Evaluation of Erosion Control Blanket Properties and Test Criteria for Specification and Design

Prepared by
Daniel T. Sommer
Amanda L. Cox
Ronaldo Luna
Department of Civil Engineering, Saint Louis University

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16. Abstract

A research project to investigate the product approval, design process, and ongoing product evaluation of erosion control blankets (ECBs) for the Missouri Department of Transportation (MoDOT) was conducted. An overview of federal and state environmental construction laws was performed noting the significance of ECBs on construction sites. Standardized erosion control testing, product approval, and design processes utilized by other state departments of transportation and those recommended by the National Transportation Product Evaluation Program were researched for further insight to typical ECB applications. A field investigation was established to study the effectiveness of two ECBs on a MoDOT construction site. MoDOT completed construction sites, which utilized ECBs, were also included in the investigation to evaluated how well vegetation was sustained and ongoing blanket degradation following site acceptance in accordance with the MoDOT Storm Water Pollution Prevention Plan (SWPPP). In addition to field site evaluations, surveys were developed and administered to record contractor and MoDOT employee ECB experiences and identify common problems and successful practices using ECBs. Recommendations for ECB approval procedures and a design process for conditions representative of Missouri were developed using insight gained through the study of common ECB product acceptance and design, the field site investigation, evaluation of completed construction sites, and the surveys of ECB experiences. The National Transportation Product Evaluation program's (NTPEP) ASTM standardized testing was recommended as the basis for product approval. For ECB design, the Revised Universal Soil Loss Equation (RUSLE) was recommended and used to establish minimum performance requirements for both product acceptance and design. Digital maps were developed using ArcGIS for Missouri's representative hydrologic and geologic conditions for use in the RUSLE. The ECB approval procedures and design process, which were developed specifically for the state of Missouri, are recommended for implementation into the MoDOT Engineering Policy Guide (EPG). An ongoing product evaluation system was also developed for ECBs to document field performance and assist in identifying ECBs that should be removed from the approved products list.

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Prepared by:

Danny Sommer, Amanda L. Cox (PI), and Ronaldo Luna
Saint Louis University
McDonnell-Douglas Hall
St. Louis, Missouri 63103

Prepared for:

Missouri Department of Transportation
105 West Capitol Avenue
P.O. Box 270
Jefferson City, Missouri 65102

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Department of Civil Engineering

Disclaimer

The opinions, findings and conclusions expressed in this publication are not necessarily those of the Department of Transportation, Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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Symbols

A	Average Annual Soil Loss $\frac{\mathbf{ton}}{\mathbf{year \cdot acre}}$
C	Coverage Factor
K	Soil Erodibility $\frac{\mathbf{ton \cdot acre \cdot hour}}{\mathbf{hundreds\ of\ acres \cdot ft \cdot ton \cdot in}}$
LS	Length-Slope Factor
N	Length-Slope Exponential Parameter
P	Practice Factor
R	Rainfall Erosivity $\frac{\mathbf{hundreds\ of\ feet \cdot ton \cdot in}}{\mathbf{acre \cdot hour}}$
S	Slope (%)

Units of Measure

%	Percent
°	Degrees
ft	foot or feet
g	grams(s)
hr	hour(s)
lb	pound(s)
in	inch(es)
in-lb	inch-pound(s)
yd	yard(s)
in^3/yd	cubic inch(es) per yard
oz	ounce(s)
oz/yd^3	ounce(s) per yard
L	liter(s)
mg	milligrams
mL	milliliters
mm	millimeter(s)
NTU	Nephelometric Units
pcf	pounds per cubic foot
psf	pounds per square foot
ppm	parts per million

Abbreviations

AASHTO	American Association of State Highway Transportation Officials
ASTM	American Society of Testing and Materials
BMP	Best Management Practice
CWA	Clean Water Act
CGP	Construction General Permit
ECB	Erosion Control Blanket
ECTC	Erosion Control Technology Council
EPA	Environmental Protection Agency
EPG	Engineering Policy Guidelines
IDOT	Illinois Department of Transportation
IowaDOT	Iowa Department of Transportation
KDOT	Kansas Department of Transportation
MoDNR	Missouri Department of Natural Resources
MoDOT	Missouri Department of Transportation
NDOR	Nebraska Department of Roads
NPDES	National Pollution Discharge Elimination System
NTPEP	National Transportation Product Evaluation Program
RECP	Rolled Erosion Control Product
RUSLE	Revised Universal Soil Loss Equation
SEC	Sediment and Erosion Control
SWPPP	Stormwater Pollution Prevention Plan
TRM	Turf Reinforcement Mat
TXDOT	Texas Department of Transportation
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
WisDOT	Wisconsin Department of Transportation

Executive Summary

A research project to investigate the product approval, design process, and ongoing product evaluation of erosion control blankets (ECBs) for the Missouri Department of Transportation (MoDOT) was conducted. An overview of federal and state environmental construction laws was performed noting the significance of ECBs on construction sites. Standardized erosion control testing, product approval, and design processes utilized by other state departments of transportation and those recommended by the National Transportation Product Evaluation Program were researched for further insight to typical ECB applications. A field investigation was established to study the effectiveness of two ECBs on a MoDOT construction site. MoDOT completed construction sites, which utilized ECBs, were also included in the investigation to evaluated how well vegetation was sustained and ongoing blanket degradation following site acceptance in accordance with the MoDOT Storm Water Pollution Prevention Plan (SWPPP). In addition to field site evaluations, surveys were developed and administered to record contractor and MoDOT employee ECB experiences and identify common problems and successful practices using ECBs. Recommendations for ECB approval procedures and a design process for conditions representative of Missouri were developed using insight gained through the study of common ECB product acceptance and design, the field site investigation, evaluation of completed construction sites, and the surveys of ECB experiences. The National Transportation Product Evaluation Program's (NTPEP) ASTM standardized testing was recommended as the basis for product approval. For ECB design, the Revised Universal Soil Loss Equation (RUSLE) was recommended and used to establish minimum performance requirements for both product acceptance and design. Digital maps were developed using ArcGIS for Missouri's representative hydrologic and geologic conditions for use in the RUSLE. The ECB approval procedures and design process, which were developed specifically for the state of Missouri, are recommended for implementation into the MoDOT Engineering Policy Guide (EPG). An ongoing product evaluation system was also developed for ECBs to document field performance and assist in identifying ECBs that should be removed from the approved products list.

1 Introduction

A research study developing specification recommendations for the selection of erosion control blankets (ECB) for the Missouri Department of Transportation (MoDOT) was conducted. The investigation included measurements of field performance for two ECBs through visual inspection, germination, soil properties, and stormwater runoff testing at a MoDOT construction site. Completed MoDOT projects were visited to observe conditions following the usage of ECBs. Additionally, surveys were developed to record various ECBs experiences which manifested successful practices. The surveys were administered to MoDOT resident engineers and inspectors and landscape contractors. The project concludes with recommendations for ECB selection, installation, maintenance, and ECB performance documentation for MoDOT construction sites.

The 1972 Clean Water Act (CWA) requires the reduction of pollutants and illicit discharge into the waters of the United States. The Environmental Protection Agency (EPA) mandates states to establish regulations and laws to show compliance to the CWA (EPA, 2007). For Missouri, the Missouri Department of Natural Resources (MoDNR) develops these regulations. For construction related activities, stormwater permits are required for areas disturbing an acre or more (MoDOT, 2014b). MoDNR issues a state operating permit for infrastructure and transportation projects. MoDOT adheres to the permit requirements including developing a plan for the reduction of pollution which discharges from construction sites (MoDOT, 2014b). MoDOT created the Storm Water Pollution Prevention Plan (SWPPP) to meet compliance. The SWPPP details best management practices (BMP) to reduce pollution generated from stormwater runoff.

Erosion and sediment transport is a significant concern as the sediment may produce unstable slopes, inadequate areas for vegetation growth, and pollutants, which may restrict the ecology of the watershed (Kelsey, 2002). During storm events, kinetic energy from rainfall and sheet flow can cause erosion making graded and exposed soil surfaces on slopes particularly susceptible to erosion (Lal, 2001). Without any means of mitigation, the erosion may result in maintenance and cost issues for overall slope stability and a noncompliance to the CWA federal law (MoDOT, 2014b).

A common practice for erosion control is through the installation of ECBs, which are rolled erosion control products (RECP) comprised of a fiber matrix made of materials such as straw, excelsior, jute, or coconut fiber threaded together by either a photodegradable or biodegradable netting (CADOT, 1999). Intended to degrade over time, ECBs act as a buffer between the stormwater runoff and the soil until vegetation is established (MoDOT, 2014b). The blanket also promotes the vegetative growth. The multifunctional component makes ECBs a popular choice for slope protection (Bhatia, 2010).

Appropriate selection of ECBs is vital to their performance in reducing slope erosion. Slope applications vary by steepness, soil type, and local hydrology. Erosion control performance for a given ECB will vary depending on the site conditions (soil, rainfall intensities, etc.) and standardized performance testing is vital to delineate appropriate applications and limitations of an ECB (ECTC, 2006). Certain characteristics for ECBs can be determined from the American Society of Testing and Materials (ASTM) tests created by ASTM International. Many of the tests originated from Erosion Control Technology Council (ECTC) standard test methods and were later approved as ASTM standards (ECTC, 2006). However, various performance tests were developed in collaboration with the American Association of State

Highway Transportation Officials' (AASHTO) National Transportation Product Evaluation Program (NTPEP) (NTPEP, 2011). The NTPEP tests offer a means of determining potential field performance from the large-scale testing for slope (ASTM D6459) and channel (ASTM 6460) performance. The smaller-scale index tests were developed for quality control measures prior to the installation of the product (NTPEP, 2011). The bench-scale performance tests are reserved as a quick, initial evaluation of an ECB.

Many state departments of transportation utilize these NTPEP test results as criteria for acceptance onto an approved products list before appropriate usage. Some state departments have developed independent field performance tests representative of the conditions the ECB would be subjected to in the state. The Texas Department of Transportation (TxDOT) and the Texas Transportation Institute (TTI) have developed independent large-scale field performance tests performed at the Sediment and Erosion Control (SEC) Laboratory (TXDOT/TTI Sediment and Erosion Control Laboratory, 2015). Products passing the tested threshold are approved as products to be used on that intended slope or designed channel shear stress or less. The Missouri Department of Transportation references TXDOT's ECB approved product list for its construction projects (MoDOT, 2014a).

Appropriate selection of an ECB for an application is vital to maintaining its economic advantage over other BMPs. The MoDOT ECB standard specifications separate ECBs into five types with Type 5 being the most conservative in terms of performance. The MoDOT cost of ECBs per square yard for construction project between 2010 and 2015 are summarized in Table 1.1 (MoDOT, 2016). Significant variability in cost for different years and ECB types is apparent. Some of this variability may be attributed to contractors buying large quantities of ECBs in bulk.

Table 1.1. MoDOT unit bid prices for ECBs (MoDOT, 2016).

Average Unit Bid Prices ($/yd²)					
Year	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 5**
2010	2.08	2.03	2.28	2.20	N/A
2011	N/A	1.63	2.25	1.61	N/A
2012	1.47	1.88	1.68	3.54	3.18
2013	2.45	2.00	1.85	4.28	2.33
2014	1.65	1.54	1.58	3.90	4.83
2015	2.30	2.03	1.93	N/A	2.60

Product approval for TxDOT requires a wait list period for testing and the associated testing fee (TXDOT/TTI Sediment and Erosion Control Laboratory, 2015). Product flexibility becomes limited as a given product would still have to earn approval from the TXDOT large-scale testing despite factors such as availability or cost of the product. Furthermore, MoDOT does not have a means of documenting failures of ECBs to determine deficient products.
The objectives for this research were to:

- Develop recommendations for ECB approval specifications that are economical and result in successful ECB performance on MoDOT construction sites;
- Create guidelines for appropriate ECB selection for slope applications; and
- Develop methods for monitoring and documenting ECB failures and develop corresponding protocols for removing products from the approved products list.

2 Literature Review

2.1 Erosion Control Laws and Regulations

Erosion control laws and regulations provide insight to the purpose of erosion control blankets (ECB). The Clean Water Act outlines the pollutants to be monitored and reduced which may impact the local ecosystem (EPA, 1972). Sediment generated from stormwater meets the criteria of a pollutant as excessive sediment loads disrupt the aquatic biota of river systems and sources of drinking water (EPA, 1999) and is a common pollutant from construction sites (EPA, 2007). The National Pollution Discharge Elimination System (NPDES) regulates point sources of pollution from industrial, municipal, and construction related activities (EPA, 1972). The CWA requires facilities or land owners to obtain a NPDES permit before discharging pollutants from the site. NPDES permits contain narrative water quality standards the site must meet before legally discharging storm or wastewater. The continued technological and construction technique advancements has motivated the EPA to revise water quality standards to the NPDES (MacCurdy, 2014) to better meet the CWA requirements of protection bodies of water "where ever attainable" (EPA, 1972). In 2009, the EPA instituted quantitative limits of turbidity as a NPDES Program requirement for construction sites disturbing ten acres or more; discharges from these sites are in violation of the NPDES if the daily average of turbidity samples exceeds 280 NTU (EPA, 2009). Many land developers and small residential contractors contested the regulation being too costly for compliance, and these limits were removed in 2014 (MacCurdy, 2014). However, the ongoing development of erosion and sediment control technology may merit future changes to the NPDES.

NPDES permits are issued by either the EPA or from an authorized agency at the state level (EPA, 1972). MoDNR is the authorized entity for the state of Missouri and grants individual permits for certain land reclamation, specialized construction projects, or unique operations facilities while still meeting federal water quality standards (Hines et al., 2015). Site activities which are of the same degree, such as construction, are issued an associated General Operating Permit (MoDNR, 2015). Construction General Permits (CGP) require the development of a SWPPP to assess the potential pollutants for the site, their sources, and the associated best management practices to meet the federal regulations of the CWA (MoDOT, 2014a).

MoDOT developed a SWPPP for its construction projects to meet the compliances of the CWA. A common pollutant noted in construction SWPPPs is sediment. The BMPs integrated into MoDOT's SWPPP include construction methods such as effective project scheduling and proper BMP selection (MoDOT, 2014b). Economically implementing temporary and permanent erosion control techniques meeting all environmental federal laws remains a priority for the execution of the SWPPP (EPA, 2007). Thus, structural BMPs such as ECBs, which have various degrees of effectiveness from product to product, require particular discernment for proper economic and environmental selection. The ECTC, AASHTO and the NTPEP developed a range of tests approved by ASTM to classify material properties and ECB characteristics to determine these critical differences (NTPEP, 2011).

2.2 ECB Standard Tests

ECB ASTM testing includes large-scale testing to evaluate field performance potential, the index-property testing to assist in quality control, and bench-scale testing to serve as an economical initial evaluation of an ECB's potential performance (NTPEP, 2011). Because of the technological advances of ECBs, revisions and withdrawal of tests have occurred to reach more precise and meaningful test results. The large-scale ASTM tests include the following:

- Protecting Hillslopes from Rainfall-Induced Erosion (ASTM D6459); and
- Protecting Earthen Channels from Stormwater-Induced Erosion (ASTM D6460).

The relevant index tests include the following:

- Density and Specific Gravity (ASTM D792);
- Nominal Thickness of Rolled Erosion Control Products (RECP) (ASTM D6525/D6525M);
- Measuring Light Penetration of a Turf Reinforcement Mat (TRM) (ASTM D6567); and
- Ultimate Tensile Properties of RECPs (ASTM D6818).

The bench-scale tests include the following:

- RECP for Ability Protecting Soil from Rain-Splash and Associated Runoff (ASTM D7101); and
- RECP Ability to Encourage Seed Germination and Plant Growth (ASTM D7322).

Large-scale, index-property, and bench-scale testing requires replicate tests to obtain a representative value for the ECB properties. Reviewing each experiment shows the critical qualities and characteristics of the ECB. Test results can be interpreted for proper ECB selection and application.

ASTM D6459 – Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion

The large-scale hill slope testing quantifies the slope-application field performance of an ECB during storm events. Using controlled artificial storm events, the test simulates field conditions and quantifies the amount of soil lost from the slope with the installed ECB. This sediment loss is compared to the soil loss observed from the same soil, storm, and slope conditions for a control slope of exposed soil. The calculated ratio of ECB soil loss to control soil loss is what is called the ECB's coverage factor. The coverage factor pertains to the Revised Universal Soil Loss Equation (RUSLE) (OMAFRA, 2012). The RUSLE is a theoretical estimate of the amount of erosion from utilizing a particular erosion control product. The RUSLE depends on factors such as location, hydrology, geology, and site conditions and usage of the investigated site (Kelsey, 2002). Obtaining a coverage factor representative of the erosion control blanket is imperative because values are empirically determined and may vary from the actual site conditions. Three control slopes and three ECB slope plots are required and the coverage factor is determined as an average of the three test results.

ASTM D6460 – Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion

Permissible shear stress is the primary metric for evaluating ECB performance for a channelized application. An ECB is installed in a channel, and flow is introduced into the channel. Flow and associated shear stress is increased until failure is observed, which is defined as a half inch of soil loss along the profile of the channel. Three experiments are conducted for the ECB after a vegetative establishment period. A fourth experiment is performed on an ECB plot without a vegetation growing period.

ASTM D792 – Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

The density and specific gravity of plastics and cellulosic fibers found in some erosion control blankets can be evaluated for quality assurance prior to installation. The procedure follows an immersion procedure with the erosion control blanket sample and distilled water. The calculated density is compared to the values of the material given in baseline tables presented in the manufacturer specifications. Values showing high variance from the accepted values and the associated standard deviations can lead to the rejection of the results. The test is recommended to be repeated twice for representative results.

ASTM D6525/D6525M – Standard Test Method for Measuring Nominal Thickness of Rolled Erosion Control Products (RECP)

Many calculations for other ECB characteristics are derived from the nominal thickness such as ultimate tensile strength. A representative thickness is determined from a set amount of test samples which a 95% probability that all test results will be within 6% of the true sample average. The number of specimens is determined from reliable estimates of previous experiments from ECBs of a similar material, or ten specimens if no reliable estimates are available.

ASTM D6566 – Standard Test Method for Measuring Mass Per Unit Area of Turf Reinforcement Mats (TRM)

The mass per unit area of a TRM is frequently used as a quality control mechanism prior to TRM installation. ECBs are also tested under ASTM D6566 as the test is generalized to encompass all RECPs. At least five separate experiments are to be performed. The average of the observed measurements as well as the sample standard deviation is to be within the accepted values specified by ASTM D6566. If large variances are observed, the ECB may fail to meet acceptance.

ASTM D6567 – Standard Test Method for Measuring the Light Penetration of a Turf Reinforcement Mat (TRM)

Similar to TRM mass per unit area, the light penetration experiment serves as a quality control protocol prior to the installation. The TRM sample is placed inside a light penetration device.

Light is illuminated on one side of the TRM, and the percentage of light penetrated is measured with a light meter on the opposite side. The number of samples varies and is dependent on observing a 95% probability that all of the test results will be within 5% of the true sample average. Calculating sample size is performed using reliable estimates of previously tested TRMs of similar material. If a reference estimate does not exist, five test specimens will be used.

ASTM D6818 – Standard Test Method for Ultimate Tensile Properties of Rolled Erosion Control Products

ASTM D6818 measures the structural integrity of the ECB. A sample of the ECB is extracted and five strips are utilized in tensile testing. The average of the five observed breaking forces is reported as the maximum tensile strength of the ECB.

ASTM 7101 - Standard Index Test Method for Determination of Unvegetated Rolled Erosion Control Product (RECP) Ability to Protect Soil from Rain-Splash and Associated Runoff Under Bench-Scale Conditions

The experiment serves as an initial substitute for the large-scale ASTM D6459 experiment providing a cost effective technique to measure the general performance of an ECB to simulated rainfall events. Soil cylindrical cores with the tested ECB and control bare are placed on an incline subjected to an artificial storm event. Three cores of the ECB and the control are tested and the average mass of sediment lost from each is reported as the test results.

ASTM D7322 - Standard Index Test Method for Determination of Rolled Erosion Control Product (RECP) Ability to Encourage Seed Germination and Plant Growth Under Bench-Scale Conditions

The long-term purpose of the ECB is to assist in the reestablishment of the vegetation and stabilization of the landscape. The ability to promote the growth of vegetation is an important characteristic of the ECB. The ECB absorbs and holds onto water and acts as a buffer against rainfall and wind and scour erosion (NTPEP, 2011). ASTM D7322 quantifies the ECB's plant growth over a 21-day growing period to a control plot under the same temperature, water amount, seed mix, and soil conditions. Three plots are required for both the ECB installed plots and the control plots. Average biomasses are used as the reported calculations.

2.3 State Procedures for ECB Approval

State procedures for ECB approval for six state departments of transportation were investigated to assess their unique requirements for inclusion in their ECB approved products list. The state agencies investigated were: the Texas Department of Transportation (TXDOT), the Kansas Department of Transportation (KDOT), Wisconsin Department of Transportation (WisDOT), Nebraska Department of Roads (NDOR), Iowa Department of Transportation (IowaDOT), and the Illinois Department of Transportation (IDOT). These states were chosen because of their proximity to Missouri. MoDOT's acceptance procedures were also noted to compare and observe similarities to the other agencies.

All of the ASTM tests evaluate specific ECB characteristics. Determining acceptable values for design is dictated by the intended application. For many departments of transportation, earning acceptance onto an approved products list is required for a certain product to be used for a particular slope and soil type (IowaDOT, 2012; KDOT, 2014; Roadside Stabilization Unit, 2007; WisDOT, 2014; TXDOT, 2015). The requirements depend on the state's climate for field performance and practical quality assurance checks from the index test results. Several states utilize the Revised Universal Soil Loss Equation (RUSLE) in determining the appropriate ECB for specified slope conditions including slope, soil type, and required service life.

As stated, the RUSLE is a theoretical approach to calculate the projected long-term erosion a particular slope may experience from soil type, hydrology, slope geometry, land usage, and land coverage (OMAFRA, 2012). The RUSLE is an expansion of the Universal Soil Loss Equation (USLE) offering more precision in soil loss estimates (Spaeth, 2003). The RUSLE is presented in Equation 2.1 where the average annual soil loss (A) (tons⁄acre) is equivalent to the product of the rainfall erosivity coefficient (R) ((100ft·ton·in)⁄(acre·hr)), soil erodibility factor (K) (ton·acre·hr)⁄(100acres·ft·-ton·in)), length-slope coefficient (LS), coverage factor (C), and the practice factor (P).

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

The average annual soil loss (A) from the erosion control blanket is compared to a tolerable annual soil loss (T) which is the amount of soil loss while still being able to economically use the land (USDA, 1997). If the annual soil loss calculated is less than the tolerable annual soil loss, the construction practice will not compromise the soil conditions with the installation of the proposed ECB. The local hydrology is factored into the equation as the rainfall ultimately induces the erosion, denoted as a rainfall erosivity coefficient (R) (OMAFRA, 2012). The soil erodibility factor (K) characterizes the soil's susceptibility for particles to dislodge and transport during storm and rainfall events (Kelsey, 2002). The Agricultural Handbook 537 (USDA 1978) empirically determined various soil erodibility factors by soil texture class, organic content, soil structure, and permeability for a 72.6-ft, 9% slope. The soil erodibility can be determined graphically from Figure 2.1.

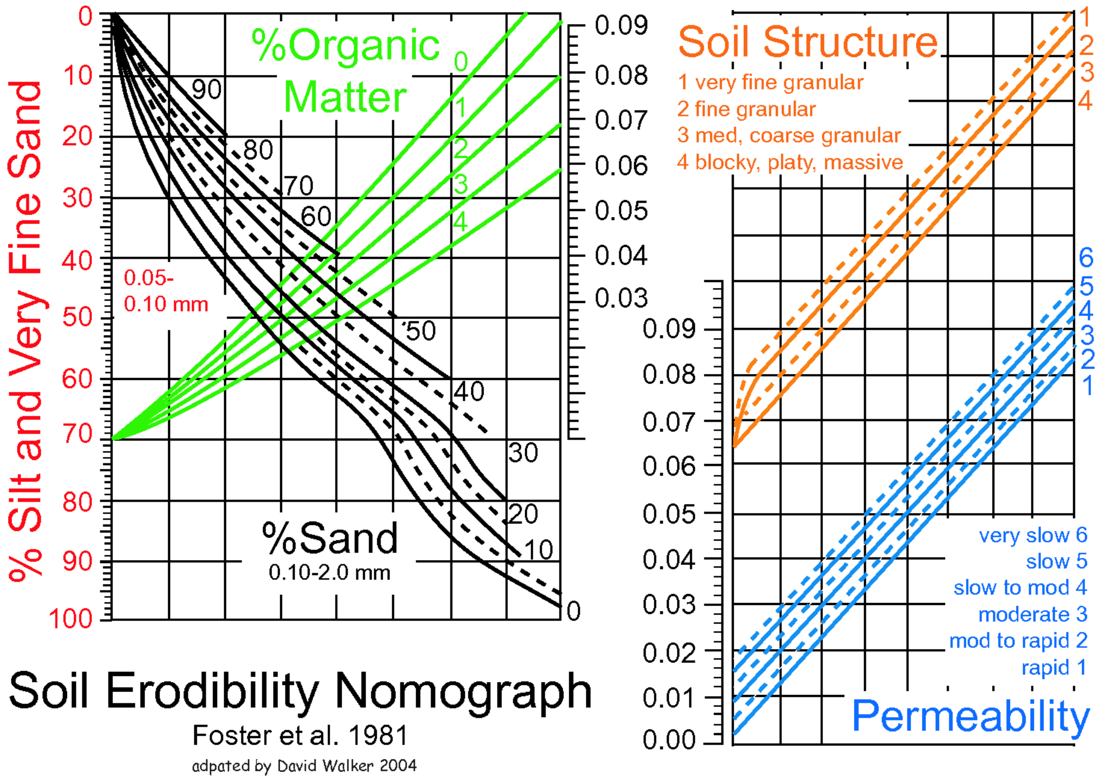

Figure 2.1. Erodibility *(K)* chart (USDA, 1978).

The length-slope factor (LS) includes the effect of the steepness and length of slope. The LS factor is computed by Equation 2.2 for slopes larger than 9% commonly found on highway construction sites (USDA, 1997):

$$LS = (16.8 \sin\theta - 0.50)\left(\frac{L}{72.5}\right)^{N} \tag{2.2}$$

where θ is the slope angle; and L is the slope length (ft). The constant N is dependent on the steepness of the slope. The length component in Equation 2.2 is identical between the USLE and the RUSLE. However, the USLE states the exponent N is empirically determined using Table 2.1 while RUSLE defines the length slope exponent N by Equation 2.3:

$$N = \frac{\beta}{\beta + 1} \tag{2.3}$$

where β is the ratio of rill erosion to inter-rill erosion (Liu et al., 1999) and can be determined by using the Equation 2.4:

$$\beta = \frac{\frac{\sin\theta}{0.0896}}{3.0(\sin\theta)^{0.8} + 0.56} \quad \textbf{(2.3)}$$

Table 2.1. N exponent for length-slope factor calculation (USDA, 1997).

Slope (%)	Less than 1	1-3	3.5-4.5	Greater than 5
N	0.2	0.3	0.4	0.5

The additional calculations and development involved with the RUSLE constant *N* is intended to assess steeper slopes typically found on construction projects. However, Lui et al. (1999) found that the RUSLE's theoretical approach overestimates the soil erosion expected on slopes steeper than 20% gradient (Liu et al., 1999). Their results show that the USLE's *N* constant for slopes larger than 5% of 0.5 is a more reliable approximation for slopes steeper than 20%.

The coverage factor (*C*) is a coefficient determined by the ASTM D6459 large-scale test. Because factors such as erodibility of the soil and the hydrology of the region cannot be altered, the selection of an appropriate ECB is critical and often the only parameter which can be controlled for erosion prevention (OMAFRA, 2012). For bare-fallow conditions, the *C-factor* is idealized as 1.0 (USDA, 1997). Highway embankments are often compacted for geotechnical stability, and bare soil conditions of the slope are not considered bare-fallow. The Toy et al. (1998) recommends a *C-factor* of 0.45 for bare soil conditions of compacted soils appropriate for conditions of highway embankments.

Land usage and landscape structures such as terracing contribute to the practice factor (*P*) in the RUSLE. The practice factor is mainly influenced by agricultural techniques and in construction applications (*P*) is idealized as 1.0 (Kelsey, 2002). Many construction projects use best management practices to supplement one another (EPA, 2007) to optimize erosion and sediment control. ECBs are usually supplemented by various BMPs which can be theorized as porous barriers (USDA-ARS, 2008). Porous barriers have an efficiency in trapping sediment, and the efficiency takes on the practice factor in the RUSLE calculation. Common BMPs and their practice factors are summarized in Table 2.2.

Table 2.2. Typical practice factor of common construction BMPs (Fitfield, 1991).

Porous Barrier	Practice Factor
Straw Bales	0.8
Gravel Filters	0.8
Silt Fence	0.5
Sediment Basins	0.5

The following sections describe the specifications and procedures for ECB product approval for TxDOT, KDOT, WisDOT, NDOR, IowaDOT, IDOT, and MoDOT. Each state department of transportation specifies testing and ECB properties which supplement the unique hydrology of the state. The other states' product approval procedures were compared to MoDOT's procedure to identify other methods for consideration in developing a new method for

MoDOT. State approval processes for the investigated states are summarized in Table 2.3. Each of the six states investigated is presented with their respective methods of evaluating hydraulic performance of ECBs, ECB index property requirements, and any additional requirements specified for ECBs. Generally, states either use ASTM tests with guidelines provided by NTPEP or testing methods developed by TxDOT and conducted at TTI. The following sections detail the TxDOT methods and methods employed by other investigated states.

Table 2.3. State ECB approval summary.

State	Large-Scale Hydraulic Testing	Index Property Testing	Further Requirements
TxDOT	TxDOT/TTI*	N/A	TxDOT/TTI Germination
Missouri	TxDOT/TTI	N/A	TxDOT/TTI Germination
Wisconsin	NTPEP (ASTM D6459 and ASTM D6460)	NTPEP Index Testing	ASTM D7322 (Germination)
Nebraska	NTPEP (ASTM D6459 and ASTM D6460) or TxDOT/TTI	NTPEP Index Testing	Nebraska In-house Germination Test
Iowa	NTPEP (ASTM D6459 and ASTM D6460) or TxDOT/TTI	NTPEP Index Testing	N/A
Illinois	N/A	Geometry (minimum width, net openings), Mass per Unit Area	N/A
Kansas	TxDOT/TTI	N/A	TxDOT/TTI Germination

*TxDOT/TTI testing discussed in Section 2.3.1

2.3.1 Texas

TxDOT created its own testing facility and ECB tests for slope protection, channel protection, and vegetative enhancement (Landphair et al., 1995). The tests were developed to stress the field performance of the ECB and simulate the type of conditions representative of the State of Texas. For instance, the large-scale NTPEP test ASTM D6459 specifies the rainfall intensities be set at increments of 2, 4, and 6 in/hr. However, this may not be representative of the type of hydrology the ECB would be subjected. Also, the reference soils for ASTM D6459 are also generalized and may not be representative of the local geology of the state. The variability in the hydrology and geology aspect of testing motivated TxDOT to develop its own large-scale testing procedures.

The testing is performed at the Texas Department of Transportation/Texas Technology Institute Sediment and Erosion Control Laboratory. The criterion is divided into two classes based on application: Slope Protection (Class I) and Channel Protection (Class II). Class I Slope Protection ECBs are further classified as specific types such as soil and magnitude of slope gradient. The testing evaluates the ability of the product to prevent erosion occurring from storm events.

The slope protection tests are conducted on a 30-ft long constructed testing bed on an adjustable incline at either 2:1 or 3:1 (H:V) slope. The soil utilized is sterilized prior to testing and the moisture content is kept constant to prevent variability in the results. The two soil types tested at the TTI SEC Laboratory are sand and clay. The sand is classified by the USDA soil classification system as loamy sand, and the clay is classified as clay loam (Li, 2013).

The erosion control product is installed onto the bed as per the instructions provided by the product manufacturer. Testing bed geometry is 30 ft by 5 ft by 9 in, and the testing bed is reconstructed with new soil following each completed test of a given ECB. The test utilizes a rainfall apparatus 14 ft above the testing bed and simulates three increments of 30-minute storms with an intensity of 3.5 in/hr each, 24 hours between tests. Rain drop sizes range from 2.20 to 2.55 mm in diameter simulating more severe storms (Marshal, 1948). Runoff is collected at the base of the testing beds and allowed to settle. The runoff is then weighed, and samples are extracted from the runoff to determine moisture content. The moisture content from the samples is then used to determine the total sediment that was eroded as a result of the experiment. The minimum requirements of the erosion control products for each type of application are shown in Table 2.4.

Table 2.4. TXDOT maximum sediment loss values for Class I slope protection products.

Type A 3:1 Clay ($lb/100ft^2$)	**Type B 3:1 Sand ($lb/100ft^2$)**	**Type C 2:1 Clay ($lb/100ft^2$)**	**Type D 2:1 Sand ($lb/100ft^2$)**
3.38	102.51	3.09	167.25

Achieving Class I Slope Protection certification for any slope also requires the ECB to pass a vegetation cover test. A sample of the erosion control product is installed in a nursery flat elevated at the tested slope, and allowed to grow for 30 days using the warm season perennial seed type for TxDOT's District 17 (TXDOT/TTI Sediment and Erosion Control Laboratory, 2015). Each flat is lined with either sand or clay, depending on the type of Slope Protection the product is being tested. All nursery beds are watered at 0.75 inches per week. Photographs and associated software are used to determine the percent covered following the growing period; the minimum vegetation coverage for product acceptance is 50%.

Class II Flexible Channel Liners are characterized into types delineating the devices in terms of effectiveness under various subjected shear stresses. Class II testing procedure calls for a testing tray to be placed within a flume, and the channel is then subjected to a particular flow estimated to exert a specific shear stress on the channel bed. The trays are prepared prior to the experiment as material liners require vegetation to be present to be able to supplement stabilization. Three testing trays are 30 ft by 1.5 ft by 4 ft in dimension and are prepared with the same fertilizer and seed that are applied to the slope protection vegetation cover tests. Three trays for each specimen are used. The flexible channel liner is installed to each tray, and the specimens are allowed to rest for 30 days. Following the 30 days, each tray is photographically evaluated to determine the vegetation coverage of the tray. The average coverage of the three trays determines if the erosion control product meets compliance to the minimum vegetative coverage of 50% (TXDOT/TTI Sediment and Erosion Control Laboratory, 2015).

Following the growing period and vegetative analysis, the trays are placed into the flume for shear stress testing. The channel is sloped either at 3% or 7% per the manufacturer's request. Each tray is tested at an initial flow beginning with a corresponding shear stress of 2.0 psf, and the test lasts two periods of 20 minutes. Sediment displacement is determined by computer generated grid method with an instrument that runs the span of the flume (TXDOT/TTI Sediment and Erosion Control Laboratory, 2015). The trays are then allowed to rest for a minimum for 48 hours before the test is repeated, increasing the shear stress applied by 1.0 psf after each repetition until material failure occurs by tearing or blanket rupturing or the maximum allowable sediment displacement is observed (Table 2.5). The shear stress requirements the trays met dictate the type of channel liner the erosion control product qualifies (TXDOT/TTI Sediment and Erosion Control Laboratory, 2015).

Table 2.5. TxDOT maximum sediment soil loss for Class II channel protection products.

Type E 0-2 psf Shear Stress (lb)	**Type F 0-4 psf Shear Stress (lb)**	**Type G 0-6 psf Shear Stress (lb)**	**Type H 0-8 psf Shear Stress (lb)**
350	500	620	800

The large-scale tests developed at the TXDOT/TTI SEC Laboratory have shown to have repeatable and reliable results (Li, 2013). Several state departments of transportation rely on the results as their own form of product approval of ECBs, for instance Missouri. These states include: Missouri, Colorado, Delaware, Florida, Kentucky, Louisiana, Nebraska, Nevada, New York, Utah, Virginia, and Kansas which participate through a pooled research fund to support the SEC Laboratory (Transportation Pooled Fund, 2011). As stated, NDOR also participates in the pooled research fund for flexibility and to supplement its own requirements for product approval. TxDOT revised the thresholds of acceptance for its product approval in July 2015 so that the participating states will experience fewer failures utilizing higher quality products (TxDOT, 2015).

2.3.2 Missouri

RECP product approval on MoDOT construction sites references the TxDOT approved products list as its own from its Standard Specifications for Highway Construction (MoDOT, 2015a). MoDOT specifies the submittal processes and procedures of TxDOT to earn placement on MoDOT's approved products list. MoDOT does not accept the NTPEP large-scale testing or the index tests. MoDOT has further requirements for the applications of ECBs and TRMs in the Standard Specifications for Highway Construction. Slope protection applications are specified as ECBs (Table 2.6), and the channel RECPs are listed under the section regarding TRMs (Table 2.7).

Table 2.6. ECB requirements from MoDOT Standard Specifications for Highway Construction.

ECB Type	Netting Type	Service Life	Slope (ft/ft)	Soil Type
Type 1	Single, quickly degradable	45-60 days	3:1 or flatter	Clay
Type 2	Single photodegradable	12 months	3:1 or flatter	Sandy
Type 3	Double photodegradable	12-18 months	2:1 or flatter	Clay
Type 4	Double photodegradable	24 months	2:1 or flatter	Sandy
Type 5	Double photodegradable	36 months	1:1 or flatter	Any

Table 2.7. TRM requirements from MoDOT Standard Specifications for Highway Construction.

TRM Type	Design Shear Stress (psf)
Type 1	3.5-6.0
Type 2	6.1-8.0
Type 3	8.1-10
Type 4	10.1 or greater

2.3.3 Wisconsin

The Wisconsin Department of Transportation utilizes many of the AASHTO NTPEP testing methods. WisDOT considers the results from both large-scale hillslope protection (ASTM D6459) and earthen-channel protection (ASTM 6460) to categorize the applications of the ECBs. The coverage factors specified are based on tests conducted on loam soil as defined by ASTM international (ASTM, 2011b). Wisconsin's soil erodibility and hydrology are both factored in through application of the RUSLE (WisDOT, 2014a). The loam soil is assumed a representative soil texture type of the state and used to better predict field performance of the ECB on WisDOT projects (WisDOT, 2014a). To account for hydrology, WisDOT requires a plot of runoff erosivity (R) versus the coverage factor (C) from ASTM D6459 results. Linear, exponential, and power regressions are to be provided along with the respective coefficients of determination. The coverage factors at a runoff erosivity of 162 for each regression are to be reported.

All NTPEP index tests are supplementary to the large-scale test results as additional requirements. WisDOT separates the ECB requirements into categories of Class I (Table 2.8), Class II, and Class III (Table 2.9) erosion control products. Each class designates service life, with Class III being the longest. The classes are further categorized into various slope and channel design applications. Class I materials have a short-term service life of at least six months. The WisDOT categories of Class I materials are Type A, Type B, Urban A, and Urban B. Urban materials must be comprised of entirely biodegradable materials. Class II erosion control products require a service life of at least three years. The types of Class II materials are

Type A, Type B, and Type C. Type A materials pertain to Jute fiber, and require no submittal for approval (WisDOT, 2014a). Product usage approval is granted through conformance to the material and geometry requirements of the Wisconsin Department of Transportation Standard Specifications for Highway and Bridge Construction (WisDOT, 2014b). Type B RECPs have no restrictions on product materials; however, Type C only allows 100% organic RECPs to be used. Types B and C are intended for slopes up to 2:1 (H:V) or flatter, both requiring a minimum permissible shear stress of 2.0 psf. Class III RECPs pertain to permanent Erosion Control Revegetative Mats (ECRM) and TRMs. ECRMs are intended to be installed on top of the soil, and the TRMs are installed onto the soil with a layer of topsoil placed over the mat. Class III Type A products pertain only to the revegetative mats; TRMs must meet the Type B, C, and D requirements. TRMs also have requirements for thickness and ground cover, which are determined from the NTPEP index tests ASTM D6525 and ASTM D6567, respectively. Their requirements are tabulated in Table 2.10.

Table 2.8. WisDOT Class I Erosion Mats material requirements.

Product Type	Maximum RUSLE Coverage Factor (C)	Minimum Permissible Shear Stress (psf)	Design Channel Shear Stress (psf)	Design Maximum Slope (ft/ft)
A	0.10	1.0	Not to be used in channels	2.5:1
B	0.10	1.5	1.5	2:1
Urban A	0.20	Netted: N/A Non-netted: 1.0	Not to be used in channels	4:1
Urban B	0.10	1.0	Not to be used in Channels	2.5:1

Table 2.9. WisDOT Class III Erosion Mats minimum performance requirements.

Product Type	Maximum RUSLE Coverage Factor (C)	Minimum Permissible Shear Stress (psf)	Design Channel Shear Stress (psf)	Design Maximum Slope (ft/ft)
A	0.10	2.0	2.0	2.:1
B	0.20	2.0	2.0	2:1
C	0.20	3.5	3.5	2:1
D	0.20	5.0	5.0	1:1

Table 2.10. WisDOT Class III Erosion Mats material requirements.

