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A Hydrological Analysis of Switchgrass Land Cover in East Tennessee

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To the Graduate Council:

I am submitting herewith a thesis written by Jordan Avery Hayes entitled "A Hydrological Analysis of Switchgrass Land Cover in East Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

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A Hydrological Analysis of Switchgrass Land Cover in East Tennessee

A Thesis Presented for the
Master of Science
Degree
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Jordan Avery Hayes
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DEDICATION

I dedicate these works to my family. You have always been supportive and understanding.

ACKNOWLEDGEMENTS

I would first like to thank Dr. John Schwartz for the opportunity to take part in this research. Next I would like to thank Dr. Jon Hathaway and Dr. Daniel Yoder. Without the expertise and guidance from this committee I would be completely lost. I especially thank Zachariah Seiden, Brandy Manka, Cory Julian Michael Walton, Tyler Bone, and Dylan Hoehn for assistance in the laboratory and field. Without their aide the project would have proven impossible. Special thanks go to Virginia Dale, Ester Parish, Jon Walton, ORNL, USDA, and IBSS for site selection, project planning, and funding. Thanks to James “Jimmy” Jones for suffering through the big December push with me. Additional thanks go to Gabrielle Sobel, my family, and my friends who each aided me extensively and understood my absence at events.

ABSTRACT

Energy needs and the recent installation of a cellulosic biofuel plant in Vonore, TN have created a demand for switchgrass in East Tennessee. Switchgrass has many strengths such as erosion protection, nutrient removal, and runoff mitigation. The Soil and Water Assessment Tool (SWAT) was selected to model the impact of transitioning traditional crops into switchgrass land cover. Field data was needed to properly calibrate the SWAT model for East Tennessee. The National Resources Conservation Service (NRCS) curve number (CN) was needed for runoff calibrations. This value was determined by both standard NRCS methods as well as an asymptotic method. The NRCS method provided an average CN of 90 for an initial abstraction of 0.20. The asymptotic method determined the CN to be 69, which is much more reasonable compared to published grassland values. The Revised Universal Soil Loss Equation (RUSLE) was used to determine the erosion reduction potential associated with switchgrass. The cropping factor of RUSLE was determined to be 0.0006 for use in SWAT calibration. The calculated C factor is only marginally better at erosion prevention than other grasses when compared against the worst case scenario, unit plot condition. Nutrient export data was also needed to verify the simulation output for switchgrass. Total phosphorus and total nitrogen were selected to validate nutrient export simulations. Total phosphorus was calculated on the range of 0.11 g/Ha to 400 g/Ha and total nitrogen was calculated on the range of 0.0007 g/Ha to 1519g/Ha. The ranges determined from field data matched published values for switchgrass when compared to traditional crops. Values determined for each previously listed strength should be selected for use in SWAT calibrations in East Tennessee.

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INTRODUCTION

The Department of Energy has requested eleven billion dollars for the 2014 budget with over twenty-five percent of this request delegated to renewable energy and reliability USDOE (2013). Such a large push for renewable energy has led the United States to look into alternative sources of energy such as bioenergy crops. One example of this push is the 30x30 plan, recently outlined in a US Department of Agriculture (USDA) report Perlack et al. (2005). The 30x30 plan calls for a replacement of 30% of petroleum based consumption with biofuels by 2030. Perlack et al. (2005) determined that the 30x30 plan is feasible under simple land area based analyses.

Economic models that incorporate water use found that the Southeast region of the US is well suited for sustainable bioenergy crop production utilizing switchgrass Baskaran et al. (2010); Mclaughlin et al. (2002). Switchgrass (*Panicum virgatum*) is a native to the Great Plains Hartman et al. (2011). Switchgrass has been closely monitored for many of its positive qualities for decades Wright and Turhollow (2010). Wright and Turhollow (2010) outline switchgrass as a biofuel that requires low input, is reliable over varying climates, and consists of deep root structures that can aid in preventing erosion processes. Switchgrass has also shown a potential to increase habitats for wildlife such as birds Murray et al. (2002). The versatile nature of its genetic makeup has proven to provide a means for a highly adaptive grass Parrish and Fike (2007). With so many beneficial characteristics it is easy to overlook one potential drawback of switchgrass. De La Torre Ugarte and others (2010) conclude that further research needs to be conducted to better determine the differences in water management needs between traditional crops and switchgrass. Many researchers have agreed with this statement, leading to research efforts to elucidate this information using such methods as nation-wide simulations Baskaran et al. (2010).

Khanna and others (2008) produced a networking map that detailed localized efforts for processing plants and transportation routes. This study reinforces the fact that biofuel efforts will need to be managed on a regional or even local level. Knisel and others (1991) suggest that real world processes typically dictate regional or even local solutions as opposed to global or national solutions fitting every scenario. One model that incorporates regional scale solutions for switchgrass implementation is the Biomass Location for Optimal Sustainability Model (BLOSM)

Parish et al. (2012). BLOSM balances six parameters for land use change with the help of the Soil and Water Assessment Tool (SWAT) Parish et al. (2012). SWAT incorporates land use characteristics, topography, soil data, and weather data to estimate water, sediment, and nutrient exports across a broad range of applicability Douglas-Mankin et al. (2010); Sang et al. (2010); Sahu et al. (2010). Simulation and model validation using field studies has been deemed vital by Ritter and Gardner (1991) along with Rachman and others (2008).

