and climate regions without impoundments. The same models were simulated again with the silt fences and straw-filled sediment tubes included. To mimic the previously performed experiments properly, the practices were generated using the impoundment database of WEPP. The dimensions implemented into WEPP were such that they reflected the known parameters from the physical model in the lab and are illustrated in Table 3.5. One key parameter of the impoundments was the slurry flow rate, which is how fast the water-fine sediment mixture passes through the practice (Barrett et al., 1995). This value was not measured during the RES#16-20 experiments, so the slurry flow rate for each of these impoundments were acquired through literature (Haan et al., 1994). Similar to the previous work, the P-factors were determined by comparing the erosion with no practice to the erosion found for each of the different sediment control devices. The equation used to calculate these P-factors can be seen in Equation 2.2.

Table 3-5. WEPP Watershed Dimensions of Impoundments.

	Filter Fence	Straw-filled Sediment Tubes
Slurry flow rate (ft/s)	0.0007	0.0125
Cross-sectional width (ft)	5	6
Stage at which flow begins (ft)	0	0
Overtopping stage (ft)	3	1.67

Chapter 4 Results and Discussion

To achieve the objectives set forth in Chapter 1, the model was calibrated and numerical simulations were performed to determine the amount of runoff and soil loss for the defined area. These numerical simulations were run with and without impoundments for each combination of soil type and climate region as described in Chapter 3.

4.1 Baseline Soil Erosion

The numerical simulations were first run without impoundments for each combination of soil type and climate region to establish the baseline erosion of the soil. The baseline erosion generated from the yearly average for the watershed for each combination of soil type and climate region can be observed in Table 4.1. Similar to the findings of RES#16-20, the variability of the soil loss and runoff at each climate regions was large. Memphis exhibited the largest ranges in both soil loss and runoff of the four regions. The soil loss observed for Memphis ranged from 1.05 to 1.86 kg/m^2, and the runoff ranged from 3,015 to 6,736 m^3. The large ranges are a direct result of the soil type as the rainfall values within a region were the same for all soil types. Upon observation, the same trends for this study and the previous study have been found between soil loss, runoff, and intensity.

Figure 4.1 shows that there is a direct relationship between both the amount of soil loss and runoff with the runoff coefficient for the differing soil types. Similar to the physically conducted experiments, the amount of soil loss and runoff have an increasing relationship with the runoff coefficient. Furthermore, there is no direct correlation between the amount of rainfall and gross soil erosion. The graphs do, however, indicate that the amount of soil loss will be larger for areas that receive larger influxes of rainfall, illustrated by Knoxville's reduced sediment loss in comparison to Memphis.

To understand the data trends, along with determining the empirical relationship between runoff coefficient and gross soil loss, a breakdown of each simulated event in the abbreviated annual assessment was conducted on the WEPP output data. The full summary of these events for each soil type and climate region can be found in Abercrombie (2002). Due to the observation that soil composition influences the soil loss more substantially than rainfall intensity, the following trends and empirical relationships will only be analyzed across the differing soil types. The summary of the average runoff volumes, runoff coefficients, and sediment yields per soil type can be observed in Table 4.2.

Through the analysis of the various events for each soil type, an empirical relationship was developed between runoff coefficient and sediment yield. For each soil type, exponential functions provided the strongest regression relationships. These regression equations can be observed in Figure 4.2 through Figure 4.6 and listed in Equations 4.1 - 4.5. For these equations, sediment yield is represented as *E*, while the runoff coefficient is represented as *RC*. The sediment yield for these regression equations is computed in kilograms.

These empirical relations can be utilized if the baseline erosion for experiments conducted with sediment control devices are unknown. If the climate region is known and a higher level of accuracy in estimating the amount of sediment yielded is desired, detailed regression equations for each combination of soil type and climate region can be found in Abercrombie (2022). As a result of the baseline for each of these events being known, these regression equations will not be utilized in this study; however, they can simplify future studies by enabling the determination of the baseline of erosion.

Table 4-1. Summary of Numerical Simulations Without Sediment Control Devices.

Soil Type	Location	Runoff (m^3)	Precipitation Volume (m^3)	Gross Soil Erosion (kg/m^2)	Runoff Coefficient
Clay Loam	Knoxville	4326	13567	0.91	0.32
	Nashville	4888	13491	1.07	0.36
	Chattanooga	6009	15287	1.42	0.39
	Memphis	6736	14846	1.05	0.45
Silt Clay	Knoxville	3474	13567	0.79	0.26
	Nashville	3988	13491	1.01	0.30
	Chattanooga	5080	15287	1.35	0.33
	Memphis	5756	14846	1.10	0.39
Silt Clay Loam	Knoxville	2042	13567	0.79	0.15
	Nashville	2580	13491	1.14	0.19
	Chattanooga	3459	15287	1.46	0.23
	Memphis	4002	14846	1.37	0.27
Silt Loam	Knoxville	1418	13567	0.89	0.10
	Nashville	1930	13491	1.31	0.14
	Chattanooga	2693	15287	1.79	0.18
	Memphis	3015	14846	1.69	0.20
Loam	Knoxville	1623	13567	0.97	0.12
	Nashville	2181	13491	1.42	0.16
	Chattanooga	2979	15287	1.89	0.19
	Memphis	3288	14846	1.86	0.22

Table 4-2. Summary of Event Averages.

Soil Type	Runoff (m^3)	Runoff Coefficient	Sediment Yield (kg/m^2)
Clay Loam	165.08 ± 167.20	0.43 ± 0.17	0.04 ± 0.06
Silt Clay	159.57 ± 161.87	0.39 ± 0.16	0.04 ± 0.06
Silt Clay Loam	138.13 ± 156.62	0.28 ± 0.15	0.06 ± 0.08
Silt Loam	127.21 ± 149.55	0.24 ± 0.14	0.09 ± 0.12
Loam	159.74 ± 237.25	0.26 ± 0.14	0.09 ± 0.12

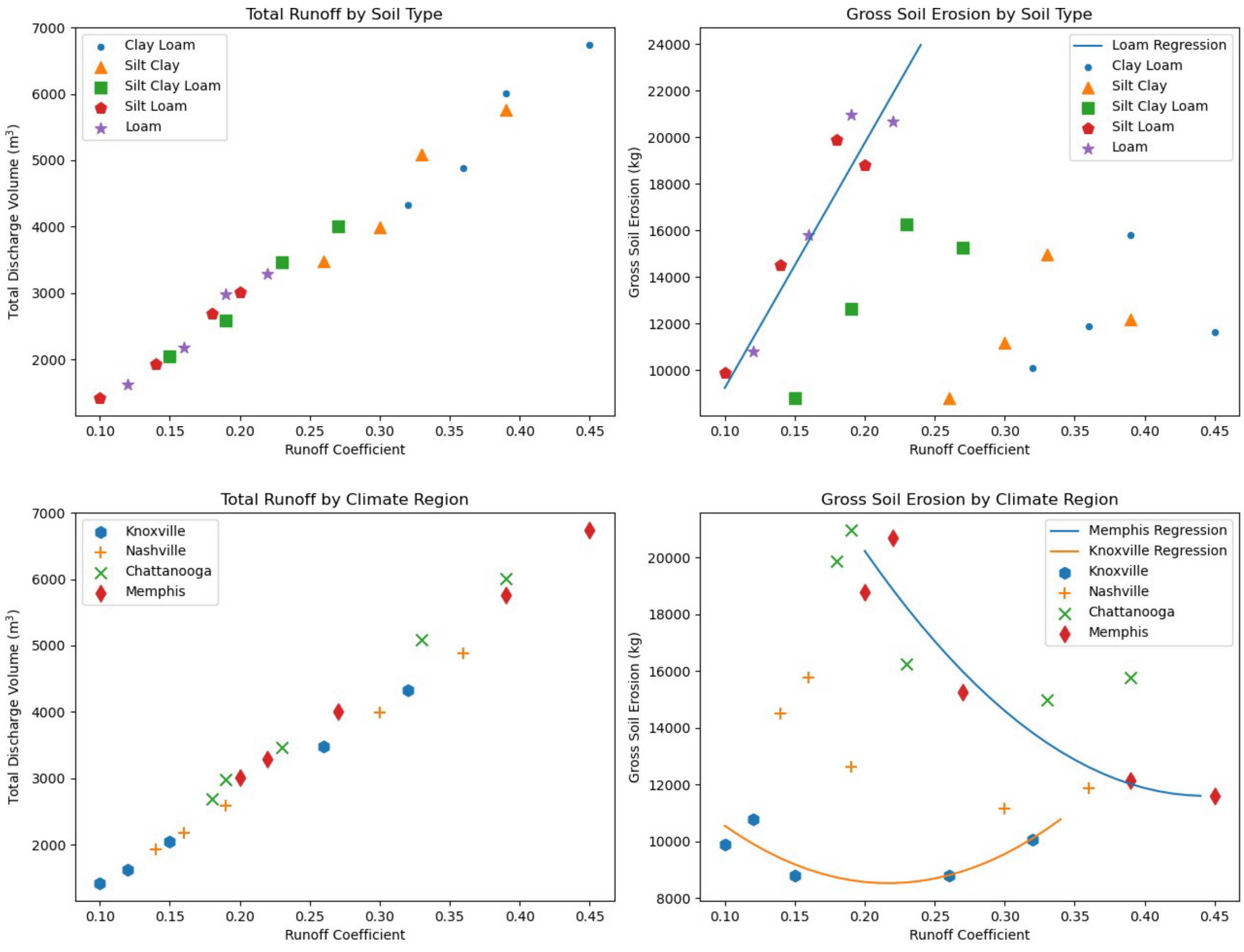

Figure 4-1. Relationships of Gross Soil Erosion and Runoff in Comparison to Runoff Coefficients.