Product Type	Minimum Thickness (in)	Minimum absorption (in^3/yd^2)
B	0.4	450
C	0.7	900
D	0.7	900

The ECB vegetative enhancement determined by the bench-scale test ASTM D7322 (RECP Ability to Encourage Seed Germination and Plant Growth) is an additional requirement for ECB approval. The ECBs are to meet a minimum percentage of germination density as a percentage of biomass density to the controlled bare soil plot. Minimum requirements are 70% vegetation density for sandy soils and 80% for clay soils.

2.3.4 Nebraska

The Nebraska Department of Roads utilizes the testing standards established by AASHTO and NTPEP. The large-scale rain-splash and sheet flow erosion test (ASTM D6459) and the earthen channel shear flow (ASTM D6460) experiment are also required or an equivalent large-scale test recognized by NDOR (NDOR, 2007).

The vegetative enhancement requirement is evaluated from an independent test developed by NDOR. Eight-inch diameter test plots are filled with six inches of commercial topsoil. Either wheat or oat seed is used for the experiment and seeded at a rate of 1.0 psf. Three plots are prepared: one as a bare-soil control, another with the tested ECB, and a third for an ECB already on the NDOR approved products list. Following the 14-day growing period, vegetative biomass is recorded. The test is repeated three times with the average of the three tests as the final result. The tested ECB must meet the minimum vegetative density of 80% germination in comparison to the control plots.

NDOR classifies ECBs into RECPs and TRMs. This classification separates the erosion control blankets by temporary (Class I) and permanent measures (Class II). Class I RECPs are separated into various types depending on service life and design slope; the types and these characteristics are tabulated in Table 2.11. The maximum slope is assumed for all slopes regardless of soil type or length. NDOR also specifies various material property guidelines for each type based on the index test results from NTPEP. The index test and general dimension requirements for the blankets are illustrated in Table 2.12. NDOR specifies that the TRMs to be used primarily as a channel protection device. All TRMs require 0.50-in by 0.50-in net opening size and minimum roll width of 6.5 ft. The required shear strength of each TRM type and its respective properties is shown in Table 2.13.

Table 2.11. NDOR design slope requirements for Class I ECBs.

Product Type	**Description**	**Service Life (months)**	**Maximum Slope (ft/ft)**	**Maximum RUSLE Coverage Factor (C)**	**Maximum Permissible Shear Stress (psf)**
Class I A	Slope Protection Netting	24	3:1	N/A	Not to be used in channels
Class I B	Light Weight quick degrading ECB	3	4:1	≤0.15@3:1	Not to be used in channels
Class I C	Light Weight Single Net ECB	12	3:1	≤0.20@3:1	Not to be used in channels
Class I D	Light Weight Double Net ECB	12	2.5:1	≤0.20@2:1	1.75
Class I E	Medium Weight Double Net ECB	24	2:1	≤0.25@1.5	2.00
Class I F	Heavy Duty ECB	36	1:1	≤0.25@1:1	2.25

Table 2.12. NDOR material requirements for Class I ECBs

Product Type	Description	Material Fill	Minimum Roll Width (feet)	Minimum Thickness (ASTM D6525) (inches)	Mass/Unit Area (ASTM D6475)	Minimum Net Size Opening	Minimum Light Penetration (ASTM D6567) (%)	Minimum Tensile Strength (ASTM D5035) (lb/ft)
Class I A	Slope Protection Netting	Photodegradable Black Synthetic Mesh	6.5	N/A	2.2 $lb/1000ft^2$	0.75 in by 0.75 in	N/A	N/A
Class I B	Light Weight Degrading ECB	Straw or Excelsior	4.0	0.25	0.40 lb/yd^2	0.50 in by 0.50 in	10%	N/A
Class I C	Light Weight Single Net ECB	Straw or Excelsior	6.5	0.25	0.50 lb/yd^2	0.50 in by 0.50 in	7%	N/A
Class I D	Light Weight Double Net ECB	Straw or Excelsior	6.5	0.25	0.50 lb/yd^2	0.50 in by 0.50 in	7%	75
Class I E	Medium Weight Double Net ECB	Straw/Coconut, Excelsior, or Coconut Fibers	6.5	0.25	0.50 lb/yd^2	0.50 in by 0.50 in	7%	100
Class I F	Heavy Duty ECB	Coconut Fibers	6.5	0.25	0.50 lb/yd^2	0.50 in by 0.50 in	7%	100

Table 2.13. NDOR material requirements for Class II TRMs

Product Type	Required Shear Strength (ASTM 6460/approved testing facilities) (vegetated) (psf)	Minimum Thickness (ASTM D6525) (inches)	Material Fill	Mass/Unit Area (ASTM D6566) (oz/yd²)	Machine Direction Tensile Strength (ASTM D6818) (lb/ft)	Transverse Direction Tensile Strength (ASTM D6818) (lb/ft)	Minimum Light Penetration (ASTM D6567) (%)	Flexibility (ASTM D6567) (in.-lb.)
Class II A	6.0	0.25	Excelsior, Coconut, or Polymer Fibers	10	125	125	20%	0.026
Class II B	8.0	0.50	100% UV Stabilized Polypropylene Fibers	10	150	150	20%	0.026
Class II C	10.0	0.50	100% UV Stabilized Polypropylene Fibers	10	175	175	20%	0.026

2.3.5 Iowa

The Iowa Department of Transportation uses NTPEP test results for the large-scale and index-property testing to determine acceptance on the IowaDOT approved products list. The classes are separated as either a RECP or TRM. RECPs are further separated into the appropriate types by performance abilities and service life. The RECP requirements for IowaDOT approved products are tabulated in Table 2.14. Although IowaDOT utilizes all of the NTPEP tests as a part of the approved products list criteria like NDOR and WisDOT, one difference is that all RECPs are eligible to be installed as a channel protection device if the maximum blanket shear stress is adequate for the design shear stress (IowaDOT, 2006). NDOR and WisDOT do not permit any ECB to be used in channels with the maximum shear stress greater than 1.75 psf and 1.5 psf, respectively.

Table 2.14. IowaDOT RECP performance and material requirements

Type	Product	Service Life (months)	Mass/Unit Area ASTM D6475 Minimum (lb/yd²)	Maximum Slope (ft/ft)	Maximum Channel Permissible Shear Stress ASTM D6460 (psf)
1B	Netless Rolled Wood Excelsior	3	0.5	4:1	0.5
1C	Single Net Rolled Wood Excelsior	3	0.5	3:1	1.5
1D	Double Net Rolled Wood Excelsior	3	0.5	2:1	1.75
2B	Netless Straw Mat/Straw-Coconut Fiber Mat	12	0.4	4:1	0.5
2C	Single Netted Straw Mat/Straw-Coconut Fiber Mat	12	0.4	3:1	1.5
2D	Double Netted Straw Mat	12	0.4	2:1	1.75
3B	Double Netted Straw-Coconut Fiber Mat	24	0.4	1.5:1	2.0
4	Double Netted Coconut Fiber Mat	36	0.4	1:1	2.25

Similarly to ECBs, TRMs are also permitted for slope and channel applications. IowaDOT further specifies the testing of the TRM by its ability to resist deterioration by exposure to the sun (ASTM D4355 Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus) (IowaDOT, 2014). The necessary requirements for TRM product approval are shown in Table 2.15.

Table 2.15. IowaDOT performance and material requirements for TRMs

Type	Thickness ASTM D6525 (inches)	Tensile Strength Machine Direction ASTM D6818 (lb/ft)	UV Resistance ASTM D4355 (% Tensile Strength Retained)	Maximum Permissible Channel Shear Stress (psf)	Slope Requirements (ft/ft)
1	0.25	125	80% @ 500 hr	7	1:1 or less
2	0.25	240	80% @ 1000 hr	10	1:1 or less
3	0.25	750	80% @ 1000 hr	12	1:1 or greater
4	0.25	3000	90% @ 3000 hr	15	1:1 or greater

2.3.6 Illinois

Illinois Department of Transportation does not have an apparent approved products list of ECBs acceptable to be used as erosion control devices. The IDOT Standard Specifications for Road and Bridge Construction 2012 (IDOT, 2012) references material requirements for erosion control products, but no approved products list was mentioned as in the case of other transportation agencies investigated. IDOT separates requirements for ECBs and TRMs as shown in Table 2.16 and Table 2.17, respectively. Coconut fiber is only allowed in combination with straw fiber and in ECBs meeting the same material requirements for the straw knitted mats stated in Table 2.16. Permissible densities of the combined material are 30% coconut fiber, 70% straw content.

Table 2.16. IDOT Standard Specifications for ECBs

Product	Minimum Width	Mass/Unit Area (ASTM D6475) (lb/yd^2) 10% tolerance	Net Openings
Excelsior Blanket	24 in	0.63	5/8 in by 5/8 in to 2 in by 1 in sized to application
Knitted Straw Mat	6.5 ft	0.5	3/8 in by 3/8 in variance of 1/8 in allowed
Heavy Duty Excelsior Blanket	24 in	1.45	0.5 in by 0.5 in
Heavy Duty Knitted Straw Mat	6.5 ft	0.5	0.5 in by 0.5 in

Table 2.17. IDOT Standard Specifications for TRMs

Tensile Strength ASTM D6818 (lb/ft)	UV Resistance ASTM D4355 (% Tensile Strength Retained)	Resiliency Minimum ASTM D6524 (% Thickness Retained)	Allowable Shear Stress ASTM D6460 (psf)
150	80	80	8

3 Geology Analysis of Missouri

3.1 Introduction

The large-scale testing of the TxDOT utilizes various soil conditions to measure field performance of ECBs (Li, 2013); and some ECBs are only acceptable to be used on certain soil conditions (TXDOT/TTI Sediment and Erosion Control Laboratory, 2015). The geology of the State of Missouri was investigated to identify common soil characteristics at MoDOT construction sites and which ECBs would be acceptable to use. The following section describes the process of formulating soil erodibility values (*K-values*) for use in the RUSLE as described in Section 2.3. The *K-values* were developed from a MoDNR surficial soil layer map (MoDNR, 2007) and information on different soil phases in the Geology and Soils Manual 1962 (Missouri State Highway Commission, 1962). The *K-value* determination procedure is outlined in Figure 3.1 and detailed in subsequent sections, and an example calculation for a soil is provided at the end of the section illustrating this process.

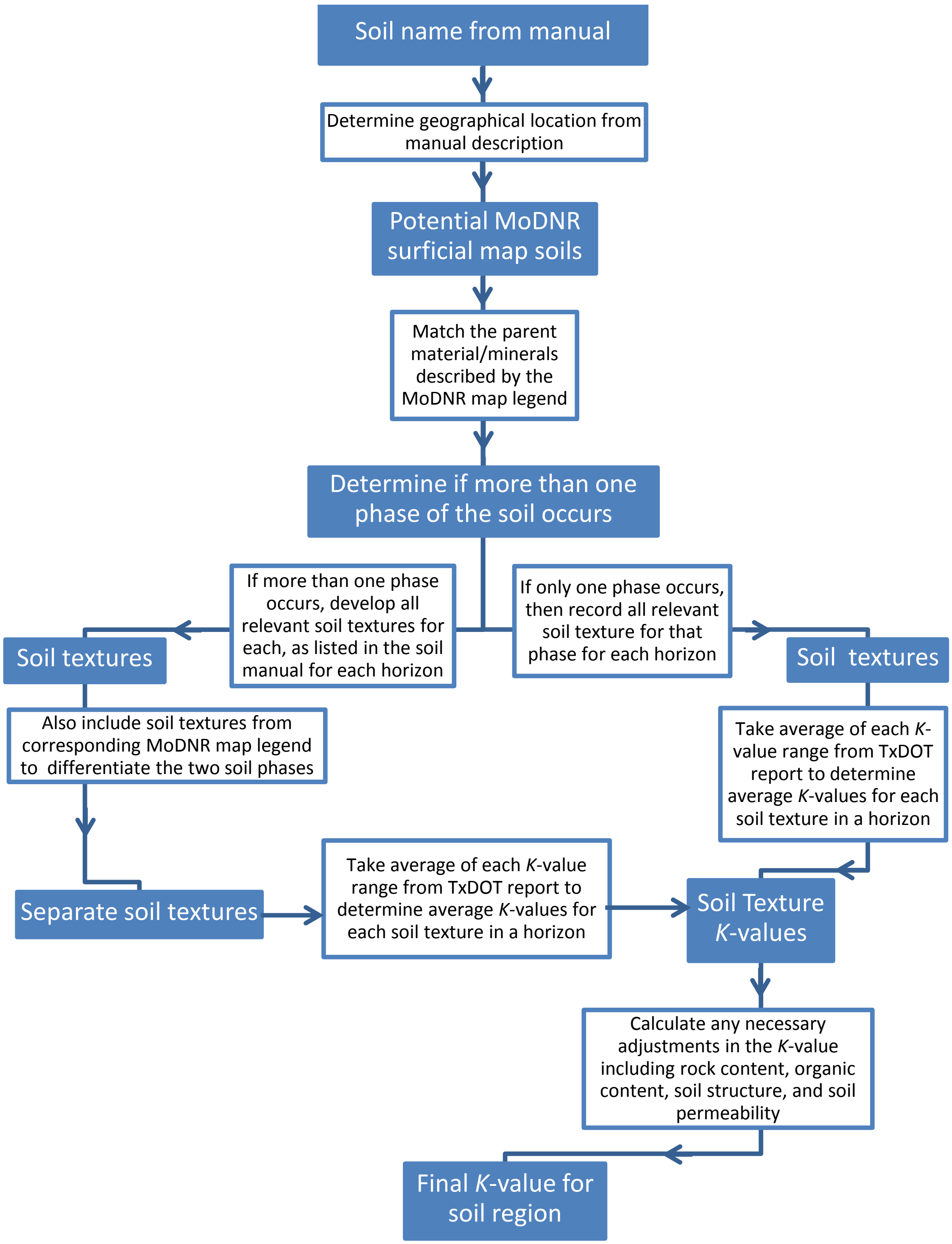

Figure 3.1. Flowchart of *K-value* determination.

3.2 MoDNR Surficial Analysis

The *K-value* analysis utilized ArcMap in conjunction with geographic soil data layers published by MoDNR (MoDNR, 2007), given by Figure 3.2. The map legend described the surficial layers so that appropriate connections to the soil information in the Geology and Soils Manual 1962 could be made. The surficial layers show Missouri to contain the following: alluvium, loess, glacial drift, residuum, bedrock, and surface water.

Alluvium is mainly composed of sediment deposited by river and stream systems located near river banks and stream valleys (Kleiss, 2000). The surrounding areas of the lakes in Missouri are also locations of various alluviums. Alluvial textures range from sand, silt, and clay. Specific alluvial textures are described on the MoDNR surficial map legend.

Loess soils result from the glacial transport of silty material. Loess was frozen silt contained in glaciers; during thawing of the glaciers, the sediment was deposited. Wind then transported the soil to its resting position (Minor, 1974). These Aeolian processes have scattered loess throughout the State of Missouri blanketing areas with thick to thin layers of the soil. The thickest deposits of loess are concentrated in relatively flat topographies (Missouri State Highway Commission, 1962).

Glacial drift develops from glacial melting of sediment blanketing the region. Glacial drift soils are generally a clay or sandy texture and predominantly reside in Northern Missouri. Glacial drift is frequently blanketed by loess; however, erosion of the fine-grained loess material has caused glacial drift to become the surface soil in many areas (Minor, 1974).

Residuum develops from the long-term weathering of exposed rock. Residuum texture is predominantly clay with varying amounts of the sand, gravel, and stone content. The residuum soil types have different mineral parent material such as chert, limestone, dolostone, and shale (MoDNR, 2007). The mineral composition dictates how the rock weathers and the soil type that will result from that weathering including soil grain size and structure.

Bedrock is the exposed rock at the ground surface from various geologic time periods. The types of bedrock outcropping are dependent on the period of the formation of the rock, such as Ordovician Period or the Mississippian Period (MoDNR, 2007). In perspective to the previous soils, bedrock is relatively unweathered and is virtually unaffected by slope erosion like alluvium, residuum, glacial drift, or loess.

Surface water is the numerous networks of streams, reservoirs, and lakes found within the State of Missouri. Surface water does not have soil or geologic properties, however, has implications to the surrounding soil types and topographies.

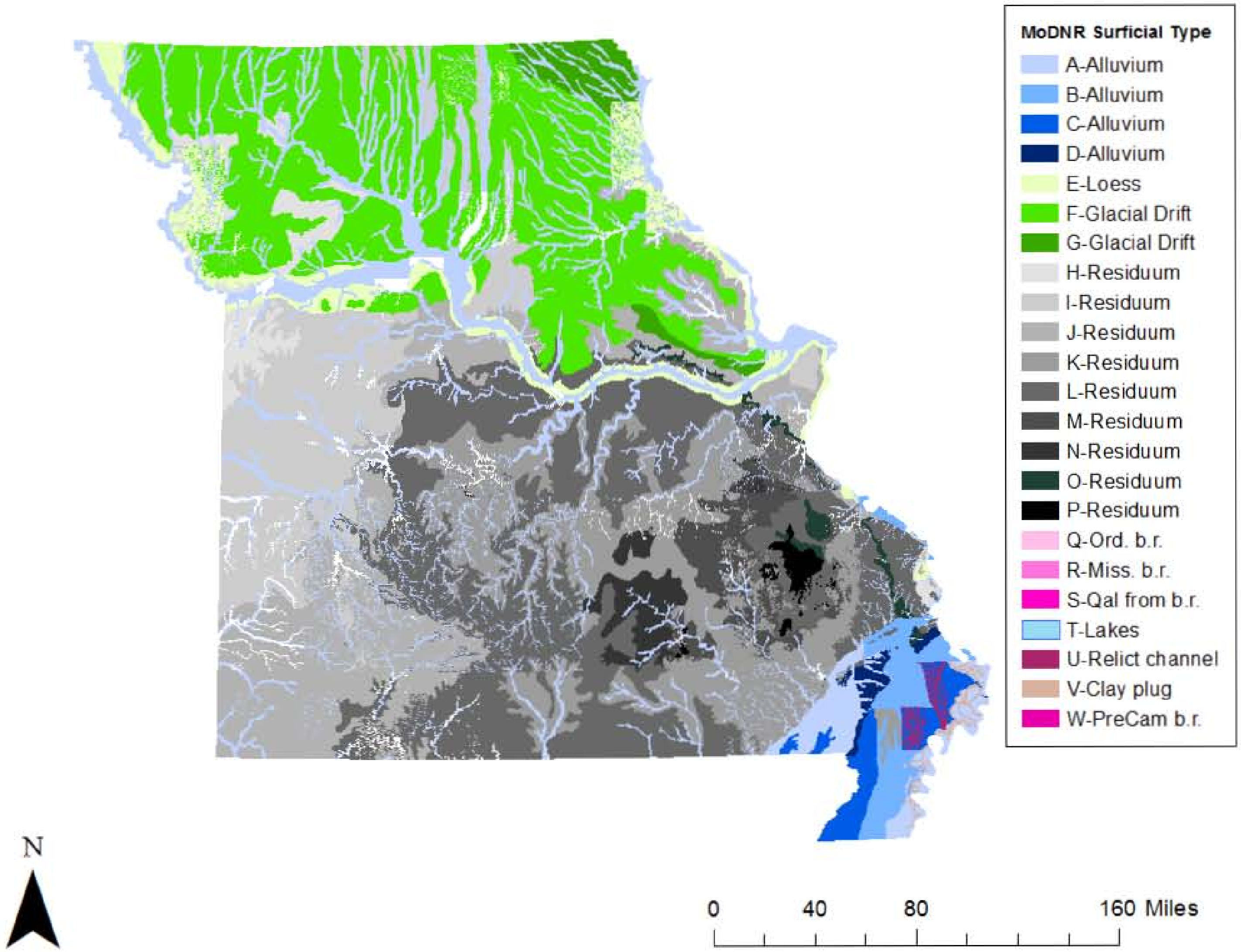

Figure 3.2. MoDNR surficial map of Missouri (MoDNR, 2007).

3.3 Soil Texture

Different soil types listed by the MoDNR surficial map have a range of soil textures classified by USDA convention (Figure 3.3) (Soil Survey Staff: Bureau of Plant Industry, 1951). USDA classifies soil having a percentage of sand, silt, and clay grain sizes. The classification separates grain sizes into three categories based on particle diameter size: 0.05 mm or larger is sand, particle diameter sizes 0.05 to 0.002 mm is silt, and smaller than 0.002 mm is clay.

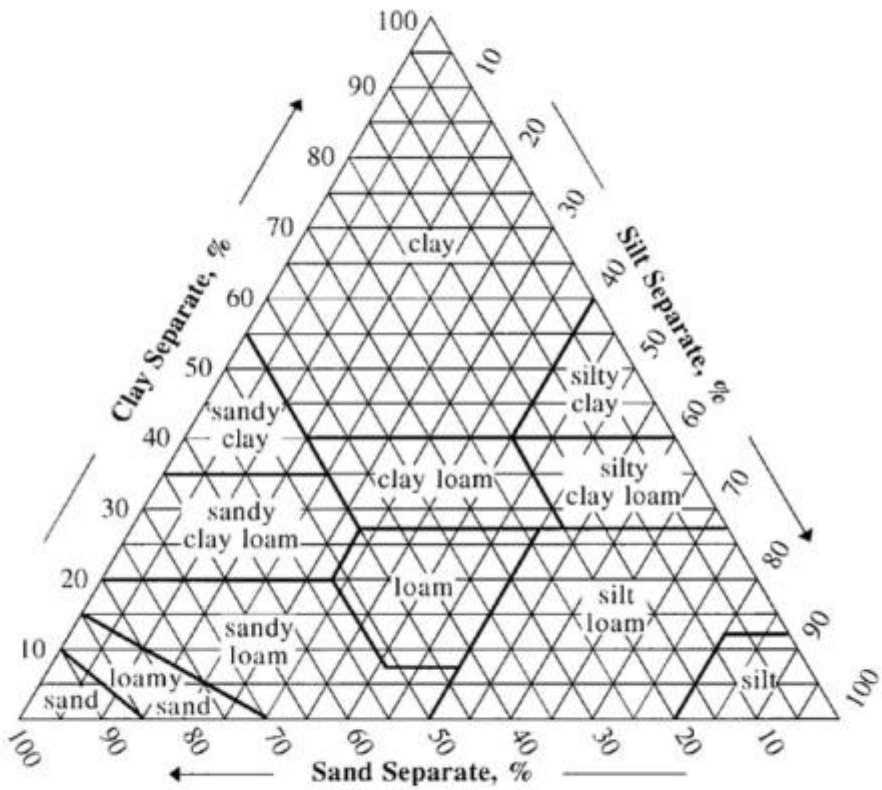

Figure 3.3. USDA soil texture triangle (Soil Survey Staff: Bureau of Plant Industry, 1951).

The MoDNR surficial map lists the entire range of soil textures for a soil type listed; however, these texture ranges are not region specific. The soil type observed in a particular location may contain only a portion of the soil textures that the description implies. Soils are classified mainly on parent rock material, mineral composition, color, and age of deposition. A more accurate analysis is necessary to determine more representative soil textures found within a particular location.

The Geology and Soils Manual describes specific locations of certain soil textures (Missouri State Highway Commission, 1962). The manual divides Missouri into four physiographic regions: the Ozarks, Western Plains, Glacial Plains, and the Southeast Missouri Lowlands (Figure 3.4). Each region classifies the soils within the region as alluvial, residual, glacial till, or loess, similar to the classification convention used by the MoDNR surficial map. Names for soil phases in each region are delineated by soil texture, plasticity, maximum compaction density, silt and clay content, color, and mineral composition. The location of the soil phase within the physiographic region is also stated allowing for determination of specific soil textures within areas of a soil type as shown in Figure 3.2.

Figure 3.4. Physiographic map of Missouri (Missouri State Highway Commission, 1962).

3.4 Soil Erodibility

Following the location of soil textures, regional soil erodibility values (*K-values*) were determined for use in the RUSLE as described in Section 2.3. The Geology and Soils Manual 1962 describes each soil type as several horizons above the bedrock. Each horizon is characterized as a range of soil textures typically encountered. Each also describes important soil traits such as rock and chert content, organic content, permeability, and grain angularity, all contributing factors to developing a *K-value* for a soil (Kelsey, 2002). For the analysis, the first two horizons were evaluated to determine a *K-value* for a region. Each horizon has varying thicknesses caused by local topography, erosion, and construction activities. The third horizon, which was not considered, is defined as "partially weathered" (Missouri State Highway Commission, 1962) and lies above the parent bedrock material. The location illustrates the lack of opportunity to experience erosion. The soil properties provided in the manual were compared to the soil features provided by the MoDNR surficial map such as color, parent material, and location. An example calculation for a region's soil erodibility is presented in Section 3.5.

The soil textures described are classified by the USDA system. The Soil Texture Triangle shown in Figure 3.3 is the graphical representation of the USDA classification. Erickson (1977) combined the graphical form of the USDA classification with soil erosion to create the Soil Erodibility Triangular Nomograph (Figure 3.5). The nomograph aids in the selection of an erodibility factor for any grain size distribution of soil. The graph assumes 2% overall organic matter content and 0-15% rock content. The nomograph is a baseline for erodibility and adjustments for organic content, soil structure, permeability, and rock content can applied as necessary to determine a representative *K-value* for a given soil (Bursztynsky et al., 1986). The tables referenced for the *K-value* adjustments are located in Appendix A.

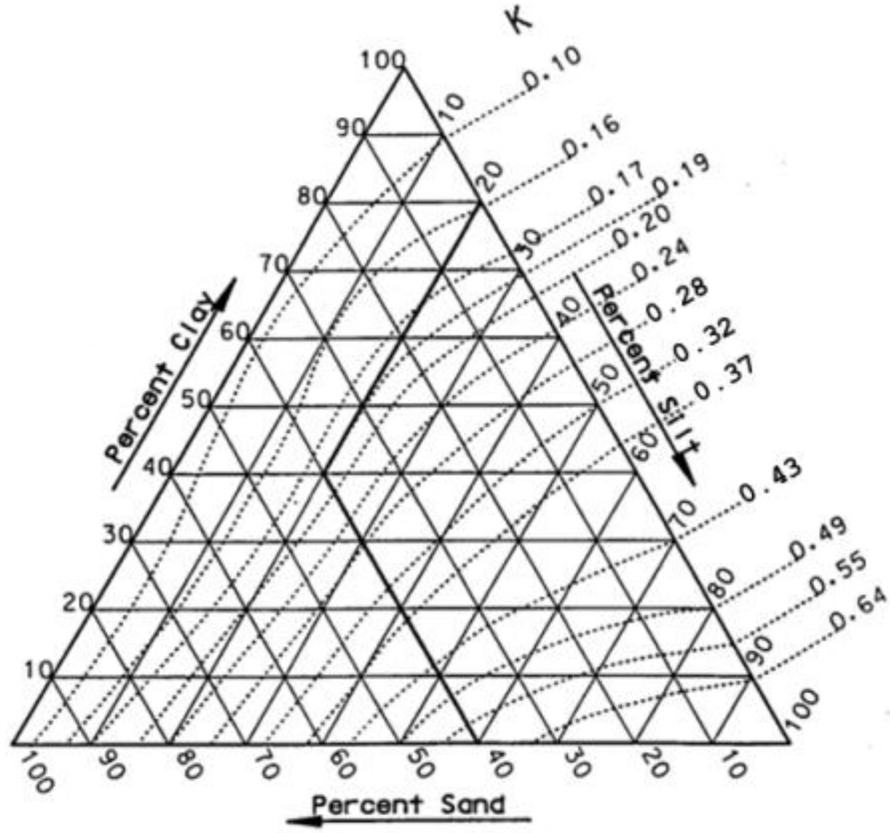

Figure 3.5. Soil erodibility (*K-value*) triangular nomograph (Erickson, 1977).

The average *K-value* range for a soil texture was used in the *K-value* analysis of Missouri to encompass all grain-size compositions of a soil texture. *K-value* deductions or additions were addressed based on the appropriate characteristics noted about the horizon. The arithmetic mean *K-value* of the horizon was calculated and the two horizons were averaged together to determine the final *K-value* for the region.

The *K-values* for each soil type identified in the Geology and Soils Manual are identified in Table B.1 of Appendix B. Each soil polygon on the MoDNR surficial map was assigned the appropriate K-value from the values determined in Table B.1. Some soils shown in the MoDNR surficial map encompass a large area and the soil represented in the shape could consist of more than one which was identified in the soils manual. An arithmetic average was taken to account for both soils within these shapes. The K-value map generated from the analysis is shown in Figure 3.6.

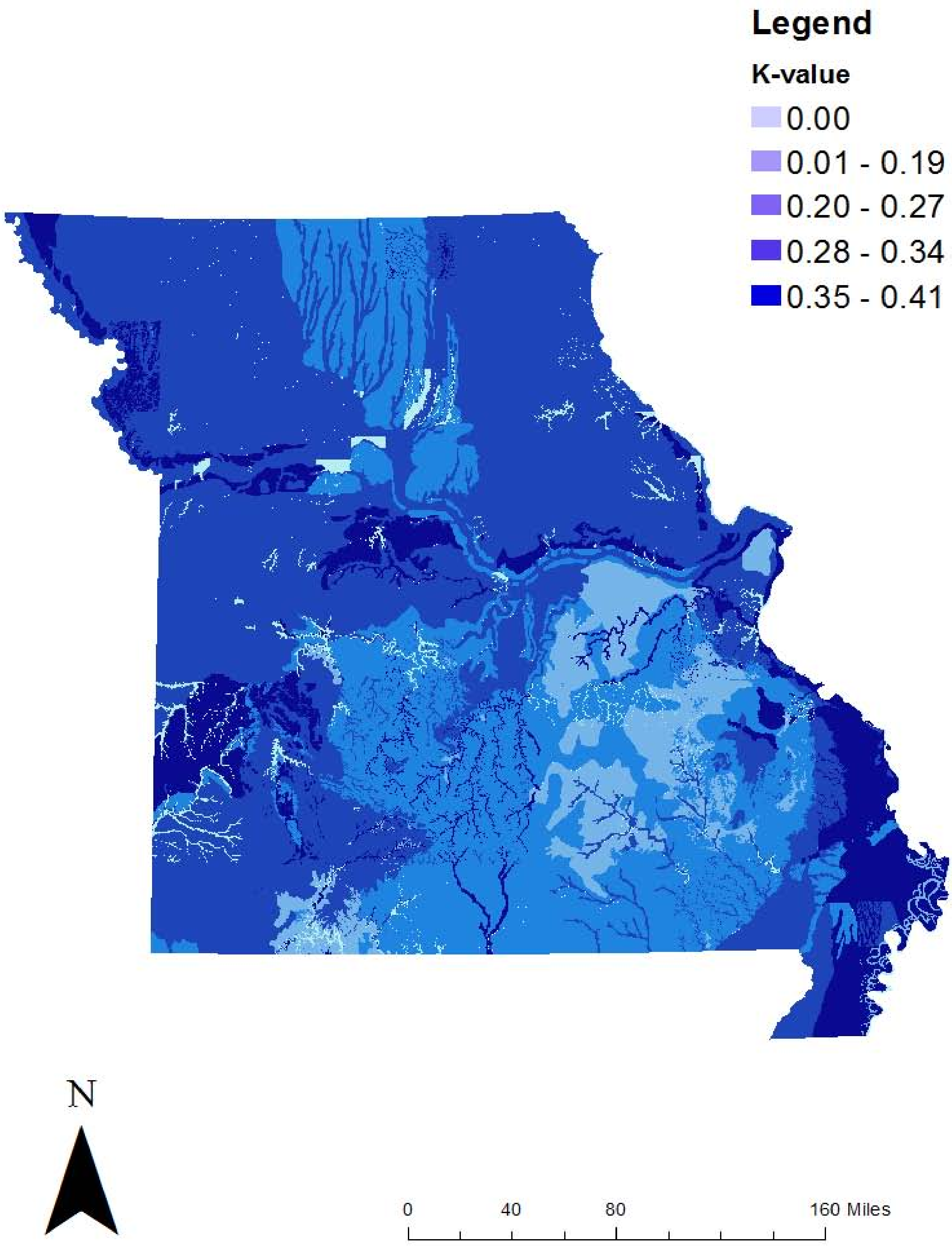

Figure 3.6. *K-value* map of Missouri.

3.5 Sample Soil Erodibility Calculation

A sample soil erodibility factor calculation is presented to illustrate the process described by Figure 3.1. Every soil listed in the Geology and Soils Manual 1962 was used in the K-value calculation of Missouri following this convention for consistency. Ashe soil was used for the example.

The Geology and Soils Manual 1962 describes the Ashe soil to be located in the Ozarks in the Saint Francois Mountain region. The parent rock material for Ashe is primarily granite which only matches the parent material description of P-Residuum from the MoDNR map legend outlined in yellow (Figure 3.7). Although Ashe soil is listed to have the suggestion of forming from limestone, because the majority of the Ashe soil is granite, only granite was considered for the parent material. Thus, Ashe consists of only P-Residuum. Only one phase of the soil occurs in the region, and both Horizon A and Horizon B were evaluated for various soil textures present. The soil texture listed in Horizon A was silt loam, and Horizon B notes silty clay throughout the layer.

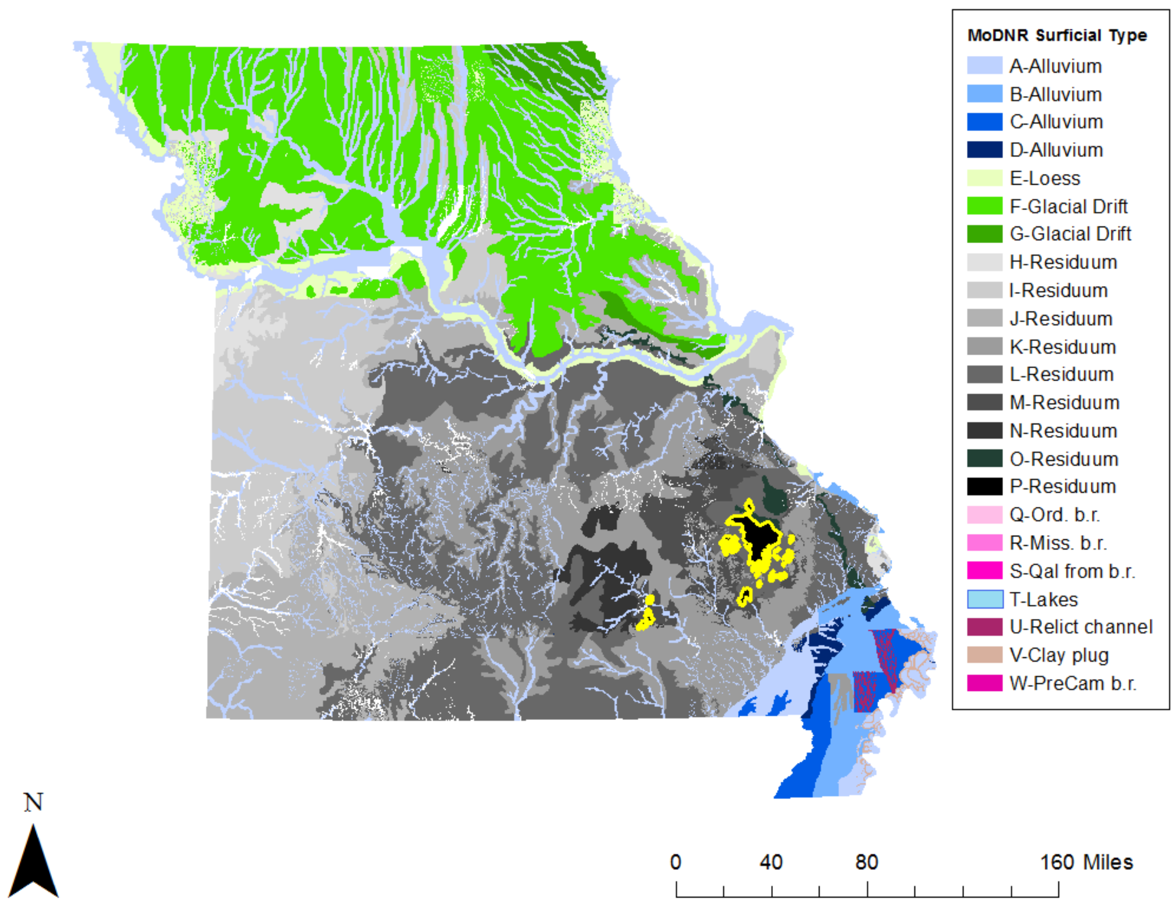

Figure 3.7. P-Residuum represents the Ashe soil highlighted in yellow.

Soil textures were used to find initial K-values as shown in Erickson's Erodibility Nomograph (Figure 3.5). TxDOT utilized the USDA texture triangle (Figure 3.3) and the

Erickson Erodibility Nomograph to develop a range of *K-values* for soil textures based on the possible composition of sand, silt, and clay particles for each (TxDOT, 1994). The TxDOT *K-value* range can be found in Appendix A. The average of the range was used for assigning *K-values* for soil textures in the horizon erodibility calculations.

The silt loam found in Horizon A has a *K-value* of 0.405. As stated in Section 3.4, the Erickson Triangular Nomograph assumes 2% organic matter and 0-15% rock content which may not be representative of the characteristics of a given soil. Adjustments may be necessary for an accurate calculation. Rock content is accounted for first as the rock content adjustments substitutes the initial *K-value* approximation with a composite one from a list of empirical values in contrast to the addition and subtraction adjustments of organic matter, permeability, soil structure, and angularity corrections.

The Geology and Soils Manual notes that the Ashe horizon A contains "considerable content of stone fragments" making an adjustment, as appropriate. The corrected *K-values* for various unadjusted, initial erodibility factors are illustrated in Table A.2 of Appendix A. Because the rock content adjustment for the silt loam of 0.405 is not listed in the table, the next highest *K-value* of 0.43 is used as a conservative approximation. Despite being described as "considerable", the percent rock content by volume was assumed to be 15-35% to account for areas where rock content may not be as high, such as the bottom of slopes and the valleys between the mountains (Missouri State Highway Commission, 1962). Using Table A.2 for a *K-value* of 0.43, the rock content adjusted *K-value* for Horizon A was determined to be 0.24.

Horizon A was then corrected for organic matter, soil grain angularity, and soil porosity. The base organic matter is at 2% and is assumed normal unless fertility or organic content is specified otherwise. The manual states Ashe is low in fertility resulting from the granite parent material, rock content, and rough topography (Missouri State Highway Commission, 1962). For low organic content, 1% organic matter is assumed. From Table A.3, adding 0.05 to the *K-value* is specified for erodibility factors between 0.20 and 0.40. Ashe was not specified with any particular angularity which would merit adjustment or any high compaction/porosity which would affect soil drainage. Further adjustments in these categories are unnecessary. Totaling all *K-value* corrections adds 0.05 from low organic content to the 0.24 determined form the rock content, yielding 0.29 for the Ashe Horizon A.

Horizon B is investigated similarly to the top layer. The silty clay has an erodibility factor of 0.22 (TxDOT, 1994). The horizon is described as "very few or no rock fragments", which makes the initial *K-value* calculation require no further rock content adjustment. The layer is low in fertility similar to Horizon A and the addition of 0.05 the appropriate correction. Soil angularity is not specified and assumed normal. The compaction and porosity also is not mentioned and assumed normal as well. The final *K-value* for Horizon B is calculated with the sum of 0.22 and 0.05 becoming 0.27. With both horizons calculated, the final *K-value* for the Ashe soils is calculated by taking the average of Horizon A and B resulting in a final erodibility factor for the Ashe soil of 0.28.

4 Field Site Investigation

Observing the field performance of an ECB is critical in understanding the variety of factors which affect the ECB's ability to control erosion. One site, located on Missouri Route N, was established in coordination with ongoing MoDOT construction projects which would utilize ECBs. Two ECB products, classified as Type 2 and Type 3, were installed on site while documenting site preparation and geometry. The ECBS were monitored throughout the study period (May 6, 2015 to January 14, 2016) including soil analysis, stormwater runoff testing, and germination.

4.1 Site Location and Layout

The field site was located near Wentzville, MO spanning approximately six miles from Route Z to Sommers Road along Route N just east of the intersection of Route N and Hepperman Road (Figure 4.1). The project's location within the St. Louis area is shown in Figure 4.2. Construction at this site included shoulder widening, pavement resurfacing, and grading activities. The project was conducted in two phases: from Route T to Route Z and from Route Z to Sommers Road. Much of the project required some form of excavation and grading, and the shoulder widening introduced re-grading the recovery areas along the sides of the road. This led to exposed slopes along the right of way making the usage of ECBs appropriate.

Figure 4.1. Aerial view of the site located on the southern side of Route N (Google, 2015).

Figure 4.2. Map of Saint Louis identifying Route N Site location (Google, 2015).

The topography of the study reach was surveyed on May 6, 2015 using a Scanstation II LiDAR. The LiDAR raw data were inputted into ArcGIS and converted into a triangulated irregular network (TIN). Slopes were determined by dividing the site into 10-ft sections, slopes were determined at each profile, and these slopes were averaged to obtain a representative value for the site. Increments at the location of the coconut wattles were skipped to prevent non-representative slope determination, and sections at both ends of the study reach were included in the calculation. The average slopes for the Type 2 ECB was 4.12:1 (H:V) and 3.09:1 (H:V) for the Type 3 ECB. The site layout is shown in Figure 4.3. Profiles 1-24 are for the Type 2 ECB, and profiles 25-40 are the Type 3 ECB. A local datum was used for determining elevations.