Production of switchgrass was further promoted by the USDA in the state of Tennessee with the construction of a full-scale cellulosic ethanol manufacturing facility in Vonore, Tennessee. Close proximity between large farming counties and the new facility allowed for necessary field studies to be conducted determining the validity of current SWAT assumptions for switchgrass. Three of the six BLOSM parameters to be analyzed in this study are the minimization of nitrogen export, phosphorus exports, and erosion. Precipitation runoff relationships, erosion relationships, and nutrient exports were studied to assess these BLOSM parameters. The SCS Curve Number, relates precipitation to potential runoff and is outlined in article one below. Article two consists of validation of SWAT assumptions for switchgrass. The Revised Universal Soil Loss Equation (RUSLE) cropping management factor (C) is used to determine the erosion potential associated with switchgrass in comparison with currently available C values for surrogate crops. Total phosphorus and Total nitrogen concentrations are calculated from collected samples to verify the current nutrient export model in SWAT for switchgrass.

CHAPTER I
CURVE NUMBER FOR SWITCHGRASS LAND COVER IN EAST TENNESSEE

A version of this chapter is planned to be published by Jordan A. Hayes, John S. Schwartz, Daniel C. Yoder, and Jon M. Hathaway in the *ASCE Journal of Irrigation and Drainage*. Co-authors, formed by the thesis committee, consisted of John S. Schwartz Ph.D., PE, Associate Professor in the Civil and Environmental Engineering Department at the University of Tennessee, Daniel C. Yoder Ph.D., Professor in the Biosystems Engineering and Soil Sciences Department at the University of Tennessee, and Jon M. Hathaway Ph.D., PE, Assistant Professor in the Civil and Environmental Engineering Department at the University of Tennessee.

Curve Numbers for Switchgrass Land Cover in East Tennessee

Jordan A. Hayes; John S. Schwartz; Daniel C. Yoder; Jon M. Hathaway

ABSTRACT

Switchgrass has become a viable source for ethanol production in East Tennessee. The environmental impacts of converting traditional crops to switchgrass are currently being modeled by the Soil and Water Assessment Tool (SWAT). SWAT models require a curve number (CN) to calibrate the runoff simulations. Three sites in East Tennessee were chosen to study the rainfall runoff relationship of switchgrass to determine a CN. CNs were determined by traditional NRCS methods as well as by an asymptotic method. An initial abstraction (λ) was determined to best fit the study data. A standard average CN =90 was determined to be an overestimate of runoff. Using the asymptotic method a CN =69, which proved more reasonable when compared to historical data for grassland land cover, was selected for use in SWAT.

INTRODUCTION

The Department of Energy has requested eleven billion dollars for the 2014 budget with over twenty-five percent of this request delegated to renewable energy and reliability USDOE (2013). The 30x30 plan calls for a replacement of 30% of petroleum based consumption with biofuels by 2030. Numerous feasibility and impact studies have been completed on the expansion of bioenergy crops; however, these studies are typically nation-wide computer models Baskaran et al. (2009). Knisel and others (1991) suggest that real world processes are best modeled on regional scales rather than global scales.

BLOSM, a regional economic and water quality model examining the effects of increased land conversion to switchgrass found an optimal outcome of increased farm profits and reduced Total Suspended Solids (TSS), Total Phosphorus (TP), and Total Nitrogen (TN) could be achieved by expanding switchgrass plots over only 1.2-1.8% of the Lower Little Tennessee watershed Parish et al. (2012). BLOSM incorporates the SWAT watershed-scale model to estimate runoff water quality from land use conversions. The SWAT model combines TR-55 hydrology and the use of the NRCS Curve Number (CN) to predict runoff. Impacts for switchgrass expansion are, in part, determined from CN changes within the watershed. To better understand these changes it is important to select a CN for switchgrass. Typically, other grassland CN values are utilized as a surrogate for switchgrass. Parish and others (2012) recognize field-based studies for East Tennessee were needed to confirm ranges selected for the SWAT model, and ultimately the outcomes of BLOSM.

This study will focus on determining CNs for switchgrass for East Tennessee. Under the assumption that any pollutants derived from switchgrass will be transported through runoff processes, it is important to determine the potential for runoff. The objectives of the study were to 1) estimate CN for switchgrass in East Tennessee from field measurements as an input to the SWAT model, and 2) compare determined CN values with similar crops. CN calculations will be completed using two separate methods. The first is the standard method, which compares rainfall and flow directly to CN values. The second is an asymptotic method that fits an infinite relationship, by the way of an asymptote, to the dataset to determine the curve number of the very large events.