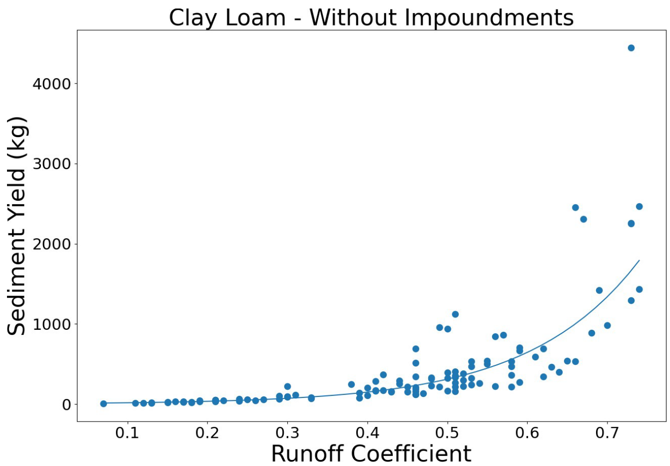

Figure 4-2. Sediment Yield per Runoff Coefficients without WEPP Impoundments for Clay Loam

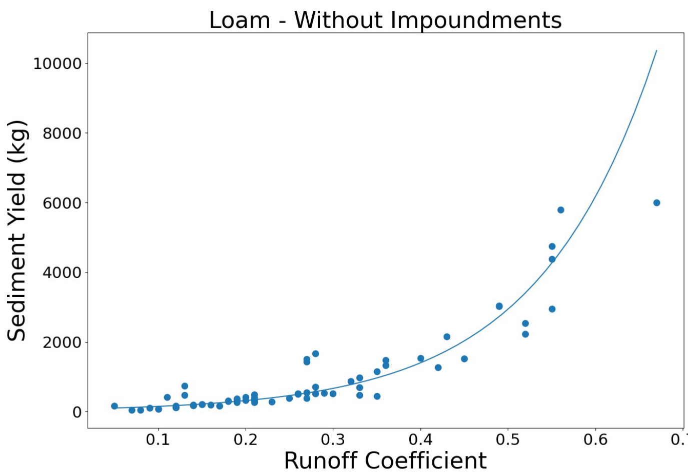

Figure 4-3. Sediment Yield per Runoff Coefficients without WEPP Impoundments for Loam.

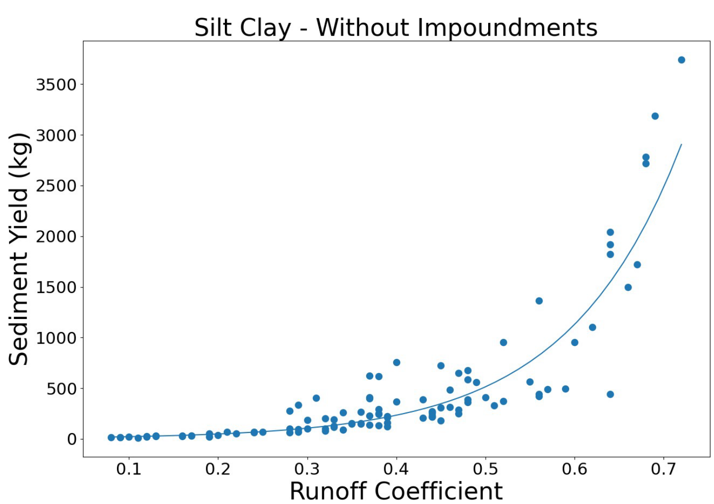

Figure 4-4. Sediment Yield per Runoff Coefficients without WEPP Impoundments for Silt Clay.

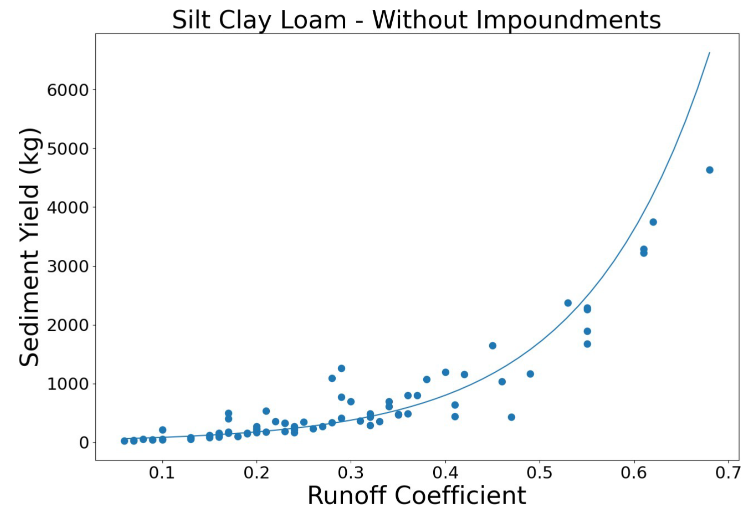

Figure 4-5. Sediment Yield per Runoff Coefficients without WEPP Impoundments for Silt Clay Loam.

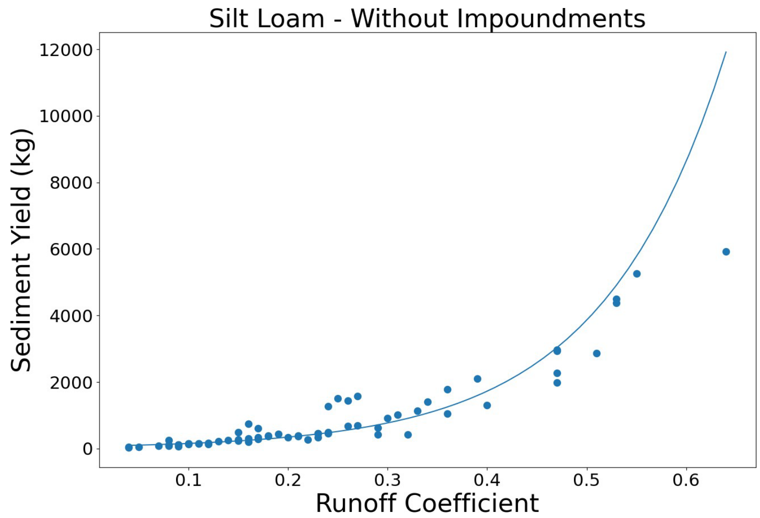

Figure 4-6. Sediment Yield per Runoff Coefficients without WEPP Impoundments for Silt Loam.

$$\text{Clay Loam: } E = 8.0844 e^{7.2981 \cdot RC} \quad (r^2 = 0.6882) \tag{4.1}$$

$$\text{Loam: } E = 72.293 e^{7.4109 \cdot RC} \quad (r^2 = 0.8408) \tag{4.2}$$

$$\text{Silt Clay Loam: } E = 38.937 e^{7.5541 \cdot RC} \quad (r^2 = 0.9235) \tag{4.3}$$

$$\text{Silt Clay: } E = 10.000 e^{7.8773 \cdot RC} \quad (r^2 = 0.8600) \tag{4.4}$$

$$\text{Silt Loam: } E = 68.760 e^{8.0547 \cdot RC} \quad (r^2 = 0.8612) \tag{4.5}$$

4.2 Soil Erosion Control Practice Factor

Once baseline erosion values were determined, the next simulation sub-sets were run using the silt fence and sediment tube impoundments for each combination of soil type and climate region. The erosion generated during the abbreviated yearly average for each soil type – climate region combination for silt fences are in Table 4.3 and for the straw-filled sediment tubes are in Table 4.4. The P-factors observed in these tables were calculated using Equation 2.2.

For both sediment control devices, the runoff and soil loss values exhibited large ranges. Comparatively, the silt fence simulations saw the smaller ranges for both set of values. Regarding soil composition, silt loam had the largest range for sediment yield from 0.47 to 0.96 kg/m^2, while clay loam and silt clay had the largest range for runoff coefficients from 0.32 to 0.45 and 0.26 to 0.39, respectively. The straw-filled sediment tubes followed similar trends for both sediment yield and runoff. Although the sediment tubes followed those trends, differences between the observed trends for the two sediment control devices were apparent for the P-factor. For each soil type, the P-factors for silt fences changed slightly but the P-factors for the sediment tubes were uniform. The silt loam simulations for the filter fences had the highest P-factor of 0.54, while silt clay loam simulations had the smallest P-factor of 0.34.

Table 4-3. Summary of WEPP Numerical Simulations with Silt Fences.

Soil Type	Location	Runoff (m^3)	Precipitation Volume (m^3)	Filter Fence Sediment Yield (kg/m^2)	Runoff Coefficient	P-Value
Clay Loam	Knoxville	4326	13567	0.42	0.32	0.46
	Nashville	4888	13491	0.50	0.36	0.47
	Chattanooga	6009	15287	0.65	0.39	0.47
	Memphis	6736	14846	0.49	0.45	0.47
Silt Clay	Knoxville	3474	13567	0.27	0.26	0.35
	Nashville	3988	13491	0.35	0.30	0.35
	Chattanooga	5080	15287	0.47	0.33	0.35
	Memphis	5756	14846	0.38	0.39	0.35
Silt Clay Loam	Knoxville	2042	13567	0.27	0.15	0.34
	Nashville	2580	13491	0.38	0.19	0.34
	Chattanooga	3459	15287	0.50	0.23	0.34
	Memphis	4002	14846	0.46	0.27	0.34
Silt Loam	Knoxville	1418	13567	0.47	0.10	0.53
	Nashville	1930	13491	0.69	0.14	0.53
	Chattanooga	2693	15287	0.96	0.18	0.54
	Memphis	3015	14846	0.90	0.20	0.53
Loam	Knoxville	1623	13567	0.38	0.12	0.39
	Nashville	2181	13491	0.55	0.16	0.39
	Chattanooga	2979	15287	0.74	0.19	0.39
	Memphis	3288	14846	0.72	0.22	0.39

Table 4-4. Summary of WEPP Numerical Simulations with Straw-filled Sediment Tubes.