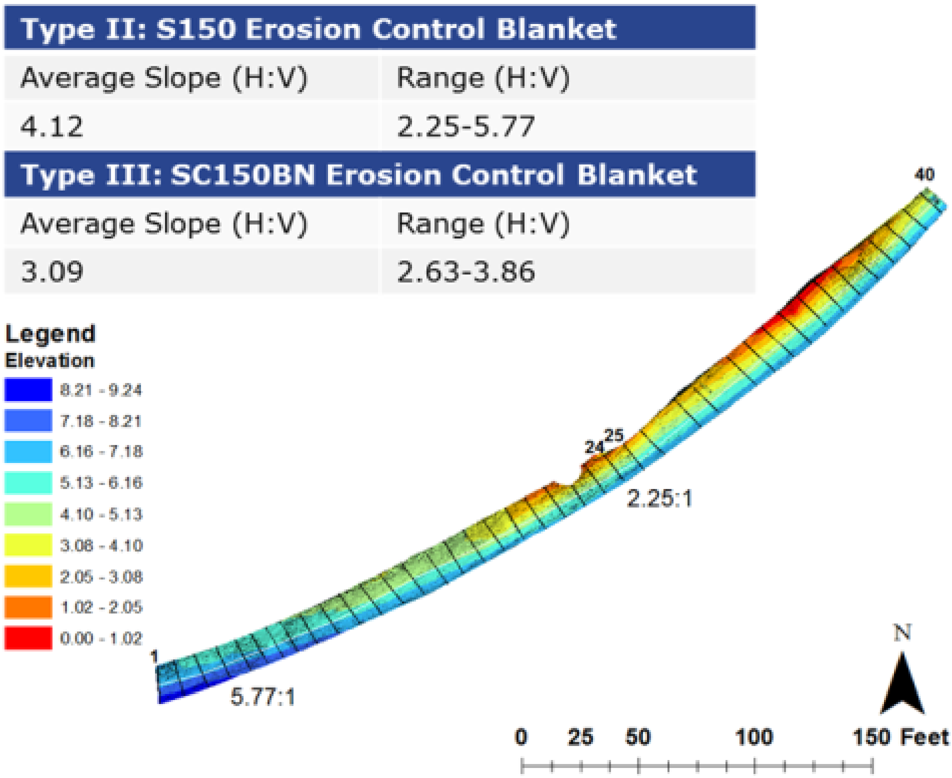

Figure 4.3. Elevation view of the Route N Site (all dimensions in feet).

4.2 ECBs at Field Site

Two erosion control blankets were used to assess field performances between products. The ECBs installed were classified as Type 2 and Type 3 as per MoDOT's Standard Specifications for Highway Construction (MoDOT, 2015a). The Type 2 and Type 3 ECBs were both manufactured by Tensar North American Green (North American Green 2016a, 2016b) Locations for the manufacturer's specification sheets for both blankets are provided: (Type 2) and (Type 3). Nine-ft samples of both ECB types were collected for index-property testing to compare reported typical manufacturer properties to the actual properties of the ECBs used. The samples were tested for tensile strength (ASTM D6818), mass per unit area (ASTM D6475), thickness (ASTM D6525), and light penetration (ASTM D6567). The results of the independent testing for both blankets are shown in Table 4.1. The tensile strength for the Type 3 ECB differed significantly from the typical manufacturer specifications. The ECB was tested to be weaker than the expected strength for both the machine and transverse directions. The Type 2 machine directional tensile strength adequately met the manufacturer expected strength with the average breaking strengths within the expected strength accounting the standard deviation to the true mean of the test results. The tensile strength of the Type 2 ECB in the transverse direction was weaker than what was expected even accounting for the standard deviation. The average and standard deviation of the Type 2 mass/unit area was also not found to be within the typical values. Further, the tested thickness for the Type 3 ECB did not match the excepted manufacturer values.

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Table 4.1. Independent test results and manufacturer specifications for both blankets.

ASTM Test		ECB Type 2 Test Results			ECB Type 3 Test Results		
		Manufacturer Specifications	Average	Standard Deviation	Manufacturer Specifications	Average	Standard Deviation
Tensile Strength (6818)	**MD - Strength (lb/ft)**	169.2	172.8	2.3	164.4	94.8	3.0
	TD - Strength (lb/ft)	164.4	118.8	3.6	226.8	99.6	1.0
	MD - Elongation (%)	17.2	17.3	3.4	7.2	35.2	8.1
	TD - Elongation (%)	33.1	16.9	4.0	10.1	40.3	7.0
Thickness (6526)	**Thickness (in)**	0.360	0.327	0.046	0.280	0.461	0.085
Light Penetration (6567)	**Light Penetration (%)**	9.8	12.2	1.4	14.1	22.1	12.3
Mass per Unit Area (6475)	**Mass per Unit Area (oz/yd^2)**	10.52	9.22	0.89	9.66	7.81	1.99

The Type 2 blanket was the S150 Erosion Control Blanket manufactured by Tensar North American Green (North American Green, 2016a). Type 2 blankets are intended for 12-month applications on 3:1 slopes or flatter with clay soil (MoDOT, 2015a). Figure 4.4 is a photograph of the Type 2 SC150 ECB, which has a material composition of 100% straw. The netting was a polypropylene photodegradable double-net threading.

Figure 4.4. Photograph of Type 2 ECB.

The Type 3 ECB installed on site was the SC150BN Erosion Control Blanket manufactured by Tensar North American Green (North American Green, 2016b). MoDOT's construction specifications show the Type 3 ECBs to be used on 2:1 or flatter slopes with sandy soils (MoDOT, 2015a). Typical lifespan of the Type 3 products following installation ranges from 12-18 months. The SC150BN Erosion Control Blanket consists of 70% straw fiber and 30% coconut fiber. The Type 3 blanket is threaded with a double-net configuration of natural organic fiber material. Figure 4.5 is a photograph of the Type 3 ECB.

Figure 4.5. Photograph of Type 3 ECB.

4.3 Site Visit Methodology

Site visits were conducted to assess various qualities of the ECBs to meet compliances to the MoDOT SWPPP including: vegetation reestablishment and control of excessive erosion. This section details field data collection and documentation methods, and Section 4.4 provides the resulting data from the field investigation. The initial site visit recorded site conditions from field observations and the extracted soil and ECB samples. The ongoing visits observed the ECB performance including overall vegetation growth, erosion control effectiveness, and tracked the rainfall for the site. Typical monitoring consisted of taking site photographs, extracting precipitation data, and recording ECB germination counts. Visits during periods of rainfall allowed for the collection of stormwater runoff samples. Site visits were conducted approximately once every two weeks beginning on May 6, 2015 and ending on January 14, 2016.

An initial visit was made on April 30 to document ECB site conditions and extract soil and ECB samples. The ECBs were anchored using 6 inch 11-gauge G-Pin staples, and the seed for re-vegetation was Kentucky Tall Fescue applied at 10-14 lb/1000ft². The installation methods appeared to have differed from the manufacturer installation recommendations provided by Tensar North American Green. The recommendations call for the ECB to be trenched at the top of the slope to better secure the blanket from being undermined (North American Green, 2016c); however, the ECBs at the Route N site were not trenched. North American Green (2016b) provides full installation recommendations for the Type 2 and Type 3 ECBs used in the field study. The study site had the ECBs installed prior to the first site visit, however, a nearby span of slope prepared for ECB installation was used to collect soil samples and observe pre-installation conditions. The grading and surface preparation of that soil was documented and confirmed as representative of the preparation used for the study site (Figure 4.6). Soil samples extracted were from this adjacent reach and tested for compaction, grain size distribution, and soil Atterberg Limits. The test results were used for classifying the soil and determining an estimated erodibility factor as used in the RUSLE.

Figure 4.6. Roadside slope prior to ECB installation.

The second site visit consisted of site photographs, sand cone compaction tests, soil sample extraction, nuclear density compaction tests, and LiDAR surveying scanning. Photographs were taken every visit as a visual assessment of erosion and vegetative reestablishment. The second visit served as a baseline for subsequent visits. Sand cone testing measures the in-place density of a slope and was performed in accordance to ASTM D1556/1556M specifications. This density is typically compared to a maximum density to determine relative compaction (ASTM, 2015). Soil compaction impacts soil erodibility and vegetative growth. Soils have definitive density limits that may restrict the growth of root penetration and overall growth (Summer, 1991). The soil sample extracted during sand cone testing was tested for the in-place moisture content. The moisture content allowed for determining the dry density to compare to the maximum dry density following the development of the laboratory compaction curve. The nuclear density testing served as a separate method of determining compaction supplementing the results of the sand cone tests.

A second visit was made the following day on May 7, 2015 for installation and launching of the Onset Hobo Data Logger tipping bucket rain gauge (Figure 4.7). The rain gauge tracked intensities and total precipitation throughout the study period. The rain gauge was secured onto a tree stump with screws and leveled with washers. A photograph of the installed rain gauge is shown in Figure 4.8. Subsequent site visits consisted of ongoing photographs of the site. The pictures taken over time reflected ECB performance and apparent deficiencies. Any noticeable areas of erosion were given particular consideration when visible and documented for every site visit. Rain gauge data were also extracted to evaluate rainfall intensities and cumulative precipitation over the two-week interval.

Figure 4.7. Onset Hobo Data Logging Rain Gauge (Onset Computer Corperation, 2015).

Figure 4.8. Installed Onset Hobo Data Logger Rain Gauge.

Photographs assisted in documenting germination as the SWPPP compliance is a visual non-numeric standard (MoDOT, 2014b). Germination was also documented using vegetative density counts, as used in ASTM D7322. The counts were made as stems and risers on a one-foot by one-foot square. A photograph of the tool is shown in Figure 4.9. The risers are each individual plants, and the stems were counted as the leaves and stems growing from each riser. The counts were made from two separate sections on each ECB resulting in a total of four measurement locations.

Figure 4.9. One-foot by one-foot square used for vegetation counts.

Site visits scheduled during periods of rainfall allowed for collection of stormwater runoff from various discharge points. The discharge points are shown in Figure 4.10, and Figure 4.11, which is a plan view of these locations. Figure 4.10a is the discharge location along the Type 3 blanket at the culvert outlet with stormwater collected immediately following the rock riprap. Water was also collected at the seam of the two blankets along the Type 2 blanket at the gap of the silt fence (Figure 4.10b). A third stormwater location was located near the rain gauge along the Type 2 span at the location where the silt fence fell over (Figure 4.10c). Another stormwater discharge point was downstream from the channel created by the culvert discharge in the vegetated area off of the MoDOT right of way (Figure 4.10d).

Figure 4.10. Stormwater sample collection locations: a) culvert outlet of Type 3 ECB; b) seam of the blankets along Type 2 span; c) near rain gauge of Type 2 ECB; and d) channel discharge downstream of culvert (photos taken July 8, 2015).

Figure 4.11. Stormwater sample location plan view.

The runoff was tested for turbidity, concentration of sediment by volume (Imhoff Cone Test), and concentration of sediment by mass (ASTM D3977). The EPA had previously set a limiting value of 280 NTU for the average turbidity of the samples taken during a given day for construction sites disturbing more than ten acres (MacCurdy, 2014). The standard was retracted in 2014, but the turbidity was measured and compared for illustrative purposes of the research. Turbidity from the runoff was determined from a HACH 2100N Laboratory Turbidimeter. The instrument has an accuracy of ± 2% plus 0.01 NTU from 0 to 1000 NTU or ±5% for readings 1000 to 4000 NTU. The Imhoff cone test (Standard Test Method 2540F) is the method of quantifying total settleable solids, measuring sediment concentration as volume per liter. MoDNR uses the Imhoff cone test as a separate water quality standard permit holders must meet when discharging runoff, and the limiting concentration specified in the Construction General Permit is 2.5 mL/L (MoDNR, 2015). The permit holder is not obliged to meet this water quality standard limit following a storm more severe than a 2-year 24-hour storm. Suspended-sediment concentration tests supplemented the results of the Imhoff cone tests. The suspended-sediment concentration measures concentration in mass per unit volume in contrast to volume per unit volume.

The runoff was collected by hand (Figure 4.12) or using a developed runoff collection device for sheet flow runoff (Figure 4.13). Grab samples were extracted by placing the bottle in the middle of the channel to prevent disturbance of the solids from the bottom of the channel, contaminating the sample (Washington State Department of Ecology, 2010). The collection device was constructed to extract the required volume sample for testing despite flow being too shallow for collection using a bottle. The device was slowly placed on the ground to collect runoff ensuring minimal disturbance of the underlying soil. After adequate collection, the device was lifted off of the ground to transfer the runoff through an opening to the collection bottle illustrated by Figure 4.14.

Figure 4.12. Collection of stormwater runoff.

Figure 4.13. Sheet-flow runoff collection device.

Figure 4.14. Sheet-flow collection device: a) water collection; and b) transfer to bottle.

4.4 Laboratory and Field Results

Identifying the soil on site was necessary to determine its vulnerability to erosion. The soil was identified using standard classification methods allowed for determining other characteristics from the categorization of the soil. The soil properties tested for classification included the following:

- Grain Size Distribution (ASTM D422);
- Atterberg Limits (ASTM D4318);
- Standard Proctor Compaction Test (ASTM D698);
- In-place Compaction of Soil (ASTM D1556/D1556M); and
- Nuclear Density Testing (ASTM D6938).

The stormwater runoff collected determined the quantitative field performance of the ECBs. The Missouri CGP and recently retracted EPA effluent limitations were comparable baselines for the results of the stormwater sample testing. The following parameters were evaluated from the runoff samples collected:

- Suspended-Sediment Concentration (ASTM D3977);
- Standard Test Method for Settleable Solids (Standard Test 2540E); and
- Turbidity (measured).

4.4.1 Soil

The soil located on site was classified per AASHTO standards (ASTM D3282), the Unified Soil Classification System (USCS) (ASTM D2487), and the USDA soil classification to better understand expected properties of the slope. AASHTO and USCS classifications require the grain-size distribution and Atterberg Limits of the soil. USDA classification only requires knowledge of the soil's grain size distribution determined by ASTM D422. The grain size distribution (Figure 4.15) is then applied to the USDA texture triangle as presented in Figure 3.3 of Section 3.3.

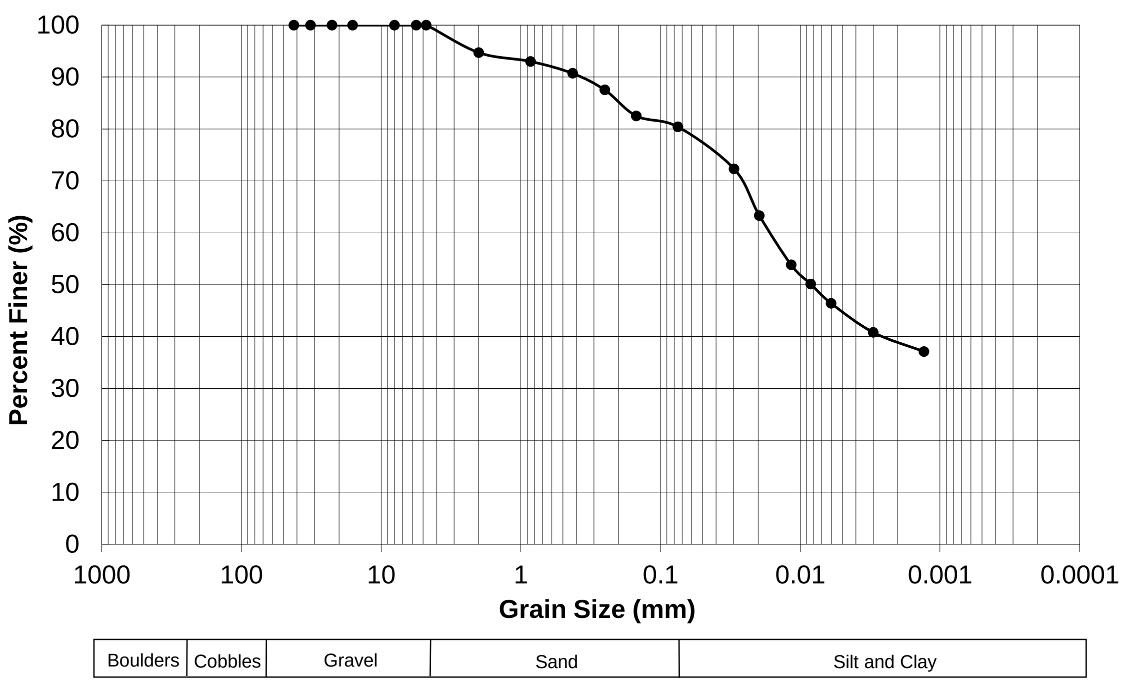


Figure 4.15. Grain-size distribution for Route N soil.

The Atterberg Limits measure the plasticity of the soil in terms of its Plasticity Index (PI) and was determined per ASTM D4319. The Liquid Limit, Plastic Limit, and Plasticity Index from the experiment were found to be 37, 18, and 19; respectively. These results combined with the grain-size distribution showed the Route N soil to be classified as A-6 Clayey Soil by AASHTO convention and Lean Clay from the USCS convention. A summary of the different soil classifications is shown in Table 4.2.

Table 4.2. Soil classification of site soil.

Classification Type	Soil Classification
USDA	Clay Loam
USCS	Lean Clay (CL)
AASHTO	A-6 Clayey Soil

The soil compaction test was conducted on the soil sample in accordance with ASTM D698 for maximum dry density and standard optimum moisture content values. The compaction curve derived from the experimental results provided in Table 4.3 is shown in Figure 4.16. The graph shows the standard optimum moisture content of 16.1% and a maximum dry unit weight of 107.2 pcf.

Table 4.3. Proctor testing experimental data.

Test Specimen	1	2	3	4	5	6	7
Target Water Content (%)	10	14	18	22	26	20	22
Weight of Test Specimen (lb)	3.25	3.36	5.09	5.12	5.08	4.93	5.43
Weight of Water Added (lb)	0.35	0.45	1.12	1.44	1.78	1.23	1.53
Compacted Weight (lb)	12.60	12.97	13.06	13.09	12.53	13.00	13.05
Proctor Mold Weight (lb)	8.93	8.93	8.93	8.93	8.93	8.93	8.93
Volume of Proctor Mold (ft^3)	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Compacted Unit Weight (pcf)	109.95	121.01	123.80	124.74	107.78	122.10	123.64
Dry Unit Weight (pcf)	99.96	106.15	104.91	102.25	85.54	101.75	103.03

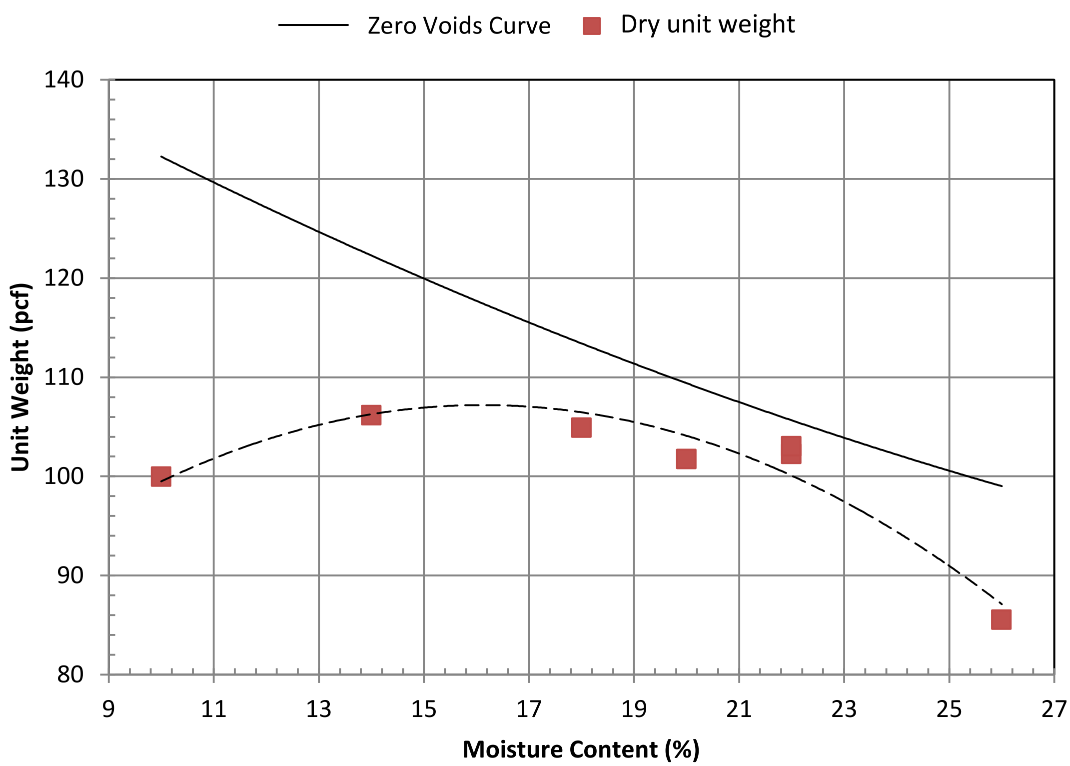


Figure 4.16. Soil standard Proctor compaction curve.

The sand cone compaction tests require the maximum dry unit weight to determine relative compaction of the subgrade. Relative compaction is expressed as a percentage of the soil in-situ dry density of the maximum dry unit weight. The complete sand cone results are shown in Table 4.4. The sand cone was refilled while filling the hole to prevent running out of sand during the test compromising the results. The relative compaction determined for the study reach was 88.4%, and the MoDOT standard specifications requires compaction of embankments to be at least 90% of the maximum unit weight (MoDOT, 2015b).

Table 4.4. Sand cone test results (soil under Type 3 ECB).

Initial Mass of sand in sand cone (g)	6953
Mass of sand cone and sand remaining when refilled (g)	5139
Mass of sand cone and sand when refilled with more sand (g)	6834
Mass of sand cone and sand after filling the hole and funnel (g)	4375
Moist mass of soil extracted from the hole (g)	714
Water Content (%)	10.0
Unit weight of Sand (pcf)	94.2
Weight of Sand contained in hole and funnel (lb)	3.999
Weight of Sand in Hole, Funnel, and Sand Cone (lb)	5.421
Volume of Hole (ft^3)	0.01510
Moist Unit weight of Soil (pcf)	104.3
Dry Unit Weight of Soil (pcf)	94.8
Relative Compaction (%)	88.4

The sand cone and proctor tests were supplemented by a nuclear density test performed in the field. The nuclear density test was performed per ASTM D6839, and the density results are shown in Table 4.5. The test was performed over both blankets at two and four inch depths. These depths were selected because they provide a good representation of soil compaction at the surface where erosion occurs. A notable difference between the testing methods is the measured moisture contents of the two tests. The nuclear testing measured moisture contents of 18.2% for the two inch depth and 17.8% for the four inch depth and the sand cone method found the moisture content to be 10%. The nuclear testing was performed onsite by a certified MoDOT technician. The moisture determination for the sand cone method was performed using the sample days after the field site visit. The waiting period may have contributed to the lower moisture content determined and relative compaction calculated.

Table 4.5. Nuclear "density" test results.

Parameter	2" Depth Type 3	4" Depth Type 3	2" Depth Type 2	4 " Depth Type 2
Dry Unit Wt. (pcf)	101.5	104.2	89.9	91
Percent Maximum Dry Unit Wt. (%)	76.0	78.7	68.8	68.0
Percent Moisture (%)	18.2	17.8	21	20.6
Percent Air Voids (%)	11	8.5	16.4	16
Void Ratio	0.677	0.618	0.874	0.852
Wet Unit Wt. (pcf)	118.8	122.7	108.8	109.7

4.4.2 Stormwater Runoff

Storm events occurring during scheduled field visits allowed for the collection and testing of stormwater runoff. The first series of runoff samples were collected on May 20, 2015 and was tested for suspended-sediment concentration as per ASTM D3977. Sample locations 1, 2, and 3 are identified as the discharge from the culvert, discharge at the seam of the two blankets, and discharge near the rain gauge, respectively (Figure 4.11). Beginning from the June 18 site visit, the locations used as the points of discharge included the same three as the first visit and the stream located in the vegetated area downstream from the culvert and is noted by Sample 4 in the results. The consideration for the MoDNR water quality standard for stormwater discharge and the former EPA turbidity standard was made for the subsequent stormwater collections. The results from the stormwater samples collected from May 20, June 18, and July 8 are summarized in Table 4.6. The complete raw data for each experiment are located in Appendix C.

Table 4.6. Stormwater sample test results.

Sample Location	Date	SSC (mg/L)	Turbidity (NTU)	Imhoff Cone (mL/L)
1	05/20/2015	176.0	N/A	N/A
	06/18/2015	127.0	141.0	0.405
	07/08/2015	40.0	34.6	0.300
2	05/20/2015	82.7	N/A	N/A
	06/18/2015	48.5	72.9	0.236
	07/08/2015	17.8	34.8	0.200
3	05/20/2015	36.9	N/A	N/A
	06/18/2015	50.2	68.9	0.475
	07/08/2015	12.8	25.5	0.300
4	05/20/2015	N/A	N/A	N/A
	06/18/2015	98.7	107.0	0.432
	07/08/2015	34.8	36.3	0.197

N/A = not available

For the SSC, the minimum value was 12.8 mg/L, the maximum is 176.0 mg/L, and an average is 90.7 mg/L. The largest turbidity was recorded as 141.0 NTU, the minimum was 25.5 NTU, the average was 65.1 NTU, and the average daily for each day was 97.45 NTU (6/18/2015) and 32.8 NTU (7/8/2015). The daily and individual averages were both less than the recently retracted EPA turbidity limit for construction sites for having a daily average turbidity less than 280 NTU. The Imhoff cone results showed a maximum of 0.475 mL/L, a minimum of 0.197 mL/L, and an average of 0.318 mL/L. All values are less than the required water quality standard set by MoDNR in the MoDOT construction NPDES permit of 2.5 mL/L.

Determining the suspended-sediment concentration served as a supplementary metric for the other experiments conducted. The findings show a correlation between suspended-sediment concentration and turbidity for the clay loam soil used on site (Figure 4.17). The results show a distinct correlation between the increase in turbidity as the suspended-sediment concentration also increases ($R^2 = 0.945$).

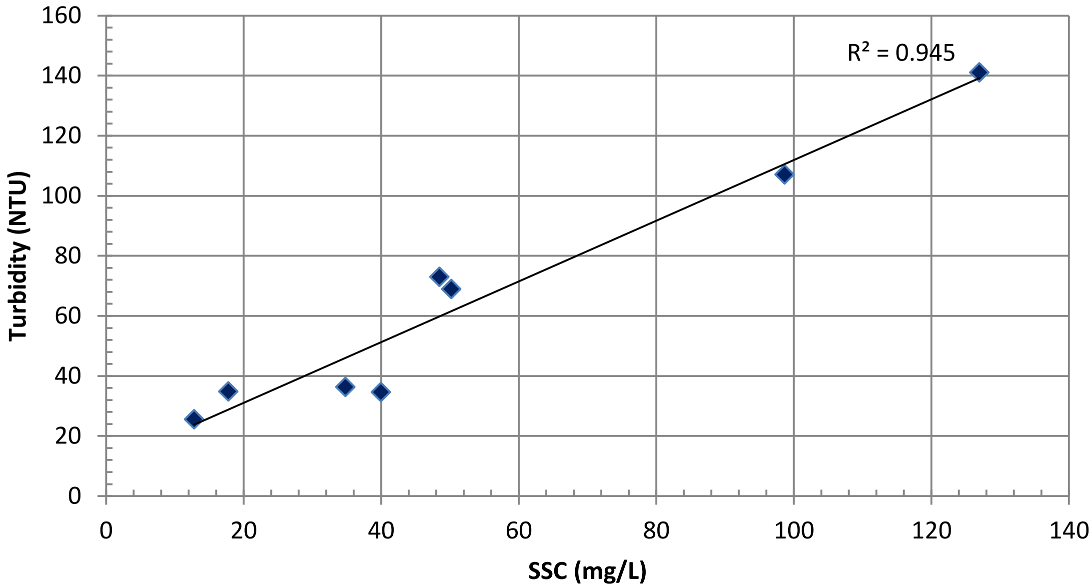


Figure 4.17. Plot of turbidity versus SSC.

The samples extracted from the June 18 site investigation comprised of filling three 250 mL HDPE bottles. Each bottle was an individual sample for the suspended-sediment concentration, turbidity, and the Imhoff cone tests. Because the Imhoff cone test requires a liter of runoff sample, the three bottles were later combined into one large sample to meet the one liter requirement. The following visits extracted the one-liter of runoff from each discharge point as required.

4.4.3 Germination

The reestablishment of vegetation on the disturbed site is the ultimate goal of ECBs. Plant growth was recorded visually and quantitatively. The visual inspection was to emulate acceptance procedures performed by MoDOT for the final acceptance of a site. The MoDOT SWPPP (MoDOT, 2014b) cites that a site must achieve at least approximately 70% germination of the site for the area to be considered reestablished from a visual inspection. The quantitative germination counts served to supplement the visual inspections.

Photographs were taken during each site visit documenting germination trends such as predominant location of germination along the reach and on the slope of the site. The effects of the ECB seam and the perimeter of the blankets on plant growth was recorded. An area of perimeter erosion was observed at the bottom of the Type 3 ECB where the edge of the blanket did not meet the silt fence. The exposed area was covered with hand applied straw. The straw eroded away and a gulley formed at this location (Figure 4.18).

Figure 4.18. Gulley erosion at bottom of Type 3 ECB.

Germination was tracked quantitatively by counts of stems and risers as per ASTM D7322. Germination was counted at various locations along the study reach. The first regular site visit included an area by the culvert over the Type 3 blanket, and locations at the seam and near the rain gauge observing growth over the Type 2 blanket. Subsequent visits included an additional location at the seam for the Type 3 blanket for a total of two count locations for each ECB. Typical count locations for each of the four locations are shown in Figure 4.19.

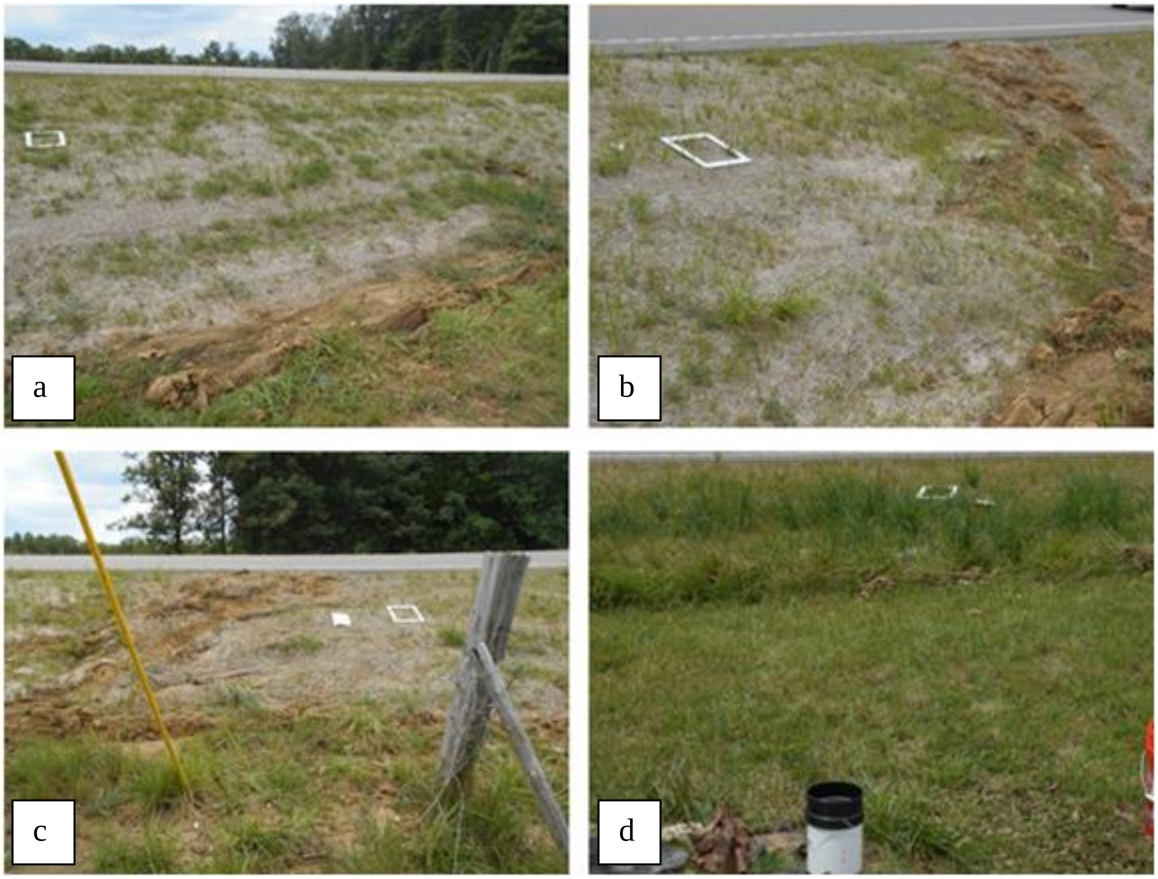


Figure 4.19. Typical germination count locations: a) left of culvert (Type 3); b) left of seam (Type 3); c) right of seam (Type 2); and d) near rain gauge (Type 2) (from July 22, 2015).

As shown in Figure 4.9 of Section 4.3, the constructed square allowed for calculating germination per square foot. Counts were conducted at a position on the slope representative of the entire count location. Photos were taken of the positioned square prior to the counting procedure to provide an analysis and meaningful results of the data. Multiple photos of the germination squares throughout the study period showing the germination progression are in Figure 4.20. Figure 4.21 is a series of site photos showing overall progression of site reestablishment. Official site reestablishment by MoDOT was granted for the site on August 17, 2015.

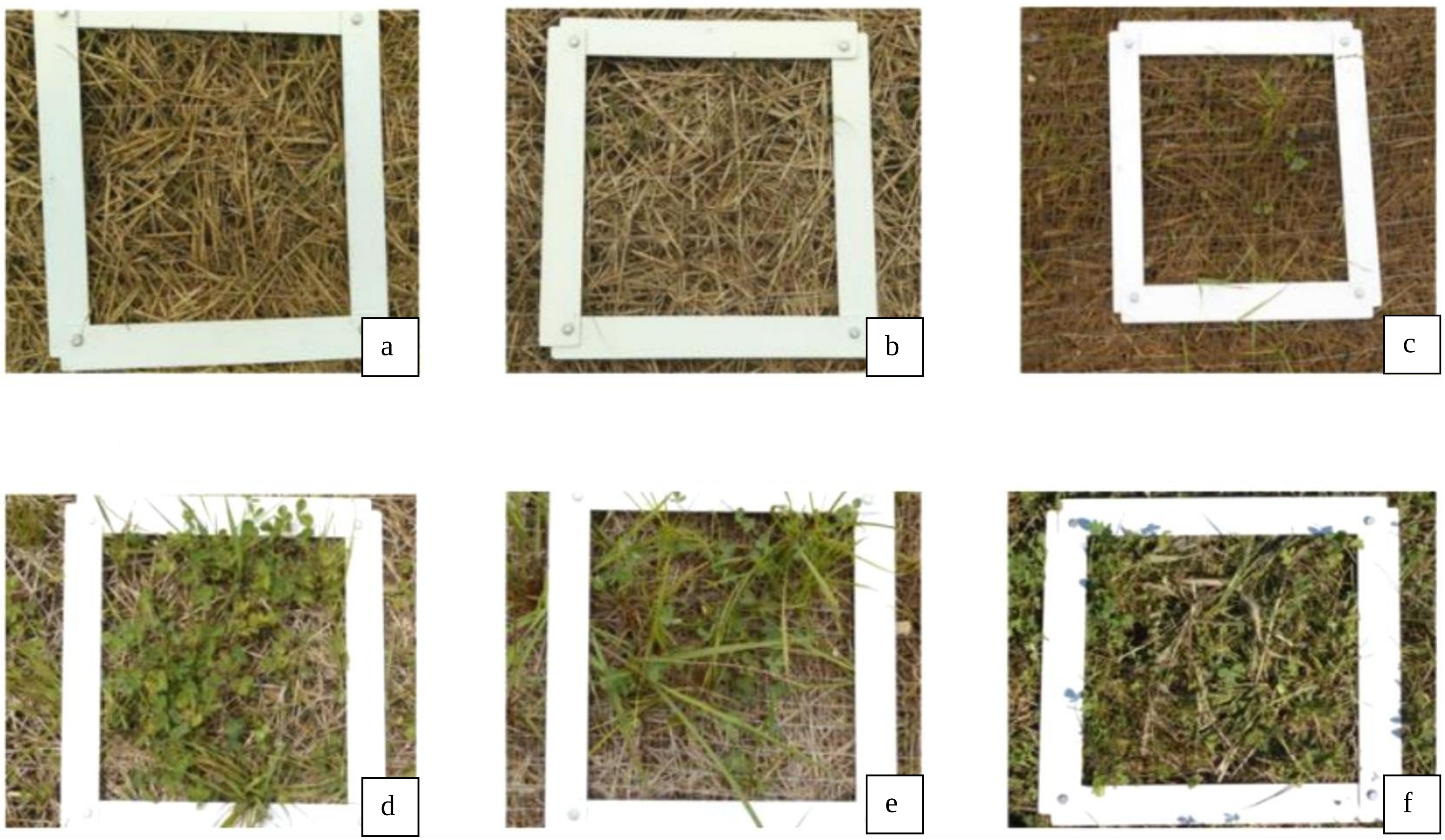


Figure 4.20. Germination counts: a) 6-3-15; b) 6-18-15; c) 7-1-15; c) 7-22-15; e) 8-19-15; and f) 9-16-15.

Figure 4.21. Site germination: a) 5-6-15; b) 6-3-15; c) 7-1-15; d) 7-22-15; e) 9-2-15; and f) 9-30-15.

The results of the germination count are summarized in Table 4.7 and Table 4.8 for the two count locations for the Type 2 and Type 3 ECB, respectively. Germination counts were made as risers and stems from the risers. As described in Section 4.3, the risers are each individual plants, and the stems are counted as the leaves and stems growing from each riser. Germination counts were not made during the July 8 visit because of the heavier rainfall event occurring during the visit. Foot traffic on the ECBs while conducting the germination counts could have potentially damaged the blankets.

Table 4.7. Stem and riser counts for Type 2 ECB.

ECB Type 2	Risers		Stem	
	Rain Gauge	Seam	Rain Gauge	Seam
5/20/2015	36	15	58	23
6/3/2015	160	103	376	161
6/18/2015	109	27	313	49
7/1/2015	93	36	410	81
7/8/2015	N/A	N/A	N/A	N/A
7/22/2015	101	28	694	98
8/5/2015	59	26	974	374
8/19/2015	96	40	488	508
9/2/2015	42	21	729	361
9/16/2015	26	18	606	430
9/30/2015	55	16	335	628
10/14/2015	42	30	720	216
1/14/2016	13	20	341	213

Table 4.8. Stem and riser counts for Type 3 ECB.

ECB Type 3	Risers		Stem	
	By Culvert	Seam	By Culvert	Seam
5/20/2015	29	N/A	46	N/A
6/3/2015	86	154	140	234
6/18/2015	87	79	203	227
7/1/2015	41	25	76	103
7/8/2015	N/A	N/A	N/A	N/A
7/22/2015	43	32	421	180
8/5/2015	44	28	445	249
8/19/2015	36	44	732	355
9/2/2015	24	23	794	595
9/16/2015	19	17	717	556
9/30/2015	20	20	436	536
10/14/2015	20	28	592	682
1/14/2016	17	15	355	240

Figure 4.22 and Figure 4.23 are plots of the riser and stem counts for the Type 2 ECB, respectively; and Figure 4.24 and Figure 4.25 are plots of the riser and stem counts for the Type 3 ECB, respectively. Initial germination was high with low amounts of stems from each riser. Later in the study as the seeds were eroded, new germination was low but the maturity of the plants that did germinate was high with significant increases in stems. Also, much of the germination was from weeds and clovers suggesting more of the original seed washed away than the overall germination may indicate. Stem and riser counts declined for both blankets near the end of the study period as the plants became dormant during the winter period.

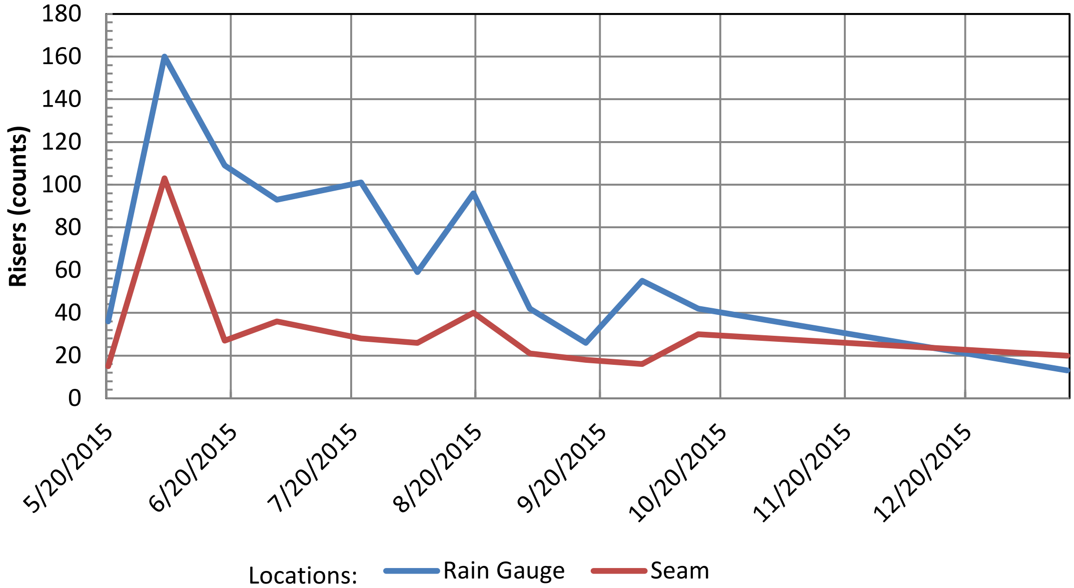


Figure 4.22. Type 2 ECB riser counts.