MATERIALS AND METHODS

Study Area

For this study, Thompson Farm located in Monroe County in East Tennessee was selected (Figure 1). Average rainfall on Thompson farm is 129 cm (50.8 in) per year with the wettest months being in the winter and the driest months in the summer National Oceanic and Atmospheric Administration (NOAA) (2013). Soils for the study area, consisting mostly of Silty loams and Silty clay loams, were categorized under hydrologic group B USDA NRCS Web Soil Survey (2013).

Within Thompson farm, four study sites were installed and named based upon installation order. Thompson 3 was eliminated due to technical errors of the monitoring equipment and frequent wildlife intrusion. The remaining sites are shown on their respective soil types in Figure 2 below and are summarized, topographically, in Table 1.

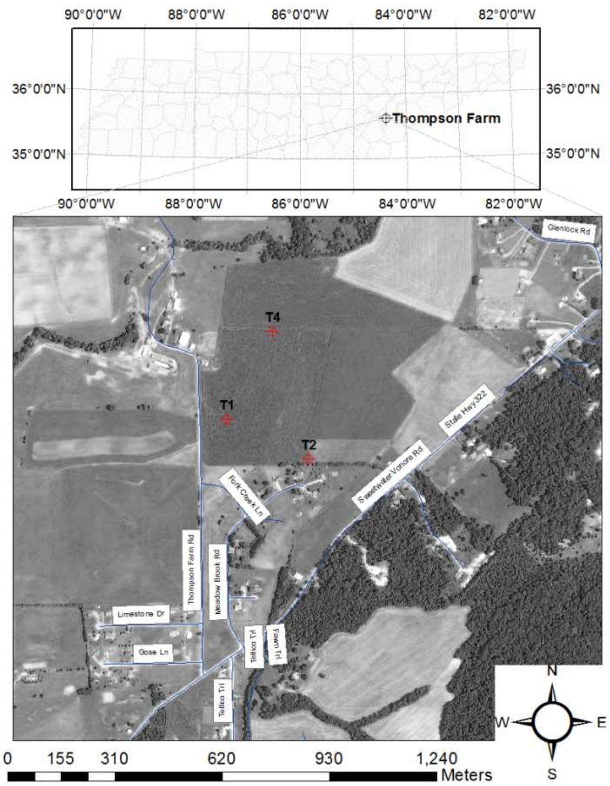


Figure 1: Thompson Farm State Location Map

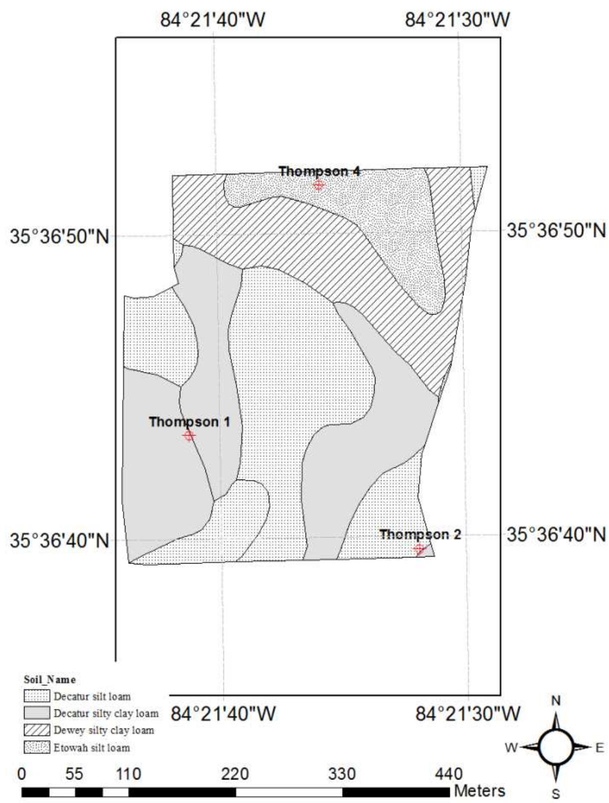


Figure 2: Thompson Farm Soil Distribution

Table 1: Thompson Farm Site Characteristics

Site	Lat	Long	Elev (m)	Drainage (m^2)	Soil Type	Hydrologic Group
T1	35.61205	84.36145	307.5	2024.78	Decatur Silty Clay Loam	B
T2	35.61432	84.35993	291.7	18452.30	Decatur Silt Loam	B
T4	35.61098	84.35885	294.4	15257.50	Etowah Silt Loam	B

Where Lat is latitude and Long is longitude (decimal degrees), elev is elevation (meters), and drainage is the contributing drainage area (square meters).