Soil Type	Location	Runoff (m^3)	Precipitation Volume (m^3)	Straw-Filled Sediment Yield (kg/m^2)	Runoff Coefficient	P-Value
Clay Loam	Knoxville	4327	13567	0.43	0.32	0.48
	Nashville	4891	13491	0.51	0.36	0.48
	Chattanooga	6013	15287	0.68	0.39	0.48
	Memphis	6739	14846	0.50	0.45	0.48
Silt Clay	Knoxville	3476	13567	0.28	0.26	0.35
	Nashville	3990	13491	0.36	0.30	0.35
	Chattanooga	5083	15287	0.47	0.33	0.35
	Memphis	5760	14846	0.38	0.39	0.35
Silt Clay Loam	Knoxville	2043	13567	0.27	0.15	0.35
	Nashville	2582	13491	0.40	0.19	0.35
	Chattanooga	3462	15287	0.51	0.23	0.35
	Memphis	4004	14846	0.47	0.27	0.35
Silt Loam	Knoxville	1418	13567	0.49	0.10	0.55
	Nashville	1931	13491	0.72	0.14	0.55
	Chattanooga	2694	15287	0.98	0.18	0.55
	Memphis	3017	14846	0.93	0.20	0.55
Loam	Knoxville	1624	13567	0.38	0.12	0.40
	Nashville	2187	13491	0.56	0.16	0.40
	Chattanooga	2981	15287	0.76	0.19	0.40
	Memphis	3290	14846	0.74	0.22	0.40

The P-factor values did not change due to different rainfall intensities or runoff and the average abbreviated data showed a uniform P-factor for each of the different soil types. As stated previously, the P-factor was directly influenced by its soil type. The soil type that achieved the lowest P-factor was silt clay loam, making it the least likely to contribute to sediment pollution. The summary of these event averages can be observed in Table 4.5 for silt fences and Table 4.6 for straw-filled sediment tubes.

Table 4-5. Statistical Results of Simulation Events for Silt Fences.

Soil Type	Runoff (m^3)	Runoff Coefficient	Sediment Yield (kg/m^2)	P-Factor
Clay Loam	164.95 ± 167.18	0.43 ± 0.17	0.02 ± 0.03	0.45 ± 0.03
Silt Clay	160.64 ± 240.13	0.39 ± 0.16	0.01 ± 0.02	0.34 ± 0.01
Silt Clay Loam	138.03 ± 156.64	0.28 ± 0.15	0.02 ± 0.03	0.33 ± 0.01
Silt Loam	127.12 ± 149.55	0.24 ± 0.14	0.05 ± 0.06	0.51 ± 0.03
Loam	135.72 ± 153.24	0.26 ± 0.14	0.03 ± 0.05	0.38 ± 0.01

In analyzing the breakdown of the events, larger variations in the data were observed. An Analysis of Variance (ANOVA) showed a significant difference in P-factor values for the silt fences and straw-filled sediment tubes (ANOVA; $p<0.05$). Although differences were significant

Table 4-6. Statistical Results of Simulation Events for Straw-filled Sediment Tubes.

Soil Type	Runoff (m^3)	Runoff Coefficient	Sediment Yield (kg/m^2)	P-Factor
Clay Loam	16.05 ± 167.22	0.43 ± 0.17	0.02 ± 0.03	0.48 ± 2.41e-3
Silt Clay	159.67 ± 161.89	0.39 ± 0.16	0.01 ± 0.02	0.35 ± 1.09e-3
Silt Clay Loam	149.99 ± 171.81	0.31 ± 0.21	0.02 ± 0.03	0.35 ± 7.72e-4
Silt Loam	127.19 ± 149.54	0.24 ± 0.14	0.05 ± 0.06	0.55 ± 1.02e-3
Loam	135.8 ± 153.25	0.26 ± 0.14	0.04 ± 0.05	0.40 ± 4.99e-4

between the sediment control devices, the P-factors analyzed by soil type were not significantly different (ANOVA; $p>0.05$). This solidifies the previous observation that the soil type is the primary component for determining the P-factor. The data used for the single factor ANOVA are in Abercrombie (2022).

Although the P-factors were similar for each soil type, slight variations were observed for silt fences that were substantial enough to impact the P-factor inserted in RUSLE. These variation in data were further analyzed for silt fences to comprehend the underlying reasons for the differences. The variation for both the runoff coefficient and the P-factor for silt fences can be observed in Figures 4.7 through 4.16.

RES#16-20 concluded that runoff volume was the primary component influencing the amount of erosion (Wilson, 2021). Similar trends were observed when analyzing the simulations with and without impoundments. The simulations for the straw-filled sediment tubes did not produce the same level of fluctuations in the P-factor as those of the silt fences because they received consistent erosion rates. One explanation for the lack of fluctuations is that the efficiency of straw-filled bales is less sensitive to the amount of runoff as it is easily overtopped. Silt fences are slightly more efficient for shorter rainfall events as these generate a smaller amount of runoff and there is less pressure to push through the fabric.

A major component that was observed to have more influence in the numerical simulations is soil composition. As observed in Figures 4.7 through 4.11, the events experienced a wide range of runoff, and the runoff observed was consistent for both sediment control devices. This indicates that while the runoff does contribute to erosivity of the soil, it is not the primary component of determining the efficiency of these sediment control devices. For both the simulations with and without impoundments, soil composition was a primary factor for soil erosion, runoff, and the efficiency of these sediment control devices.

Other studies have observed that soil composition is a primary component impacting the efficiency of sediment control devices, especially silt fences (e.g., Faucette et al., 2008). Wishowki et al. (1998) found that the overall efficiency of these devices decreased as the soil

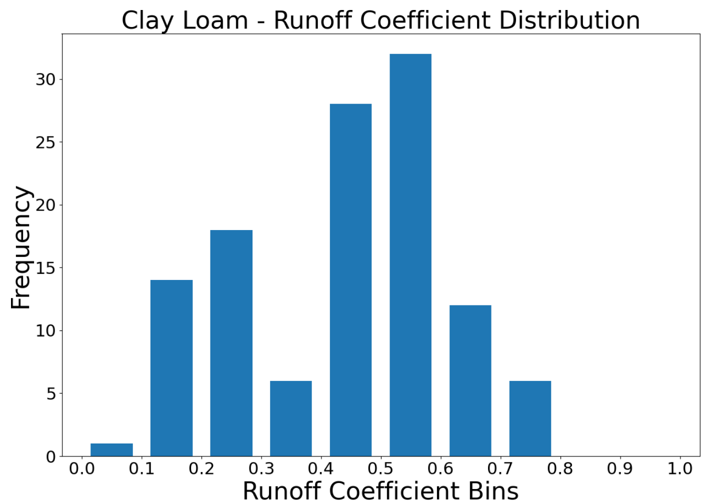

Figure 4-7.WEPP Simulations: Runoff Coefficient Distribution for Clay Loam.

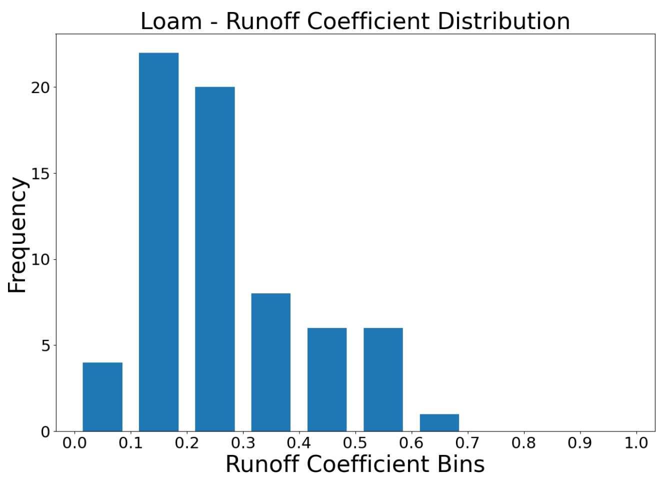

Figure 4-8. WEPP Simulations: Runoff Coefficient Distribution for Loam.

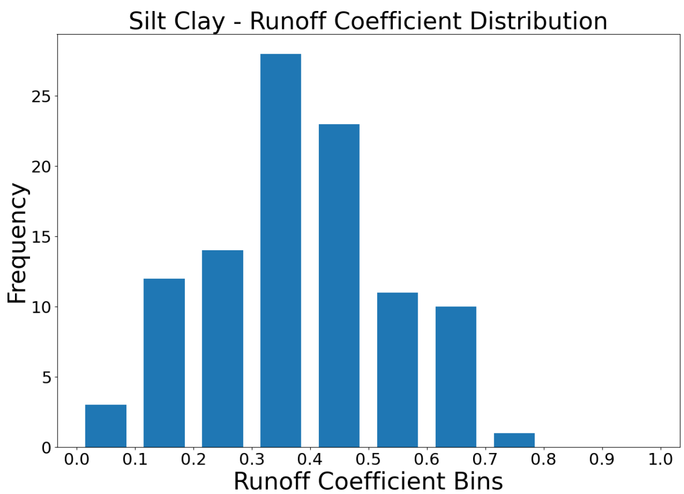

Figure 4-9. WEPP Simulations: Runoff Coefficient Distribution for Silt Clay.

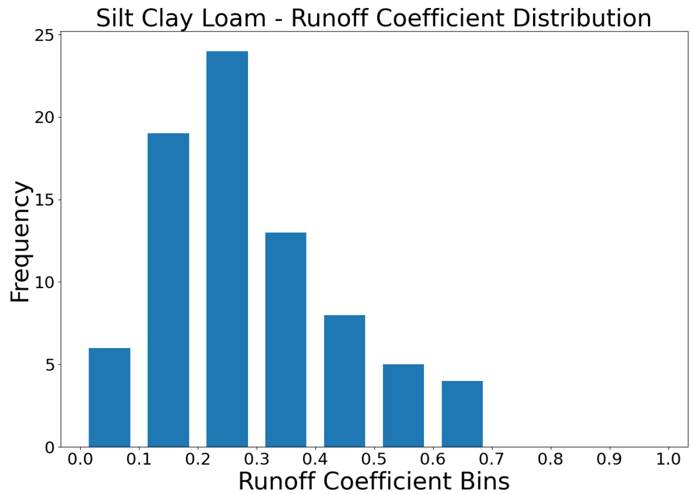

Figure 4-10. WEPP Simulations: Runoff Coefficient Distribution for Silt Clay Loam.