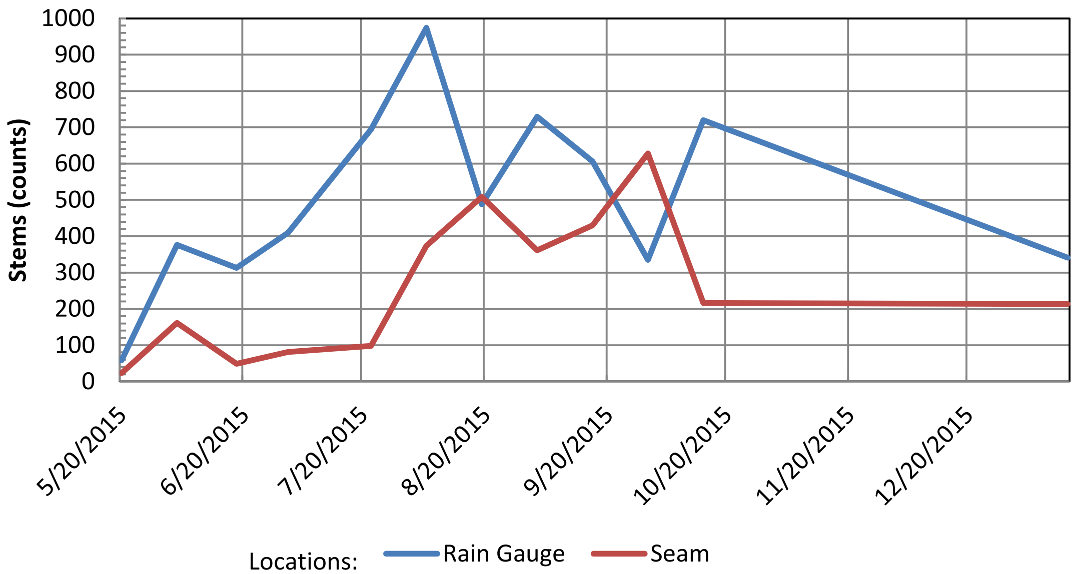


Figure 4.23. Type 2 ECB stem counts.

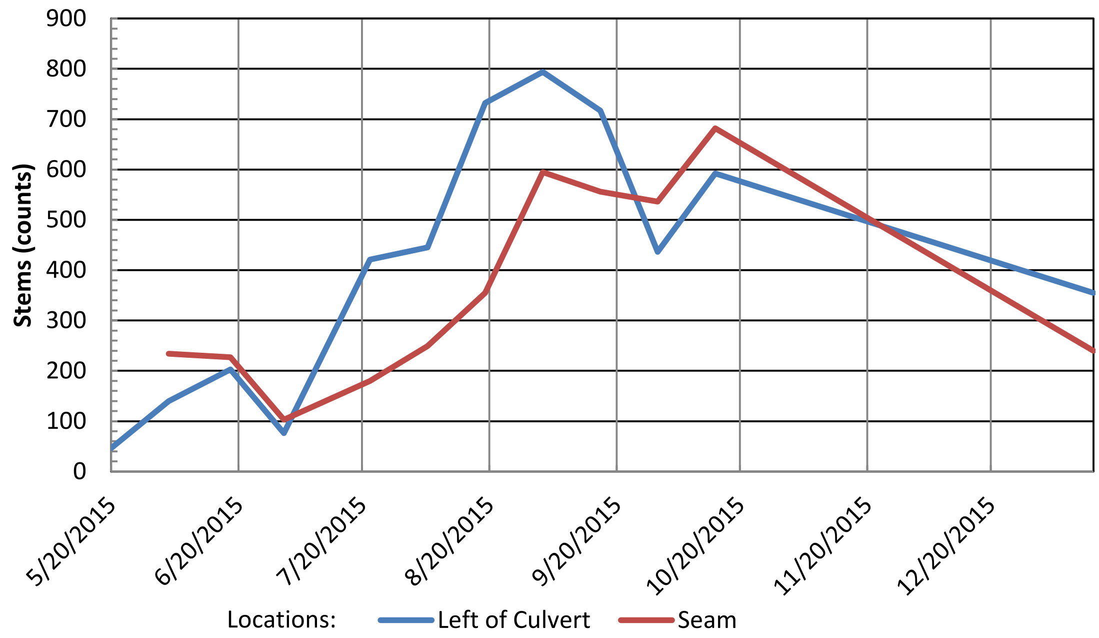


Figure 4.24. Type 3 ECB riser counts.

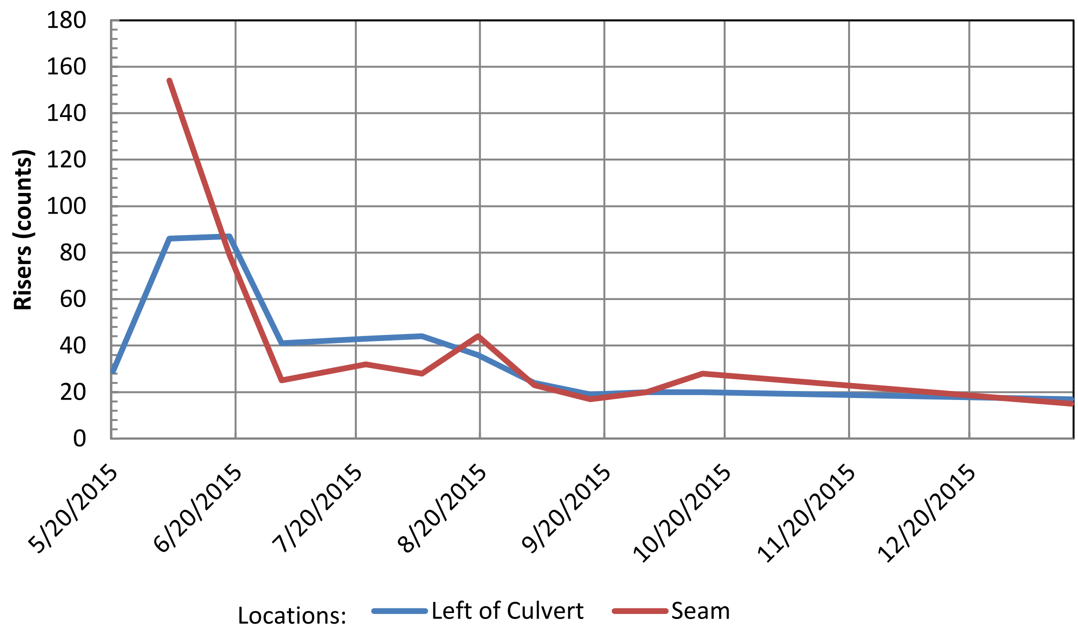


Figure 4.25. Type 3 Stem Counts.

4.4.4 Hydrology

Rainfall was tracked throughout the study period using the Hobo Data Logger rain gauge. Using a tipping bucket allowed for tracking precipitation and determining intensities of potential storms. Rainfall intensities can attribute to any apparent erosion or rupturing following the event (Lal, 2001). Rainfall intensities during the site visits were identified to associate the runoff samples with an intensity to distinguish trends between the results and rainfall intensity.

The rain gauge was installed on May 7, 2015, and data were extracted during site visit, approximately once every two weeks. Due to technical malfunctions in the rain gauge, data were unable to be extracted from September 16, 2015 to October 14, 2015 and from January 11, 2016 to January 14, 2016. The overall Route N hyetograph is shown in Figure 4.26. Using the precipitation data, site visits during periods of rainfall could be analyzed to determine the associated intensity during the runoff sample collection. For the site visits on May 20, June 18, and July 18, the intensities during runoff collection were 0.05 in/hr, 0.07 in/hr, and 0.01 in/hr, respectively.

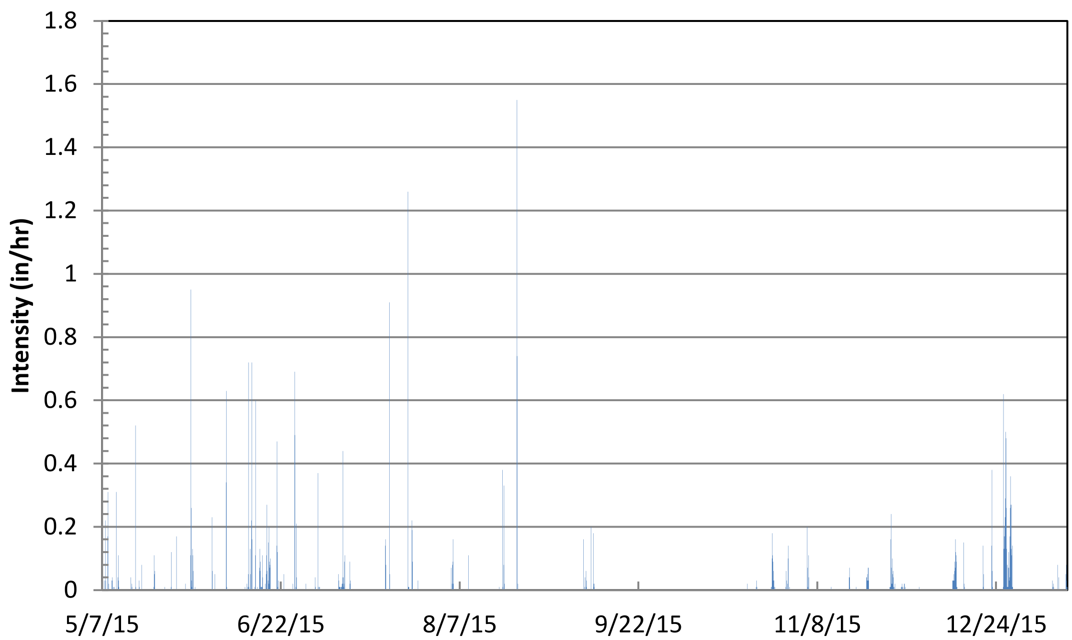


Figure 4.26. Hyetograph for Route N.

4.5 Conclusions

Several conclusions were made from the field investigation. The installation method used in the field was different than the specified technique from the manufacturer. Laboratory testing has ideal installation conditions that strictly adhere to manufacturer installation recommendations. The laboratory performance and the field performance of an ECB may vary if separate installation methods are used to secure the ECB to the slope. Further, some of the measured

ECB index properties (thicknesses and tensile strength) deviated from the manufacturer's product specifications. Verifying ECB specifications for every field application is not practical. However, periodically conducting index property testing on ECBs being used in the field and comparing those results to the manufacturer's specifications is recommended to monitor ECB quality.

Following installation, the blanket was observed to not have direct contact with the subgrade in some locations (tenting), specifically over large rocks and debris such as soda cans. The "tenting" could have contributed to erosion of the seed displacing it down the slope which was observed to be. Also, the edge of the Type 3 ECB did not meet the silt fence at the bottom of the slope, and gulley erosion at the bottom of the slope was observed to be the predominant germination location. Much of the germination recorded was clover and other invasive species; the original Kentucky Fescue was located near the bottom from the erosion. The study period experienced the wettest June on record for Missouri with 13.14 in of precipitation. All stormwater samples taken were still below the water quality limit imposed by the MoDNR and the removed turbidity limit for stormwater.

5 Investigation of Previous MoDOT ECB Projects

Three completed MoDOT construction projects featuring ECBs located within St. Charles County were visited on September 4, 2015: Route Z, Route D, and Route DD (Figure 5.1). All sites had ECBs installed approximately two years prior to the visit. Post-project conditions of the ECB applications were documented to evaluate continued performance and vegetation reestablishment. All three sites were found to be predominantly silty with some sand content, and all sites had been previously accepted by MoDOT inspectors as a completely reestablished slope in accordance to the MoDOT SWPPP (70% uniform germination across the disturbed area). Site visits were conducted with MoDOT representatives to obtain their assessment on the condition and progression of site reestablishment.

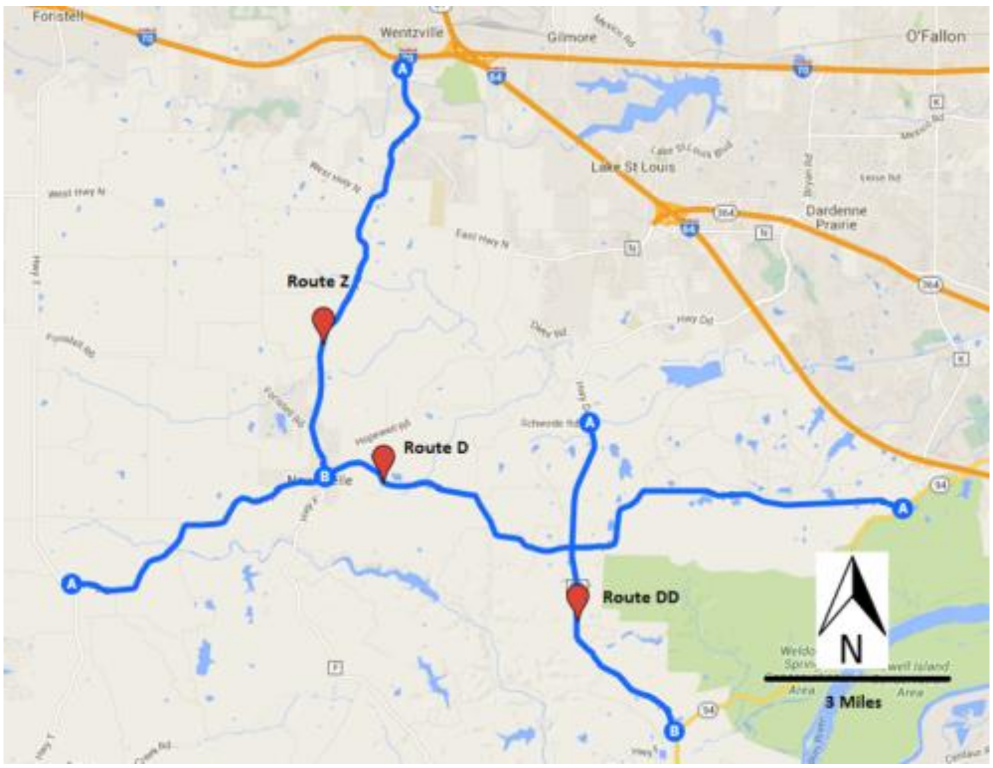


Figure 5.1. Map of the visited sites in St. Charles County (Google, 2015).

5.1 Route Z

The Route Z project utilized a single-net ECB described as either a Type 1 or Type 2 product. Documentation was lacking from the project to properly identify the blanket. The ECB was installed in a drainage ditch along the side of the highway. The site had maintained uniform germination (Figure 5.2). The main issue involved the blanket not making contact with the ground along the entire ditch surface, which led to observed undercutting and channelized erosion apparent along the bottom of the channel. MoDOT representatives indicated that a single-net blanket may not be appropriate for channelized applications to retain material for proper anchoring to the surface experiencing channelized stormwater flow. The gulley erosion at the bottom of the ditch is shown in Figure 5.3.

Figure 5.2. Route Z drainage ditch.

Figure 5.3. Gulley erosion near the bottom of the ditch at Route Z.

5.2 Route D

The Route D ECB application was similar to the Route Z project with an ECB installed in a channelized application. The primary difference between the two was the type of ECB used. Route Z utilized a quickly degradable blanket while Route D appeared to have used a TRM (Figure 5.4) as the soil stabilization practice. The TRM can be characterized by the thick black netting.

Figure 5.4. TRM used on the Route D project.

Utilizing a thicker blanket affected the reestablishment following project completion. Two reaches of the Route D were investigated where the TRM was used, and in both instances the TRM had not sufficiently degraded. One reach was in direct sunlight (Figure 5.5), and the other was in the shade of nearby trees (Figure 5.6). The lack of sunlight combined with the less light penetration offered by TRMs most likely contributed to the little germination observed in Figure 5.6 (Crase et al., 2014). However, both locations experienced little germination showing that the amount of sunlight was likely not the main factor in the vegetation growth. The usage of a TRM showed to be unsuccessful at promoting germination following the initial acceptance of the site. The issue could also be derived from the ECB design selection. If an ECB type is specified, the contractor can only use a product from the approved products list. Although the MoDOT specification is categorized by service life and longevity, the TxDOT approved products list is not. For instance, the TxDOT approved products list for a 3:1 or flatter sandy slope will have ECBs which are quickly degradable and TRMs which are slow degrading blankets. Also, TxDOT has an approval based on association where if one blanket meets the criteria for the 2:1 sandy slope, the ECB is automatically placed on the less severe 3:1 sandy slope so blankets intended for much steeper applications may be placed on the 3:1 slopes. Because both ECBs met the sediment yield threshold, both blankets qualify for the same approved products list. Because of the lack of classification of the TxDOT approved products list into the service life categories, MoDOT construction specifications could lead to TRMs and ECBs being incorrectly selected on MoDOT sites not degrading sufficiently.

Figure 5.5. TRM located on a slope exposed to direct sunlight.

Figure 5.6. TRM located on a slope under tree cover.

5.3 Route DD

The ECBs installed on Route DD were the same TRMs installed on Route D; however, the Route DD site had a channelized application of the TRM and a gradual slope serving as a recovery area for vehicles on the other side of the road. The TRM installed in the channel was downstream of a culvert concentrating flow. The concentrated flow caused the TRM anchors to become loose and the TRM to fold over on itself from the hydraulic forces (Figure 5.7). Erosion then undermined the TRM along the bottom of the channel from lack of proper TRM contact. Vegetation established relatively well for the ditch except along the center of the channel where erosion had occurred as shown in Figure 5.8.

Figure 5.7. Route DD TRM unraveling from culvert scour.

Figure 5.8. Slope downstream of the culvert outlet at Route DD.

The other ECBs at the Route DD site included blankets on the recovery area. The recovery area was characterized by moderately sloped areas on the MoDOT right of way (Figure 5.9). The same TRM product was used as in the culvert ditch application. Again, the TRM had experienced insufficient degradation and apparent areas of minimal germination illustrated in Figure 5.10.

Figure 5.9. Sloped area along Route DD.

Figure 5.10. Area of low germination.

The lack of degradation causes numerous problems in regards to maintenance. Mowing the reestablished slope covered with a TRM that has not degraded sufficiently or has had enough germination to conceal the blanket can cause the mower blades to get caught in the blanket damaging the mower or ripping the blanket. Removing the blanket can pull up nearby grass making the site vulnerable to erosion and having an undesired appearance (Figure 5.11). MoDOT representatives noted that a consistent concern with using ECBs was the lack of degradation and germination. Landowners adjacent to the MoDOT right-of-ways mow the area for aesthetics. With insufficient degradation, landowners have been known to remove the blankets because of the consistent slow degradation an undesired appearance.

Figure 5.11. TRM that has been caught in lawn mower blades.

5.4 Conclusions

All three of the sites investigated exhibited both extremes in ECB selection: rapidly degrading materials to reestablish the slope quicker or conservative selections for the blanket provided protection for a long period of time. Also, channelized ditches and conventional slopes were both represented in these projects. The primary difference between the sites was the ECBs selected. The straw material of the quickly-degrading single-net blanket from Route Z eroded away leaving the soil vulnerable in the surface of the ditch causing the gulley erosion at the bottom despite the sufficient degradation. In contrast, the TRMs used on the recovery area slope of Route DD had not degraded sufficiently for new grass to germinate following winter and other dormant periods. The slow degradation has led to landowners manually removing the blankets or ripping of the blankets during mowing operations. The visits have shown that using an extremely conservative ECB or TRM does not guarantee the successful reestablishment. The weakness in the TxDOT ECB product approval becomes apparent where all ECBs and TRMs meeting a slope threshold are considered appropriate for that application when the longevities are drastically different. Although the MoDOT standard specifications categorizes the ECBs by longevity, not applying it to the TxDOT approved products list for a formal approved products list for Missouri leads to mistakes in product usage from the contractor. ECB service life has shown to be an important aspect to the success of the disturbed site.

6 ECB Survey

MoDOT and its general contractors and landscaping contractors contribute to the design, installation, and ultimate effectiveness of ECBs on sites throughout the state. The purpose of this task was to compile ECB experiences from numerous implementations to identify performance patterns related to installation, maintenance, and assisting BMPs. Surveys were developed to record ECB experiences attested by each entity. The surveys addressed three relevant areas to the typical execution of reestablishing slopes with ECBs: pre-installation procedures and conditions, ECB functionality and maintenance with respect to MoDOT's SWPPP, and comparative evaluations of ECBs. As the role of MoDOT, general contractors, and the landscape contractors in terms of the SWPPP vary, their role in how the ECB is placed and maintained also varies. Each survey was individualized to each entity to capture their relevant experiences. In addition to site conditions and installation methods, all three surveys inquired about ECB performance based on manufacturers, MoDOT classifications, netting types, material composition, and specific products. The surveys were not designed to produce quantitative and statistically significant results because the total number of potential participants was small. However, the intent of the surveys was to gain anecdotal insight into successful and unsuccessful ECB applications.

The surveys were developed and executed using the Google Forms interface and user responses were recorded and tabulated automatically. Survey questions were grouped into three categories: ECB site conditions, MoDOT SWPPP compliance, specific ECB performance, and other pertinent ECB experiences. The surveys presented to MoDOT resident engineers and inspectors, the general contractors, and the landscaping contractors are located in Appendix D. The surveys were conducted over several months extracting the final responses for analysis in January 2016. The survey was administered by MoDOT to 38 MoDOT resident engineers, 220 MoDOT construction inspectors, 70 general contractors, and 11 landscape contractors. Of the survey sample, ten MoDOT resident engineer and inspector responses were recorded (3.9% response rate), and five landscape contractor responses were recorded (45.5% response rate). No general contractor survey responses were submitted. The following sections detail the role of each entity, survey responses and summarize the important findings from the survey.

6.1 Survey of MoDOT Resident Engineers and Inspectors

MoDOT is the permit holder for the NPDES and holds primary responsibility for the re-establishment of the site (MoDOT, 2014b). MoDOT creates the SWPPP with the site BMP layout, develops material specifications of the BMP, holds jurisdiction over any deviations from specifications, and grants the final acceptance of the installed BMP. MoDOT is also responsible for the upkeep and ongoing maintenance of the BMPs during the routine SWPPP inspections throughout the project (MoDNR, 2015). The questions posed to the MoDOT resident engineers and inspectors are specific to procedures, specifications, and deviations from what is specified.

6.1.1 ECB Site Conditions and Pre-installation Procedures

Site condition questions addressed typical site conditions for installation of ECBs including common soil types and site preparation procedures. The responses for the MoDOT resident engineers and inspectors noted that clayey, silty, and sandy soils are common for MoDOT construction sites. The variety of soil types is consistent with the geology of Missouri as presented in Section 3. Although all of the soil types are mentioned as commonly experienced, only the clayey and sandy soils were reported as the soils causing the most failures of ECBs.

Site preparation questions prompted responses regarding common procedures for subgrade preparation for ECB installation. All of the responses noted that the slope of the site was assessed prior to ECB installation. The geometry of the slope is specified on the plan drawings and critical to the stability of the site. Several responses indicated soil compaction was a pre-installation consideration. Having proper compaction affects the germination ability of the seed impeding growth if the compaction restricts root penetration into the soil (Summer, 1991). A MoDOT employee who reported success using ECBs assessed the subgrade gradation, soil compaction, and also further noted that the soil gradation was considered. Expanding the understanding of the site soil could reduce errors associated with using an ECB for an inappropriate soil.

6.1.2 MoDOT SWPPP Compliance

ECBs were introduced to MoDOT construction sites as a result of the MoDOT SWPPP. Survey questions related to MoDOT SWPPP compliance addressed the following topics: using an ECB over the specified BMP, common ECB items inspected during a SWPPP inspection, common maintenance requirements from the SWPPP inspection, typical failure modes of ECBs, and the supplemental BMPs used in conjunction with ECBs.

MoDOT designers specify BMPs on the plan drawings and any change in the type of BMP used in the field is made by the MoDOT resident engineer or inspector during construction (MoDOT, 2014b). Six of the survey responses reported that steep slopes were addressed with ECB instead of the BMP specified. Half of the responses stated that ECBs were used in place of the BMP if the BMP either failed at the existing location or failed elsewhere on the site. Other responses reported more practical reasons such as the ease of working with the ECB in closeness to traffic proximity, the manpower and scheduling of the subcontractors, and using ECBs on areas where mulch sprayers cannot reach.

SWPPP inspections monitor the erosion control and reestablishment progress of disturbed areas. SWPPP reports document BMP conditions and specify necessary maintenance or changes for continued compliance. The MoDOT resident engineers and inspectors were prompted to comment on related items documented during the SWPPP routine inspections, including the supplementary BMPs used, common maintenance requirements, and the failure modes experienced. Regarding items documented during routine inspections, many responses indicated that recording the seed growth was a primary inspection item and other items included the condition of supplementary BMPs. If continued maintenance of supplementary BMPs is necessary, the ECB could be a contributing factor to their condition. Survey responses also noted that anchoring pattern and movement of the blanket along the slope is also recorded during the SWPPP inspections. Improper anchoring can contribute to an ECB not making proper contact with the underlying soil, reducing the ECB erosion-control efficacy. Identifying improper ECB installations could help prevent undermining rill and gulley erosion. Also, maintenance issues such as reseeding may be reduced as the initial seed would not wash out from underneath the blanket.

Regarding ECB failure modes, many of the responses included erosion at the perimeter or seams of the ECBs. Gulley and rill erosion underneath the blanket was also reported. Overall lack of germination was identified as the primary cause of failures. Insufficient germination may result from the undercutting and anchor instability; thus, the anchor instability should be periodically inspected to prevent the ultimate germination failure.

The MoDOT SWPPP specifies that BMPs are not stand-alone technologies and should always be used to supplement each other (MoDOT, 2014b). ECBs can be supplemented by a variety of BMPs for the successful reestablishment of the slope. Ditch checks and wattles are common flow diffusers which trap sediment and slow down concentrated flow (MoDOT, 2014b). Flow reduction provided by these types of BMPS could assist in preventing erosion underneath the blanket and displacement of the seed along the slope laterally. Mulching and crimping can also be used providing additional coverage to the area. Many engineers and inspectors indicated using temporary pipe and slope drains to reduce the sheet flow over the slope from the roadway. Temporary pipes and slope drains must be installed properly and inspected regularly to prevent any concentrated flow from undercutting and eroded the perimeter of the ECB, which was reported as a common failure mode of the blanket. In all cases, correct BMP installation is necessary for its successful implementation (EPA, 2007).

6.1.3 Specific ECB Performance

The survey included identifying ECBs as consistently successful or unsuccessful ECBs by manufacturer, MoDOT longevity classification as per standard specifications (MoDOT, 2014a), netting type, material composition, and particular products. Of the three responses given for manufacturers with products exhibiting successful reestablishments American Excelsior was reported for all three and North American Green was reported on two surveys. No manufacturer was mentioned as having continued problems on MoDOT sites by the resident engineers and inspectors showing that although some manufactures may consistently have high quality products, no manufacturer has a history of producing lower quality products insufficient for application.

The ECB classifications noted as more successful were the Type 1 (45-60 days) and Type 2 (12 months) ECBs. These types have the shortest service life and degrade the quickest. One response reported the Type 4 (24 month service life) ECBs had the most issues during application. The same MoDOT employee noted that heavier blankets have the most trouble with seed germination. Another MoDOT construction manager stated that the Type 2 ECBs have the highest success rate and the Type 1 blankets had the most issues contrary to the successes of some of the other responses. Survey respondents noted that single biodegradable netted blankets also have issues. For responses noting Type 2 ECBs as successful, both double photodegradable and single biodegradable netting types were also reported. Straw and wood excelsior were the primary materials of success for the responses given and specific successful products reported include American Excelsior's Curlex (Type 1), and North American Green's SC150 (Type 4).

6.1.4 ECB Experiences

Additional experiences with ECBs provided by the MoDOT resident engineers and inspectors provided insight to other factors not covered by the questions and prompts in the survey or reaffirmed conclusions made from the responses. One response reported that heavier blankets have more issues with promoting germination, and two responses noted that rill and gulley erosion forming beneath the blanket are the biggest issues surrounding the use of ECBs.

6.2 Survey of Landscaping Contractors

The landscaping subcontractors select the specific ECB and install the blanket. The landscaper is also responsible for any mitigation and maintenance that may be specified from the general contractor following a SWPPP inspection. The landscaping contractor survey stressed the material quality control, installation processes, and ECB product selection.

6.2.1 ECB Site Conditions and Pre-installation Procedures

The landscape contractors are directly involved with the installation procedures, handling of the ECBs, and general quality control. The landscape contractors primarily note that MoDOT resident Engineers and inspectors specify the ECB manufacturer recommendations for installation. In terms of installation interruptions, two contractors stated that installation is continued the following day as per manufacturer recommendations. One of these responses stated that reseeding is performed if a rainfall event occurred and washed away the seed over the exposed portion. All of the contractors stated that defective ECBs are determined visually as the blanket is unrolled for installation. One contractor reported that any deficiencies are found in the single-net straw blankets while double-netted straw or straw/coconut blankets rarely have issues. This contractor noted the deficiencies as inconsistency in the thickness of the ECB. Regarding ECB storage on site, all contractors reported that all ECBs are treated the same. One contractor stores all ECBs inside, and another stated that ECBs are stored indoors and are covered from the sun if stored outside. Other contractors store the ECBs out of the sun in a dry place. The consistency in storage practices show that premature degradation may not be a caused from inappropriate storage practices and instead the longevity or the materials of the ECB itself. Typical quality assurance documentation during installation varied between contractors. One contractor reported that nothing was documented while another said the MoDOT Daily Inspection Reports served as quality control.

6.2.2 MoDOT SWPPP Compliance

After a routine SWPPP inspection, MoDOT will issue necessary maintenance items for the ECBs and the landscape contractor is responsible for making these corrections. Common maintenance items following a SWPPP inspection the landscape contractors reported include restapling loose areas of blanket and repairing erosion occurring under the blanket, one contractor primarily experiences the undermining in ditches. Another contractor stated that a common maintenance item was correcting concentrated points of entry of water onto the blanket surface which may lead to erosion under the blanket.

6.2.3 Specific ECB Performance

Landscape contractors were also prompted to attest to successful or unsuccessful ECBs under the same categorization as the MoDOT resident engineer and inspector survey. One contractor reported having no success with any ECBs. For one project, this contractor thought rock protection should have been used instead of the specified ECB; ultimately, this ECB installation was undermined and led to gully erosion. The other four contractors all had success with North American Green, American Excelsior, and Western Excelsior products. Three of the four responses also mentioned Landlok, and one mentioned ErosionBlanket.com. Similar to the testaments of the MoDOT resident engineers and inspectors, no landscape contractors listed any manufacturers as consistently producing products having difficulties indicating manufacturers generally produce high quality ECBs.

The most successful ECB classifications for the landscape contractors were the Type 2 (12 months) and the Type 3 (12-18 months) reported three times each. Two contractors found success with Type 4 (24 months) ECBs. In contrast, the majority of problems occurring with ECBs were from Type 1 (45-60 days) blankets. Predominantly double photodegradable netting had the most success; however, one contractor stated that the biodegradable and photodegradable single-net ECBs also had success. In contrast, the remaining contractors reported that both single-netting types led to frequent problems. The landscape contractors all noted wood excelsior as an ECB material composition exhibiting successful implementations. Three reported that straw, and one additionally stated that coconut composition worked well. ECB material compositions the contractors had difficulties working with included jute fiber, straw, coconut, and various TRM materials. One contractor said that ECB material compositions that are successful or unsuccessful are circumstantial to the application attributing the failures to using the wrong product as opposed to the wrong material. The results showing that materials are both successful for one contractor and unsuccessful for another would support this claim.

Many of the landscape contractors preferred working with several specific ECB products. The following lists specific products that were listed as preferred by some of the landscape contractors:

- AEC Premier Straw Double Net (Type 2) manufactured by American Excelsior;
- SC150 (Type 4) manufactured by North American Green;
- Excel S-1 (Type 3) manufactured by Western Excelsior;
- Curlex II (Type 1) manufactured by American Excelsior; and
- Curlex III (Type 4) manufactured by American Excelsior.

One landscape contractor reported difficulties with Excel S-1 (Western Excelsior), SC 150 (North American Green), and Landlok S1 (Propex). The contractor commented that because of the lack of a seeding season by MoDOT, seeding place in the summer dries initial germination and requires reseeding. According to one survey response, initial overseeding practices seemingly only worked for the Curlex (wood pulp) products.

6.2.4 ECB Experiences

Additional experiences with ECBs provided by the landscape contractors gave insight to other factors not covered by the questions and prompts in the survey or reaffirmed conclusions made from the responses. One contractor commented that the mat thickness restricted plant growth hindering the final reestablishment of the slope. A possible thickness limitation or minimum light penetration would allow for better growing conditions of the seed. Another noted the germination issue with the lack of a seeding season by MoDOT forcing the seeding in the summer when the grass immediately dried up upon germination having difficulties with establishment and that overseeding is not very effective and only seemed to be successful for wood pulp based products. The contractor with no success using ECBs stated ECBs were used in place of rock protection and were inappropriate. In contrast, another landscape contractor was very pleased with the application of ECBs and recommended their further use.

6.3 Conclusions

Comparing the results from the two surveys provides similarities and conclusions regarding ECB considerations for product approval and product specifications. The critical findings from the survey include the following:

- MoDOT Inspectors and engineers should check instability/stability of ECB anchors and maintain and/or prevent any concentrated points of entry of runoff during SWPPP inspections. During SWPPP inspections, germination is inspected as the reestablishment of the slope is the ultimate goal. However, inspecting and maintaining other items which may indicate undercutting or washing the seed away may prove critical to slope reestablishment such as proper perimeter anchorage and preventing concentrated points of entry for runoff.
- Installation quality of any BMP is critical to its performance. However, MoDOT lacks any mechanism for quality control of installed ECBs. Developing and instituting a uniform installation quality control checklist for ECBs is recommended to help ensure successful ECB applications.
- Generally, single-net ECBs have the most difficulty in application.
- Type 1 and Type 2 ECBs are predominantly preferred by both landscape contractors and MoDOT resident engineers and have shown to be successful.

7 Specifications for ECB Product Approval

An approved products list is a list of products meeting certain performance and/or physical requirements to be considered acceptable for a particular application. For ECB approved product lists, the blankets have been categorized by the following factors: netting type, service life, and maximum intended slope and soil type. The categories assist the designer when generalizing ECB selection into ECB types suited for certain slopes, soil types, and longevities when selecting ECBs for a SWPPP plan. The categories have requirements the ECBs must meet to be considered acceptable for that category verifying the performance and physical characteristics of the ECB for the intended slope and soil type for the category which the manufacturer wants to receive approval. Currently, MoDOT utilizes the TxDOT approved products list for its ECBs. Any product to be used on a MoDOT construction site must meet the minimum requirements of the TxDOT large-scale testing. Other testing methods include the NTPEP standardized testing that several other state departments of transportation have instituted as their method of product approval. The NTPEP standardized ASTM testing and the TxDOT independent testing were investigated to develop recommendations for MoDOT's product approval.

The NTPEP large-scale testing is based on the RUSLE applying a coverage factor to account for ECB erosion resistance under specific conditions. NTPEP testing (ASTM D6459) determines a C-factor corresponding to ECB hydraulic testing performance. The ECB properties determined by large-scale, index-property, and bench-scale testing are a standardized way of evaluating ECB properties and performance.

The independent testing of TxDOT is derived from meeting CWA compliances. The revisions to these thresholds are based on meeting the ongoing changes to the NPDES and other state water quality standards. The testing supplements the slope stability testing with a germination enhancement test encompassing all aspects of the ECB. With a pass/fail type of testing, determining the adequacy of an ECB for a certain slope application requires little discernment.

The connection between TxDOT independent testing and NTPEP's testing was investigated. An analysis was conducted to determine if product performance could be correlated to ECB index properties using information from TxDOT's approved products list. The approved products list was divided into classifications: 1) products that were removed from the list in 2015 because of the smaller limits established on product acceptance (Group 2014) and 2) products that are currently on the list which met the stricter requirements (Group 2015). Categorically, Group 2014 did not meet the maximum soil loss requirement and Group 2015 did meet the requirement. Mass per unit area, light penetration, and thickness were compared for the two groups to determine if any of the index properties correlated to ECB erosion control performance. The results for mass per unit area versus light penetration and mass per unit area versus blanket thickness for the TxDOT Type A ECBs are shown in Figure 7.1 and Figure 7.2, respectively. The Type A blankets are for clay soils on 3:1 slopes, and the threshold for sediment yield was lowered to 3.38 lb/100ft^2 (TxDOT, 2015). The vegetation density minimum requirement of 50% was not changed. The plots of the complete analysis for all TxDOT Types are provided in Appendix E.

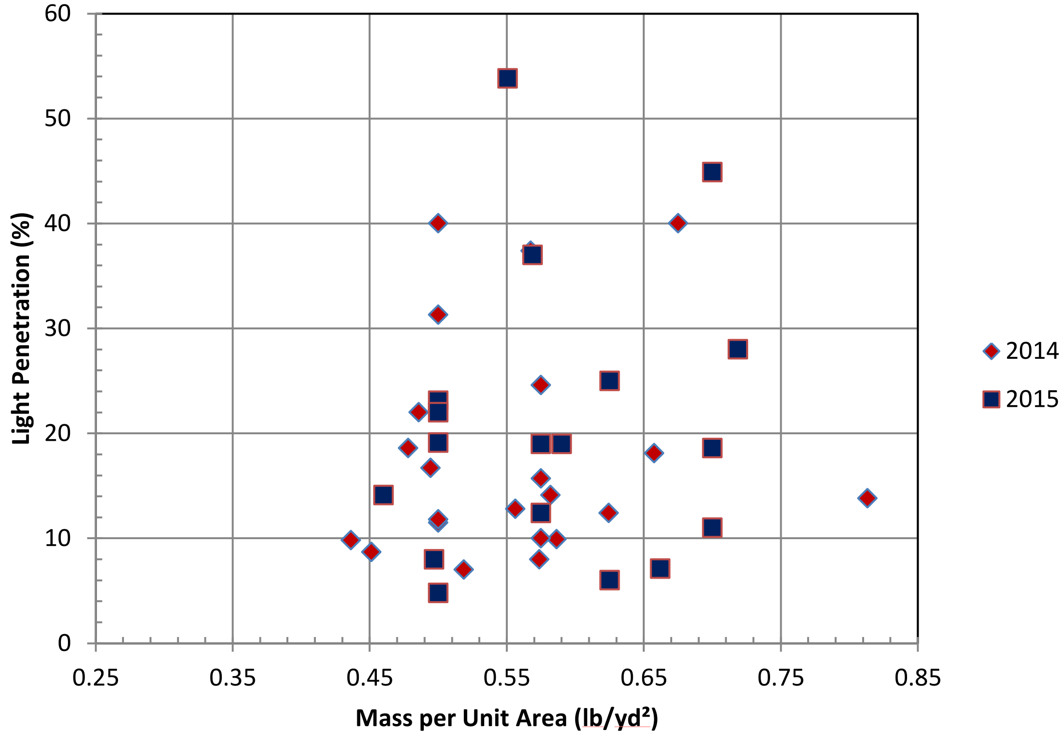


Figure 7.1. Mass per unit area and light penetration for Type A.

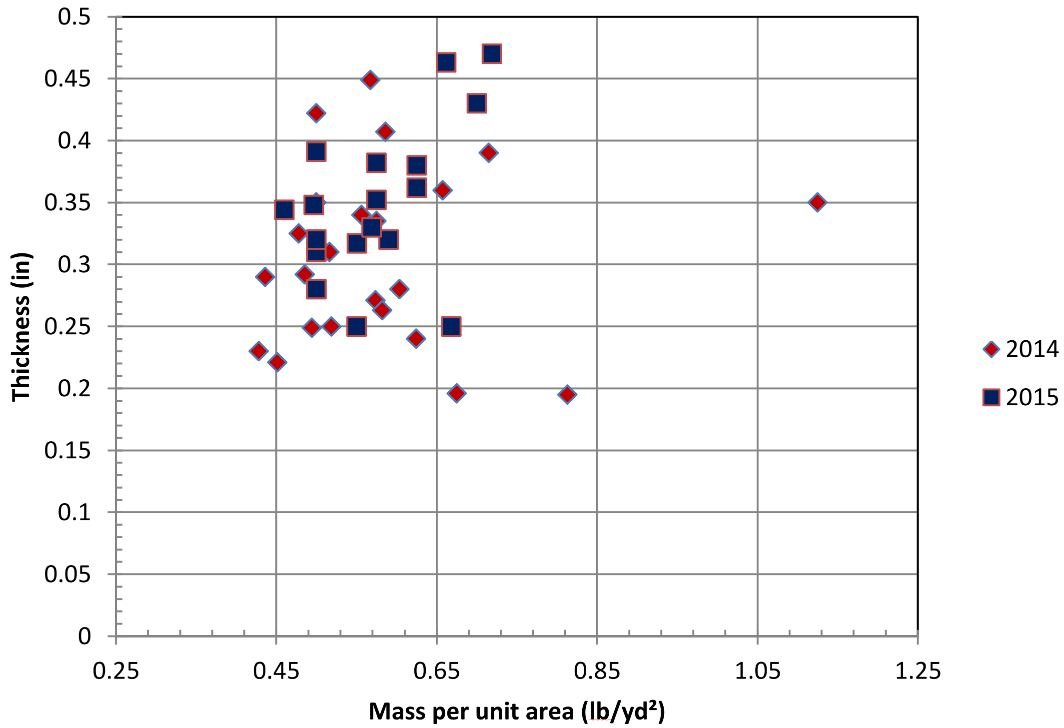


Figure 7.2. Mass per unit area and thickness for Type A.