Experimental Plot Design

Each site was outfitted with the following equipment: (1) ISCO 3700 Portable Sampler, (2) ISCO 4230 ,Bubbler Type, Flow Meter, (3) 45.75 cm (1.5 ft) TRACOM fiberglass H-Flume, and (4) 12 Volt 55-amp-hour all weather Power Sonic sealed rechargeable battery. To better direct the runoff flows into the sampling equipment, plastic berms were attached to the head of the flume and extended upslope approximately one meter. A concrete pad was poured between and behind each berm in a manner that reinforced the entry-way so that the programming maximum depth (0.1524 meter or 6 inches) could be maintained in large flows before spilling around the collection efforts. In addition to each site's standard equipment, an ISCO tipping bucket rain gauge was added to Thompson 1 (Figure 3) for precipitation measurements during the study period. All equipment was tested and calibrated prior to implementation to the field and was properly leveled and maintained throughout the study. Watershed delineation was performed using ArcGIS.

Data acquisition and runoff sampling were directly linked into the flume design. The sampling tube and bubbler line both connected directly to the flume's cast in place wells by the use of hollowed metal tubes. These tube lengths and depths are calculated based upon the flume size. The bubbler line from the ISCO 4230 Flow Meter determined water level based upon induced pressures in the still well. The sampling well is positioned opposite of the bubbler line well as a potential indicator of flume misalignment. Sampler well debris is evacuated prior to intake by the use of large bubble expulsions.

Figure 3: Typical Equipment Layout with Rain Gauge

Rainfall and Runoff Measurements and Sampling efforts

The ISCO 3700 Portable Samplers connect directly to the ISCO 4230 Flow Meters allowing for conditional programming options and data transfer. The sampling unit offers options based on sample timing, volumes, and compositing. Data collection and conditional programming options are informed by the flow meter. For the purposes of this study all collection efforts were conditionally based flow-proportional samples. Runoff was collected at even flow increments throughout a storm after the water level reached a minimum sampling tolerance. Maintenance and sample collection were performed on a weekly basis with data collection completed on a biweekly basis.

Data was collected from fall 2012 through February 2014. Originally, more farms were included in the study starting in fall 2012. Two of these farms underwent a crop transition from switchgrass to another crop. These farms did not produce any valuable data and have been omitted from this study. Thompson farm was selected in February 2013 as a potential replacement site for these farms and was installed the following month. The useful range of data is therefore April 2013 through February 2014. Data was downloaded through direct connection to the ISCO 4230 Flow Meter via ISCO Flowlink software.

Curve Number Computations

The Soil Conservation Service (SCS), now the National Resource Conservation Service (NRCS), CN method was developed to provide runoff estimates. General equations are outlined in Chapter 10 of the National Engineering Handbook (2004), as well as in many other references such as Hawkins (1985, 1993, 2009), Hjemfelt (1991), and Bosznay (1989). The relationship developed by the NRCS is as follows:

Equation (1): valid when $P>I_a$, otherwise Q = 0

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Equation (2) valid for all I_a

$$I_a = \lambda S$$

Where Q = direct storm runoff; P = rainfall depth (mm); I_a = initial abstraction; S = potential maximum storage; and λ = is an initial abstraction coefficient. All units used were in SI units of millimeters. Hawkins (1993) suggests a λ value of 0.05 may be more accurate than a λ value of 0.20 for urban land covers, however, NEH Chapter 10 (2004) maintains that a value of 0.20 is more accurate for agricultural conditions. Values of λ of 0.05 and, 0.20 were used to calculate S values throughout the study to determine which is more appropriate for usage with switchgrass in East Tennessee. ISCO samplers collected the flow and rainfall values used to calculate the CN directly. S values and CNs were calculated for each storm from the following equations:

Equation (3) valid for all λ:

$$S = \frac{2\lambda P + Q(1 - \lambda) - \sqrt{Q(1 - \lambda)^2 + 4\lambda QP}}{2\lambda^2}$$

Equation (4) valid for 0<CN<100

$$S = \frac{25400}{CN} - 254$$

Values of S (mm) were calculated for each storm (ranging from 0 to infinity) and then translated into CNs.

A second method for determining the CN is the asymptotic method Hawkins (1993). The asymptotic method involves a preliminary data treatment known as frequency matching. Frequency matching is completed by matching sorted rainfall depths with separately sorted runoff flow depths to provide depths of matching return periods as opposed to event matched values. Schneider and McCuen (2005) reiterate the importance of frequency matching under the logic that bias is reduced. The basic theory of the asymptotic method assumes that the CN will change with precipitation values until a diminished rate of returns has been reached. Hjemfelt (1991) generalizes CN behavior as inversely proportional to precipitation magnitude under standard conditions. Hawkins (1993) outlines three major asymptotic relationships that a dataset may exhibit. The first is a standard response which exhibits behavior that converges to a value as large storms are approached. The second relationship is the violent response in which CNs will steadily increase until a plateau is reached. Third is the complacent behavior relationship which does not converge or plateau as storm sizes increase. In this study, all sites exhibited standard asymptotic relationships and will use the standard asymptotic fit. The fit asymptote will then provide an equation for determining the CN of a theoretically infinite precipitation event. Using the standard asymptotic fit equation, determination of the point at which the CN ceases to decrease due to precipitation amount increases, can be completed. The general equation outlined by Hawkins (1993) is as follows:

Equation (5) valid for all CNs exhibiting standard asymptotic behavior.

$$CN(P) = CN_\infty + (100 - CN_\infty)e^{-kP}$$

Where CN(P) is the equation to fit, CN_∞ is the infinite CN value which is converged upon, k is an asymptotic shaping factor, and P is precipitation in mm.