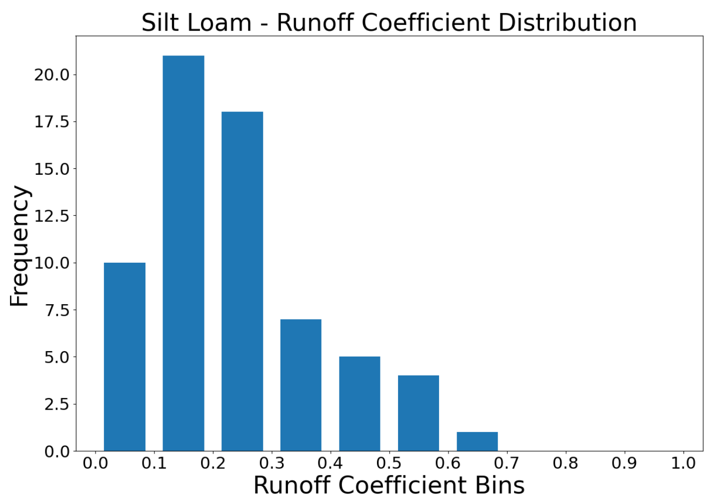

Figure 4-11. WEPP Simulations: Runoff Coefficient Distribution for Silt Loam.

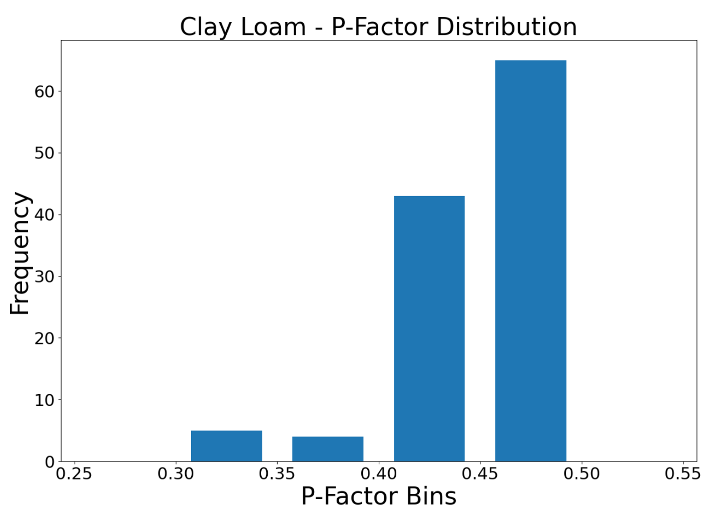

Figure 4-12. WEPP Simulations: P-Factor Distribution for Clay Loam.

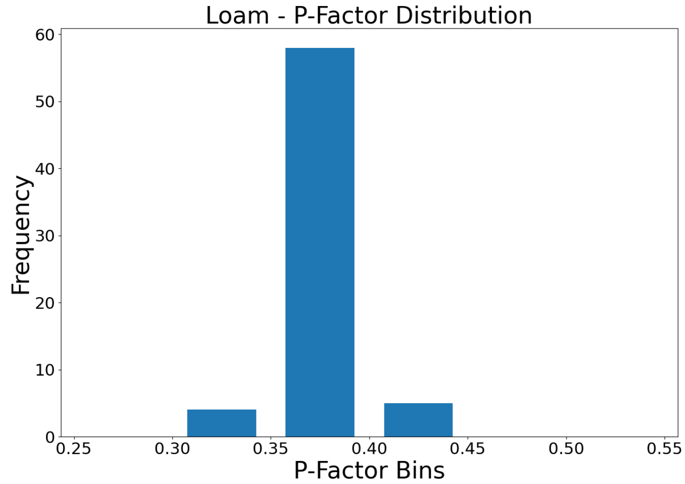

Figure 4-13. WEPP Simulations: P-Factor Distribution for Loam.

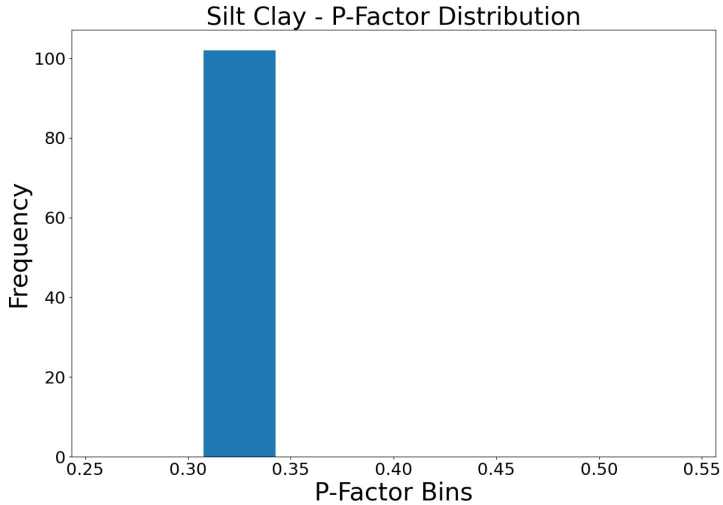

Figure 4-14. WEPP Simulations: P-Factor Distribution for Silt Clay.

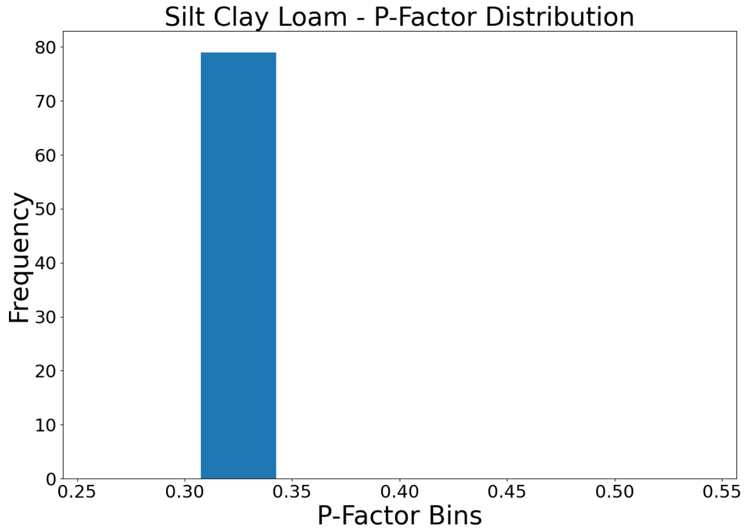

Figure 4-15. WEPP Simulations: P-Factor Distribution for Silt Clay Loam.

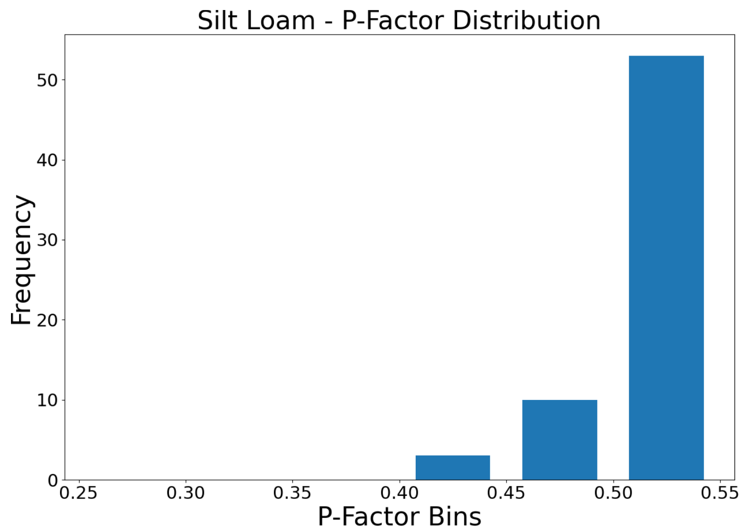

Figure 4-16. WEPP Simulations: P-Factor Distribution for Silt Loam.

particle size decreased. Barrett et al. (1998) found that 92% of the total suspended solids in the runoff from silt fences were composed of clay and silt. Similar observations can be seen in Table 4.7 which summarizes the soil composition breakdown for silt fences. A more detailed breakdown can be observed in Appendix B. For this study, the simulations showed that the fences were able to retain a significant amount of sand but were unable to provide any considerable retention for silt and clay particles. The efficiency of these devices directly correlates to the soil composition because sediment control devices are designed to mitigate the amount of soil erosion by retaining the soil through a physical barrier. Silt fences physically retain the soil through the use of a mesh barrier. Any particle that is smaller than the gaps in the mesh barrier will not be retained by the silt fence. Straw-filled sediment tubes have similar retention abilities.

The soil composition and method of retention for these sediment control devices can offer insight into the level of efficiency for these devices and the variation observed in Figure 4.7 through Figure 4.16. The variation for both silt loam and clay loam were greater than that for the other soil types. Along with silt loam and clay loam having more variation, they both had higher sediment yield, with a decreased efficiency. These observations and distinct groupings can be further seen in Figure 4.17. This figure further validates that clay loam and silt loam experience similar results compared to the other soil types. The erosion can be correlated to the properties of the soil components and the retention methods of these devices explained prior.

For the simulations without impoundments, loam had the highest sediment yield followed by clay loam and silt loam. These three soil types experience more erosion than the other soil types because they have substantially more sand. As a result of its larger particle size, sand will

Table 4-7. Summary of Soil Composition Breakdown of the P-Factor for Silt Fences

Soil	Soil Composition	P-Factor
Clay Loam	Clay	0.93
	Silt	0.98
	Sand	0.00
Loam	Clay	0.92
	Silt	0.97
	Sand	0.01
Silt Clay Loam	Clay	0.92
	Silt	0.98
	Sand	0.00
Silt Clay	Clay	0.92
	Silt	0.98
	Sand	0.00
Silt Loam	Clay	0.92
	Silt	0.97
	Sand	0.01

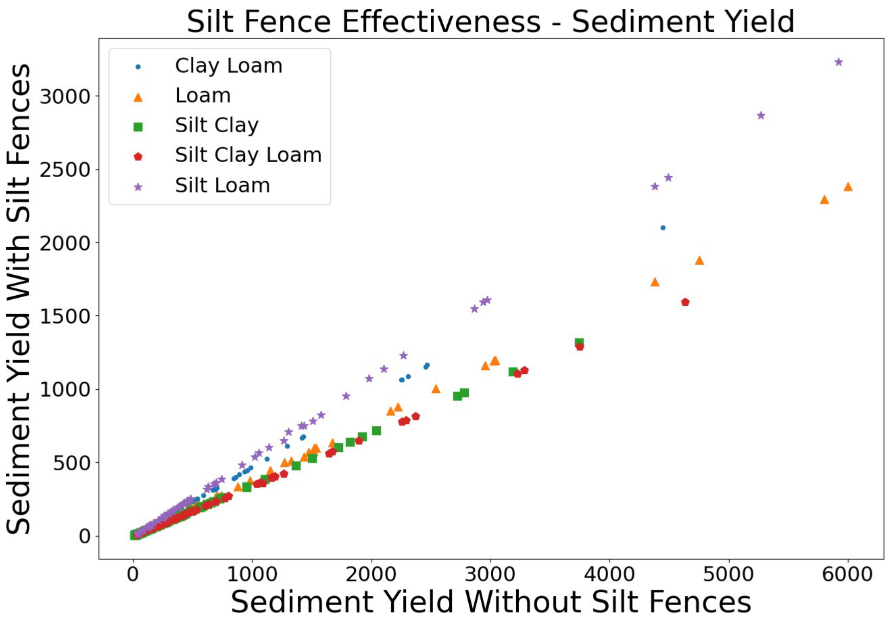

Figure 4-17. Silt Fence Effectiveness for Sediment Yields.

erode easier than both clay and silt. Although loam has the greatest sediment yield in the numerical simulation performed without impoundments, the amount of soil export is drastically decreased by thee sediment control devices. The ability for loam to undergo this decrease in sediment yield is due to the capability for these sediment control devices to capture sand particles. The high levels of sand present in both clay loam and silt loam would suggest that these devices could successfully capture a significant amount of the eroded soil; however, these soils have the highest P-factor which indicates a lower efficiency.