The analysis clearly showed no distinct correlation between product performance and ECB index properties indicating that index property results cannot be used as a surrogate for rainfall testing to determine product approval. Although the TxDOT testing has a long wait list period, the repeatability and development of thresholds which verifies an ECB being compliant with the CWA makes the testing still appropriate for product acceptance. Instituting a system of product acceptance through the NTPEP convention is recommended; however, maintaining the flexibility of allowing products to be submitted with TxDOT independent testing results is also recommended. The following section outlines the recommendations for product acceptance procedures which integrate guidelines per NTPEP convention, and TxDOT testing results.

7.1 Recommendations for Product Acceptance Procedures

Having specifications for product approval which categorizes ECBs into classifications with established application ranges simplifies the ECB selection process. The categories not only simplify selection but also assist the designer by establishing specific performance criteria and properties for each category. Having procedures for product approval holds the manufacturer accountable for proper documentation of their product. Requiring submittal of product documentation allows for tracking all approved products. A product change in trade name would be better recorded and transitioned if MoDOT had the previous information on the ECB. Documentation for ECBs seeking product approval for slope applications should include the following information:

- Product literature and manufacturer specifications;
- Recommended installation procedures; and
- NTPEP testing documentation signed by authorized testing facility personnel for ASTM D6459 and ASTM D5035 or any large-scale independent testing documentation signed by authorized testing facility personnel.

7.1.1 Product Literature and Manufacturer Specifications

Required literature from the manufacturer includes the product trade name, product physical description, material composition including percent by material, netting type, service life of the blanket, storage and handling procedures, and intended slope application. Manufacturer specifications include typical characteristics expected from the product such as index property test and bench-scale test results. This documentation is critical for tracking product trade name changes. Also, this provides a means of tracking characteristics of products that were removed from the approved products list for continued problems on MoDOT construction sites.

7.1.2 Recommended Installation Procedures

Submittals of recommended installation procedures are necessary to ensure proper ECB installation. The manufacturer should provide descriptions on how to install the blanket. Description of the necessary grading and surface conditions of the soil should be described in this documentation as well. Installation methods should include plan drawings of staple patterns and trenching conventions. Recommended staple types should to be described.

7.1.3 NTPEP Test Documentation

Test documentation should include all required information to be documented and calculated as per ASTM D5035 – Standard Test Method for Breaking Force and Elongation of Textile Fabrics

(Strip Method). The required information documented as per ASTM D6459 – Standard Test method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion should also be included. The test should to be conducted on loam soil as loam soil is a conservative average for soils in Missouri and using one soil type simplifies submittal procedures. For manufacturers using TxDOT's independent testing for acceptance, only the results for either 3:1 sand or 2:1 sand are acceptable. The clay has a lower potential for sediment yield than the loam soil required for the NTPEP ASTM D6459, contrary to sandy soils (Summer, 1991). The sand substitute is a conservative replacement for loam.

7.2 Product Acceptance Guidelines

The product acceptance guidelines are developed to categorize the ECBs into classifications based on ECB performance and physical characteristics. The template for these classifications was taken from the ECTC installation guide of ECBs and TRMs (ECTC, 2008). The template is also the basis for product approval for NDOR and IowaDOT as described in Section 2. Recommended product approval procedures were developed by integrating the ECTC classification template with information obtained through the field investigation, site visits, and surveys. As shown in Table 7.1, ECB specification is separated into categories by typical service life of the ECB: Ultra Short-Term (Type 1), Short-Term (Type 2), Extended Term (Type 3), and Long-Term (Type 4). The recommended guidelines exclude the single-net blankets that were included in the original ECTC guidelines. The responses from the survey dictated the omission of single-net blankets.

Table 7.1. Recommended classifications for ECB product approval.

ECB Type	Description	Material Composition	Longevity	Maximum Gradient (H:V)	Maximum Coverage Factor (C)	Maximum Tensile Strength (lb/ft)
1.A	Mulch Control Nets	A photodegradable synthetic mesh or woven biodegradable natural fiber netting	3 months	5:1	≤ 0.10 @ 5:1	5.0
1.B	Netless Rolled Erosion Control Blankets	Natural and/or polymer fibers mechanically interlocked and/or chemically adhered together to form an RECP	3 months	4:1	≤ 0.10 @ 4:1	5.0
1.C	Light-Weight Double-Net Erosion Control Blankets	Natural and/or polymer fibers mechanically bound together by two rapidly degrading, synthetic or natural fiber nettings	3 months	3:1	≤ 0.15 @ 3:1	50.0
1.D	Heavy Double-Net Erosion Control Blankets	Processed degradable natural and/or polymer fibers mechanically bound together between two rapidly degrading, synthetic or natural fiber nettings	3 months	2:1	≤ 0.20 @ 2:1	75.0
2.A	Mulch Control Nets	A photodegradable synthetic mesh or woven biodegradable natural fiber netting	12 months	5:1	≤ 0.10 @ 5:1	5.0
2.B	Netless Rolled Erosion Control Blankets	Natural and/or polymer fibers mechanically interlocked and/or chemically adhered together to form an RECP	12 months	4:1	≤ 0.10 @ 4:1	5.0
2.C	Light-Weight Double-Net Erosion Control Blankets	Natural and/or polymer fibers mechanically bound together by two degrading, synthetic or natural fiber nettings	12 months	3:1	≤ 0.15 @ 3:1	50.0
2.D	Heavy Double-Net Erosion Control Blankets	Processed degradable natural and/or polymer fibers mechanically bound together between two degrading, synthetic or natural fiber nettings	12 months	2:1	≤ 0.20 @ 2:1	75.0
3.A	Mulch Control Nets	A photodegradable synthetic mesh or woven biodegradable natural fiber netting	24 months	5:1	≤ 0.10 @ 5:1	25.0
3.B	Erosion Control Blankets	An erosion control blanket composed of processed slow degrading natural or polymer fibers mechanically bound together between two slow degrading synthetic or natural fiber nettings to form a continuous matrix	24 months	1.5:1	≤ 0.25 @ 1.5:1	100.0
4	Erosion Control Blankets	An erosion control blanket composed of processed very slow degrading natural or polymer fibers mechanically bound together between two slow degrading synthetic or natural fiber nettings to form a continuous matrix	36 months	1:1	≤ 0.25 @ 1:1	125.0

ASTM D6459 test results are reported as a function of erosivity which can be specialized to a particular region and also reports the experimental C-factor associated with the erosivity of the experiment. The ASTM D6459 laboratory test specifies three 20-minute durations of 2 in/hr, 4 in/hr, and 6 in/hr intensity storms. The cumulative erosivity (R) of these events is commonly around 162. Erosivity values have units described in Section 2; however, the units are not commonly expressed in testing reports and other documentation and herein are expressed without units. The range of average erosivity values for each county in the state of Missouri ranges from 178 to 269 (USDA, 1997). From the reported C-factor regression equation that relates C-factor to erosivity, the average erosivity value for Missouri (224) should be used to determine the representative C-factor for ECBs used in the state.

Products seeking approval using TxDOT independent testing results are designated their appropriate category based on blanket longevity. Acceptance through TxDOT independent testing for 3:1 and 2:1 sand requires no more than 102.51 psf and 167.25 psf of sediment yield (TXDOT/TTI Sediment and Erosion Control Laboratory, 2015). The TxDOT test under bare-soil conditions yielded 1709.6 psf for 3:1 sand and 3885.3 psf for 2:1 sand slopes (TxDOT, 1994). The C-factor is calculated as the ratio of the sediment yield from an ECB to the sediment yield under normal bare soil conditions. For an ECB to pass the TxDOT independent test for these two slope gradients, an ECB can have a maximum C-factor of 0.06 (3:1 sand) and 0.043 (2:1 sand). Because these calculated C-factors are less than the maximum thresholds set in Table 7.1, allowing ECB products that have met these TxDOT requirements on the approved products list for these categories is a conservative alternative for the ASTM D6459 test.

7.3 Channelized Applications

RECPs seeking approval for channelized applications have a separate set of testing criteria for product approval. Currently, MoDOT uses the TxDOT large-scale testing for channelized applications for threshold acceptance. Thresholds are dependent on the amount of soil displaced from the channel taking profiles along the reach. The ASTM standard for large-scale channelized testing (ASTM D6460) similarly records performance by recording the profiles along the reach testing the RECP under increasing increments of estimated shear stress until failure is observed. The TxDOT channelized testing also requires RECPs to pass of the vegetation test for approval. The ASTM D6460 does not have a vegetation enhancement element. It is recommended that both results of TxDOT independent testing and ASTM D6460 be acceptable for RECP channelized product approval. ASTM D6460 should be conducted on loam soil as defined by the standard. Product submittals should be identical to ECBs with the testing results of either TxDOT independent testing or ASTM D6460 in place of the slope protection tests (ASTM D6459 and ASTM D 5035).

ASTM D6460 and the TxDOT independent testing both determine the approximate design shear stress an RECP is appropriate for before failure. Because of the similarity between the two tests, the proposed product acceptance categories do not differ from the current delineation: Type 1 (0-2 psf), Type 2 (0-4 psf), Type 3 (0-6 psf), and Type 4 (0-8 psf). The addition of ASTM D6460 testing would increase the flexibility and ease of RECPs receiving approval for the MoDOT approved products list for channelized applications.

8 Recommendations for ECB Design Specifications

A design approach was developed for ECB specification based on the RUSLE, which was detailed in Section 2.3. The site conditions, type of establishment (temporary or permanent), and local geology dictate the type of ECB to be used. The recommended design procedure is to apply the RUSLE in conjunction with the ECB C-factors to determine an annual soil loss for a given application. To determine erosion control adequacy, the calculated soil loss is commonly compared to a threshold soil loss determined as the maximum soil loss without compromising the vegetative growth potential of the land. Ports and Smith (1976) recommend 15 tons/acre annual loss as the maximum threshold for construction sites. For product design specifications, the proposed design tool sets 15 tons/acre soil loss as the threshold and solves for the maximum allowable slope length each type of ECB shown in Table 7.1.

ArcGIS was utilized to develop representative erodibility and rainfall erosivity values for each physiographic region in Missouri as shown in Figure 3.4. The erodibility shapefiles from Figure 3.6 were converted into a raster, and the zonal statistic mean was calculated for the average erodibility for each physiographic region. The result of this computation is provided in Appendix F. The region erosivity was performed similarly. The EPA Isoerodent map shown in Figure 8.1 was georeferenced over the Missouri physiographic map layer. Digitizing the isoerodent map created contours which were interpolated to obtain an erosivity raster. The zonal statistical mean of erosivity was computed to determine the representative region annual erosivity. The resulting map is provided in Appendix F. As the erodibility and erosivity are the only two spatially dependent variables in the RUSLE, combining these variables into one map simplifies the calculation. The product of each physiographic region's respective erodibility and erosivity values (KR factor) were computed and are shown in Figure 8.2. The KR factors were divided into three zones: 61 (Zone 1), 70 (Zone 2), and 86 (Zone 3) as shown in Figure 8.3. Zone 1 includes the Glaciated Plains, the Ozarks, and the St. Francois Mountains and assumes all three regions to have a KR factor of 61. Zone 2 is for the Western Plains, and Zone 3 is the Southeast Lowlands region. A Missouri county layer was overlaid to Figure 8.3 to better asses a project location spatially. The RUSLE was applied to each zone to calculate the maximum allowable slope length for each ECB type. It is recommended to use the region of more severe conditions for counties that are located within more than one physiographic region.

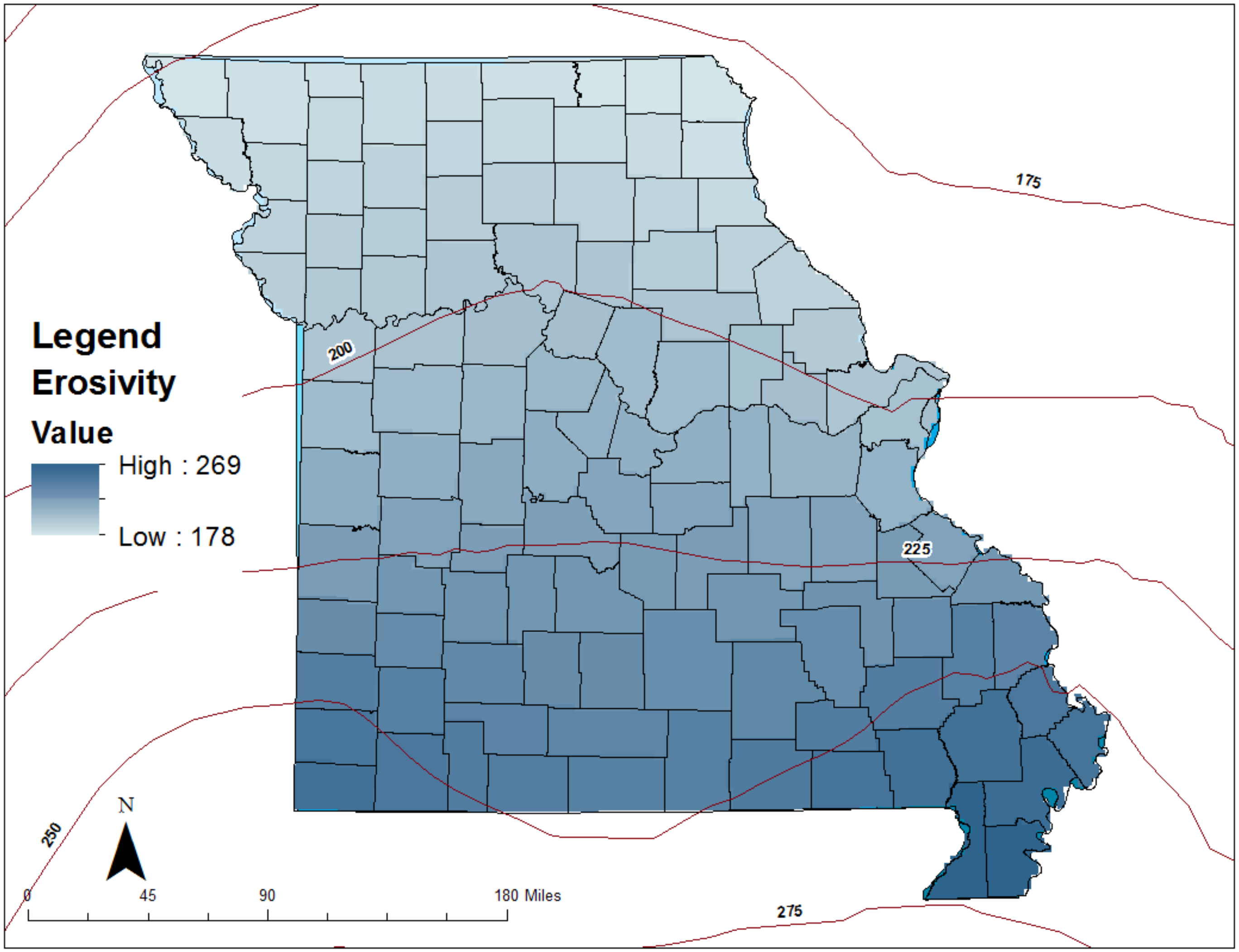


Figure 8.1. Isoerodent map of Missouri (adapted from USDA 1997).

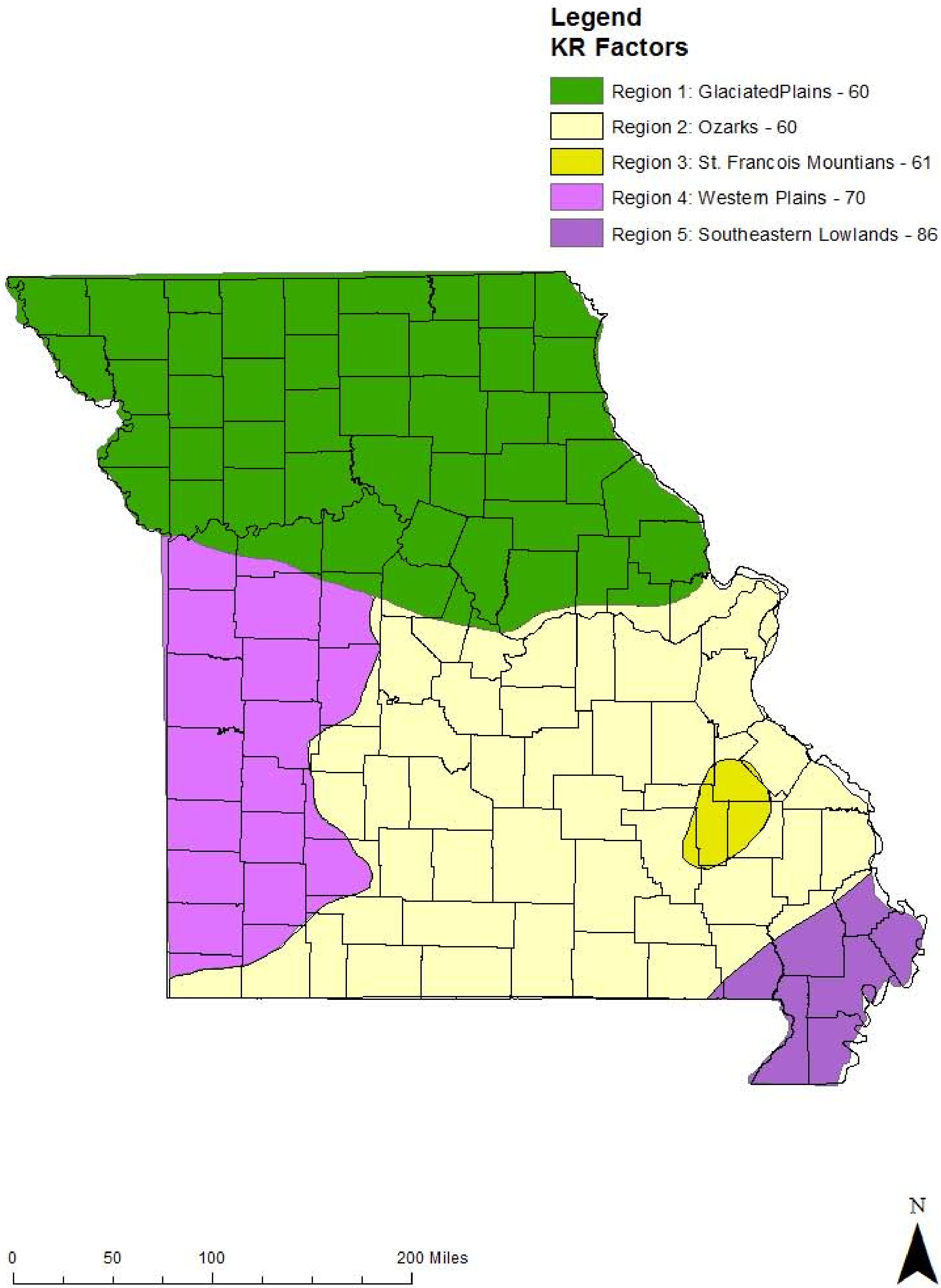


Figure 8.2. KR factors for physiographic regions of Missouri.

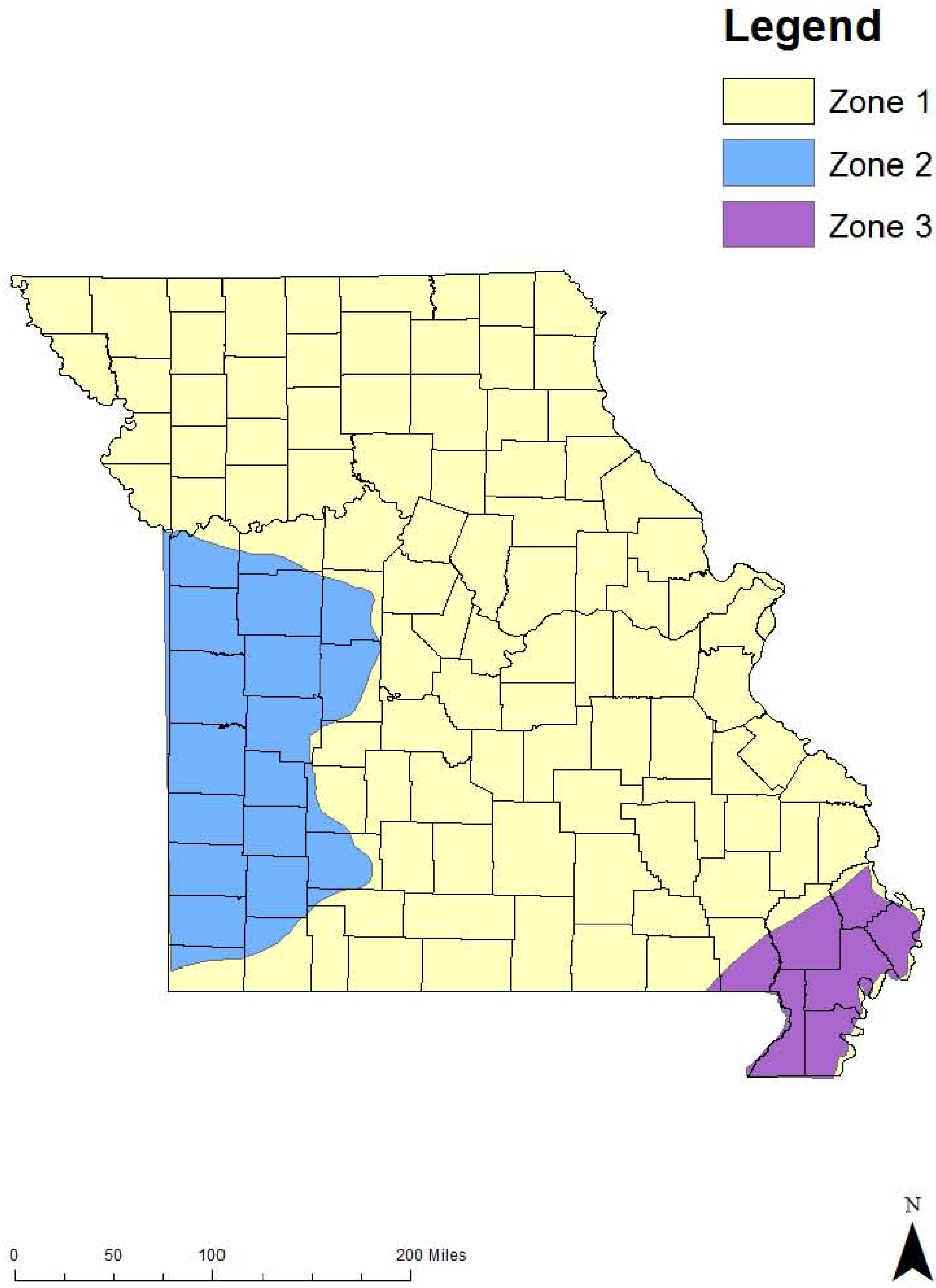


Figure 8.3. KR zones for ECB design specifications.

The calculation of maximum allowable slope length assumes one year of blanket usage, and 100% of the annual erosivity. The Type 1 ECBs have a service life of less than one year (three months); therefore an adjusted erosivity was determined. To calculate soil loss for a time interval less than one year, the erosivity index (EI) must be determined for the region (USDA, 1997). The EI value corresponds to cumulative percentages for every two weeks throughout the year and linear interpolation is recommended for dates in between the given data (EPA, 2012). The percentages represent the fraction of expected annual erosivity that has occurred over the area for a given time period. Five EI areas are located in Missouri, and the most severe three-month period of cumulative annual erosivity of the five areas was used for the Type 1 erosivity value, which was 53%.

The slope and C-factor used in the RUSLE calculation were derived from the ECB type's maximum slope and maximum allowable C-factor. Furthermore, construction site soils for highway embankments require compactive effort for geotechnical stabilization. The soil erodibility values used are for bare-fallow conditions (C factor of 1.0) (USDA, 1997), and an adjustment is required for a more representative and accurate calculation. For a compacted embankment on construction sites, (Toy et al., 1998) recommend a C factor of 0.45 for bare soil conditions.

A practice management factor of 1.0 was used in the calculation of the Type 1 ECBs, which indicates no additional BMPs. The short service life would make the usage of silt fences or wattles less economically practical. Silt fences were assumed for Type 2, Type 3, and Type 4 blankets (0.50 Practice Factor). The addition of a silt fence with a Type 1 ECB would extend the maximum length allowable by a factor of four. The resulting lengths were rounded to the nearest five feet (Table 8.1).

Table 8.1. Recommended maximum allowable slope lengths for ECB types.

ECB Type	Name	Maximum Slope (H:V)	Maximum Length (ft)		
			Zone 1	**Zone 2**	**Zone 3**
1A	Mulch Control Nets	5:1	990	750	495
1B	Netless Rolled Erosion Control Blankets	4:1	605	460	305
1C	Light-Weight Double-Net Erosion Control Blankets	3:1	150	115	75
1D	Heavy Double-Net Erosion Control Blankets	2:1	40	30	20
2A	Mulch Control Nets	5:1	1110	840	560
2B	Netless Rolled Erosion Control Blankets	4:1	680	515	340
2C	Light-Weight Double-Net Erosion Control Blankets	3:1	170	130	85
2D	Heavy Double-Net Erosion Control Blankets	2:1	45	35	20
3A	Mulch Control Nets	5:1	1110	840	560
3D	Erosion Control Blankets	1.5:1	15	15	10
4	Erosion Control Blankets	1:1	10	10	5

The maximum allowable slope lengths for the three zones are illustrated graphically in Figures 8.4 through 8.6. The dashed lines designate distances and slopes where an ECB can be used, and the solid line denotes lengths and slope where the ECB is recommended. As shown in the design matrices, many types of ECB are appropriate for a variety of applications based on the assumption that ECB types are sufficient for any gradient shallower than the maximum specified gradient. Discretion is required by the designer to select the most economical and practical ECB. Because the calculations show that ECB lengths for the 1:1 slope gradients are not higher than 10 ft, other forms of erosion control are recommended for this gradient beyond this maximum length. Designers can also manually calculate maximum slope length using the RUSLE procedure, if site specific soil data are known. The MoDOT EPG assists MoDOT designers during the design phase of a construction project. Existing construction standard specifications for ECBs and TRMs are located in Appendix G. Recommendations for new construction standard specifications for ECBs and TRMs are also located in Appendix G along with a recommended approved products list template to accompany the standard specifications.

Zone 1		Slope Steepness																	
Type	Name	5:1			4:1			3:1			2:1			1.5:1			1:1		
		0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+
1A	Mulch Control Nets																		
1B	Netless Rolled Erosion Control Blankets																		
1C	Light-Weight Double Net Erosion Control Blankets																		
1D	Heavy Double-Net Erosion Control Blankets																		
2A	Mulch Control Nets																		
2B	Netless Rolled Erosion Control Blankets																		
2C	Light-Weight Double Net Erosion Control Blankets																		
2D	Heavy Double-Net Erosion Control Blankets																		
3A	Mulch Control Nets																		
3B	Erosion Control Blankets																		
4	Erosion Control Blankets																		

Figure 8.4. Recommended ECB design matrix for Zone 1.

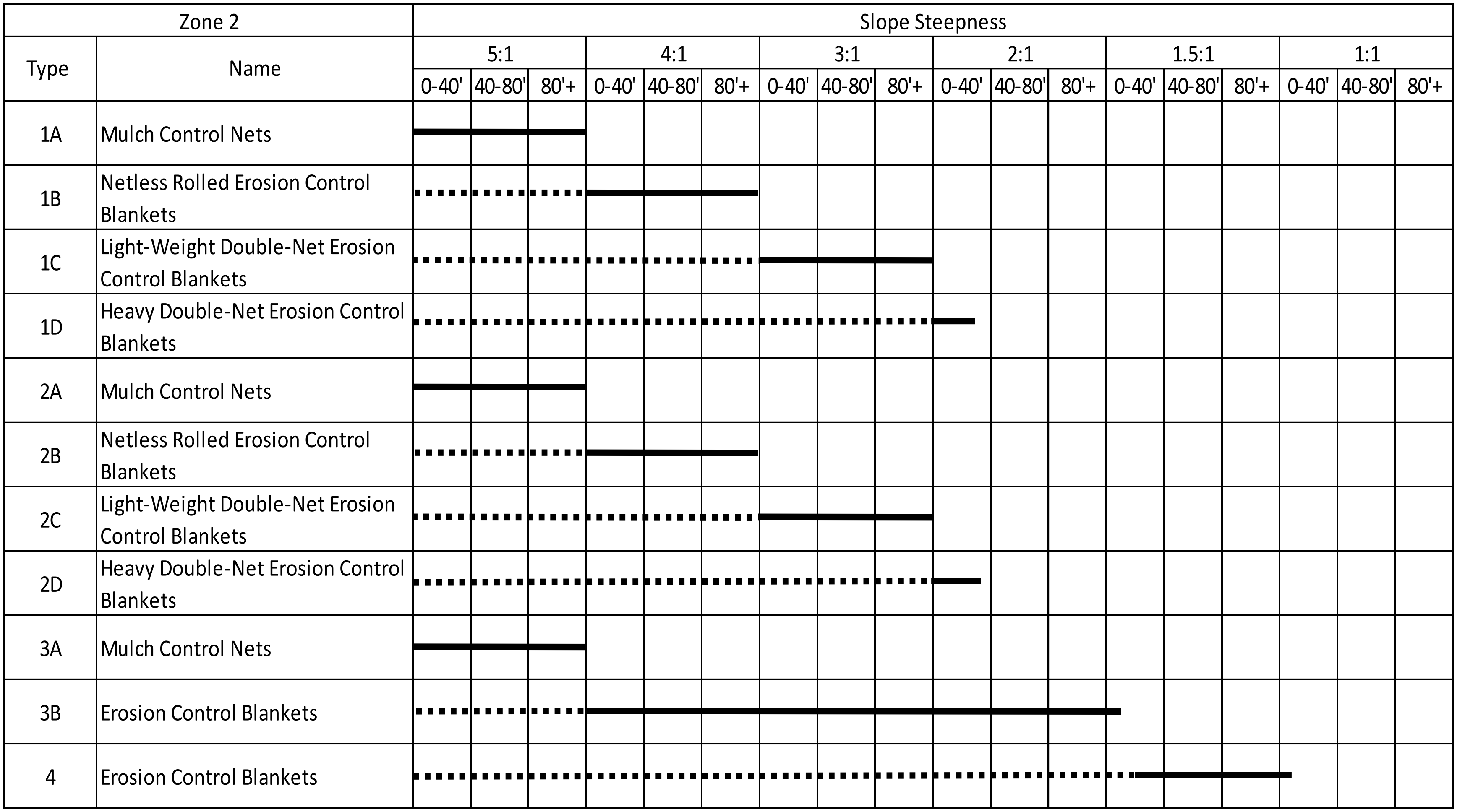


Figure 8.5. Recommended ECB design matrix for Zone 2.

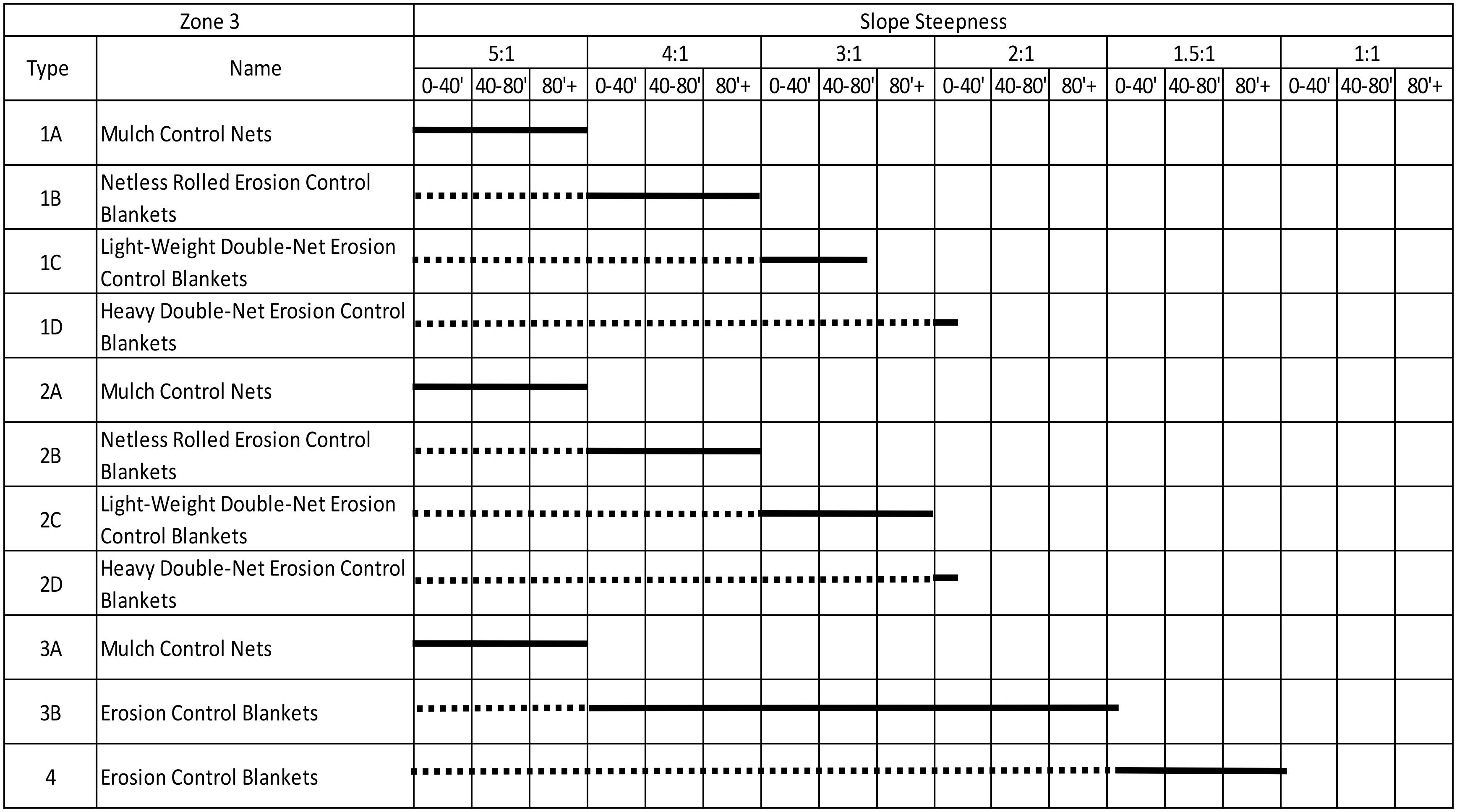


Figure 8.6. Recommended ECB design matrix for Zone 3.

8.1 Example Calculation

The ECB design matrices were derived from an algebraic manipulation of the RUSLE inputting the appropriate values for each ECB type and zone parameters and solving for the maximum allowable length. Two example calculations of maximum slope lengths are presented in this section to demonstrate how the proposed design methods can be used: a construction project in Pulaski County and the Route N study site in St. Charles County. The example calculations are conducted for a Type 2C light-weight double-net erosion control blanket.

8.1.1 Example Calculation for Pulaski County

The design matrices presented in Figures 8.4 to 8.6 are employed for the county ECB design example in addition to directly computing the maximum slope length. Pulaski County is located in Zone 1 as identified in Figure 8.7 and thus the design matrix presented in Figure 8.4 is employed and specifies that for the Type 2C ECB, the slope length can be greater than 80 ft.

The following steps detail how to directly compute the maximum allowable slope length for the Pulaski County example:

Step 1. Identify recommended soil loss limit for construction sites to be used on the RUSLE (Equation. 8.1): maximum soil loss (*A*) is 15 tons/acre.

$$15\,tons/acre = KR \cdot L \cdot S \cdot C \cdot P \tag{8.1}$$

Step 2. Identify the *KR-factor* zone site based on Figure 8.3: *KR* = 0.61 for Pulaski County (Figure 8.7).

Step 3. Identify the coverage factor (*C*) for the ECB: *C* = 0.15 which is the maximum allowed for the Type 2C blankets (Table 7.1). An additional coverage factor of 0.45 for bare soil conditions of compacted soils is also required. The total coverage factor is equal to the product of the two coverage factors: C_{total} = 0.0675.

Step 4. Identify the practice factor (*P*) for the site: Type 2C ECBs utilize silt fences as additional sediment control, and a practice factor (*P*) of 0.5 is used (Table 2.2).

Step 5. Calculate the slope factor (*S*) for the site geometry: per product specifications (Table 7.1), Type 2C blankets have a maximum allowable slope of 3:1 with an associated angle of incline of 18.4° (0.322 radians); the slope factor (*S*) is calculated as 4.81 as shown in Equation 8.2:

$$S = (16.8\sin(\theta) - 0.50) = (16.8\sin(18.4°) - 0.50) = 4.81 \tag{8.2}$$

Step 6. Substitute values determined in Steps 1 through 5 and the expression for the length factor (*L*) from Equation 8.3 into the RUSLE (Equation 8.1), and solve for the slope length (λ): the maximum slope length (λ) for a Type 2C blanket in Pulaski County on a 3:1 slope is computed as 166 ft by solving Equation 8.4:

$$L = \left(\frac{\lambda}{72.5} \right)^{0.5} \tag{8.3}$$

$$15\,\text{tons/acre} = KR \cdot L \cdot S \cdot C \cdot P = (61)\left(\frac{\lambda}{72.5} \right)^{0.5} (4.81)(0.0675)(0.5) \tag{8.4}$$

$$\lambda = 166\,\text{ft}$$

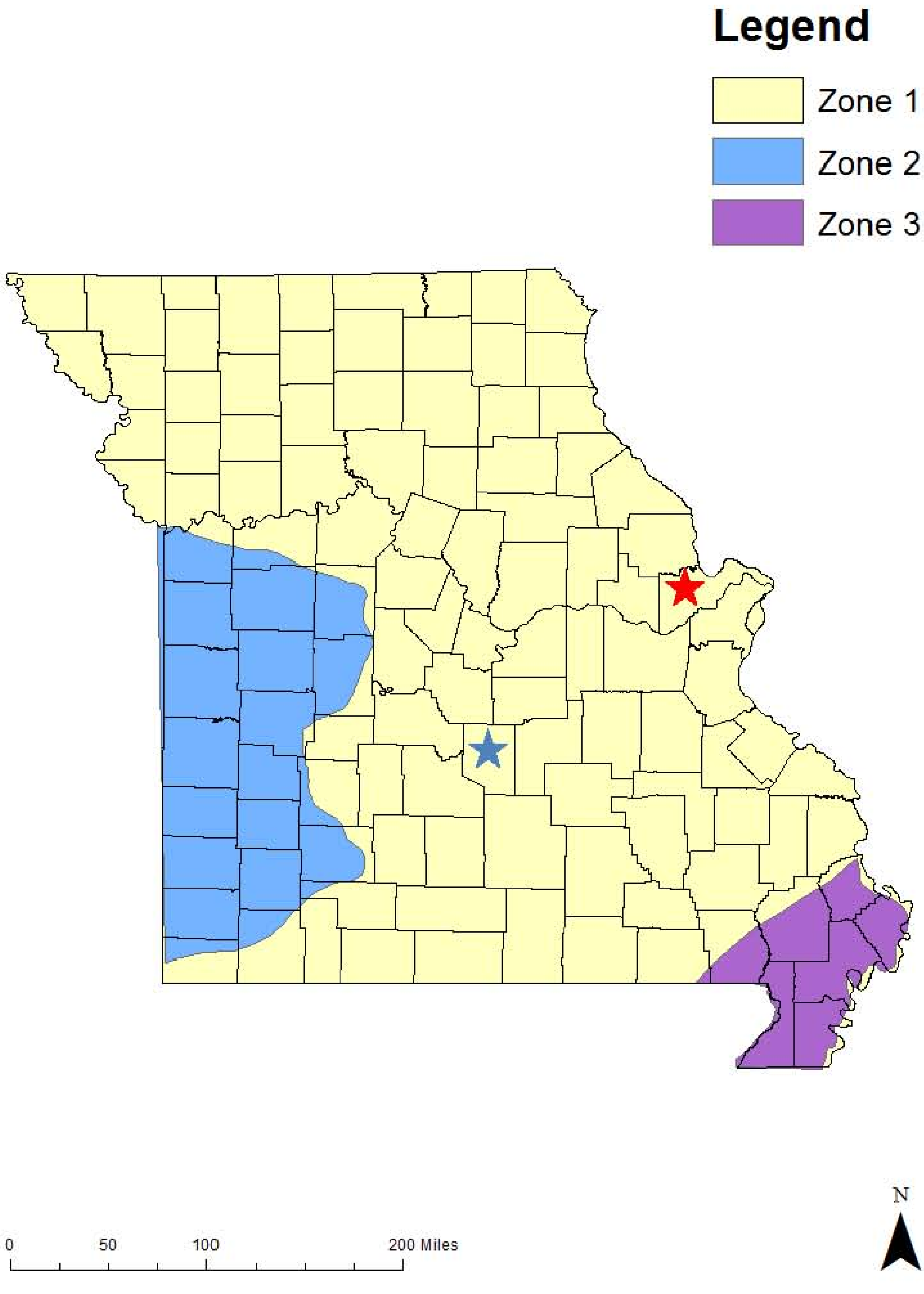


Figure 8.7. KR factors for Pulaski County (blue star) and Route N (red star).