This equation is fit by reducing the error of this equation with the frequency matched data. One notable feature of this method is that the method will typically report much lower CNs than the standard calculations Hawkins (1993) and Hoomehr et al. (2013). This lowered relationship is due to the larger storms controlling the asymptotic bases of the equations. In other words, the

lower bound of the asymptote is driven by the larger precipitation events which typically exhibit substantially lowered CNs.

Antecedent Condition

All forms of the CN methods rely on Antecedent Moisture Conditions (AMC) or the Antecedent Runoff Condition (ARC) as a reference to determining the initial abstractions and runoff potentials. NEH Chapter 10 (2004) no longer recommends the AMC method. Currently, the ARC method may be used as a surrogate to determine preceding conditions' effects on potential runoff. Many others have taken issue with the antecedent condition assumptions as well. Hawkins (1985) refers to the AMC as an "error band" or even a source of variability. Heggen (2001) considers an antecedent precipitation index to be inaccurate due, in part, to the inaccurate assumption that storms operate on a 24-hour day. Mishra and Singh (2006) conclude that current AMC criteria are unrealistic. Ponce and Hawkins (1996) state that the antecedent condition "lacks guidance". Continuing this logic, Hjemfelt (1991) reasons that AMC may be a catch all for other variables not included in the CN method. A recent study in East Tennessee showed that for East Tennessee, Curve Number antecedent conditions suggest similar runoff potential conditions and tended toward a median condition Hoomehr et al. (2013). Considering the scrutiny, all antecedent conditions are assumed to be that of the average condition (II).

RESULTS

Hydrologic Data

95 events were monitored during the study period. Of these 95 events, 30 events were captured at Thompson 1, 29 events were captured at Thompson 2, and 36 events were captured at Thompson 4. Monitored precipitation ranged from 0.25 mm to 79.76 mm with and average rainfall depth per storm of 12.46 mm (Table 2). This range is considered invaluable to this process as a large range of cumulative storm depths provides a more representative CN across a variety of storm events Schneider and McCuen (2005).

Table 2: Monitored Precipitation Data

Precipitation Summary Stats (mm)				
Stat	**All**	**Thompson 1**	**Thompson 2**	**Thompson 4**
Min	0.25	0.25	0.25	0.25
25th-Percentile	1.40	1.27	2.54	1.27
Median	5.08	1.02	6.86	5.97
75th-Percentile	13.08	10.41	12.95	19.09
Max	79.76	65.28	78.49	79.76
Mean	**12.46**	**8.96**	**12.71**	**15.19**