The high variability and decreased efficiency are direct results of the soil properties. For example, silt loam and clay loam have high silt contents and silt is a key factor affecting the efficiency of these devices because it is less likely to form stable aggregates that can be retained by the sediment control devices. Clay particles form more stable aggregates due to their surface charge (Fernandez-Ugalde, 2013) which allows them to be retained by erosion control practices. Although silty clay and silt clay loam also have high levels of silt, they also have high levels of clay to aid in aggregate formation.

Another component that may help explain the differences in the practices' efficiency is the hydraulic conductivity of the soil. The simulations showed that the hydraulic conductivity decreased as the runoff coefficient increased (Figure 4.18). Hydraulic conductivity reflects the capability of water to infiltrate into the soil (Elhakeem et al., 2018). A soil type that has a higher hydraulic conductivity can infiltrate more water, resulting in a decrease in runoff. A decrease in runoff is crucial to reducing erosion as the corresponding decrease in the entrainment force translates to less detachment. This reinforces a conclusion drawn from RES#16-20 that the runoff coefficient is an excellent indicator of erosivity (Wilson, 2021).

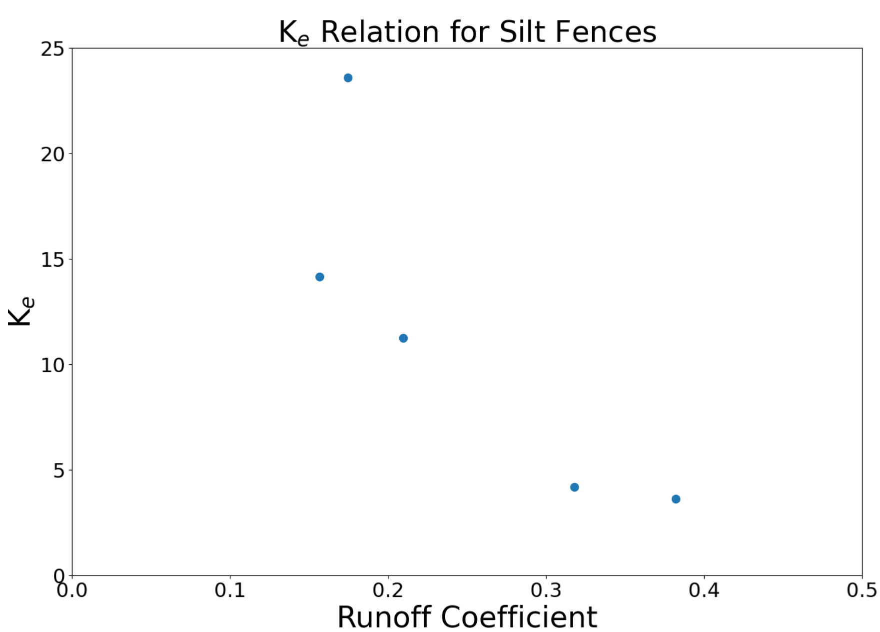

Figure 4-18. Hydraulic Conductivity Compared to Runoff Coefficients for Silt Fences.

To compute P-factor values for the simulations with impoundments, an analysis of the various events was performed to determine empirical relationships between sediment yield and runoff coefficient, which can be found in Abercrombie (2002). These regression equations helped estimate the erosion for a given amount of rainfall. Along with the sediment yield, an empirical relationship was developed between the P-factor and the runoff coefficient. The regression equations for the silt fence are in Equations 4.6 through 4.10 and Figures 4.19 through 4.23. For each equation, the P-factor is represented as *P*, while the runoff coefficient is represented as *RC*.

These regression equations were only generated for silt fences. The breakdown of the event data for straw-filled sediment tubes saw almost no variation in P-factor values, and thus, did not generate strong regression equations. Even though regression equations were not generated for the sediment tubes, a P-factor value can still be determined. The P-factor for this practice will be the P-factor that was calculated utilizing the data generated from the numerical simulations for each soil type.

$$\text{Clay Loam:} \quad P = 0.503RC^{0.1317} \quad (r^2 = 0.8533) \tag{4.6}$$

$$\text{Loam:} \quad P = 0.4094RC^{0.0561} \quad (r^2 = 0.8192) \tag{4.7}$$

$$\text{Silt Clay Loam:} \quad P = 0.3499RC^{0.0373} \quad (r^2 = 0.7454) \tag{4.8}$$

$$\text{Silt Clay:} \quad P = 0.3598RC^{0.0561} \quad (r^2 = 0.7876) \tag{4.9}$$

$$\text{Silt Loam:} \quad P = 0.5884RC^{0.0902} \quad (r^2 = 0.8293) \tag{4.10}$$

The determination of these P-factors is crucial for entities in industry or academia to estimate erosion from a site. A reference table of the P-factors for RUSLE determined in this study, generated specifically for the state of Tennessee, can be found in Table 4.8.

Table 4-8. Summary Table of RUSLE P-Factors for Silt Fences and Straw-filled Sediment Tubes.

Practice	Soil	P-Value
Silt Fences	Clay Loam	0.46
	Silt Clay	0.35
	Silt Clay Loam	0.34
	Silt Loam	0.53
	Loam	0.39
Straw-Filled Sediment Tubes	Clay Loam	0.48
	Silt Clay	0.35
	Silt Clay Loam	0.35
	Silt Loam	0.55
	Loam	0.40

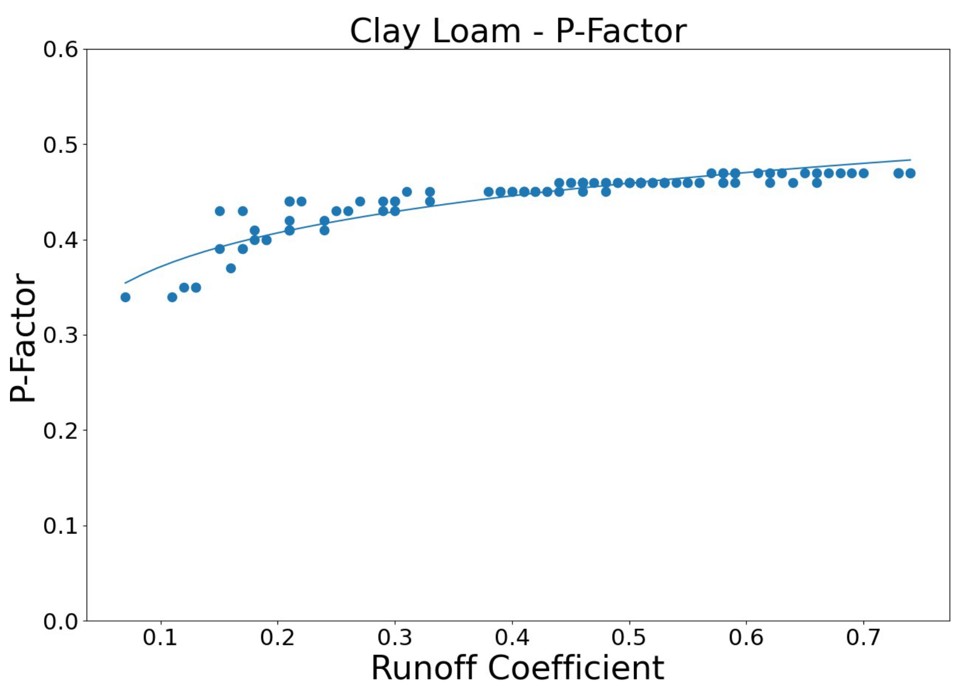

Figure 4-19. Simulation Results: P-Factor Regression for Clay Loam.

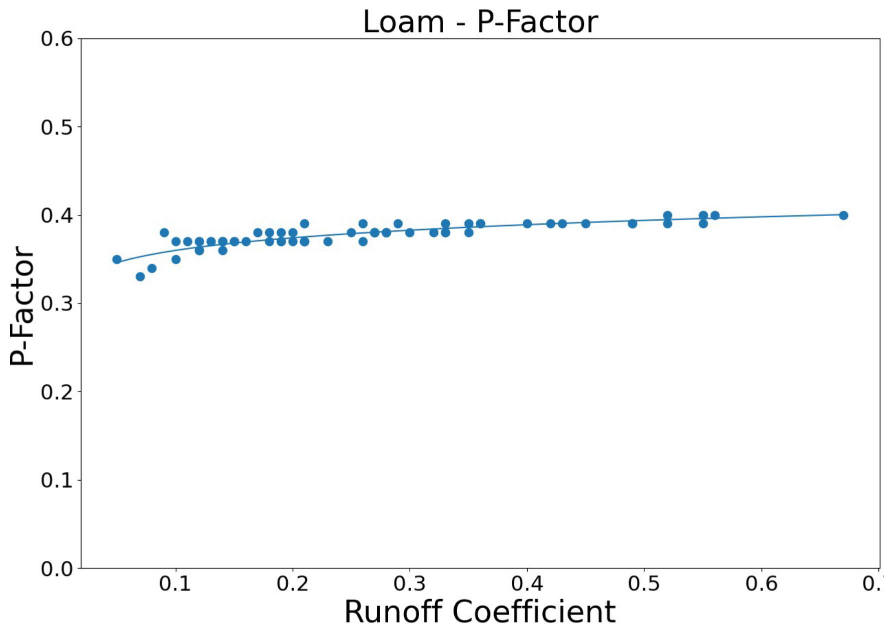

Figure 4-20. Simulation Results: P-Factor Regression for Loam.