8.1.2 Example Calculation for Route N Field Site

Route N has known soil data, and the erodibility and erosivity can be determined separately to determine a site-specific KR factor. The product of the calculated site-specific erodibility and the associated erosivity region (Appendix F) are used in place of the KR factor in the calculation. The soil analysis of the study site provides information that can be used to determine a site-specific erodibility k-value.

The following steps detail how to directly compute the maximum allowable slope length for the Route N example with site-specific soil information:

Step 1. Identify recommended soil loss limit for construction sites to be used on the RUSLE (Equation. 8.1): maximum soil loss (*A*) is 15 tons/acre:

$$15\, tons/acre = K \cdot R \cdot L \cdot S \cdot C \cdot P \quad \textbf{(8.5)}$$

Step 2. Identify the erodibility value from known soil characteristics: the Route N soil was determined to be Clay Loam (Table 4.2). Sand, silt, and clay percentages were determined from the gradation analysis to be 23%, 38%, and 19%, respectively; using the Erickson Nomograph shown in Figure 3.5 of Section 3, 0.30 is the preliminary erodibility factor (*K*). The site was assumed to have normal angularity, porosity, and organic content, and the gradation also showed that the soil has between 0-15% rock content. Thus, the preliminary erodibility factor of 0.30 requires no further adjustments: $K = 0.30$.

Step 3. Identify the erosivity value based on site location: Figure 8.1 was used to determine site-specific erosivity (*R*), which was found to be 200 for St. Charles County: $R = 200$.

Step 4. Identify the coverage factor, (*C*): the ECB coverage factor is 0.15 which is the maximum allowed for the Type 2C blankets (Table 7.1). An additional coverage factor of 0.45 for bare soil conditions of compacted soils is also required: the total coverage factor (C) = 0.0675.

Step 5. Identify the practice factor, (*P*), for the site: Type 2C ECBs utilize silt fences as additional sediment control, and a *P* of 0.5 is used (Table 2.2).

Step 6. Calculate the slope factor (*S*) for the site geometry: the LiDAR scans from Figure 4.3 of Section 4 show the average slope for the reach to be 3.65:1 (H:V); the slope of 3:1 will be assumed for the calculation as a conservative estimate of the variation throughout the study reach. Thus, the slope factor (*S*) is calculated as 4.81 as shown in Equation 8.2 of the previous example:

Step 7. Substitute values determined in Steps 1 through 6 and the expression for the length factor (*L*) from Equation 8.3 into the RUSLE (Equation 8.5), and solve for the slope length (λ): the maximum slope length (λ) for a Type 2C blanket at the Route N Site is computed as 172 ft by solving Equation 8.6:

$$15\,\text{tons/acre} = K \cdot R \cdot L \cdot S \cdot C \cdot P = (0.3)(200)\left(\frac{\lambda}{72.5}\right)^{0.5}(4.81)(0.0675)(0.5) \qquad \textbf{(8.6)}$$

$$\lambda = 172\,\text{ft}$$

The average slope length for the Route N site is 13.1 ft; thus, a Type 2.C ECB would be acceptable for the site.

9 ECB Field Performance Quality Control

Construction application of an ECB may yield differing results than a highly-controlled laboratory setting leading to failures despite the estimated performance (TxDOT, 1994). Establishing a database of successful and unsuccessful applications of ECBs is recommended as it would assist MoDOT in identifying products that should be removed from the approved products list and help in identifying characteristics of successful applications. Not all failures may be attributed to the ECB; some ECBs may fail but were designed or installed incorrectly. Ongoing evaluation can serve as a mechanism to identify practices or procedures that have proven unsuccessful and may assist as a learning tool for future applications.

Utilizing a uniform document completed by MoDOT engineers and inspectors to assist with quality control of ECB field performance is recommended for the database. The field performance quality control form should be completed when any of the following has occurred:

- Site acceptance in accordance with the MoDOT SWPPP;
- Rupturing or movement of the blanket requiring repining or blanket replacement;
- Gulley erosion or other erosion undercutting the blanket requiring re-grading underneath the ECB;
- Reseeding the blanket caused by insufficient germination in the area; and
- Any assessed fines attributed to the ECBs from SWPPP of other NPDES non-compliances.

A form was developed for the quality control of ECBs and is located in Appendix H. The form addresses general site characteristic such as the date, county, and project contract number. The form categorizes the ECB type (as per the recommended convention described in Section 7), ECB product name, manufacturer, supplier/distributor, and the subcontractor responsible for installation. Methods of installation are also noted in the form including any deviations from the manufacturer recommendations. The form includes identification of ECBs successes and failures. Four types of failures are delineated on the form: rupturing/movement of ECB, undercutting and gulley erosion, lack of germination, lack of blanket degradation. Furthermore, a description of the ECB successful application or the nature of the failure is included in the form. Finally, if failure occurred, the form requires recommendations on continued use of the product despite the failure or if its removal from the approved products list should be considered. If the ECB is recommended to be used again, the form requires information detailing recommendations to prevent repeated failure. Photographs should be attached to the submitted form to illustrate the magnitude of the failure.

The general characteristics reported on the form provide basic site and project information. The background information allows for the opportunity to communicate with the correct personnel regarding questions or input for ECBs potentially being used in other parts of the state or the ECB's ultimate removal from the approved products list. The county location could be compared to the general location's soil erodibility as shown in Figure 3.6 of Section 3. An undercutting/gulley failure, for instance, observed in an area of highly-erosive soils may not merit product removal compared to a similar failure with less-erosive soils.

Noting the ECB product name helps identify specific products that are repeatedly not performing well and may need to be removed from the approved products list. Reporting the type of ECB classification from the specifications assists in identifying which ECB types have the most failures. Noting the consistent problems in a particular type would indicate unsatisfactory specification requirements for the ECBs classification, not necessarily specific products. Revision of that ECB classification for product approval may be necessary to prevent insufficient ECBs meeting acceptance requirements. The manufacturer and distributer are to be noted in case defective products are installed caused by improper storage, shipping, and/or handling. The subcontractor responsible for installation may be an indicator of inadequate field performance independent of the ECB if a particular subcontractor is involved with numerous failures. Similarly to the subcontractor influence, if the manufacturer recommendations for ECB installation were not followed, the installation practice may influence the eventual ECB failure. Deviations from suggested installation procedures are to be noted on the form to determine any significance the change may have had on the performance.

Removing a product following three separate failure incidents is recommended. Variability in field conditions on each construction site may affect the ECB; however, three incidents indicates a pattern of poor ECB performance. Three reports are believed to manifest consistent deficiencies from the ECBs and merit consideration for product removal from the approved products list.

9.1 ECB Quality Control Example

To demonstrate application of the ECB field performance quality control plan, it was applied to the four sites investigated in this study: the Route N study site and the three visited completed sites of Route D, Route DD, and Route Z. The Route N site experienced gulley erosion along a portion of the reach (Figure 4.18), but the instance occurred because the ECB did not extend to the silt fence. Straw crimping was used instead, and the erosion occurred because of the misuse of the straw crimping, not the ECB performance. Route N achieved establishment without any re-stapling or reseeding and was considered a successful application of the two ECBs. Route D and Route DD both utilized TRMs in place of ECBs, and both sites achieved reestablishment. Even though the current state of each site suggests difficulty in sustained germination of the area, the initial seeding was successful. Completion of the ECB quality control form at the time of site acceptance would identify the sites as having successful ECB applications.

The Route Z ECB application had a single-net straw ECB used in a channel application. The channel did not establish well along the bottom of the channel where the ECB did not complete make contact with the ground. The concentrated flow likely washed the seed away, and the single-net blanket was unable to retain the straw matrix. The area became exposed and gulley erosion occurred along the bottom of the channel. The channel would have needed to be reseeded to meet vegetation requirements. The Route Z ECB application meets one of the four failure conditions which require completing a quality control form. The following example illustrates the general completion of the form. Information regarding the ECB product name/manufacturer was not provided during the site visits; however, in cases of an actual failure that information would be available to the MoDOT inspector or resident engineer. The photos referenced are Figures 5.2 and 5.3, respectively.

ECB Performance Quality Control Form 1/2

Name: MoDOT construction inspector
Date: September 4, 2015
Project Number: N/A
County: St. Charles County
ECB Type: Type 1
ECB Product Name: N/A
Manufacturer: N/A
Distributor: N/A
Subcontractor responsible for installation: N/A
Were manufacturer recommendations for installation followed? ☒ Yes ☐ No

If not, what deviations were made?

Was the site accepted as a completely reestablished slope in accordance to the MoDOT SWPPP (70% uniform germination across the disturbed area)? ☐ Yes ☒ No

Successes observed at the site (check all that apply):

- ☐ No visible sediment deposition downstream of site
- ☒ Primarily vegetated with grasses used in seeding
- ☐ No visible excessive gulley or rill erosion

Additional comments regarding successful application:

Failures observed at the site (check all that apply):

- ☐ Rupturing/Movement of Blanket
- ☒ Undercutting/Gulley Erosion
- ☒ Lack of Germination
- ☐ Lack of Degradation

If failure occurred, describe the nature of the failure:
The single-net ECB was located in a channelized application. The blanket did not entirely make contact with the bottom of the channel, and the single-net was unable to retain the straw fill for the channel. The straw and the underlying seed washed away and gulley erosion formed along the bottom of the channel. The area is not establishing and will require reseeding.

Would you recommend this product to be used again? ☐ Yes ☒ No

If yes, what recommendations would you have to prevent similar failures?

(Attach Photos of ECB failure if applicable)

10 Conclusions and Recommendations

A research project was conducted to develop recommendations for ECB product approval procedures, product design, and a system for removing deficient ECBs from the approved products list unique to MoDOT. An overview of the Clean Water Act and its relevance to erosion control was performed. Federal and state permitting requirements were assessed for construction site stormwater discharge. Standardized testing methods of NTPEP (ASTM) and the TxDOT independent testing which measure the performance or physical characteristics of ECBs were analyzed. A surficial investigation of Missouri was performed to determine representative soil conditions of the state. A field study site was used to track ECB performance in a construction application observing field conditions. Construction sites completed approximately two years earlier were visited to document long-term ECB performance including revegetation and blanket degradation for a variety of applications. Surveys were developed and administered to record MoDOT and contractor experiences with ECBs highlighting the critical problems or common issues.

The literature review, field site investigation, and survey responses informed the development of specification recommendations for product approval. Product approval procedures was developed based on recommended guidelines established by the ECTC using the NTPEP ASTM standardized testing as the metric for field performance acceptance and physical property criteria. ECB product approval was developed that categorizes ECBs first by longevity, then by intended slope gradients. An ECB design process was developed based on an application of the RUSLE. A design-matrix tool was developed by calculating the maximum allowable slope length for each ECB type and incorporating erodibility and erosivity coefficients that are representative of Missouri geology and hydrology characteristics. The following sections provide summaries and conclusions for specific tasks.

10.1 Geology Analysis of Missouri

The surficial characteristics of Missouri were analyzed in terms of the soil's erodibility for usage in the RUSLE. A MoDNR ArcGIS surficial layer was used in conjunction with soil literature for the state of Missouri to determine representative erodibility values for soils in different locations throughout the state. Soils were classified from descriptions in the literature cross referenced to the USDA classification method. Once the soil was properly classified per USDA convention the appropriate erodibility value was applied from empirical values that soil classification typically exhibits. Following the initial erodibility calculation, corrections for rock content, organic content, soil permeability, and soil angularity were made to determine the most accurate erodibility based on the soil description for that area. The erodibility was calculated and each polygon in the MoDNR surficial layer was given an erodibility representative from the soil literature for Missouri.

10.2 Field Site Investigation

The field site investigation observed the field performance of two different ECB types under actual field conditions at the Route N construction site. The site was adjacent to Route N with an approximated slope of 3:1 (H:V). Initial site conditions were assessed including site geometry from LiDAR surveying, soil extraction for soil classification testing, and obtaining ECB samples for laboratory index testing. Ongoing visits documented the visual performance of the ECBs regarding overall site germination and areas of significant erosion. Germination counts were made throughout the study reach to quantify the blankets' effectiveness in promoting vegetation growth over time. Rainfall at the site was tracked using a tipping bucket rain gauge to determine intensities during storm events. Visits during periods of rainfall included collection of stormwater samples which were tested for turbidity, suspended-sediment concentration, and volumetric concentration (Imhoff cone test).

Several conclusions were derived from the Route N study site. The installation appeared to have differed from the manufacturer recommendations where the blanket did not make direct contact to the soil in areas, and neither ECB was trenched at the top of the slope as specified. Loose blanket contact caused the underlying seed to erode down the slope and most of the germination was located near the bottom of the slope. Because the erosion of the seed, weeds became the predominant plant growth in areas along the span and new plant growth ceased over time with effectively only the maturing of the plants that initially germinated as the recorded growth. Blanket rupturing was observed near the seam of the two blankets caused by an ATV or other off-road vehicle. Despite the significant tearing, the stormwater samples at the nearby point of discharge all recorded turbidity values less than the recently removed EPA standard and Imhoff cone test results were less than the Missouri water quality standard for the MoDOT NPDES. Furthermore, all stormwater samples collected during the study had turbidity and Imhoff cone test results less than the maximum allowable standards established by the EPA and MoDOT NPDES, respectively.

10.3 Investigation of Previous MoDOT ECB Projects

Three construction sites completed approximately two years earlier were visited to document ECB performance and post-project site conditions. The site visits were conducted with MoDOT representatives to attest to particular considerations or issues with the installed blankets. Observations from the sites were compiled to identify common ECB issues. Sites which used a TRM or a conservative slow-degrading ECB on shallow gradients requiring minimal slope protection were observed to not have successful vegetation reestablishment. From the sites visited, the TRMs utilized had not sufficiently degraded. The TRMs were still visible and were lacking germination. Although the TRM provided sufficient vegetation growth for initial site acceptance from MoDOT, post-project conditions showed that the sites were unable to sustain the vegetation. The presence of the TRMs can also make maintenance difficult and cause rupturing of the blankets during lawn mowing operations resulting in exposed soil. Further, TRMs with insufficient vegetation established had an undesired appearance for nearby landowners. This led to some TRMs and blankets being manually removed by home owners exposing the soil making it vulnerable to erosion.

10.4 MoDOT Surveys

MoDOT resident engineers and inspectors and the landscape contractors have different roles in ECB the applications on MoDOT construction sites. A survey was conducted to record their respective experiences with ECBs related to preinstallation and site conditions, MoDOT SWPPP compliance, specific ECB product performance preferences, and any other relevant experiences.
MoDOT administered the surveys and responses were recorded from ten MoDOT resident engineers and inspectors (3.9% response rate), five landscape contractors (45.5% response rate), and zero general contractors (0% response rate). Due to the limited number of survey responses, survey results could not produce statistically significant quantifiable information. Accordingly,

survey results were considered anecdotal and used to provide insight into specific experiences with ECBs.

Comparing the results from the two surveys indicated some patterns. Germination is commonly inspected during SWPPP inspections because the final reestablishment and acceptance is dependent on overall site germination. Addressing the perimeter anchorage, blanket movement or rupturing, and entry points for concentrated runoff during inspection may help prevent significant erosion and washing away of the seed. Also, an installation checklist would improve the quality control of ECB installation. Survey results also indicated that the single-net blankets frequently experienced problems, and the Type 1 and Type 2 double-net ECBs were the most preferred by the MoDOT engineers and inspectors and the landscape contractors.

10.5 Recommendations for ECB Product Approval

Recommendations for ECB product approval were developed based on an adaptation of the ECTC guidelines for ECB product specification. For product approval, the following documentation should be provided by the manufacturer: product literature and specification sheets, installation guidelines, test report from large-scale hydraulic testing (ASTM D6459 with loam), and test report from tensile strength index property testing (ASTM D5035). MoDOT's current acceptance procedure based on TxDOT independent testing should still be considered an acceptable substitute for ASTM D6459 if the ECB is tested over sandy soil. ECBs are accepted to different classifications (13 total classifications) based on manufacturer-specified service and application slope. For product approval, the ECB C-factor determined through ASTM D6459 testing must be less than the maximum allowable C-factor for that category; and the reported tensile strength of the ECB must be greater than the minimum tensile strength required.

10.6 Specifications for ECB Design

ECB design incorporates the RUSLE to identify acceptable blankets from different classifications in the approved products list. County averaged erodibility and erosivity maps for Missouri were developed using GIS. The average erodibility and erosivity values for the counties were multiplied together to form a KR factor for each county. Three zones were delineated from the range of KR factors throughout the state. A design matrix for each of the three zones was created calculating the maximum allowable slope length an ECB could be used for each ECB classification and slope combination. The design solved for a maximum allowable length by setting the estimated annual soil yield to 15 tons per acre, the maximum annual soil loss recommended by Ports and Smith (1976) for construction sites.

10.7 ECB Quality Control Plan

An ECB quality control system was developed that establishes a database tracking ECB failures on MoDOT construction projects. A form was created for MoDOT resident engineers and inspectors to complete when an ECB failure occurs on site where failures are defines as: rupturing/tearing of the ECB, undercutting/gulley erosion, lack of germination, and lack of blanket degradation. The form requires general product information about the blanket and indicating if the manufacturer installation recommendations were followed. On the form, the type of failure is identified and a description of the failure is required to better assess how the failure occurred. The form also requests recommendations to prevent future failures if the

MoDOT engineer or inspect believes the ECB should be used again. Photographs of the failure must be attached to supplement the information provided in the form. ECBs should be considered for removal from the approved products list if more than three failures are recorded.

10.8 Future Recommendations

The project revealed numerous topics which are recommended to be investigated with further research. The erodibility values used in the research are empirical values obtained from testing on a 72.5-ft long, 9% slope. Developing erodibility values from typical highway cross-section slopes such as 33% or 50% would reduce the uncertainty associated with erodibility for soils used in ECB applications. Also, the C-factor for each laboratory-tested ECB is dependent on the geometry even if the soils are the same. It is recommended to investigate if one C-factor regression can be developed for the ECB encompassing the erosivity as well as the slope and length to prevent having to test the blanket on multiple soils and slopes. Also, research to develop a seeding chart for MoDOT specifying what type of seed should be used during certain months throughout the year is recommended and may optimize germination.

References

ASTM. (2011a). ASTM D6524 Standard Test Method for Measuring the Resiliency of Turf Reinforcement Mats (TRMs). West Conshohocken, PA: American Society of Testing and Materials.

ASTM. (2011b). ASTM D6459 Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion. West Conshohocken, PA: American Society for Testing and Materials International.

ASTM. (2012). ASTM D6460 Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion. West Conshohocken, PA: American Society of Testing and Materials.

ASTM. (2013a). ASTM D7101 Standard Index Test method for Determination of Unvegetated Rolled Erosion Control Product (RECP) Ability to Protect Soil from Rain-Splash and Associated Runoff Under Bench-Scale Conditions. West Conshohocken, PA: American Society of Testing and Materials.

ASTM. (2013b). ASTM D7322 Standard Index Test Method for Determination of Rolled Erosion Control Product (RECP) Ability to Encourage Seed Germination and Plant Growth Under Bench-Scale Conditions. West Conshohocken, PA: American Society of Testing and Materials.

ASTM. (2013c). ASTM D792 Standard Test Method for Density and Specific Gravity (Relative Density) of Plastics by Displacement. West Conshohocken, PA: American Society of Testing and Materials.

ASTM. (2014a). ASTM D4355/D4355M Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus. West Conshohocken, PA: American Society of Testing and Materials.

ASTM. (2014b). ASTM D6525/D6525M Standard Test Method for Measuring Nominal Thickness of Rolled Erosion Control Products. West Conshohocken, PA: American Society of Testing and Materials.

ASTM. (2014c). ASTM D6567 Standard Test Method for Measuring Light Penetration of a Turf Reinforcement Mat (TRM). West Conshohocken, PA: American Society of Testing and Materials.

ASTM. (2014d). ASTM D6818 Standard Test Method for Ultimate Tensile Properties of Rolled Erosion Control Products. West Conshohocken, PA: American Society of Testing and Materials.

ASTM. (2015). ASTM D1556/D1556M Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method. West Conshohocken, PA: American Society of Testing and Materials International.

Bhatia, S. e. (2010). Comparison of Geosynthetic Rolled Erosion Control Product (RECP) Properties Between Laboratories. *International Conference on Scour and Erosion* (pp. 212-221). San Francisco: ASCE.

Bursztynsky et al. (1986). *Erosion and Sediment Control Handbook.* New York: McGraw Hill, Inc.

CADOT. (1999, August). Soil Stabilization Using Erosion Control Blankets. *Construction Storm Water Pollution Prevention Bulletin*. Sacramento, CA: California Department of Transportation.

Collazo et al. (2009). *Leica Geosystems High-Definition Surveying Basic Training Manual.* Norcross: Leica Geosystems, Inc.

Crase et al. (2014). An Economical Solution for Flood Protection and Channel Erosion Control. *IPWEA Queensland Conference* (pp. 1-10). Caloundra: Institute of Public Works Engineering Australasia.

ECTC. (2006). *A Technical Guidance Manual Terminology, Index, & Performance Testing Procedures for Rolled Erosion Control Products.* Roxborough: Erosion Control Technology Council.

ECTC. (2008). *Installation Guide for Rolled Erosion Control Products (RECPs) Including Mulch Control Nettings (MCNs), Open Weave Textiles (OWTs), Erosion Control Blankets (ECBs), and Turf Reinforcement Mats (TRMs).* Retrieved from www.ectc.org: http://www.ectc.org/assets/docs/ectc_apr08_ectcspecificationfinal.pdf

EPA. (1972). *Clean Water Act of 1972.* Washington D.C.: Environmental Protection Agency.

EPA. (1999). *Storm Water Technology Fact Sheet Turf Reinforcement Mats.* Washington D.C.: Environmental Protection Agency.

EPA. (2007). *Developing Your Stormwater Pollution Prevention Plan.* Washington D.C.: Environmental Protection Agency.

EPA. (2009). *Effluent Limitations Guidelines and Standards for Construction and Development Point Source Category.* Washington D.C.: EPA.

EPA. (2012, March). Stormwater Phase II Final Rule: Construction Rainfall Erosivity Waiver. Washington D.C., Maryland, USA.

Erickson, A. (1977). *Aids for Estimating Soil Erodibility - K Value Class and Soil Loss Tolerance.* Salt Lake City: USDA Soil Conservation Service.

Fitfield, J. (1991). What are Acceptable Sediment Yields from Sites Undergoing Construction? *Proceedings of Conference XXII* (pp. 71-80). Orlando: International Erosion Control Association.

Google. (2015, July 24). Map. *Google Maps*. Saint Louis, Mo, USA: Google.

Hines et al. (2015). *Claims Related to Stormwater Discharges.* Washington D.C.: Transportation Research Board of the National Academies.

IDOT. (2012). IDOT Standard Specifications for Road and Bridge Construction 2012. Springfield, IL: Illinois Department of Transportation.

IowaDOT. (2006). *Iowa Construction Site Erosion Control Manual.* Ames: Iowa Department of Natural Resources.

IowaDOT. (2014). *Standard Specifications for Road and Bridge Construction.* Ames: Iowa Department of Transportation.

KDOT. (2014). *Standard Specifications for Road and Bridge Construction.* Topeka: Kansas Department of Transportation.

Kelsey, K. (2002). *Use of the Revised Universal Soil Loss Equation on an Event-by-Event Basis.* Steven's Point: College of Natural Resources University of Wisconsin-Steven's Point.

Kleiss, B. e. (2000). *Water Quality in the Mississippi Embayment, Mississippi, Louisiana, Arkansas, Missouri, Tennessee, and Kentucky, 1995-98.* Reston: U.S. Geological Survey.

Lal, L. (2001). Soil Degradation by Erosion. *Land Degradation & Development*, 519-539.

Landphair et al. (1995). *The 1994 Performance Results for Erosion Control Blankets, Mulches, and Channel Liners.* Austin: Texas Department of Transportation.

Li, M. H. (2013). Comparing Erosion Control Products' Performance Results from Field and Large-Scale Laboratory Testing. *Indian Geotechnical Journal*, 382-387.

Liu et al. (1999). Slope Length Effects on Soil Loss for Steep Slopes. *Sustaining the Global Farm* (pp. 784-788). West Lafayette, IN: International Soil Conservation Organization.

MacCurdy, M. (2014, March 2014). *EPA Revises CWA Construction Stormwater Rule; Removes Controversial Numeric Turbidity Limits*. Retrieved from Marten Law: http://www.martenlaw.com/newsletter/20140319-epa-revises-cwa-stormwater-rule

Marshal, J. a. (1948). The Distribution of Raindrops with Size. *Journal of Meteorology*, 165-166.

Minor, P. (1974). *Soil Survey of DeKalb County, Missouri.* Washington D.C.: United States Department of Agriculture - Soil Conservation Service.

Missouri State Highway Commission. (1962). *Geology and Soils Manual 1962.* Jefferson City: Missouri State Highway Commission.

MoDNR. (2007). Missouri Environmental Geology Atlas 2007. Rolla, MO.

MoDNR. (2015, July 22). *Stormwater Permits.* Retrieved from http://dnr.mo.gov/env/wpp/permits/wpcpermits-stormwater.htm

MoDOT. (2014a). *Geotextile Field Section Table 1 Qualified Erosion Control Blankets.* Jefferson City: Missouri Department of Transportation.

MoDOT. (2014b). *Stormwater Pollution Prevention Plan.* Jefferson City: Missouri Department of Transportation.

MoDOT. (2015a, July 1). Section 1011 Geotextile. *General Provisions and Supplemental Specifications to 2011 Missouri Standard Specifications for Highway Construction*. Jefferson City, MO, USA.

MoDOT. (2015b, July 1). Section 203 Roadway and Drainage Excavation, Embankment and Compaction. *General Provisions and Supplemental Specifications to 2011 Missouri Standard Specifications for Highway Construction*. Jefferson City, MO.

MoDOT. (2016, June 1). *Contractor Resources, General Information*. Retrieved from Missouri Department of Transportation: http://www.modot.org/business/contractor_resources/bid_opening_info/bidGenInfo.shtml

NDOR. (2007). *Approved Products List Submittal Procedures.* Lincoln: Roadside Stabilization Unit, Nebraska Department of Roads.

North American Green. (2016a). *Material and Performance Specification Sheet: S150 Erosion Control Blanket.* Retrieved from Environmental Construction Solutions: http://www.wsconnelly.com/environmental-solutions/products/s150--double-net-straw.php?category=rolled-erosion-control-products&pid=1437

North American Green. (2016b). *Material and Performance Specification Sheet: SC150BN Erosion Control Blanket.* Retrieved from Environmental Construction Solutions: http://www.wsconnelly.com/environmental-solutions/products/product.php?product=sc150-bio-net&category=rolled-erosion-control-products&pid=1409

North American Green. (2016c). *Literature Downloads, Installation Guidelines.* Retrieved from Tensar North American Green: http://nag-prelive.kmp.co.uk/Downloads?searchKeywords=installation#

NTPEP. (2011). *AASHTO/NTPEP Erosion Control Products Guide.* Washington D.C.: American Association of State and Highway Transportation Officials, National Transportation Evaluation Program.

OMAFRA. (2012). *Universal Soil Loss Equation Fact Sheet.* Guelph: Ontario Ministry of Agriculture, Food and Rural Affairs.

Onset Computer Corporation. (2015). HOBO Rain Gauge Data Logger. Bourne, MA, USA: Onset Computer Corporation.

Ports and Smith. (1976). Maryland Highway Erosion and Sediment Control: Evaluation and Future Directions. *Land Application of Waste Matter* (pp. 262-275). Des Moines: Soil Conservation Society of America.

Soil Survey Staff: Bureau of Plant Industry, S. a. (1951). *Handbook 18.* Washington D.C.: US Government Printing Office.

Spaeth, K. et al. (2003). Evaluation of USLE and RUSLE on Estimated Soil Loss on Rangeland. *Journal of Range Management*, 234-246.

Summer, M. E. (1991). *Handbook of Soil Science.* Boca Raton: CRC Press.

Toy et al. (1998). *Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands.* Denver: Office of Surface Mining Reclamation and Enforcement: U.S. Department of the Interior.

Transportation Pooled Fund. (2011). *The Erosion Control Laboratory.* Retrieved from www.pooledfund.org: http://www.pooledfund.org/Details/Study/7

TxDOT. (1994). *Temporary Erosion Control Measures Design Guidelines for TxDOT.* Austin: Texas Department of Transportation.

TxDOT. (2015). Changes to Approved Products List (APL) for Erosion Control Devices. *TXDOT White Paper: Changes to APL*. Austin, TX, USA: Texas Department of Transportation.

TxDOT. (2015, August). *Changes to Approved Products List (APL) for Erosion Control Devices.* Retrieved from Texas Department of Transportation: http://ftp.dot.state.tx.us/pub/txdot-info/mnt/erosion/product_evaluation/approved-products-list.pdf

TXDOT/TTI Sediment and Erosion Control Laboratory. (2015). *Final Performance Analysis.* Austin: Texas Department of Transportation.

USDA. (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation.* Washington D.C.: U.S. Government Printing Office.

USDA-ARS. (2008, May 15). RUSLE2 User's Reference Guide. Washington D.C., Maryland: United States Department of Agriculture.

Washington State Department of Ecology. (2010). *How to do Stormwater Sampling A Guide for Industrial facilities.* Olympia: Washington State Department of Ecology.

WisDOT. (1990). *Highway Construction Site Erosion and Pollution Control Manual.* Olympia, WA: Washington State Department of Transportation.

WisDOT. (2014a). Erosion Control and Storm Water Product Acceptability Lists User Guide and Submittal Procedures. Madison, WI: Wisconsin Department of Transportation.

WisDOT. (2014b). Wisconsin Department of Transportation Standard Specifications for Highway and Bridge Construction. Madison, WI: Wisconsin Department of Transportation.

Appendix A: K-Value Calculation Data

Table A.1. Soil texture *K-value* ranges (TxDOT, 1994).

Soil Erodibility Guide		
Soil Texture	**K-Value Range**	**Average *K-value***
Sand	0.02-0.05	0.035
Fine Sand	0.10-0.16	0.130
Very Fine Sand	0.28-0.42	0.350
Loamy Sand	0.08-0.12	0.100
Loamy Fine Sand	0.16-0.24	0.200
Loamy Very Fine Sand	0.30-0.44	0.370
Sandy Loam	0.19-0.27	0.230
Fine Sandy Loam	0.24-0.35	0.295
Very Fine Sandy Loam	0.33-0.47	0.400
Loam	0.29-0.38	0.335
Silt Loam	0.33-0.48	0.405
Silt	0.42-0.60	0.510
Sandy Clay Loam	0.21-0.27	0.240
Clay Loam	0.21-0.27	0.240
Silty Clay Loam	0.26-0.37	0.315
Sandy Clay	0.12-0.14	0.130
Silty Clay	0.19-0.25	0.220
Clay	0.13-0.20	0.165

Table A.2. Rock content adjustment (WisDOT, 1990).

	***K-Values* adjusted for Rock Content (%)**		
Unadjusted *K-Value*	**15-35**	**35-60**	**60-75**
0.1	0.05	0.05	0.02
0.15	0.1	0.05	0.02
0.17	0.1	0.05	0.02
0.2	0.1	0.05	0.02
0.24	0.15	0.1	0.05
0.28	0.15	0.1	0.05
0.32	0.17	0.1	0.05
0.37	0.2	0.1	0.05
0.43	0.24	0.15	0.1
0.49	0.28	0.15	0.1
0.55	0.32	0.17	0.1
0.64	0.37	0.2	0.1

Table A.3. *K-value* organic material correction.

	Correction Factor for Organic Content (%)				
K-Value	**0**	**1**	**2**	**3**	**4**
Greater than 0.40	+0.14	+0.07	0	-0.07	-0.14
0.20-0.40	+0.10	+0.05	0	-0.05	-0.10
Less than 0.20	+0.06	+0.03	0	-0.03	-0.06

Table A.4. *K-value* granularity correction.

Structure	***K-Value* Correction**
Very Fine Granular	-0.09
Fine Granular	-0.06
Moderate or Coarse Granular	-0.03

Table A.5. *K-value* porosity correction.

Permeability	***K-Value* Correction**
Compact Soil or pH greater than 9.0	+0.03
Many Medium or Coarse Pores	-0.03

Appendix B: K-Values for Missouri Soils

Table B.1. *K-values* assigned to soils from the Geology and Soils Manual from 1962.

Soil Name	MoDNR Soil Category	Location	Horizon	Soil Texture	*K-Value* (unadjusted)	Rock Content (%)	Organic Content (%)	Permeability	Structure	Adjusted *K-Value*	Final *K-Value*
Sharkey	V-Clay Plug	Southeast Lowlands	A	Silty Clay, Clay Loam	0.23	0-15	3	normal	normal	0.18	**0.16**
			B	Sandy Clay	0.13	0-15	2	normal	normal	0.13	
Clarks-ville	N-Residuum	Ozarks (Central Region)	A	Gravelly Silty Loam	0.195	15-35, 35-60	2	normal	coarse granular	0.165	**0.13**
			B	Gravelly Silty Clay	0.125	15-35, 35-60	2	normal	coarse granular	0.095	
	M-Residuum	Ozarks (Central Region)	A	Clay	0.165	0-15	2	normal	normal	0.165	**0.19**
			B	Silty Clay	0.22	0-15	2	normal	normal	0.22	
Hanceville	I-Residuum	Ozarks (East Central Portion of Region)	A	Sand, Sandy Clay Loam	0.1375	15-35	2	normal	normal	0.1	**0.18**
			B	Fine Sandy Loam, Sandy Clay Loam	0.2675	0-15	2	normal	normal	0.2675	
Bates	L-Residuum	Southwest Portion of State	A	Fine Sandy Loam, Very Fine Sandy Loam, Silt Loam	0.367	15-35	2	normal	normal	0.2	**0.15**
			B	Silt Loam, Loam, Clay Loam	0.327	35-60	2	normal	normal	0.1	
Baxter	L-Residuum	Western Plains (Bordering Ozarks)	A	Silt Loam	0.405	15-35, 35-60	2	medium pores	normal	0.165	**0.17**
			B	Silt Loam	0.405	15-35, 35-60	2	medium pores	normal	0.165	
Lebanon	L-Residuum	Ozarks (throughout Ozark Region)	A	Silt Loam	0.405	15-35, 35-60	1	normal	normal	0.225	**0.18**

Soil Name	MoDNR Soil Category	Location	Hori-zon	Soil Texture	*K-Value* (unadjusted)	Rock Content (%)	Organic Content (%)	Permeability	Structure	Adjusted *K-Value*	Final *K-Value*
			B	Silty Clay Loam, Silty Clay	0.2675	15-35, 35-60	2	normal	normal	0.125	
	I-Residuum	Ozarks (Eastern Missouri)	A	Silt Loam	0.405	15-35, 35-60	1	normal	normal	0.225	**0.18**
			B	Silty Clay Loam, Sandy Clay	0.2225	15-35, 35-60	2	normal	normal	0.125	
Ashe	P-Residuum	Saint Francois Mountains	A	Silt Loam	0.405	15-35	1	normal	normal	0.29	**0.28**
			B	Silty Clay	0.22	0-15	1	normal	normal	0.27	
Craw-ford	J-Residuum	Western Plains (Springfield Area)	A	Silt Loam	0.405	0-30	2	normal	normal	0.3225	**0.25**
			B	Silty Clay Loam	0.315	15-35	2	normal	normal	0.17	
	I-Residuum	Western Plains (Springfield Area)	A	Silty Loam	0.405	0-15	2	normal	normal	0.405	**0.36**
			B	Silty Clay Loam	0.315	0-15	2	normal	normal	0.315	
	L-Residuum	Ozarks/Western Plains (Springfield, Cooper, Jackson Counties)	A	Silt Loam, Gravelly Silt Loam	0.36375	0-15; 0-15, 15-35	3	normal	normal	0.31375	**0.3**
			B	Silty Clay Loam, Gravelly Silty Clay Loam	0.27875	0-15; 0-15, 15-35	2	normal	normal	0.27875	
Lint-onia	D-Alluvium	Southeast Lowlands	A	Loamy Sand, Loamy Fine Sand	0.15	0-15	1	medium pores	normal	0.15	**0.25**
			B	Fine Sandy Loam, Sandy Clay Loam	0.2675	0-15	1	compact	normal	0.3475	
	C-Alluvium	Southeast Lowlands (Western Border of Boot Heel)	A	Fine Sandy Loam	0.295	0-15	2	normal	normal	0.295	**0.28**
			B	Silty Clay, Silty Clay Loam	0.2675	0-15	2	normal	normal	0.2675	
Put-nam	I-Residuum	Glacial Plains (Northern Central	A	Silt Loam	0.405	0-15	3	normal	normal	0.355	**0.26**

Soil Name	MoDNR Soil Category	Location	Hori-zon	Soil Texture	*K-Value* (unadjusted)	Rock Content (%)	Organic Content (%)	Permeability	Structure	Adjusted *K-Value*	Final *K-Value*
		Missouri)	B	Clay	0.165	0-15	2	normal	normal	0.165	
	F-Glacial Drift	Glacial Plains (North Central Missouri)	A	Silt Loam	0.405	0-15	2	normal	normal	0.405	**0.27**
			B	Clay	0.165	0-15	2	compact	fine granular	0.135	
Grund-y	E-Loess	Glacial Plains (Central Missouri)	A	Silt Loam	0.405	0-15	3	normal	normal	0.355	**0.27**
			B	Silty Clay, Clay	0.1925	0-15	2	normal	normal	0.1925	
	E-Loess	Glacial Plains (Northeastern Misouri)	A	Silt Loam	0.405	0-15	3	compact	normal	0.385	**0.29**
			B	Silty Clay, Clay	0.1925	0-15	2	normal	normal	0.1925	
Osw-ego	J-Residuum	Western Plains (Southwest Missouri)	A	Silt Loam	0.405	0-15	2	normal	normal	0.405	**0.27**
			B	Clay	0.165	0-15	2	normal	moderate granular	0.135	
Cher-okee	I-Residuum	Western Plains (Southwest Missouri flat, level regions)	A	Fine Sandy Loam	0.295	0-15	1	compact	normal	0.325	**0.28**
			B	Clay	0.165	0-15	1	compact	normal	0.225	
	H-Residuum	Western Plains (Western Missouri)	A	Silt Loam, Silty Clay	0.3125	0-15	1	compact	normal	0.3925	**0.31**
			B	Clay	0.165	0-15	1	compact	normal	0.225	
Wa-bash	A-Alluvium	Glacial Plains (North and Northeastern Missouri)	A	Silt Loam	0.405	0-15	3	normal	normal	0.355	**0.29**
			B	Silty Clay	0.22	0-15	2	normal	normal	0.22	
Eldon	J-Residuum	Western Plains (Southwest)	A	Silt, Gravelly Silt	0.34	0-15; 35-60	2	normal	normal	0.34	**0.26**

Soil Name	MoDNR Soil Category	Location	Hori-zon	Soil Texture	*K-Value* (unadjusted)	Rock Content (%)	Organic Content (%)	Permeability	Structure	Adjusted *K-Value*	Final *K-Value*
			B	Silty Clay, Gravelly Silty Clay	0.185	0-15; 15-35	2	normal	normal	0.185	
Summ-it	I-Residuum	Western Plains (Along the Missouri Border near Middle of Region)	A	Silt Loam	0.405	0-15	3	normal	fine granular	0.295	**0.31**
			B	Silty Clay Loam	0.315	0-15	2	normal	normal	0.315	
Lindly	F-Galcial Drift	Glacial Plains (Northeast Missouri)	A	Silt Loam	0.405	0-15	1	normal	normal	0.455	**0.34**
			B	Loam	0.335	15-35	1	normal	moderate granular	0.22	
	G-Glacial Drift	Glacial Plains (Northeast Missouri)	A	Silt Loam	0.405	0-15	1	normal	normal	0.455	**0.32**
			B	Sandy Loam	0.23	15-35	1	normal	normal	0.18	
Shelby	F-Glacial Drift	Glacial Plains (Northwest Missouri)	A	Silt Loam, Fine Sandy Loam	0.35	0-15	2	normal	normal	0.35	**0.32**
			B	Loam, Sandy Clay Loam	0.2875	0-15	2	normal	normal	0.2875	
	H-Residuum	Glacial Plains (Northwest Missouri)	A	Silt Loam, Fine Sandy Loam	0.35	0-15	2	normal	normal	0.35	**0.34**
			B	Loam	0.335	0-15	2	normal	normal	0.335	
Hagers-town	J-Residuum	Ozarks (Eastern Portion of State)	A	Silt Loam	0.405	0-15	1	normal	normal	0.455	**0.33**
			B	Silty Clay	0.22	0-15	1	normal	fine granular	0.21	
	H-Residuum	Ozarks (Eastern Portion of State)	A	Silt Loam	0.405	0-15	1	normal	normal	0.455	**0.36**
			B	Silty Clay	0.22	0-15	1	normal	normal	0.27	
Osage	A-Alluvial	Western Plains	A	Silt Loam	0.405	0-15	3	normal	normal	0.355	**0.34**

Soil Name	MoDNR Soil Category	Location	Hori-zon	Soil Texture	*K-Value* (unadjusted)	Rock Content (%)	Organic Content (%)	Permeability	Structure	Adjusted *K-Value*	Final *K-Value*
			B	Silt, Silty Clay	0.365	0-15	3	normal	normal	0.315	
Wave-rly	A-Alluvium	Ozarks (Southeast Portion of Region Bordering Crowley's Ridge Area)	A	Silt Loam	0.405	0-15	2	normal	normal	0.405	**0.34**
			B	Silty Clay, Silty Clay Loam	0.2675	0-15	2	normal	normal	0.2675	
Hunt-ington	A-Alluvium	Ozarks	A	Silt Loam	0.405	0-15	3	normal	normal	0.355	**0.36**
			B	Silt Loam, Silt, Silty Clay, Fine Sandy Loam	0.3575	0-15	2	normal	normal	0.3575	
Marsh-al	E-Loess	Glacial Plains (Northern Missouri)	A	Silt Loam	0.405	0-15	3	normal	normal	0.355	**0.36**
			B	Silt Loam, Silty Clay Loam	0.36	0-15	2	normal	normal	0.36	
Union	L-Residuum	Ozarks (North and Northeastern Portion of the Ozark Region)	A	Silt Loam	0.405	0-15	2	normal	normal	0.405	**0.36**
			B	Silty Clay Loam	0.315	0-15	2	normal	normal	0.315	
Gerald	I-Residuum	Western Plains	A	Silt	0.51	0-15	2	compact	normal	0.54	**0.37**
			B	Clay	0.165	0-15	2	compact	normal	0.195	
Knox	E-Loess	Glacial Plains (Along Middle of State and Northwest)	A	Silt Loam, Fine Sandy Loam, Very Fine Sandy Loam	0.37	0-15	2	normal	normal	0.37	**0.37**
			B	Silt Loam, Fine Sandy Loam, Very Fine Sandy Loam	0.37	0-15	2	normal	normal	0.37	
Sarpy	U-Relicit Channel	Southeast Lowlands	A	Fine Sandy Loam, Very Fine Sandy Loam	0.3475	0-15	2	normal	normal	0.3475	**0.37**
			B	Very Fine Sandy Loam	0.4	0-15	2	normal	normal	0.4	

Soil Name	MoDNR Soil Category	Location	Hori-zon	Soil Texture	*K-Value* (unadjusted)	Rock Content (%)	Organic Content (%)	Permeability	Structure	Adjusted *K-Value*	Final *K-Value*
Boone	I-Residuum	Western Plains (Transitional Soil Bordering Oswego Soil)	A	Silt Loam, Silty Clay Loam	0.36	0-15	1	normal	normal	0.41	**0.39**
			B	Silty Clay Loam	0.315	0-15	1	normal	normal	0.365	
Mem-phis	E-Loess	Ozarks/Glacial Plains (East Part of State along Mississippi River)	A	Silt Loam	0.405	0-15	2	normal	normal	0.405	**0.41**
			B	Silt Loam	0.405	0-15	2	normal	normal	0.405	
Tilsit	O-Residuum	Ozarks (Eastern Portion of State)	A	Silt Loam	0.405	0-15	1	normal	normal	0.455	**0.41**
			B	Silt Loam, Silty Clay Loam	0.36	0-15	2	normal	normal	0.36	

Appendix C: Stormwater Runoff Raw Experimental Data

Table C.1. Suspended-sediment concentration results 5-20-15.