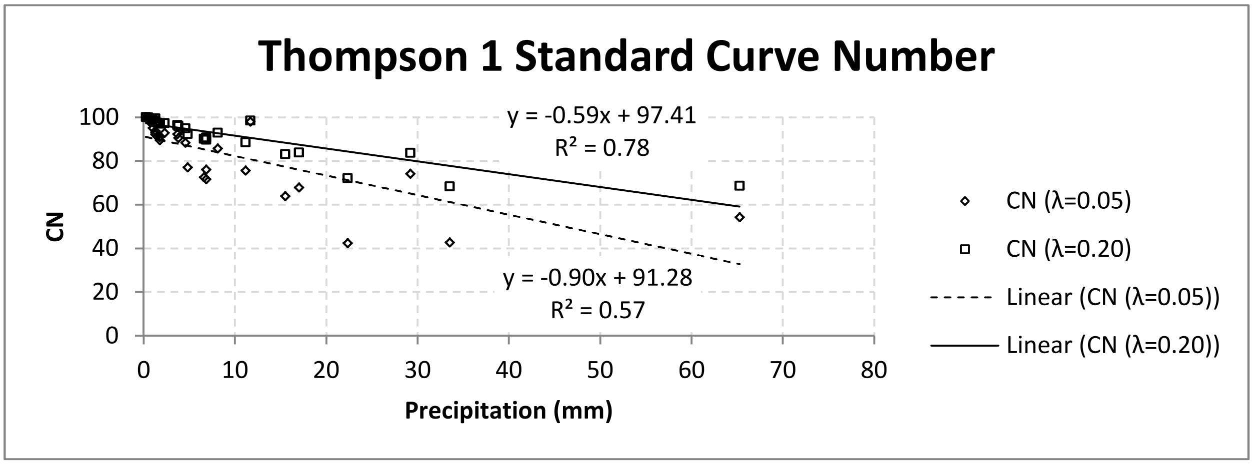
Standard Curve Number Calculation

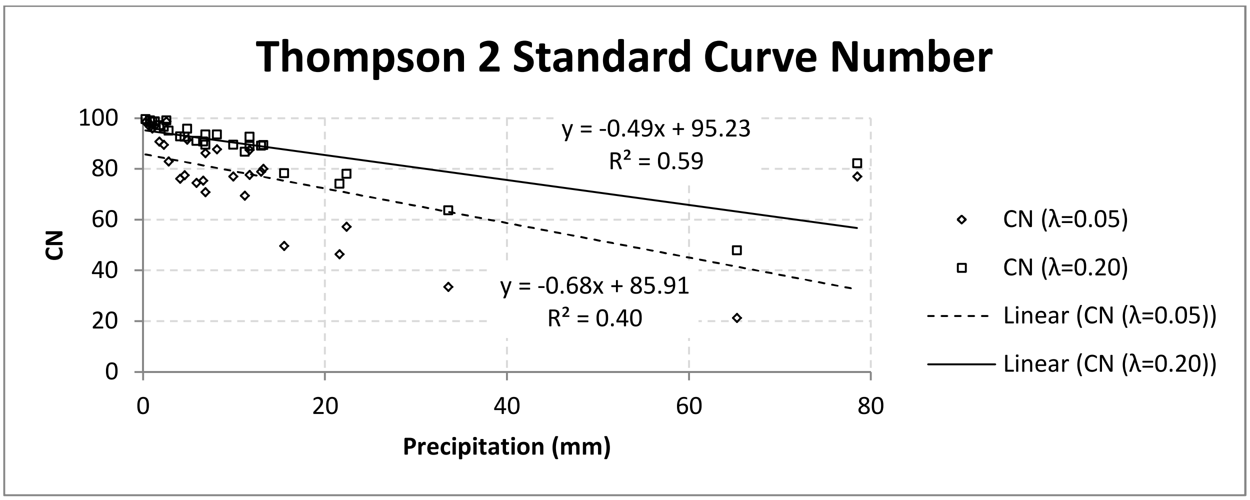
CNs were calculated from the two λ values (0.05 and 0.20) to determine the best fit λ value. Thompson 1 CNs ranged from 42 to 100 for a λ value = 0.05 with a mean CN of 83 (σ=16). Thompson 1 CNs for λ=0.20 ranged from 68 to 100 with a mean CN of 92 (σ=9). Thompson 2 CNs ranged from 21 to 99 for λ=0.05 with a mean CN of 77 (σ=19). Thompson 2 CNs for λ=0.20 ranged from 48 to 100 with a mean CN of 89 (σ=11). Thompson 4 CNs ranged from 21 to 100 for λ=0.05 with a mean CN of 75 (σ=23). Thompson 4 CNs for λ=0.20 ranged from 45 to 100 with a mean CN of 88 (σ=14). Overall, Thompson farm CN averages are 78 and 90 for λ=0.05 and 0.20, respectively. All CN results are summarized below in Table 3.

Both λ value calculations are shown for Thompson 1, 2, and 4 below in Figure 4. This figure fits each dataset to a linear trendline. Correlation (R^2 values) to the trendline is used to compare the two λ values. Thompson 1 shows the relationship to the trendline as an R^2 value of 0.78 and 0.57 for λ = 0.05 and 0.20, respectively. Thompson 2 R^2 values for λ = 0.05 and 0.20 are 0.59 and 0.40, respectively. Thompson 4 linear fit R^2 values are 0.60 and 0.38 for λ = 0.05 and 0.20, respectively.

Table 3: Curve Number Calculations: Summary Statistics

	Standard CN			Asymptotic CN		
Thompson 1	Min	42.40	68.27	**CN_INF**	**61.02**	**66.46**
	Max	99.99	99.99	K	0.10	0.04
	Mean	**83.31**	**92.17**	SSE	0.00	0.00
	STD	15.91	8.92	R^2	0.95	0.97
	λ	0.05	0.20	λ	0.05	0.20
	Standard CN			Asymptotic CN		
Thompson 2	Min	21.27	47.88	**CN_INF**	**47.24**	**66.45**
	Max	98.60	99.55	K	0.07	0.04
	Mean	**77.29**	**89.01**	SSE	0.00	0.00
	STD	19.10	11.34	R^2	0.88	0.91
	λ	0.05	0.20	λ	0.05	0.20
	Standard CN			Asymptotic CN		
Thompson 4	Min	20.53	44.91	**CN_INF**	**57.15**	**73.53**
	Max	99.84	99.90	K	0.16	0.08
	Mean	**74.84**	**87.74**	SSE	0.00	0.00
	STD	23.30	13.64	R^2	0.94	0.96
	λ	0.05	0.20	λ	0.05	0.20