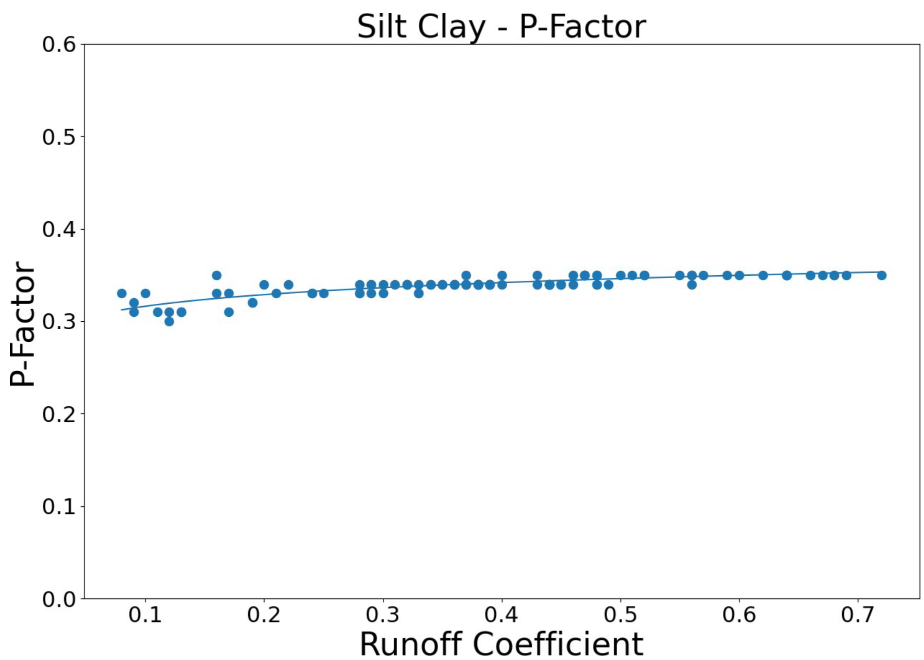

Figure 4-21. Simulation Results: P-Factor Regression for Silt Clay.

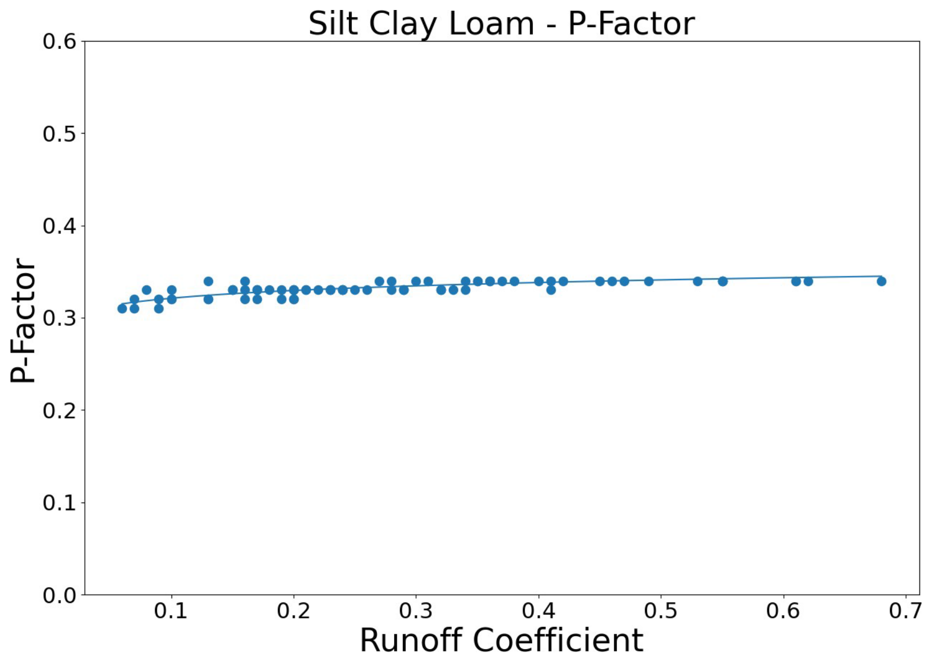

Figure 4-22. Simulation Results: P-Factor Regression for Silt Clay Loam.

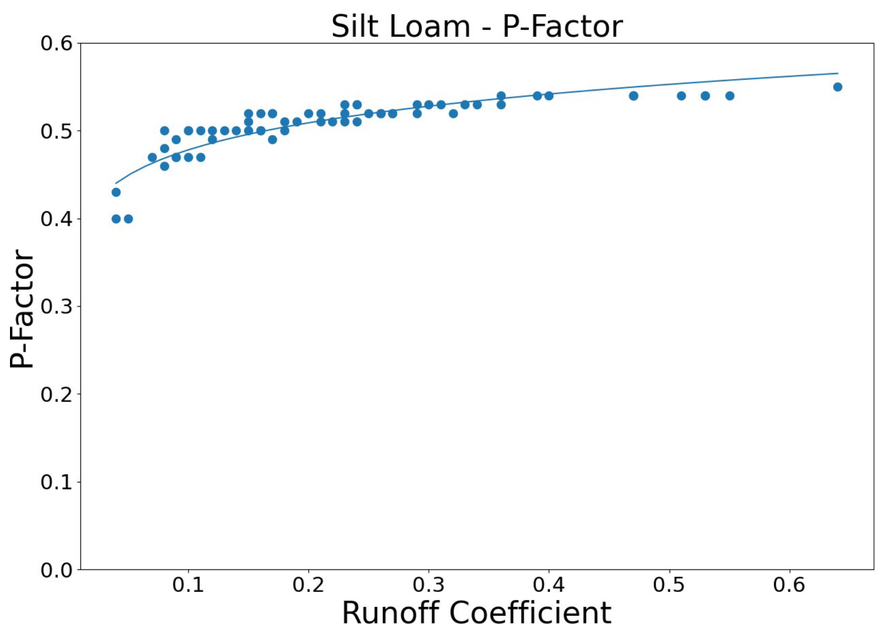

Figure 4-23. Simulation Results: P-Factor Regression for Silt Loam.

4.3 GIS Maps of P-Factor for Tennessee

P-factors based on soil types across the state of Tennessee suitable for silt fences and straw-filled sediment tubes are shown in Figures 4.24 and 4.25, respectively. These P-factors follow what has been reported in Table 4.8.

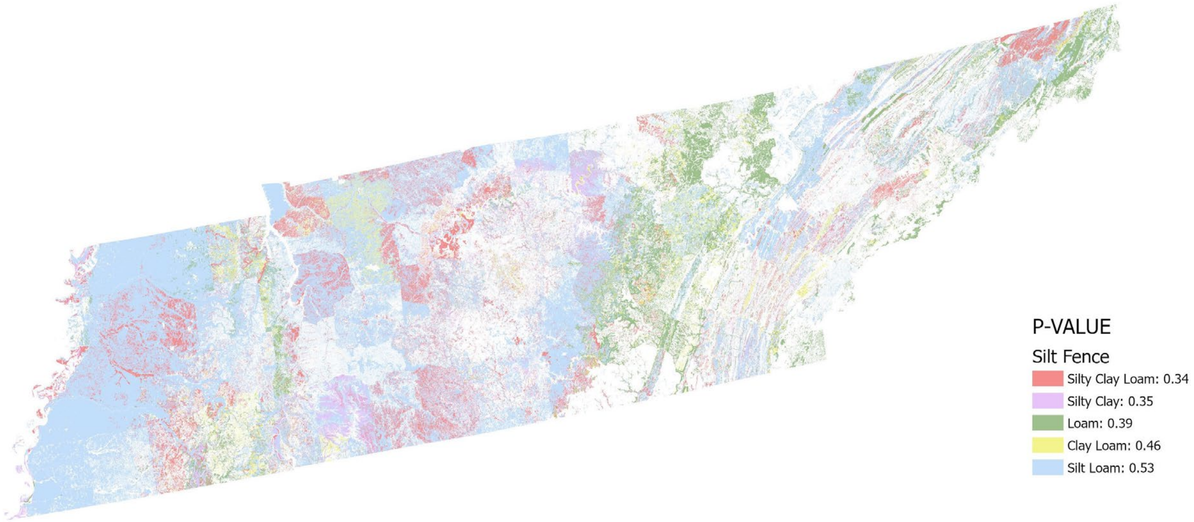

Figure 4-24. GIS map of P-Factors for silt fences within Tennessee.