Sediment			
Sample	**1**	**2**	**3**
Whole Weight (g)	149.82	192.64	222.98
Empty Bottle Weight (g)	26.92	26.93	26.85
Net Weight of Sample (g)	122.90	165.71	196.13
Evaporating Dish Total (g)	2.0489	2.0241	2.0104
Evaporating Dish Only (g)	1.9926	1.972	1.9721
Net Weight After Drying (g)	0.0563	0.0521	0.0383
Dissolved Sediment Content of Sample			
Sample	**1**	**2**	**3**
Amount of Water Pipetted (mL)	3	6	5
Weight of Evaporating Dish + Sediment (g)	2.0308	1.9996	2.0046
Weight of Evaporating Dish (g)	2.0291	1.9963	2.0022
Net Weight of Sediment (g)	0.0017	0.0033	0.0024
Dissolved Solids Correction (g)	0.0368	0.0391	0.0312
Corrected Weight of Sediment (g)	0.0195	0.0131	0.0071
Concentration (ppm)	158	78.8	36.2
Concentration (mg/L)	176	82.7	36.9

Table C.2. Suspended-sediment concentration results for June 18, 2015.

Sediment				
Sample	**1**	**2**	**3**	**4**
Whole Weight (g)	800.57	894.91	897.83	761.17
Empty Bottle Weight (g)	79.12	78.98	79.29	79.34
Net Weight of Sample (g)	721.45	815.93	818.54	681.83
Evaporating Dish Total (g)	2.0944	2.0888	2.0319	2.1176
Evaporating Dish Only (g)	1.9908	2.0321	1.9694	2.0202
Net Weight After Drying (g)	0.1036	0.0567	0.0625	0.0974
Dissolved Sediment Content of Sample				
Sample	**1**	**2**	**3**	**4**
Amount of Water Pipetted (mL)	2.6	2.3	2.7	2.3
Weight of Evaporating Dish + Sediment (g)	1.9862	2.0104	2.0048	2.0096
Weight of Evaporating Dish (g)	1.9854	2.0097	2.0038	2.0083
Net Weight of Sediment (g)	0.0008	0.0007	0.001	0.0013
Dissolved Solids Correction (g)	0.0185	0.0183	0.0222	0.0339
Corrected Weight of Sediment (g)	0.0851	0.0384	0.0403	0.0634
Concentration (ppm)	118	47.1	49.2	93.1
Concentration (mg/L)	127	48.5	50.2	98.7

Table C.3. Suspended-sediment concentration results for July 8, 2015.

Sediment				
Sample	**1**	**2**	**3**	**4**
Whole Weight (g)	1114.19	1051.6	1075.32	1072.28
Empty Bottle Weight (g)	78.54	78.36	78.69	78.55
Net Weight of Sample (g)	1035.65	973.24	996.63	993.73
Evaporating Dish Total (g)	2.0698	2.0404	2.0526	2.0112
Evaporating Dish Only (g)	2.0162	2.0055	2.025	1.9715
Net Weight After Drying (g)	0.0536	0.0349	0.0276	0.0397
Dissolved Sediment Content of Sample				
Sample	**1**	**2**	**3**	**4**
Amount of Water Pipetted (mL)	2.8	2.7	2.8	3.1
Weight of Evaporating Dish + Sediment (g)	2.0256	2.0195	2.0148	1.9611
Weight of Evaporating Dish (g)	2.025	2.0187	2.0141	1.9608
Net Weight of Sediment (g)	0.0006	0.0008	0.0007	0.0003
Dissolved Solids Correction (g)	0.0129	0.0178	0.0150	0.0058
Corrected Weight of Sediment (g)	0.0407	0.0171	0.0126	0.0339
Concentration (ppm)	39	17.6	12.6	34.1
Concentration (mg/L)	40	17.8	12.8	34.8

Table C.4. Turbidity results June 18, 2015.

Sample 1	
Reading (NTU)	141.0
Sample 2	
Reading (NTU)	72.9
Sample 3	
Reading (NTU)	68.9
Sample 4	
Reading (NTU)	107.0

Table C.5. Turbidity results July 8, 2015.

Sample 1	
Reading (NTU)	34.6
Sample 2	
Reading (NTU)	34.8
Sample 3	
Reading (NTU)	25.5
Sample 4	
Reading (NTU)	36.3

Table C.6. Imhoff cone results June 18, 2015.

Sample 1	
Amount of Sample (mL)	740
Reading (mL)	0.300
Concentration (mL/L)	0.405
Sample 2	
Amount of Sample (mL)	846
Reading (mL)	0.200
Concentration (mL/L)	0.236
Sample 3	
Amount of Sample (mL)	843
Reading (mL)	0.400
Concentration (mL/L)	0.475
Sample 4	
Amount of Sample (mL)	695
Reading (mL)	0.300
Concentration (mL/L)	0.432

Table C.7. Imhoff cone results July 8, 2015.

Sample 1	
Amount of Sample (mL)	1000
Reading (mL)	0.300
Concentration (mL/L)	0.300
Sample 2	
Amount of Sample (mL)	1000
Reading (mL)	0.200
Concentration (mL/L)	0.200
Sample 3	
Amount of Sample (mL)	1000
Reading (mL)	0.300
Concentration (mL/L)	0.300
Sample 4	
Amount of Sample (mL)	1016
Reading (mL)	0.200
Concentration (mL/L)	0.197

Appendix D: MoDOT and Contractor Surveys

MoDOT Resident Engineer and Inspector

1. What are common soil types encountered when Installing ECBs?
   - ☐ Clayey (cohesive and sticky)
   - ☐ Silty (dusty and loose)
   - ☐ Sandy (granular and gritty)
   - ☐ Other (please describe)

2. Is there a soil type that causes the majority of failures experienced?
   - ☐ Clayey (cohesive and sticky)
   - ☐ Silty (dusty and loose)
   - ☐ Sandy (granular and gritty)
   - ☐ Other (please describe)

3. Select all of the following considered for site preparation prior to ECB installation:
   - ☐ Soil Gradation (particle size)
   - ☐ Soil Compaction
   - ☐ Embankment/Slope Grading
   - ☐ Other (please specify)

4. What type of field conditions would dictate the usage of an ECB over the type of BMP specified on the plan drawings (e.g. wattles, silt fences, etc.)?
   - ☐ Availability of materials
   - ☐ Failure of existing BMP specified
   - ☐ Scheduling/Subcontractor manpower
   - ☐ Other (please specify)

5. During routine SWPPP inspections, what are common items inspected and documented in regards to ECBs?

6. What are common failure modes observed for ECBs?
   - ☐ Tears
   - ☐ Blanket degrading too quickly
   - ☐ Erosion at the seams
   - ☐ Erosion at the perimeter
   - ☐ Instability of ECB anchors around the perimeter
   - ☐ Exposed soil and lack of germination for slope reestablishment
   - ☐ Other (please specify)

7. What are typical BMP measures used as supplements to ECBs?
   - ☐ Mulching and crimping

☐ Temporary pipe and slope drains
☐ Ditch checks
☐ Straw wattles
☐ Silt fences
☐ Other (please specify)

8. What are the most common maintenance requirements for an installed ECB following a MoDOT SWPPP inspection?

9. Which manufacturer(s) have ECBs that exhibit a high success rate?
☐ North American Green
☐ American Excelsior
☐ Western Excelsior
☐ Landlok
☐ Other (please specify)

10. Which ECB classification(s) exhibit a high success rate?
☐ Type 1 (45-60 days)
☐ Type 2 (12 months)
☐ Type 3 (12-18 months)
☐ Type 4 (24 months)
☐ Type 5 (36 months)

11. Which ECB netting type(s) exhibit a high success rate?
☐ Single biodegradable
☐ Single photodegradable
☐ Double photodegradable

12. Which ECB material composition(s) exhibit a high success rate?
☐ Straw
☐ Wood Excelsior
☐ Jute Fiber
☐ Coconut
☐ Other (please specify)

13. Which specific ECB product(s) exhibit a high success rate?
☐ AEC Premier Straw Double Net
☐ Excel S-1
☐ North American Green SC150
☐ Landlok S1
☐ Other (please specify)

14. Which ECB manufacturer(s) have frequent reoccurring problems or failures?
☐ North American Green

☐ American Excelsior
☐ Western Excelsior
☐ Landlok
☐ Other (please specify)

15. Which ECB classification (s) have frequent reoccurring problems or failures?
☐ Type 1 (45-60 days)
☐ Type 2 (12 months)
☐ Type 3 (12-18 months)
☐ Type 4 (24 months)
☐ Type 5 (36 months)

16. Which ECB netting type(s) have frequent reoccurring problems or failures?
☐ Single biodegradable
☐ Single photodegradable
☐ Double photodegradable

17. Which ECB material composition(s) have frequent reoccurring problems or failures?
☐ Straw
☐ Wood Excelsior
☐ Jute Fiber
☐ Coconut
☐ Other (please specify)

18. Which specific ECB product(s) have frequent reoccurring problems or failures?
☐ AEC Premier Straw Double Net
☐ Excel S-1
☐ North American Green SC150
☐ Landlok S1
☐ Other (please specify)

19. Please provide any additional information on the topic of ECBs that you feel would be helpful for this study:

General Contractors

1. Is there a soil type that causes the majority of failures experienced?
☐ Clayey (cohesive and sticky)
☐ Silty (dusty and loose)
☐ Sandy (granular and gritty)
☐ Other (please describe)
2. What type of soil is commonly introduced to field sites as fill material?
☐ Clayey (cohesive and sticky)

☐ Silty (dusty and loose)
☐ Sandy (granular and gritty)
☐ Other (please describe)

3. What are the most common maintenance requirements for an installed ECB following a MoDOT Stormwater Pollution Prevention Plan (SWPPP) inspection?

4. Which manufacturer(s) have ECBs that exhibit a high success rate?
☐ North American Green
☐ American Excelsior
☐ Western Excelsior
☐ Landlok
☐ Other (please specify)

5. Which ECB classification(s) exhibit a high success rate?
☐ Type 1 (45-60 days)
☐ Type 2 (12 months)
☐ Type 3 (12-18 months)
☐ Type 4 (24 months)
☐ Type 5 (36 months)

6. Which ECB netting type(s) exhibit a high success rate?
☐ Single biodegradable
☐ Single photodegradable
☐ Double photodegradable

7. Which ECB material composition(s) exhibit a high success rate?
☐ Straw
☐ Wood Excelsior
☐ Jute Fiber
☐ Coconut
☐ Other (please specify)

8. Which specific ECB product(s) exhibit a high success rate?
☐ AEC Premier Straw Double Net
☐ Excel S-1
☐ North American Green SC150
☐ Landlok S1
☐ Other (please specify)

9. Which ECB manufacturer(s) have frequent reoccurring problems or failures?
☐ North American Green
☐ American Excelsior
☐ Western Excelsior

- ☐ Landlok
- ☐ Other (please specify)

10. Which ECB classification (s) have frequent reoccurring problems or failures?
    - ☐ Type 1 (45-60 days)
    - ☐ Type 2 (12 months)
    - ☐ Type 3 (12-18 months)
    - ☐ Type 4 (24 months)
    - ☐ Type 5 (36 months)

11. Which ECB netting type(s) have frequent reoccurring problems or failures?
    - ☐ Single biodegradable
    - ☐ Single photodegradable
    - ☐ Double photodegradable

12. Which ECB material composition(s) have frequent reoccurring problems or failures?
    - ☐ Straw
    - ☐ Wood Excelsior
    - ☐ Jute Fiber
    - ☐ Coconut
    - ☐ Other (please specify)

13. Which specific ECB product(s) have frequent reoccurring problems or failures?
    - ☐ AEC Premier Straw Double Net
    - ☐ Excel S-1
    - ☐ North American Green SC150
    - ☐ Landlok S1
    - ☐ Other (please specify)

14. Please provide any additional information on the topic of ECBs that you feel would be helpful for this study:

Landscape Contractors

1. Are any general installation methods specified by the resident engineer or MoDOT?
    - ☐ Manufacturer recommendations
    - ☐ Other (please specify)

2. What is the procedure followed when there is an interruption in the installation of the ECBs (inclement weather, man power)?

3. What inspections are performed on the ECBs prior to installation to measure defective material?

4. What are the procedures on ECB storage? Do they vary by manufacturer MSDS or are all ECBs treated the same in terms of storage?

5. What is commonly documented during the installation of the ECBs for quality control?

6. What is the most common maintenance requirement for an installed ECB following a MoDOT SWPPP inspection?

7. Which manufacturer(s) have ECBs that exhibit a high success rate?
   ☐ North American Green
   ☐ American Excelsior
   ☐ Western Excelsior
   ☐ Landlok
   ☐ Other (please specify)

8. Which ECB classification(s) exhibit a high success rate?
   ☐ Type 1 (45-60 days)
   ☐ Type 2 (12 months)
   ☐ Type 3 (12-18 months)
   ☐ Type 4 (24 months)
   ☐ Type 5 (36 months)

9. Which ECB netting type(s) exhibit a high success rate?
   ☐ Single biodegradable
   ☐ Single photodegradable
   ☐ Double photodegradable

10. Which ECB material composition(s) exhibit a high success rate?
   ☐ Straw
   ☐ Wood Excelsior
   ☐ Jute Fiber
   ☐ Coconut
   ☐ Other (please specify)

11. Which specific ECB product(s) exhibit a high success rate?
   ☐ AEC Premier Straw Double Net
   ☐ Excel S-1
   ☐ North American Green SC150
   ☐ Landlok S1
   ☐ Other (please specify)

12. Which ECB manufacturer(s) have frequent reoccurring problems or failures?
   ☐ North American Green

☐ American Excelsior
☐ Western Excelsior
☐ Landlok
☐ Other (please specify)

13. Which ECB classification (s) have frequent reoccurring problems or failures?
☐ Type 1 (45-60 days)
☐ Type 2 (12 months)
☐ Type 3 (12-18 months)
☐ Type 4 (24 months)
☐ Type 5 (36 months)

14. Which ECB netting type(s) have frequent reoccurring problems or failures?
☐ Single biodegradable
☐ Single photodegradable
☐ Double photodegradable

15. Which ECB material composition(s) have frequent reoccurring problems or failures?
☐ Straw
☐ Wood Excelsior
☐ Jute Fiber
☐ Coconut
☐ Other (please specify)

16. Which specific ECB product(s) have frequent reoccurring problems or failures?
☐ AEC Premier Straw Double Net
☐ Excel S-1
☐ North American Green SC150
☐ Landlok S1
☐ Other (please specify)

17. Please provide any additional information on the topic of ECBs that you feel would be helpful for this study:

Table D.1. Survey responses MoDOT resident engineers and inspectors.

Responses to Question 1: What are common soil types encountered when installing ECBs?
Clayey (cohesive and sticky)
Clayey (cohesive and sticky), Some top soil
Clayey (cohesive and sticky), Rocky
Clayey (cohesive and sticky), Silty (dusty and loose)
Clayey (cohesive and sticky), Sandy (granular and gritty)

Silty (dusty and loose)
Silty (dusty and loose), Sandy (granular and gritty)
Clayey (cohesive and sticky)
Silty (dusty and loose), Sandy (granular and gritty)
Clayey (cohesive and sticky), Sandy (granular and gritty)
Responses to Question 2: Is there a soil type that causes the majority of failures experienced?
Clayey (cohesive and sticky)
N/A
Clayey (cohesive and sticky), Rocky
Clayey (cohesive and sticky), Silty (dusty and loose)
N/A
Haven't seen failures
Sandy (granular and gritty)
N/A
Sandy (granular and gritty)
Sandy (granular and gritty)
Responses to Question 3: Select all of the following considered for site preparation prior to ECB installation:
Embankment/Slope Grading
Soil Compaction, Embankment/Slope Grading
Embankment/Slope Grading
Soil Compaction, Embankment/Slope Grading
Embankment/Slope Grading, amount of runoff
Soil Gradation (particle size), Soil Compaction, Embankment/Slope Grading
Soil Gradation (particle size), Soil Compaction, Embankment/Slope Grading
Embankment/Slope Grading
Embankment/Slope Grading
Embankment/Slope Grading
Responses to Question 4: What type of field conditions would dictate the usage of an ECB over the type of Best Management Practice (BMP) specified on the plan drawings?
Steep Slopes
Failure of existing BMP specified
Failure of existing BMP specified, Slope Grades
embankment slope of 3:1 or greater
Failure of existing BMP specified, slope
Failure of existing BMP specified
Steep slopes and slopes that are easily erodible. Areas not easily reached with mulch sprayer
Proximity to traffic
Scheduling/Subcontractor manpower
Failure of existing BMP specified, Steeper slopes

Responses to Question 5: During routine Stormwater Pollution Prevention Plan (SWPPP) inspections, what are common items inspected and documented in regards to ECBs?
Seed Growth
Any seed growth, erosion under blanket
Seed Growth
Silt Fence, Rock ditch checks, ECB, sediment basins, Type 2 ditch checks
Make sure that it is still in place(tied down) or not rolled up and that it has not washed underneath.
Just that the blanket and associated BMPs (typically ditch checks) are still intact and functioning properly.
Are they properly anchored. Were they installed prior to rills and washes forming. Have washes and rills developed after placement of ECB.
Erosion beneath the blanket. Blanket not staying in place, or wadding up. Adequate vegetative growth.
Is the blanket rolled up at edge of shoulder due to traffic/wind? Is there undermining beneath the blanket?
If BMP's are needed, working properly, or need corrections. Usually the ECB's are shown as being installed in a comment section when areas have been stabilized with the ECB.
Responses to Question 6: What are common failure modes observed for ECBs?
Instability of ECB anchors around the perimeter, Exposed soil and lack of germination for slope reestablishment
Blanket degrading too quickly, Exposed soil and lack of germination for slope reestablishment, Seen it undercut the blanket as well
Tears, Blanket degrading too quickly, Erosion at the seams, Erosion at the perimeter, Instability of ECB anchors around the perimeter, Exposed soil and lack of germination for slope reestablishment, Erosion under blanket
water concentrating at random location and eroding embankment under the ECB
Erosion at the perimeter, rills underneath the blanket
N/A
Erosion at the perimeter, Exposed soil and lack of germination for slope reestablishment, improper embedment at top of slopes
Erosion at the seams, Erosion at the perimeter, Instability of ECB anchors around the perimeter, Erosion under the ECB in ditches
Erosion at the perimeter, Instability of ECB anchors around the perimeter
Erosion at the seams, Erosion at the perimeter, Exposed soil and lack of germination for slope reestablishment
Responses to Question 7: What are typical BMP measures used as supplements to ECBs?
General Seed and Mulch with overspray
Ditch checks, Silt fences
Temporary pipe and slope drains, Ditch checks, Silt fences
Temporary pipe and slope drains, Ditch checks, Silt fences
Ditch checks, If installed in a ditch, use rock ditch check at the beginning of the blanket
Mulching and crimping, Ditch checks

Ditch checks, Silt fences, flocculant socks
Ditch checks, Straw wattles
Mulching and crimping, Straw wattles
Mulching and crimping, Temporary pipe and slope drains, Ditch checks, Straw wattles, Silt fences
Responses to Question 8: What are the most common maintenance requirements for an installed ECB following a MoDOT SWPPP inspection?
Reseed
N/A
Replacing and Re-Pinning of blanket
Erosion under the blanket.
N/A
Have not seen any - just started using ECBs and what rain we have had has not caused a need for maintenance.
Correct improper anchoring and embedment.
N/A
Keeping the top perimeter of blanket tacked down.
Erosion under blanket where it is not overlapped correctly.
Responses to Question 9: Which manufacturer(s) have ECBs that exhibit a high success rate?
Unaware
N/A
North American Green, American Excelsior, Western Excelsior, Landlok
N/A
N/A
Curlex
N/A
N/A
North American Green, American Excelsior
N/A
Responses to Question 10: Which ECB classification(s) exhibit a high success rate?
Type 1 (45-60 days)
N/A
N/A
Type 2 (12 months)
N/A
Type 1 (45-60 days)
Type 2 (12 months)
N/A
Type 2 (12 months)
N/A
Responses to Question 11: Which ECB netting type(s) exhibit a high success rate?

N/A
N/A
N/A
N/A
N/A
N/A
Double photodegradable
N/A
Single biodegradable
N/A
Responses to Question 12: Which ECB material composition(s) exhibit a high success rate?
All
N/A
N/A
N/A
N/A
Straw
Straw
N/A
Wood Excelsior
N/A
Responses to Question 13: Which specific ECB product(s) exhibit a high success rate?
Unaware
N/A
N/A
N/A
N/A
Curlex
N/A
N/A
North American Green SC150
N/A
Responses to Question 14: Which ECB manufacturer(s) have products with frequent reoccurring problems or failures?
Unaware
N/A
N/A
N/A
N/A
N/A
N/A

N/A
N/A
N/A
Responses to Question 15: Which ECB classification(s) have frequent reoccurring problems or failures?
Type 4 (24 months)
N/A
N/A
N/A
N/A
N/A
Type 1 (45-60 days)
N/A
N/A
N/A
Responses to Question 16: Which ECB netting type(s) have frequent reoccurring problems or failures?
N/A
N/A
N/A
N/A
N/A
N/A
Single biodegradable
N/A
N/A
N/A
Responses to Question 17: Which ECB material composition(s) have frequent reoccurring problems or failures?
N/A
N/A
N/A
N/A
N/A
N/A
N/A
N/A
N/A
N/A
Responses to Question 18: Which specific ECB product(s) have frequent reoccurring problems or failures?

N/A
N/A
N/A
N/A
N/A
N/A
N/A
N/A
N/A
N/A
Responses to Question 19: Please provide any additional information on the topic of ECBs that you feel would be helpful for this study:
Typically the heavier the Mat the less that seed germinates
N/A
The biggest issue with using ECBs is that, unless the slope is finished very smooth/flat, the ECB will not make contact with the ground over the entire surface. Finishing slopes to this precision is problematic over large areas and 2:1 slopes. This prevents the mulch from retaining soil moisture and protecting seedlings. It allows erosion to occur under the blanket and very frequently results in long term failure of the seeded area. The area typically looks good as the blanket covers up issues, but as a long term solution, my experience along the Route 60 corridor has not shown promise.
N/A
The biggest problem that I have had with ECB are rills forming underneath the blanket. Then it is a waste because it has to be ripped up to allow the slopes to be refinished.
Temper these responses with the recent installation. So far they have held up very well, with some moderate rain.
N/A
I do not have a varied enough experience with ECBs to compare the different types, materials, or manufactures. I have seen them used in ditches and slopes on mostly clayey soils.
N/A
N/A

Table D.2. Survey responses landscape contractors.

Responses to Question 1: Are any general installation methods specified by the Resident Engineer or MoDOT?
Manufacturer recommendations
Manufacturer recommendations
Contractor
Manufacturer recommendations
Manufacturer recommendations
Responses to Question 2: What is the procedure followed when there is an interruption in the installation of the ECBs (inclement weather, man power)?

It depends on the type of slope we are working with when installing the blanket. We will always bury the blanket at the top of the slope. We usually install the blanket from the bottom working our way up the slope when possible, However, some slopes are better installed rolling the blanket down the slope. The exposed areas may need grading again to eliminate any rilling or washing
We have not experienced any installation interruptions.
Common sense
Continue installation as per manufactures recommendations.
Typically if the area is seeded we have 24 hours to get it covered. Anything outside of that time frame would need regrading/re-seeding if there was a meaningful rainfall event. Re-Fertilizing can be extremely detrimental unless there had been a rain that clearly washed material away.
Responses to Question 3: What inspections are performed on the ECBs prior to installation to evaluate defective material?
You are unable to tell the condition of the ECB until it is rolled out. At that time, you look for defects in the proper thickness of the mulch especially on straw mats. Single net straw mats are usually the only ones with that issue. Double net straw mats or mats with coconut rarely have defect issues.
Production and quality staff perform a visual inspection, defective materials are not installed.
None inspected as its rolled out
None
Visual. Material is very consistent. Site conditions, or installation practices usually cause the deficiencies.
Responses to Question 4: What are procedures on ECB storage? Do they vary by manufacturer Material Safety Data Sheets (MSDS) or are all ECBs treated the same in terms of storage?
Our terms are all ECBs should be stored inside.
Typically materials are delivered as needed. Stored materials are covered to protect from rain.
Out of weather
All treated the same. We try to keep them in our shop or if they are outside, we cover them.
Typically all are treated the same. Store in a dry location out of the sun.
Responses to Question 5: What is commonly documented during the installation of the ECBs for quality control?
Our employees look for proper grading and the proper preparation of the slope (removing large rocks or dirt clods or tree debris) Trenching in the top row of the blanket and using enough staples to keep good blanket contact with the soil.
Proper inspection techniques and locations of installations.
N/A
Nothing
MODOT has a DIR checklist to cover quality control.
Responses to Question 6: What are the most common maintenance requirements for an installed ECB following a MoDOT Stormwater Pollution Prevention Plan (SWPPP) inspection?
Rills under the blanket, not enough staples, mat too thick to allow vegetation to establish
Proper installation and seed growth. Our experiences are these products do not promote growth. We have also seen several locations where the blankets were undermined when placed in ditches.
Still in place and no runoff
N/A
re-pin. repair erosion under blanket, and point of entry for the water.
Responses to Question 7: Which manufacturer(s) have ECBs that exhibit a high success rate?

North American Green, American Excelsior, Western Excelsior, Landlok
We hve not had success with any manufactures
North American Green, American Excelsior, Western Excelsior
North American Green, American Excelsior, Western Excelsior, Landlok
North American Green, American Excelsior, Western Excelsior, Landlok, Erosion Blanket.com
Responses to Question 8: Which ECB classification(s) exhibit a high success rate?
Type 2 (12 months), Type 3 (12-18 months)
None
Type 2 (12 months), Type 3 (12-18 months)
Type 2 (12 months), Type 3 (12-18 months), Type 4 (24 months), Type 5 (36 months)
Type 3 (12-18 months), Type 4 (24 months), Type 5 (36 months)
Responses to Question 9: Which ECB netting type(s) exhibit a high success rate?
Double photodegradable
N/A
Single biodegradable, Single photodegradable, Double photodegradable
Double photodegradable
Double photodegradable
Responses to Question 10: Which ECB material composition(s) exhibit a high success rate?
Straw, Wood Excelsior
None
Straw, Wood Excelsior
Straw, Wood Excelsior, Coconut
Wood Excelsior
Responses to Question 11: Which specific ECB product(s) exhibit a high success rate?
AEC Premier Straw Double Net, North American Green SC150
None
AEC Premier Straw Double Net, Excel S-1, North American Green SC150
AEC Premier Straw Double Net, Excel S-1, North American Green SC150, Landlok S1
Am. Excesior Curlex II and III
Responses to Question 12: Which ECB manufacturer(s) have products with frequent reoccurring problems or failures?
one no more than the other
All
N/A
None
N/A
Responses to Question 13: Which ECB classification(s) have frequent reoccurring problems or failures?
Type 1 (45-60 days)
Type 1 (45-60 days), Type 2 (12 months), Type 3 (12-18 months), Type 4 (24 months), Type 5 (36 months)

Type 2 (12 months), Type 3 (12-18 months)
Type 1 (45-60 days)
Type 1 (45-60 days), Type 2 (12 months), Type 5 (36 months)
Responses to Question 14: Which ECB netting type(s) have frequent reoccurring problems or failures?
Single biodegradable, Single photodegradable
Single biodegradable, Single photodegradable, Double photodegradable
N/A
Single biodegradable, Single photodegradable
Single biodegradable, Single photodegradable
Responses to Question 15: Which ECB material composition(s) have frequent reoccurring problems or failures?
depends on circumstances or maybe wrong product choice for situation
Straw, Wood Excelsior, Jute Fiber, Coconut
N/A
Jute Fiber
Straw, Coconut, Various TRM materials
Responses to Question 16: Which specific ECB product(s) have frequent reoccurring problems or failures?
not a fan of single net blanket except in short term needs
AEC Premier Straw Double Net, Excel S-1, North American Green SC150, Landlok S1
N/A
None
Excel S-1, North American Green SC150, Landlok S1
Responses to Question 17: Please provide any additional information on the topic of ECBs that you feel would be helpful for this study:
Choosing the right product for the intended result. The biggest failure I see is some mats are too thick to allow the vegetation to establish which is what you are usually after in the first place.
We have had very little success with any of the products. Areas where these products are specified should have rock protection.
N/A
I think that MODOT should use ECB on more of their projects. I think it works great.
The biggest draw back to ECB, and TRM is that MODOT has no seeding season. Therefore when forced to seed in June/July/August there is often germination that takes place and the new grass burns up before it can establish. When the blankets are in place you cannot re-seed under them. Few have a very good success rate with overseeding practices. The Curlex (Wood Pulp) products seem to have the highest germination rate when overseeded.

Appendix E: TxDOT Index Property and Performance Analysis

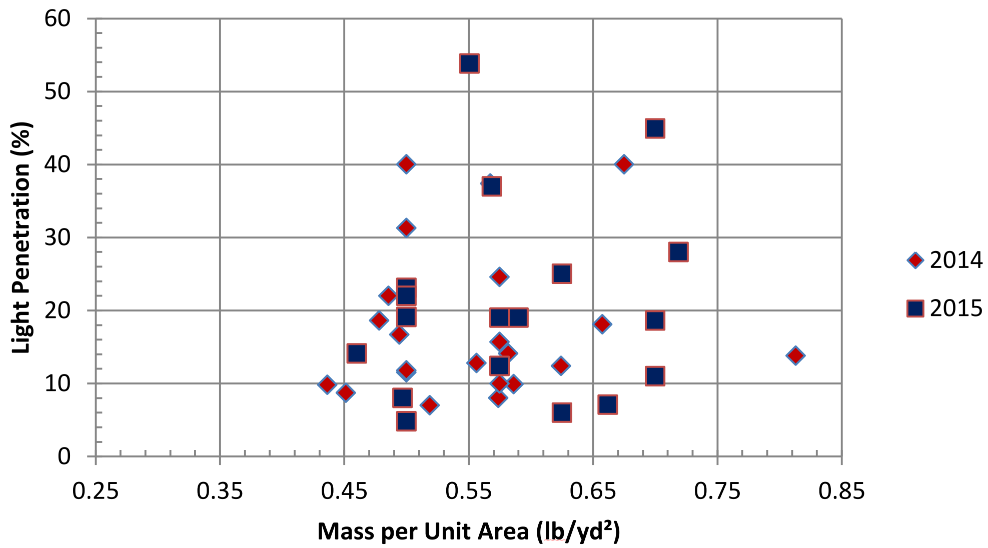


Figure E.1. Mass per unit area and light penetration for Type A.

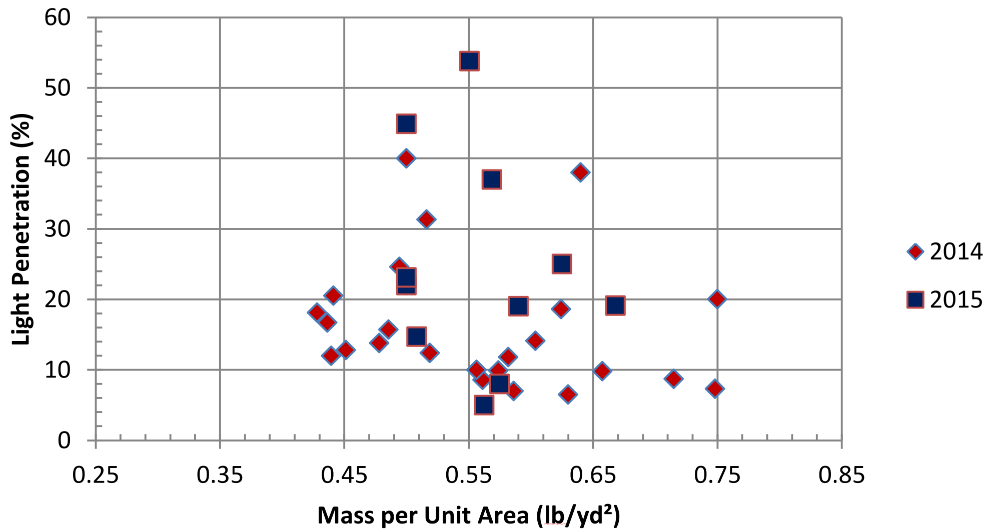


Figure E.2. Mass per unit area and light penetration for Type B.

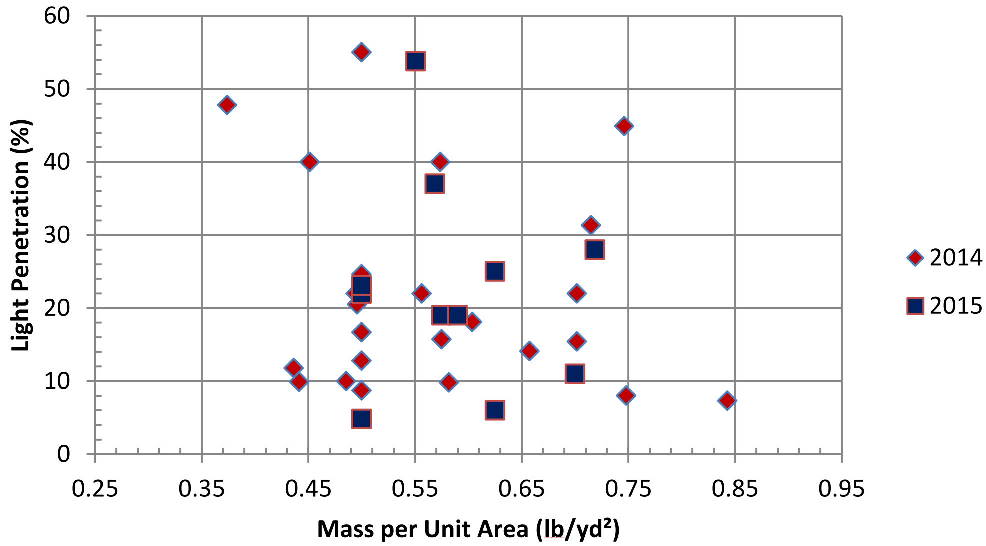


Figure E.3. Mass per unit area and light penetration fort Type C.

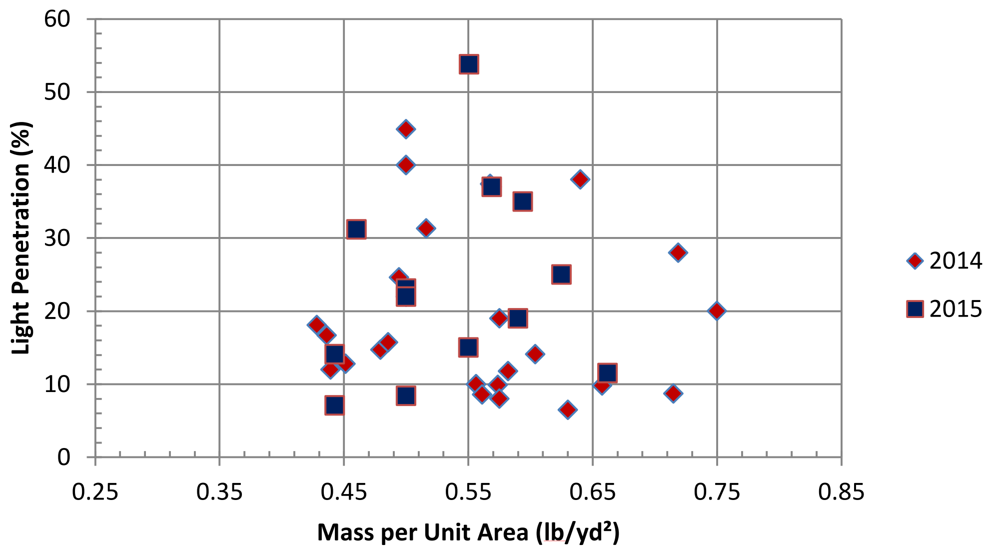


Figure E.4. Mass per unit area and light penetration for Type D

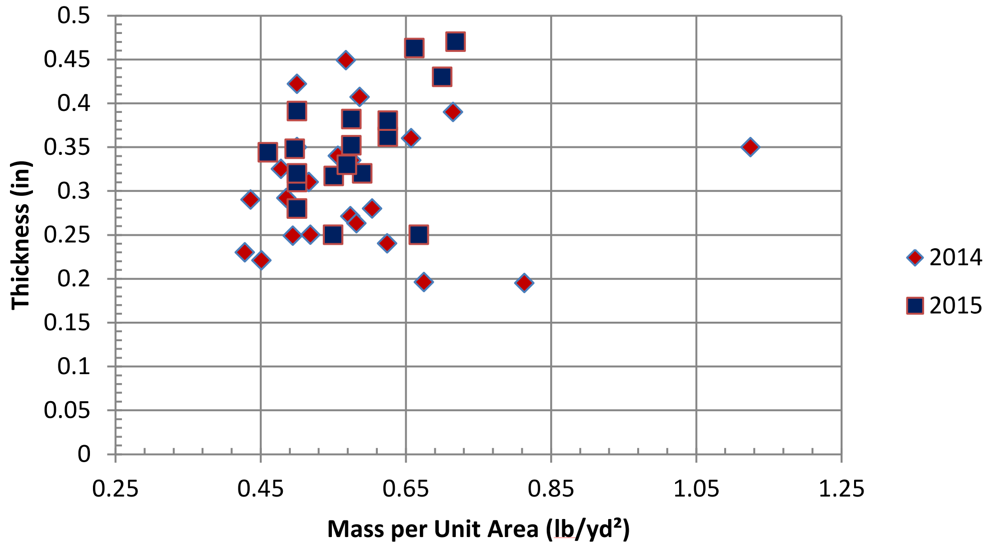


Figure E.5. Mass per unit area and thickness for Type A.