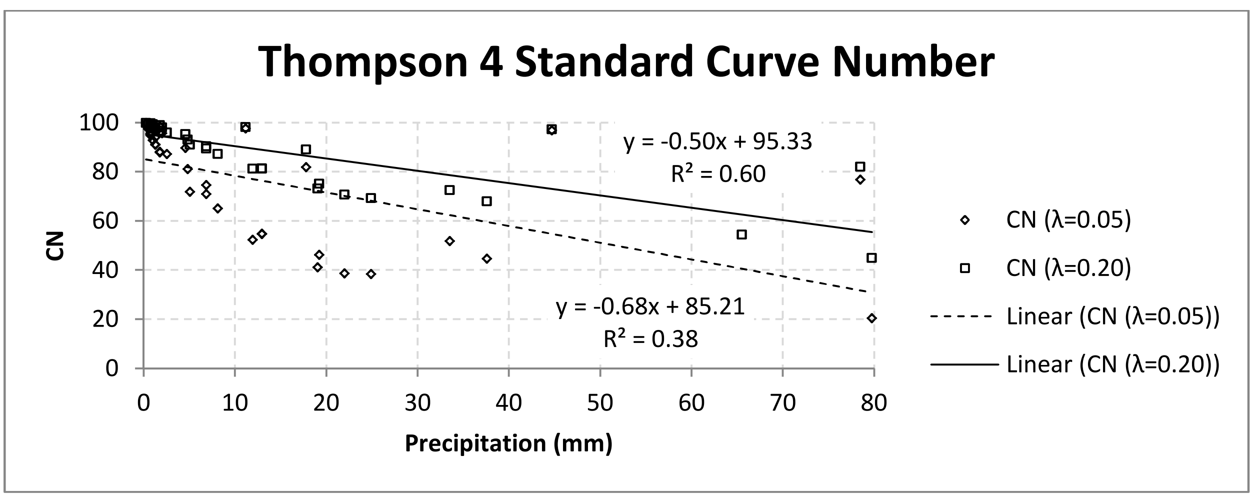
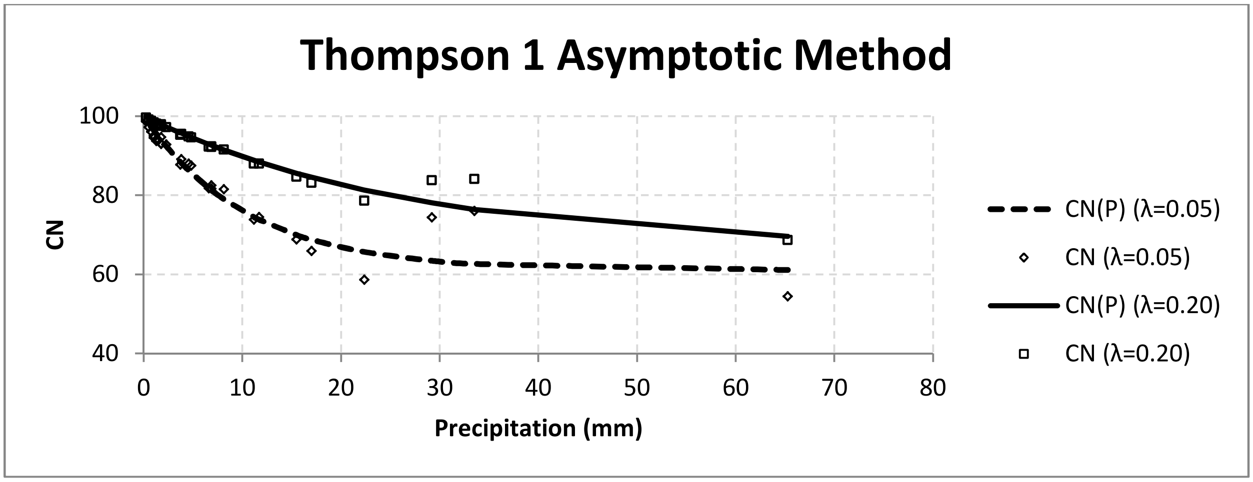
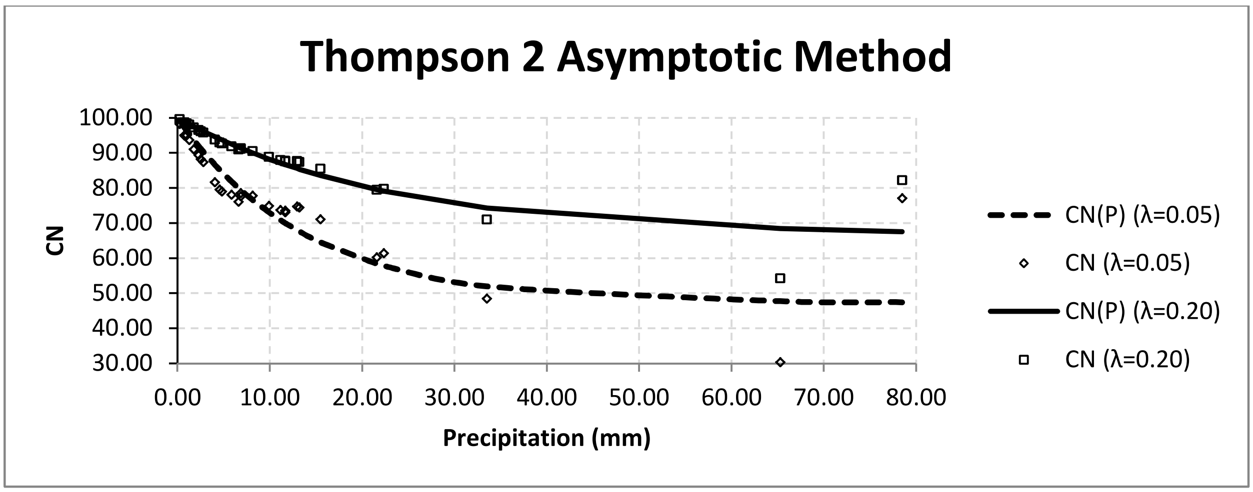