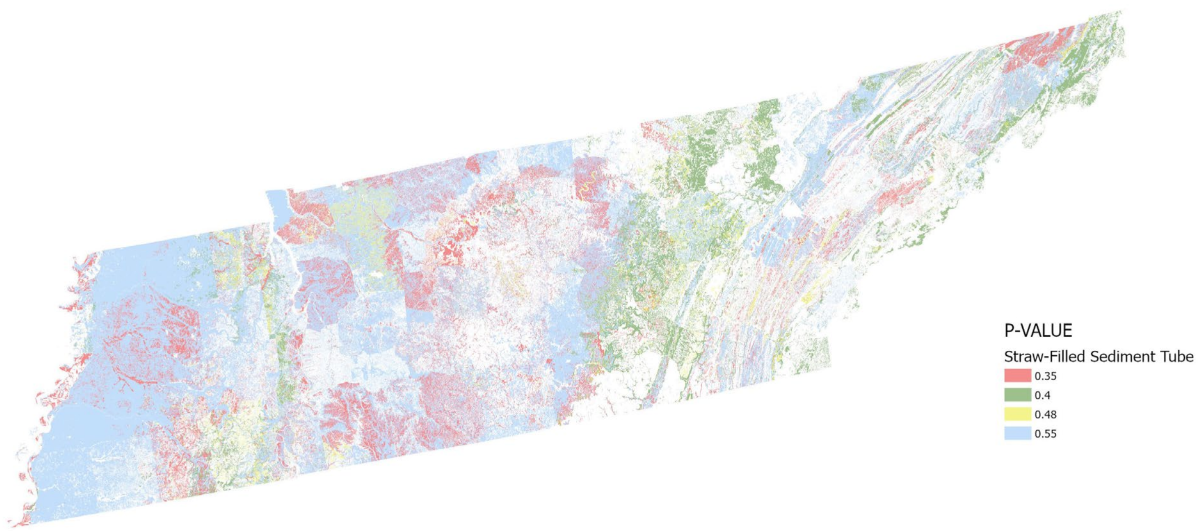

Figure 4-255. GIS map of P-Factors for straw-filled sediment tubes within Tennessee.

Chapter 5 Conclusion

This study was conducted utilizing the generated hillslopes and watershed models for WEPP. For this study, 15 WEPP hillslope model scenarios were calibrated to educate 20 watershed model scenarios without impoundments for determining baseline erosion rates and 40 watershed model scenarios with silt fences and straw-filled sediment tubes for determining the practice efficiency. These simulations encompassed different combinations of soil types and climate regions within Tennessee. From these simulations, a summary reference table (Table 4.8) was generated for the different erosion control practice factors (i.e., P-factors). The soil type with the best P-factor of 0.34 for silt fences was silt clay, while the silt loam simulations produced a P-factor of 0.55 for straw-filled sediment tubes. The range observed in the P-factors is representative of those found in literature (Gogo-Abite and Choptra 2013; Kelsey et al. 2006) and the previously conducted experiments of RES#16-20 (Wilson, 2021). The factors found for this study can be directly inserted into the revised universal soil loss equation (RUSLE) to estimate the total soil loss of a defined area.

The summary reference table (Table 4.8) was generated based upon the observation that soil type was the primary element influencing the P-factor and that the P-factor varied minimally across the different rainfall events for each soil type. This finding was attributed to the soil composition and hydraulic conductivity.

Additionally, it was observed that the BMPs in this study were ineffective at retaining finer soil particles due to the nature of the retention for these sediment control devices. This inability resulted in the sediment control devices for silt loam and clay loam being less effective at reducing the amount of sediment yield. The silt clay and silt clay loam simulations showed the highest efficiencies due to their large presence of clay. The clay particles in these soils were able to form stable aggregates with silt particles, and these aggregates were able to be retained by these practices.

The trend observed pertaining to the hydraulic conductivity indicated that as the hydraulic conductivity decreased, the soil erosion increased. Although these trends were apparent, they were not an exact correlation. The slight deviation of these trends can be explained through the length of the simulated time period. Due to the limitations of the WEPP model, each simulation had to be conducted for a full year. This extended length provides time for a multitude of events to occur. The frequency and duration of these events directly influenced the moisture content, which impacts the partitioning of rainfall to runoff and infiltration. Although soil composition and hydraulic conductivity both influence the amount of soil erosion, the moisture content can also contribute to the amount of soil loss. If rainfall events happen in a condensed amount of time, the soil may not receive adequate time to dry out, resulting in the soil being saturated and unable to infiltrate more runoff. The lack of infiltration will ultimately increase the amount of water that is running across the soil as runoff, providing more opportunities for erosion to occur. Similar outcomes will occur if a rainfall event occurs over an extended duration because the soil will become oversaturated. Additionally, the rainfall events influence the soil composition over time. As a rainfall event occurs, erosion will take place, and different size particles will erode at varying rates. Over time, the percents of clay, silt, and sand will vary, resulting in mild fluctuations to the P-factor of both sediment control devices.

This study can be easily built upon and continued. One recommended future study would be to conduct these numerical simulations for various climate lengths, enabling a more complete understanding to be developed for how the composition of these soil types fluctuates over time and the corresponding influence this fluctuation has on the generated P-factors. Another avenue could be to broaden the study by incorporating more soil types and climate regions. Doing so would provide P-factors for soils outside of the common soil types found in the state of Tennessee and would allow the P-factors to be more broadly utilized across climate regions. This study was limited to silt fences and straw-filled sediment tubes due to the lack of slurry flow rates in literature. The data found in this study could be expanded upon if additional physical experiments were performed utilizing the same uniform experimental set-up to find the different slurry flow rates of erosion control practices and sediment control devices. The regression equations generated could be utilized to find the baseline erosion and new numerical simulations could be generated for those practices.

References

AASHTO. 2014. *Standard Practice for NTPEP Evaluation of Erosion Control Products and Sediment Retention Devices*. #ECP 14-01. Washington DC.

Abaci, O., and AN. Papanicolaou. 2009. Long-term effects of management practices on water-driven soil erosion in an intense agricultural sub-watershed: monitoring and modelling. *Hydrological Processes*. 23(19):2818–2837.

Abercrombie, K.W. 2022. *Quantifying Support Practice Sub-Factor Values for Erosion-Control and Sediment Retention Device*. MS Thesis, University of Tennessee, Knoxville.

Ascough, J.C., et al. 1995. WEPP User Summary. NSERL Report 11. USDA. 1196 Bldg. SOIL West Lafayette, IN 47907-1196.

Barrett, M.E., et al. 1998. An evaluation of geotextiles for temporary sediment control. *Water Environment Research*. 70(3):283–290.

Chapman, J.M., C.L. Proulx, M.A.N. Veilleux, C. Levert, S. Bliss, M.E. Andre, N.W.R. Lapointe, and S.J. Cooke. 2014. Clear as mud: A meta-analysis on the effects of sedimentation on freshwater fish and the effectiveness of sediment-control measures. *Water Research*. 56:190-202.

Elhakeem, M., et al. 2018. Understanding saturated hydraulic conductivity under seasonal changes in climate and land use. *Geoderma*. 315:75–87.

Elliot, W.J. 1990. A compendium of soil erodibility data from WEPP cropland soil field erodibility experiments 1987 & 88. (3.) Agricultural Research Service, US Department of Agriculture.

Faucette, L.B., et al. 2009. Large-scale performance and design for construction activity erosion control best management practice. *Journal of Environmental Quality*. 38(3): 1248–1254.

Faucette, L.B., K.A. Sefton, A.M. Sadeghi, and R.A. Rowland. 2008. Sediment and phosphorus removal from simulated storm runoff with compost filter socks and silt fence. *Journal of Soil and Water Conservation*. 63:(4)257-264.

Faucette, L.R., L.M. Risse, C.F. Jordan, M.L. Cabrera, D.C. Coleman, and L.T. West. 2006. Vegetation and soil quality effects from hydroseed and compost blankets used for erosion control in constructed activities. *Journal of Soil and Water Conservation*. 67(6):536-544.

Fernández-Ugalde, O., et al. 2013. Clay mineralogy differs qualitatively in aggregate-size classes: clay-mineral-based evidence for aggregate hierarchy in temperate soils”. In: *European Journal of Soil Science* 64(4): 410–422.

Fifield, J.S. 2005. Designing for effective sediment and erosion control on construction sites. *Environmental & Engineering Geoscience*. 11(2): 187–188.

Flanagan, D.C., and M.A. Nearing. 1995. *Water Erosion Prediction Project: Hillslope profile and watershed model documentation*. NSERL report No.10. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN.

Foster, G.R., D.C. Flanagan, M.A. Nearing, L.J. Lane, L.M. Risse, and S.C. Finkner. 1995. *Hillslope Erosion Component* (Chapter 11). In: Water Erosion Prediction Project: Hillslope profile and watershed model documentation, NSERL report No. 10 (eds. D.C. Flanagan & M.A. Nearing), pp. 1–12. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN.

Garcia, C.B., J. Monical, R. Bhattarai, P.K. Kalita. 2015. Field evaluation of sediment retention devices under concentrated flow conditions. *Journal of Soils and Sediments*. 15:2022-2031.

Gilley, J.E., et al. 1993. Critical shear stress and critical flow rates for initiation of rilling. *Journal of Hydrology*. 142(1-4):251–271.

Gogo-Abite, I., and M. Chopra. 2013. Performance evaluation of two silt fence geotextiles using a tilting testbed with simulated rainfall. *Geotextiles and Geomembranes*. 39:30-38.

Haan, C.T., et al. 1994. *Design Hydrology and Sedimentology for Small Catchments*. Elsevier Publ.

Hangul, A.R. 2017. *In service performance evaluation of Erosion Prevention Sediment Control (EPSC) devices*. M.S. Thesis. University of Tennessee – Knoxville.

Kaufman, M.M. 2000. *Erosion control at construction sites: The science–policy gap*. pp. 1, 2.

Kelsey, K., T. Johnson, and R. Vavra. 2006. Needed information: Testing, analysis, and performance values for slope interruption perimeter control BMPs. *International Erosion Control Association Conference Technical Session Proceedings*. Long Beach, CA.

Laflen, J.M., and D.C. Flanagan. 2013. The development of US soil erosion prediction and modeling. *International Soil and Water Conservation Research*. 1(2): 1–11.

Laflen, J.M., L.J. Lane, and G.R. Foster. 1991. WEPP—a next generation of erosion prediction technology. *Journal of Soil Water Conservation*. 46(1): 34–38.

Ledermann, T., K. Herweg, H.P. Liniger, F. Schneider, H. Hurni, and V. Prasuhn. 2010. Applying erosion damage mapping to assess and quantify off-site effects of soil erosion in Switzerland. *Land Degradation and Development*. 21: 353-366.

Lindley, M.R., B.J. Barfield, and B.N. Wilson. 1995. *Surface Impoundment Element Model* Description (Chapter 14). In: Water Erosion Prediction Project: Hillslope profile and watershed model documentation, NSERL report No. 10 (eds. D.C. Flanagan & M.A. Nearing), pp. 1–12. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN.