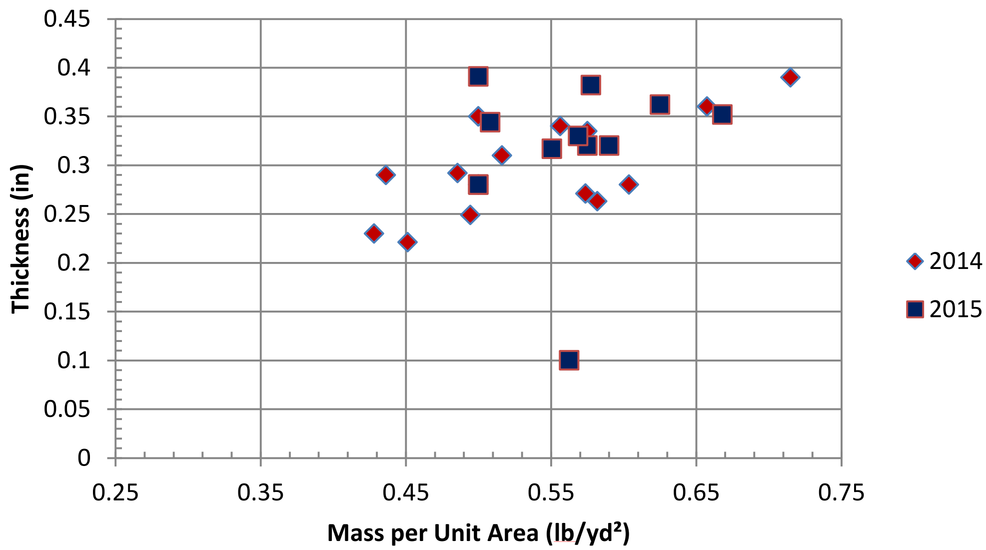


Figure E.6. Mass per unit area and thickness for Type B

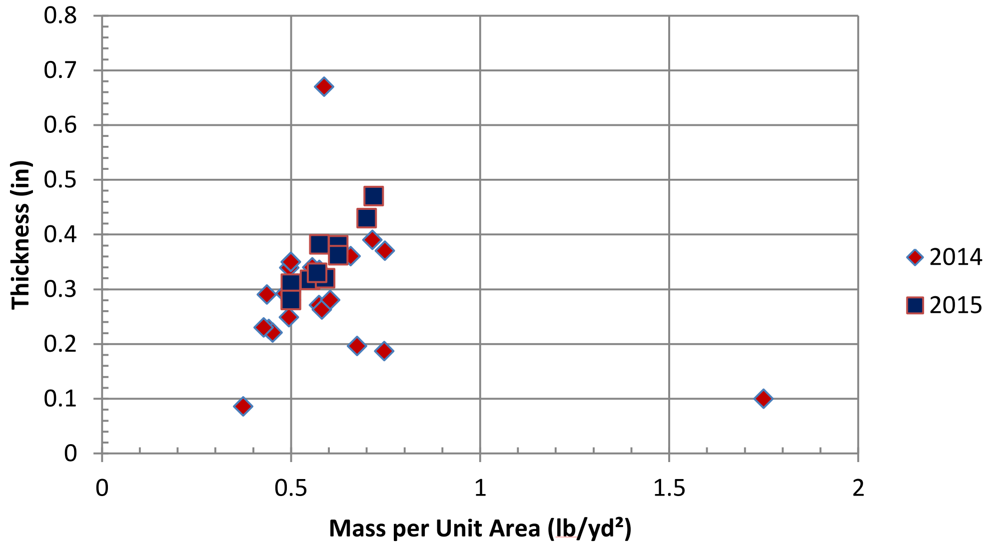


Figure E.7. Mass per unit area and thickness for Type C.

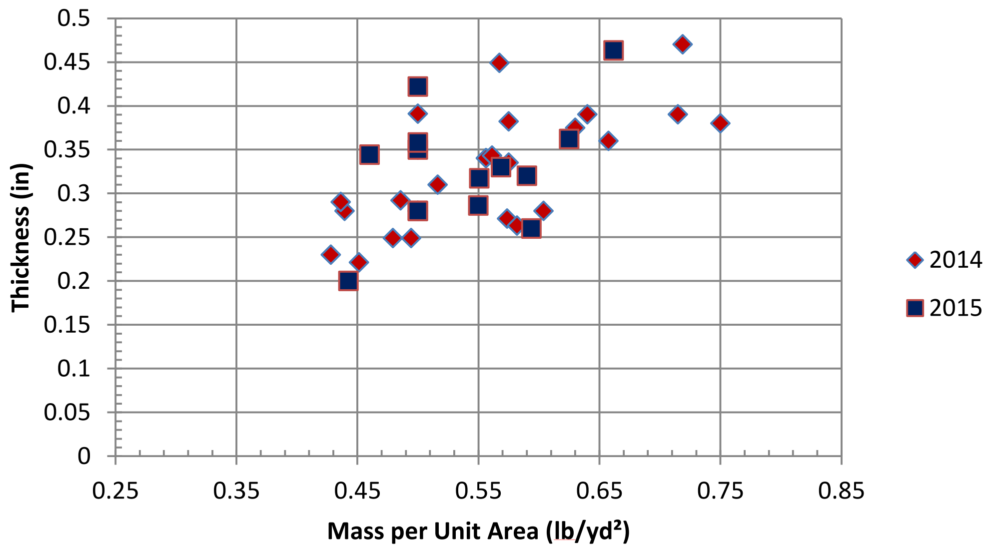


Figure E.8. Mass per unit area and thickness for Type D.

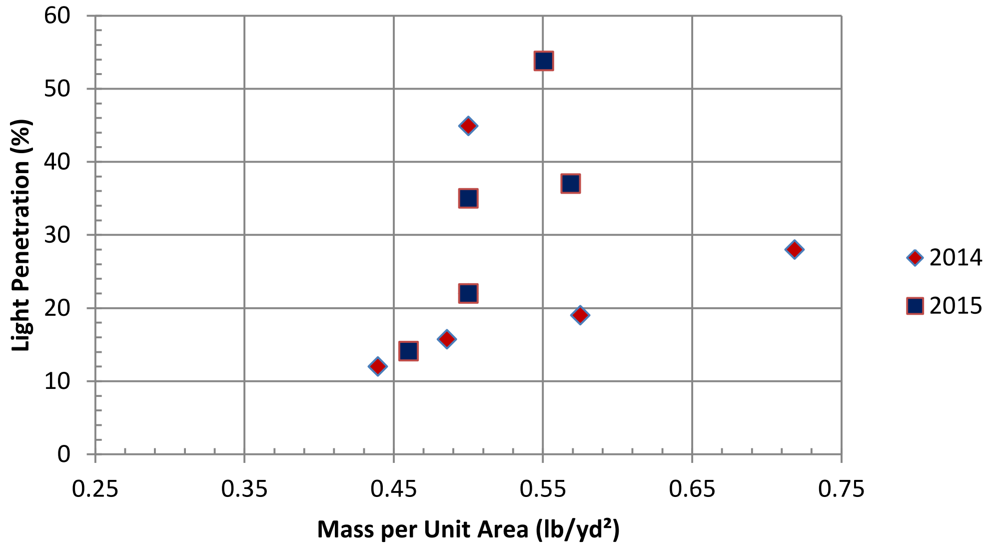


Figure E.9. Single-net ECB mass per unit area and light penetration for Type D.

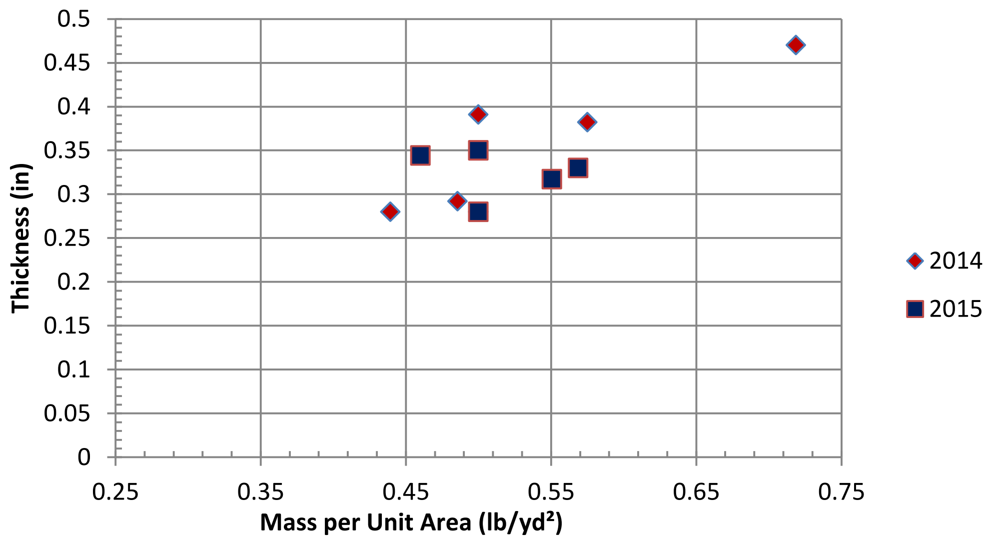


Figure E.10. Single-net ECB Mass per unit area and thickness for Type D.

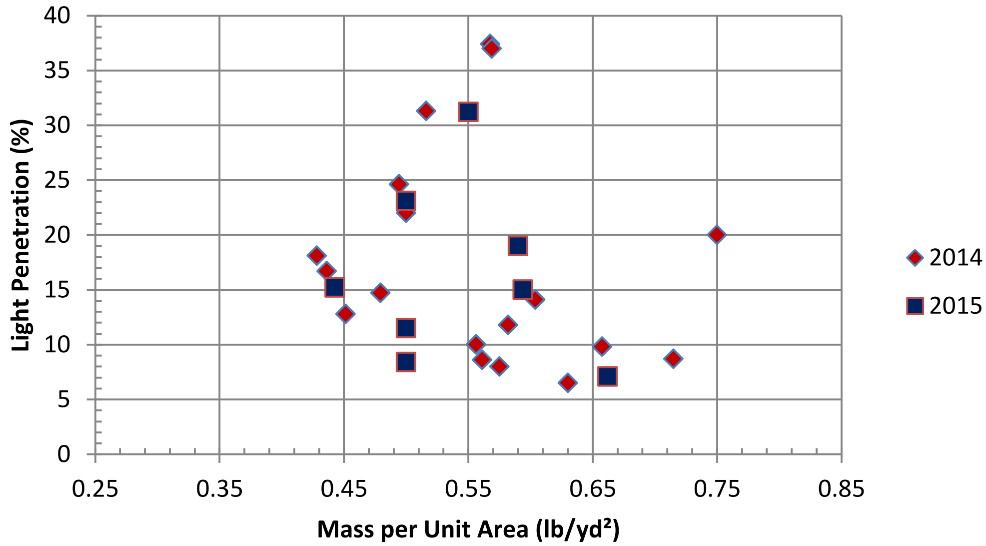


Figure E.11. Double-net ECB mass per unit area and light penetration for Type D.

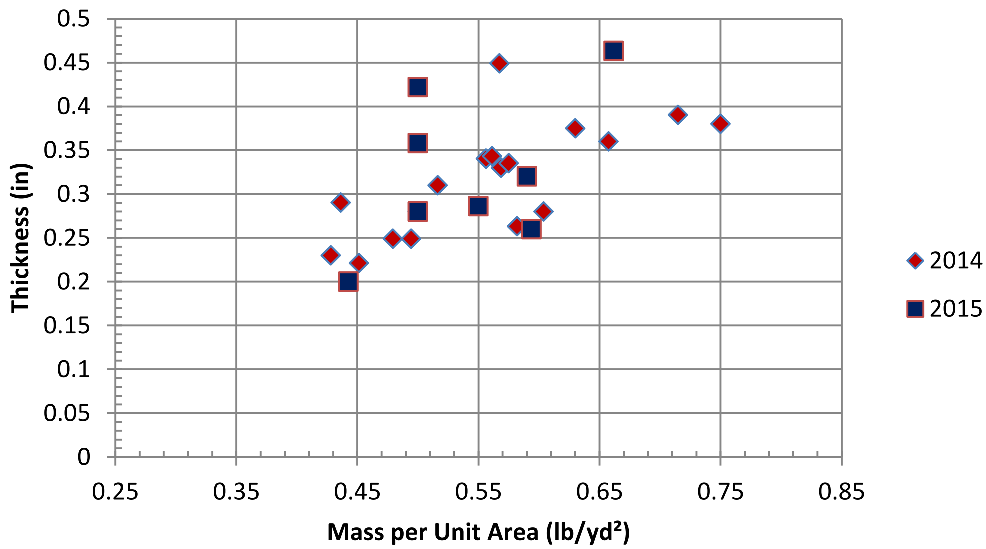


Figure E.12. Double-net ECB mass per unit area and thickness for Type D.

Appendix F: Missouri Erodibility and Erosivity Maps

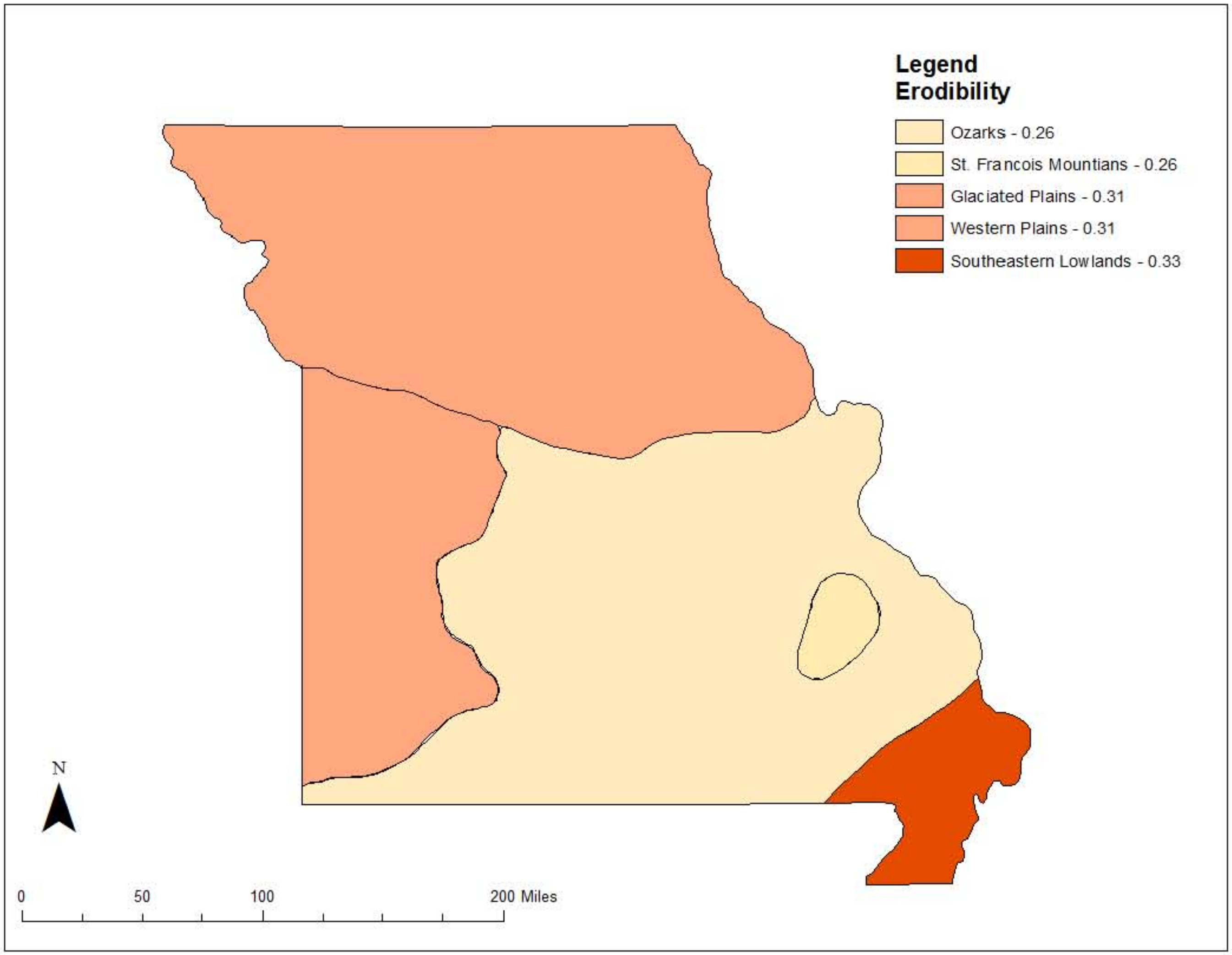


Figure F.1. Average erodibility value for each physiographic region in Missouri.

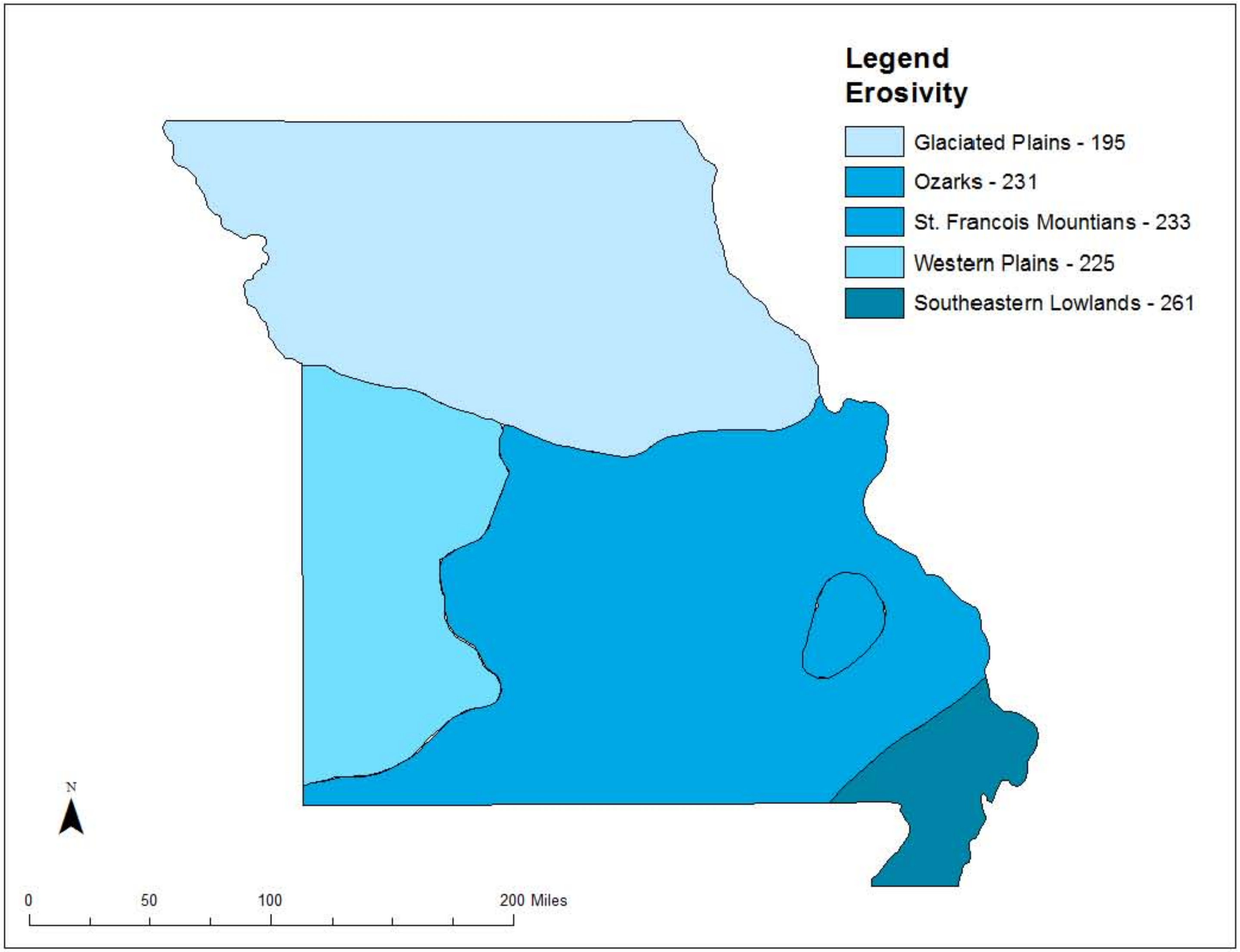


Figure F.2. Average erosivity value for each physiographic region in Missouri.

Appendix G: EPG and Construction Specification Recommendations

Previous EPG Guidelines for Temporary Erosion Control Blankets

Temporary Erosion Control Blankets (Sec. 806.90)

Description (Sec. 806.90.1)

Erosion control blankets and plastic netting are used to prevent erosion of seeded areas for a period of time sufficient for the seed to produce a root system capable of providing permanent erosion protection. Blankets are manufactured with wood fiber (excelsior), jute, coconut coir fiber, and synthetic materials. Blankets are used where the volume or velocity of runoff exceeds ditch check capabilities, where sediment from the project can severely impact an environmentally sensitive water body or where the roadway soil types are highly susceptible to erosion.

Erosion control blankets and turf reinforcement mats must be considered for:

- Fill slopes greater than 10 feet high
- Ditch slopes greater than 10 percent
- Highly erodible soils
- Fluctuating water levels
- High ditch flows
- High sheet flow
- Standard seeding and mulching will not withstand anticipated runoff
- Around high quality water bodies.

Material (Sec. 806.90.2)

See Storm Water Pollution Prevention Plan (SWPPP) - Erosion Stabilization Mats and Blankets.

Specific material specifications are found in Section 1011 of the Missouri Standard Specifications for Highway Construction.

Construction Requirements (Sec. 806.90.3)

Inspection forces should watch erosion control blanket installation. Details to be observed are:

- Lap joints should be in direction of water flow.
- Check slots must be at right angles to water flow.
- Anchor staples must be fully driven and properly spaced.

Method of Measurement (Sec. 806.90.4)

Measurements are based on surface area covered. Field notes should be based on measurements along the surface and should develop the following data:

- Station Limits.

- Location (Rt., Lt., or Median).
- Type of netting.
- Length.
- Width
- Area.
- Date of measurement.
- Party taking measurements.

Field notes should be entered directly into a bound book. The person in charge of measurements should sign the notes.

Basis of Payment (Sec. 806.90.5)

No additional guidance.

Proposed Recommended EPG Guidelines for Temporary Erosion Control Blankets

Temporary Erosion Control Blankets (Sec. 806.90)

Description (Sec. 806.90.1)

Erosion control blankets and plastic netting are used to prevent erosion of seeded areas for a period of time sufficient for the seed to produce a root system capable of providing permanent erosion protection. Blankets are manufactured with wood fiber (excelsior), jute, coconut coir fiber, and synthetic materials. Blankets are used where the volume or velocity of runoff exceeds ditch check capabilities, where sediment from the project can severely impact an environmentally sensitive water body or where the roadway soil types are highly susceptible to erosion.

Erosion control blankets and turf reinforcement mats must be considered for:

- Fill slopes greater than 10 feet high
- Ditch slopes greater than 10 percent
- Highly erodible soils
- Fluctuating water levels
- High ditch flows
- High sheet flow
- Standard seeding and mulching will not withstand anticipated runoff
- Around high quality water bodies.

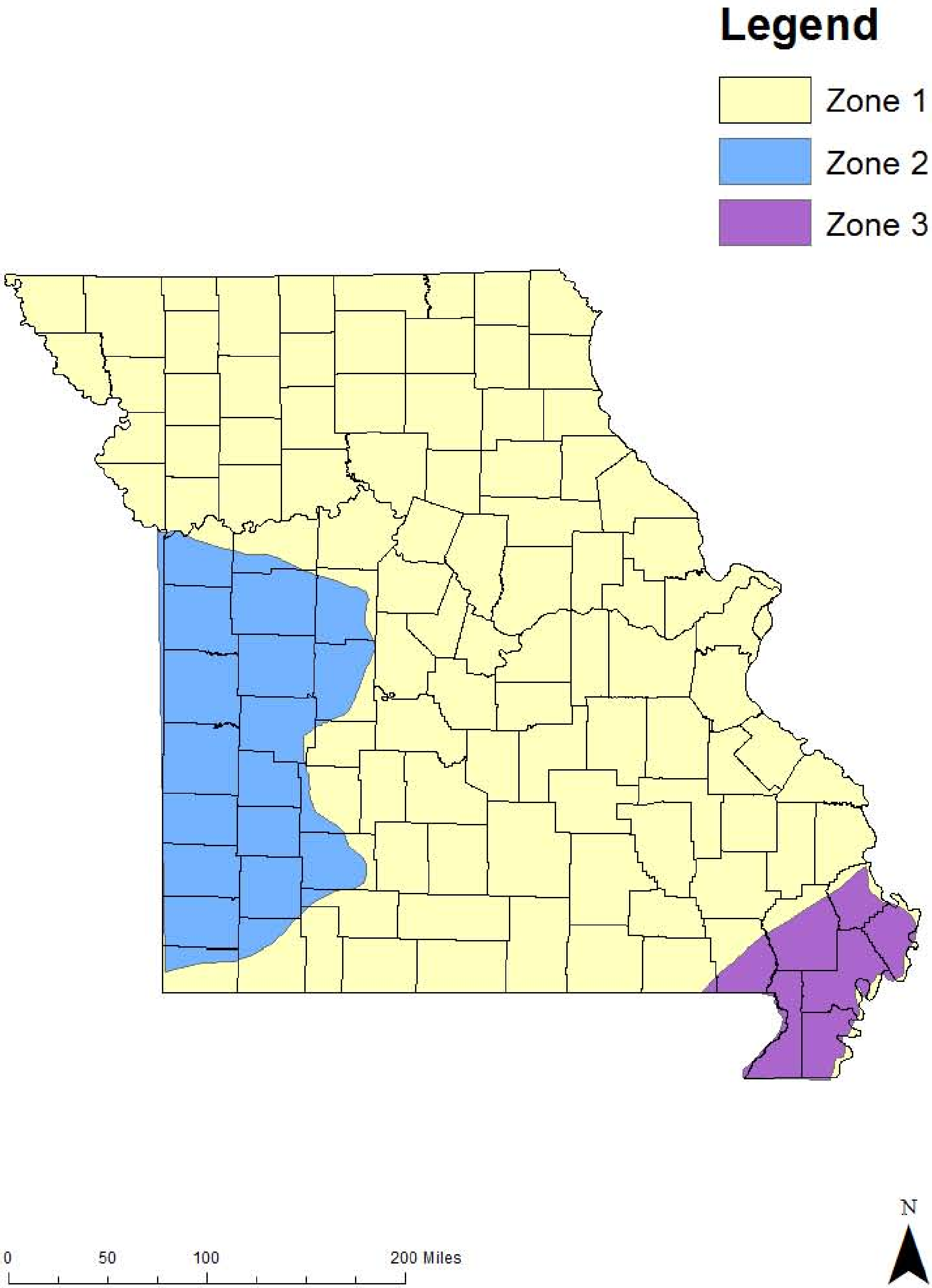
Material (Sec. 806.90.2)

See Storm Water Pollution Prevention Plan (SWPPP) - Erosion Stabilization Mats and Blankets.

Specific material specifications are found in Section 1011 of the Missouri Standard Specifications for Highway Construction.

Design Guidance (Sec 806.90.3)

The implementation of erosion control blankets must be performed by geographic location of the project. The following map shows each Missouri county assigned a zone delineated by erosion susceptibility.



When the project county zone is identified, the ECB design shall be based off of the following design table for the corresponding zone. Counties overlapping zones should use the higher zone for design. All Type 2, Type 3, and Type 4 ECBs are assumed to include silt fences as supplementary BMPs. Instituting silt fences with Type 1 ECBs would increase the maximum allowable slope length by a factor of 4. The following design charts are a visual aid in designing ECBs for a given application. The dashed lines indicate instances where an ECB can be used, and the bold lines indicate instances when an ECB should be used. The engineer's discretion is to be used to determine the appropriate service life for the site when selecting the appropriate ECB type (Type 1 – 3 months, Type 2 – 12 months, Type 3 – 24 months, Type 4 – 36 months).

ECB Type	Name	Maximum Slope (H:V)	Maximum Length (ft)		
			Zone 1	Zone 2	Zone 3
1A	Mulch Control Nets	5:1	990	750	495
1B	Netless Rolled Erosion Control Blankets	4:1	605	460	305
1C	Light-Weight Double-Net Erosion Control Blankets	3:1	150	115	75
1D	Heavy Double-Net Erosion Control Blankets	2:1	40	30	20
2A	Mulch Control Nets	5:1	1110	840	560
2B	Netless Rolled Erosion Control Blankets	4:1	680	515	340
2C	Light-Weight Double-Net Erosion Control Blankets	3:1	170	130	85
2D	Heavy Double-Net Erosion Control Blankets	2:1	45	35	20
3A	Mulch Control Nets	5:1	1110	840	560
3D	Erosion Control Blankets	1.5:1	15	15	10
4	Erosion Control Blankets	1:1	10	10	5

Zone 1		Slope Steepness																	
Type	Name	5:1			4:1			3:1			2:1			1.5:1			1:1		
		0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+
1A	Mulch Control Nets	—	—	—															
1B	Netless Rolled Erosion Control Blankets	···	···	···	—	—	—												
1C	Light-Weight Double Net Erosion Control Blankets	···	···	···	···	···	···	—	—	—									
1D	Heavy Double-Net Erosion Control Blankets	···	···	···	···	···	···	···	···	···	—								
2A	Mulch Control Nets	—	—	—															
2B	Netless Rolled Erosion Control Blankets	···	···	···	—	—	—												
2C	Light-Weight Double Net Erosion Control Blankets	···	···	···	···	···	···	—	—	—									
2D	Heavy Double-Net Erosion Control Blankets	···	···	···	···	···	···	···	···	···	—								
3A	Mulch Control Nets	—	—	—															
3B	Erosion Control Blankets	···	···	···	—	—	—	—	—	—	—	—	—						
4	Erosion Control Blankets	···	···	···	···	···	···	···	···	···	···	···	···	—	—	—			

Zone 2		Slope Steepness																	
Type	Name	5:1			4:1			3:1			2:1			1.5:1			1:1		
		0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+
1A	Mulch Control Nets																		
1B	Netless Rolled Erosion Control Blankets																		
1C	Light-Weight Double-Net Erosion Control Blankets																		
1D	Heavy Double-Net Erosion Control Blankets																		
2A	Mulch Control Nets																		
2B	Netless Rolled Erosion Control Blankets																		
2C	Light-Weight Double-Net Erosion Control Blankets																		
2D	Heavy Double-Net Erosion Control Blankets																		
3A	Mulch Control Nets																		
3B	Erosion Control Blankets																		
4	Erosion Control Blankets																		

Zone 3		Slope Steepness																	
Type	Name	5:1			4:1			3:1			2:1			1.5:1			1:1		
		0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+	0-40'	40-80'	80'+
1A	Mulch Control Nets																		
1B	Netless Rolled Erosion Control Blankets																		
1C	Light-Weight Double-Net Erosion Control Blankets																		
1D	Heavy Double-Net Erosion Control Blankets																		
2A	Mulch Control Nets																		
2B	Netless Rolled Erosion Control Blankets																		
2C	Light-Weight Double-Net Erosion Control Blankets																		
2D	Heavy Double-Net Erosion Control Blankets																		
3A	Mulch Control Nets																		
3B	Erosion Control Blankets																		
4	Erosion Control Blankets																		

Construction Requirements (Sec. 806.90.4)

Inspection forces should watch erosion control blanket installation. Details to be observed are:

- Lap joints should be in direction of water flow.
- Check slots must be at right angles to water flow.
- Anchor staples must be fully driven and properly spaced.

Method of Measurement (Sec. 806.90.5)

Measurements are based on surface area covered. Field notes should be based on measurements along the surface and should develop the following data:

- Station Limits.
- Location (Rt., Lt., or Median).
- Type of netting.
- Length.
- Width.
- Area.
- Date of measurement.
- Party taking measurements.

Field notes should be entered directly into a bound book. The person in charge of measurements should sign the notes

Previous Standard Specifications for ECBs from General Provisions and Supplemental Specifications to 2011 Missouri Standard Specifications for Highway Construction

1011.3.5 Erosion Control Blankets. Erosion control blankets (ECB) shall be certified by the manufacturer to meet the following criteria:

ECB Type	Netting Type	Longevity	Slopes	Soil Type
Type 1	Single, Quickly degradable	45-60 days	3:1 or flatter	Clay
Type 2	Single Photodegradable	12 months	3:1 or flatter	Sandy
Type 3	Double Photodegradable	12-18 months	2:1 or flatter	Clay
Type 4	Double Photodegradable	24 months	2:1 or flatter	Sandy
Type 5	Double Photodegradable	36 months	1:1 or flatter	Any

1011.3.6 Turf Reinforcement Mats. Turf reinforcement mats (TRM) shall be certified by the manufacturer for open flow channels and shall meet the following calculated shear stress:

TRM Type	Calculated Shear Stress (psf)
Type 1	3.5-6
Type 2	6.1-8
Type 3	8.1-10
Type 4	10.1 or greater

Recommended Standard Specifications for ECBs from General Provisions and Supplemental Specifications to 2011 Missouri Standard Specifications for Highway Construction

10113.5 Erosion Control Blankets (ECB). Erosion control blankets shall be prequalified and categorized based on performance testing by ASTM D6459 and the physical testing of ASTM D5035. The ASTM D6459 performance testing may be substituted with the performance testing conducted by the Texas Department of Transportation and the Texas Transportation Institute. Erosion control blankets shall meet the following requirements.

ECB Type	Description	Material Composition	Longevity	Maximum Gradient	C-factor	Minimum Tensile Strength
1.A	Mulch Control Nets	A photodegradable synthetic mesh or woven biodegradable natural fiber netting	3 months	5:1	≤ 0.10 @ 5:1	5 lb/ft
1.B	Netless Rolled Erosion Control Blankets	Natural and/or polymer fibers mechanically interlocked and/or chemically adhered together to form an RECP	3 months	4:1	≤ 0.10 @ 4:1	5 lb/ft
1.C	Light-Weight Double-Net Erosion Control Blankets	Natural and/or polymer fibers mechanically bound together by two rapidly degrading, synthetic or natural fiber netting	3 months	3:1	≤ 0.15 @ 3:1	50 lb/ft
1.D	Heavy Double-Net Erosion Control Blankets	Processed degradable natural and/or polymer fibers mechanically bound together between two rapidly degrading, synthetic or natural fiber nettings	3 months	2:1	≤ 0.20 @ 2:1	75 lb/ft
2.A	Mulch Control Nets	A photodegradable synthetic mesh or woven biodegradable natural fiber netting	12 months	5:1	≤ 0.10 @ 5:1	5 lb/ft
2.B	Netless Rolled Erosion Control Blankets	Natural and/or polymer fibers mechanically interlocked and/or chemically adhered together to form an RECP	12 months	4:1	≤ 0.10 @ 4:1	5 lb/ft
2.C	Light-Weight Double-Net Erosion Control Blankets	Natural and/or polymer fibers mechanically bound together by two degrading, synthetic or natural fiber netting	12 months	3:1	≤ 0.15 @ 3:1	50 lb/ft
2.D	Heavy Double-Net Erosion Control Blankets	Processed degradable natural and/or polymer fibers mechanically bound together between two degrading, synthetic or natural fiber nettings	12 months	2:1	≤ 0.20 @ 2:1	75 lb/ft
3.A	Mulch Control Nets	A slow degrading synthetic mesh or woven natural fiber netting	24 months	5:1	≤ 0.10 @ 5:1	25 lb/ft
3.B	Erosion Control Blankets	An erosion control blanket composed of processed slow degrading natural or polymer fibers mechanically bound together between two slow degrading synthetic or natural fiber nettings to form a continuous matrix	24 months	1.5:1	≤ 0.25 @ 5:1	100 lb/ft
4	Erosion Control Blankets	An erosion control blanket composed of processed slow degrading natural or polymer fibers mechanically bound together between two slow degrading synthetic or natural fiber nettings to form a continuous matrix	36 months	1:1	≤ 0.25 @ 5:1	125 lb/ft

1011.3.5.1 Anchors. Anchors as recommended by the erosion control product manufacturer shall be used.

1011.3.5.2 Test Methods.
Erosion control blankets shall be tested and evaluated by ASTM D6459 and ASTM D5035. ASTM D6459 shall be tested on loam soil defined by ASTM D6459. The calculated C-factor for the tested slope shall be determined from the reported C-factor regression equation using an erosivity value of 224. Type 1.A, Type 2.A, and Type 3.A mulch control nets must be tested in conjunction with pre-applied mulch material. The Texas DOT testing may be substituted for acceptance for materials tested on slopes categorized as "sandy".

Minimum tensile strength shall be tested in accordance with ASTM D5035 in the machine direction.

The blankets will also be evaluated on the basis of their performance in the field.

1011.3.5.3 Certification.
The contractor shall furnish a manufacturer's certification to the engineer for each lot of material furnish stating the name of the manufacturer, the chemical composition of the filaments or yarns and certifying that the material supplied is in accordance with this specification. The certification shall include or have attached typical results of tests from specific lots for all specified requirements.

1011.3.6 Turf Reinforcement Mats. Turf reinforcement mats (TRM) shall be certified by the manufacturer for open flow channels and shall meet the following calculated shear stress:

TRM Type	Calculated Shear Stress (psf)
Type 1	3.5-6
Type 2	6.1-8
Type 3	8.1-10
Type 4	10.1 or greater

1011.3.6.1 Anchors. Anchors as recommended by the product manufacturer shall be used.

1011.3.6.2 Test Methods.
Erosion control blankets shall be tested and evaluated by either ASTM D6460 or by the Texas DOT independent testing. The test results must indicate the maximum allowable shear strength. ASTM D6460 shall be tested on the loam soil defined by ASTM D6460.

The blankets will also be evaluated on the basis of their performance in the field.

1011.3.6.3 Certification.
The contractor shall furnish a manufacturer's certification to the engineer for each lot of material furnish stating the name of the manufacturer, the chemical composition of the filaments or yarns and certifying that the material supplied is in accordance with this specification. The certification shall include or have attached typical results of tests from specific lots for all specified requirements.

Previous ECB Approved Products List for ECBs from General Provisions and Supplemental Specifications to 2011 Missouri Standard Specifications for Highway Construction

See Texas Department of Transportation Approved Product List.*
http://www.txdot.gov/inside-txdot/division/maintenance/erosion-control.html

*In addition to the erosion control material listed on the website linked above (Texas Department of Transportation), the following erosion control materials shall be considered conditionally approved pending test results obtained from TTI.

Type	Brand Name	Manufacturer

Recommended ECB Approved Products List for ECBs from General Provisions and Supplemental Specifications to 2011 Missouri Standard Specifications for Highway Construction

GEOTEXTILE
FIELD SECTION 1011 TABLE 1
QUALIFIED EROSION CONTROL BLANKETS

Class 1 "Slope Protection" Type B and Type D erosion control blankets from the Texas Department of Transportation Approved Product List are also acceptable for use. The contractor is responsible for providing the necessary information that products used from the Texas Department of Transportation Approved Product List meet the required longevity specified by MoDOT.

http://www.txdot.gov/inside-txdot/division/maintenance/erosion-control.html

Type 1: Ultra Short-Term ECBs (3 month functional longevity)

Type	Brand Name	Manufacturer

Type 2: Short-Term ECBs (12 month functional longevity)

Type	Brand Name	Manufacturer

Type 3: Extended-Term ECBs (24 month functional longevity)

Type	Brand Name	Manufacturer

Type 4: Long-Term ECBs (36 month functional longevity)

Type	Brand Name	Manufacturer

Appendix H: ECB Performance Quality Control Form (blank)

Name:______________________________________
Date:______________________________________
Project Number:________________________________
County:______________________________________
ECB Type:____________________________________
ECB Product Name:______________________________
Manufacturer: ________________________________
Distributor: _________________________________
Subcontractor responsible for installation: ____________________
Were manufacturer recommendations for installation followed? ☐ Yes ☐ No

If not, what deviations were made?

____
____
____
____
____

Was the site accepted as a completely reestablished slope in accordance to the MoDOT SWPPP (70% uniform germination across the disturbed area)? ☐ Yes ☐ No

Successes observed at the site (check all that apply):

- ☐ No visible sediment deposition downstream of site
- ☐ Primarily vegetated with grasses used in seeding
- ☐ No visible excessive gulley or rill erosion

Additional comments regarding successful application:

____
____
____
____

Failures observed at the site (check all that apply):

- ☐ Rupturing/Movement of Blanket
- ☐ Undercutting/Gulley Erosion
- ☐ Lack of Germination
- ☐ Lack of Degradation

If failure occurred, describe the nature of the failure:

____
____
____
____

Would you recommend this product to be used again? ☐ Yes ☐ No

If yes, what recommendations would you have to prevent similar failures?

____

____

____

____

____

(Attach Photos of ECB failure if applicable)

Insert Photo

Insert Photo