Liu, Y., B.A. Engel, D.C. Flanagan, M.W. Gitau, S.K. McMillan, and I. Chaubey. 2017. A review on effectiveness of best management practices in improving hydrology and water quality: Needs and opportunities. *Science of the Total Environment*. 601-602:580-593.

Moore, A.D., et al. 2007. Calibrating WEPP model parameters for erosion prediction on construction sites. *Transactions of the ASABE*. 50(2): 507–516.

Muste, M., R. Ettema, C. Mutel, R. Gomez, P. Shaffer, and K. Yu. 2002. *Erosion control for highway applications – Phase 1: Review and synthesis of literature*. A Final Report to the Iowa Department of Transportation TR-464. Ames, IA.

National Transportation Product Evaluation Program (NTPEP). 2021. http://www.ntpep.org/Pages/ default.aspx

Papanicolaou, A.N., and O. Abaci. 2008. Upland erosion modeling in a semihumid environment via the water erosion prediction project model. *Journal of Irrigation and Drainage Engineering*, 134(6), pp.796-806.

Parsons, A.J., R.E. Brazier, J. Wainwright, and D.M. Powell. 2006. Scale relationships in hillslope runoff and erosion. *Earth Surface Processes and Landforms*. 31(11):1384-1393.

Renard, K.G., et al. 1994. RUSLE revisited: status, questions, answers, and the future. *Journal of Soil and Water Conservation*. 49(3): 213–220.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. *Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)*. U.S. Department of Agriculture-Agriculture Handbook No. 703.

Renard, K.G., et al. 1994. RUSLE revisited: status, questions, answers, and the future. *Journal of Soil and Water Conservation*. 49(3): 213–220.

Schwartz, J.S., and J.M. Hathaway 2018. *In-Service Performance Evaluation of Erosion Prevention and Sediment Control (EPSC) Devices*. Tech. rep. Tennessee. Department of Transportation. (cit. on p. 3).

Sonneveld, B.G.J.S., and M.A. Nearing. 2003. A nonparametric/parametric analysis of the Universal Soil Loss Equation. *Catena*. 52(1):9-21.

Sprague, C.J., and J.E. Sprague. 2012. *BMP testing for erosion and sediment control-final report*. TRI Environmental, Anderson, SC.

Sprague, C.J., P. Kemp, and K. Malusky. 2014 Independent, Full-Scale Evaluation of Erosion and Sediment Control BMPs. *Land & Water*. Nov/Dec 2014:22-29.

Stolpe, N.B. 2005. A comparison of the RUSLE, EPIC and WEPP erosion models as calibrated to climate and soil of south-central Chile. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science*. 55(1): 2–8.

Stone, J.J., L.J. Lane, E.D. Shirley and M. Hernandez. 1995. *Hillslope Surface Hydrology* (Chapter 4). In: Water Erosion Prediction Project: Hillslope profile and watershed model documentation, NSERL report No. 10 (eds. D.C. Flanagan & M.A. Nearing), pp. 1–12. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN.

TDOT. 2012. *The Tennessee Department of Transportation Design Division Drainage Manual*. Nashville, TN.

Theisen, M.S., and K. Spittle. 2006. A quantitative comparison of sediment retention devices under standardized test conditions.

(http://files.tlhort.com/topicassets/attachments/ta_413_paper_-_comparison_of_sediment _retention_devices_-_2006.pdf).

Tiwari, A.K., et al. 2000. Evaluation of WEPP and its comparison with USLE and RUSLE. *Transactions of the ASAE*. 43(5): 1129.

Toy, T.J., G.R. Foster, and K.G. Renard. 1999. RUSLE for mining, construction and reclamation lands. *Journal of Soil and Water Conservation*. 54(2):462-467.

Tyner, J.S., D.C. Yoder, B.J. Chomicki, and A. Tyagi. 2011. A review of construction site best management practices for erosion control. *Transactions of the ASABE*. 54(2):441-450.

Williams, J.R. 1991. Runoff and water erosion. *Modeling Plant and Soil Systems*. 31:439-455.

Wilson, C.G. K.M. Wacha, A.N. Papanicolaou, H.A. Sander, V.B. Freudenberg, B.K.B. Abban, and C. Zhao. 2016. Dynamic assessment of current management in an intensively managed agroecosystem. *Journal of Contemporary Water Research & Education*. 158:148-171

Wilson, C.G., 2021. *Performance Base Testing for Erosion Prevention and Sediment Control (EPSC) Devices*. Tech. rep. Tennessee. Department of Transportation.

Wishowski, J.M., et al. 1998. Trap efficiencies of filter fabric fence. *ASAE Annual Meeting*, Paper No. Vol. 982158 (cit. on pp. 13, 35).

Zech, W.C., J.L. Halverson, and T.P. Clement. 2008. Intermediate-scale experiments to evaluate silt fence designs to control sediment discharge from highway construction sites. *Journal of Hydrologic Engineering*. 13(6):497-504.

Zheng, M., and X. Chen. 2015. Statistical determination of rainfall-runoff erosivity indices for single storms in the Chinese Loess Plateau. *PLoS ONE*. 10(3): e0117989.

Appendices

Appendix A

WEPP Model Calibration Data

Soil Type	Clay Loam 2.31	Clay Loam 3.29	Clay Loam 4.1	Silty Clay 2.31	Silty Clay 3.29	Silty Clay 4.1	Silty Clay Loam 2.31	Silty Clay Loam 3.29	Silty Clay Loam 4.1	Silty Loam 2.31	Silty Loam 3.29	Silty Loam 4.1	Loam 2.31	Loam 3.29	Loam 4.1
Moisture Level	25	25	25	25	25	25	75	75	60	75	65	40	75	75	75
K_i (kg·s/m^4)	1000000	500000	500000	1000000	400000	400000	1000000	1000000	400000	1000000	1000000	1000000	1000000	1000000	1000000
K_r (s/m)	0.005	0.005	0.005	0.005	0.005	0.002	0.005	0.005	0.002	0.005	0.005	0.005	0.005	0.005	0.005
τ_c (Pa)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	6.5	5.5	5.5	5.5	5.5	5.5	5.5
K_e (mm/h)	2	4	6	2.5	4.5	6.5	8	13.32	13.32	11	16.06	16.06	14	25	37.5
Runoff (in)	0.31	0.44	0.54	0.28	0.43	0.55	0.13	0.24	0.31	0.09	0.12	0.14	0.1	0.14	0.14
Runoff Volume (L)	26.33	37.38	45.87	23.79	36.53	46.72	11.04	20.39	26.33	7.65	10.19	11.89	8.50	11.89	11.89
Sediment (kg/m^2)	0.11	0.15	0.25	0.10	0.12	0.17	0.05	0.06	0.08	0.03	0.06	0.09	0.03	0.07	0.09
Sediment (kg)	0.37	0.50	0.85	0.33	0.41	0.57	0.15	0.21	0.25	0.10	0.20	0.28	0.11	0.22	0.29
Percent Sediment	-4.69	-11.01	22.58	-16.39	-17.39	-22.04	29.28	23.94	18.88	-25.12	3.31	19.45	40.39	1.86	17.26
Percent Runoff	11.21	10.85	9.14	10.22	8.94	7.73	-24.98	-2.73	0.78	-31.43	-14.12	-4.55	-24.15	1.65	-5.61

Appendix B

Sediment Erosion Simulation Results

Soil	Location	Soil Composition	Inflow (kg)	Outflow (kg)	Retained (kg)	Efficiency
Clay Loam	Chattanooga	Clay	1210.0	1123.0	87.20	0.93
		Silt	1203.0	1181.0	22.15	0.98
		Sand	829.5	1.5	828.00	0.00
	Knoxville	Clay	774.3	715.5	58.89	0.92
		Silt	770.3	751.9	18.44	0.98
		Sand	531.0	1.1	529.90	0.00
	Memphis	Clay	888.4	821.5	66.88	0.92
		Silt	883.8	866.0	17.77	0.98
		Sand	609.2	1.5	607.70	0.00
	Nashville	Clay	913.7	845.4	68.23	0.93
		Silt	909.0	890.5	18.44	0.98
		Sand	626.5	1.5	625.00	0.00
Loam	Chattanooga	Clay	1338.0	1232.0	105.80	0.92
		Silt	1526.0	1489.0	36.49	0.98
		Sand	2144.0	13.3	2130.00	0.01
	Knoxville	Clay	688.7	631.8	56.90	0.92
		Silt	785.3	759.2	26.12	0.97
		Sand	1103.0	11.8	1092.00	0.01
	Memphis	Clay	688.7	631.8	56.90	0.92
		Silt	785.3	759.2	26.12	0.97
		Sand	1103.0	11.8	1092.00	0.01
	Nashville	Clay	1008.0	923.2	85.12	0.92
		Silt	1150.0	1116.0	33.92	0.97
		Sand	1615.0	12.9	1603.00	0.01
Silt Clay Loam	Chattanooga	Clay	1540.0	1420.0	120.20	0.92
		Silt	818.8	800.4	18.37	0.98
		Sand	336.5	1.1	335.40	0.00
	Knoxville	Clay	1540.0	1420.0	120.20	0.92
		Silt	818.8	800.4	18.37	0.98
		Sand	336.5	1.1	335.40	0.00
	Memphis	Clay	1445.0	1327.0	117.80	0.92
		Silt	768.2	748.4	19.79	0.97
		Sand	315.7	0.7	315.00	0.00
	Nashville	Clay	1202.0	1102.0	100.50	0.92
		Silt	639.2	621.3	17.90	0.97
		Sand	262.7	1.6	261.10	0.01
Silt Clay	Chattanooga	Clay	1825.0	1691.0	133.90	0.93
		Silt	1332.0	1306.0	25.26	0.98
		Sand	79.2	0.1	79.12	0.00
	Knoxville	Clay	1071.0	987.2	83.42	0.92
		Silt	781.3	761.6	19.77	0.97
		Sand	46.5	0.2	46.32	0.00
	Memphis	Clay	1484.0	1372.0	112.00	0.92
		Silt	1083.0	1062.0	20.67	0.98
		Sand	64.5	0.1	64.32	0.00
	Nashville	Clay	1364.0	1261.0	103.20	0.92
		Silt	995.2	974.4	20.77	0.98
		Sand	59.2	0.1	59.15	0.00