Figure 4: Standard Curve Number Plots

Asymptotic Curve Numbers

Values for the asymptotic method were determined for each site. All equations were fit by reducing the error of the standard asymptotic equation developed by Hawkins (1993) equation 5 and the frequency matched values of λ =0.05 and 0.20. Asymptotic method CNs for Thompson 1 were 61 and 66 for λ =0.05 and 0.20, respectively. Thompson 2 CN values for the asymptotic method were 47 and 66 for λ =0.05 and 0.20, respectively. Asymptotic CN values for Thompson 4 were 57 and 74 for λ =0.05 and 0.20, respectively. Correlation was determined between the CN(P) fit curve and the frequency matched CNs. Thompson 1 correlation was 0.95 and 0.97 for λ =0.05 and 0.20, respectively. Thompson 2 correlation was 0.88 and 0.91 for λ =0.05 and 0.20, respectively. Thompson 4 correlation was 0.94 and 0.96 for λ =0.05 and 0.20, respectively.





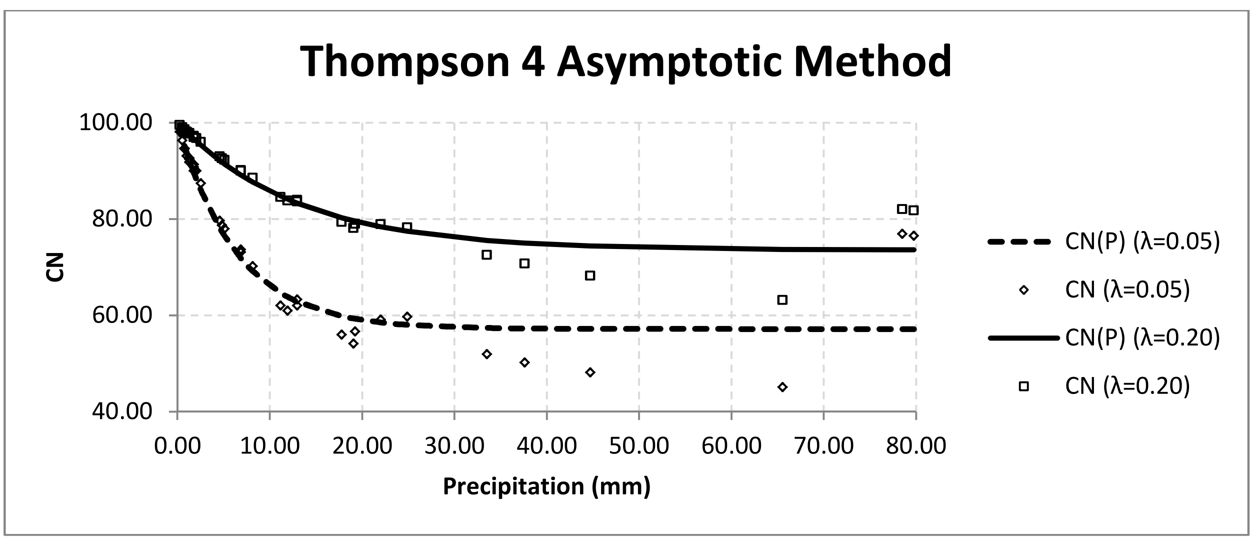


Figure 5: T1 Asymptotic Fit

DISCUSSION

Published CN values for similar crops are provided in Table 4 below from NEH chapter 9 (2004). Values for switchgrass have typically been chosen as grassland or rangeland. For example, Kiniry (2008) and Brother et al. (2001) select a CN value of 71 as a surrogate for switchgrass. The values selected for these two studies match values for grassland between the fair and poor hydrologic conditions.

Standard CN Figures show higher R^2 values for datasets fit to a line under the assumption of λ values equal to 0.20 than those equal to 0.05. Under this evidence, λ=0.20 appear more appropriate for the site. This is congruent with NEH chapter 10 which assumes λ values equal to 0.20 for agricultural lands. Standard CNs for Thompson 1, 2, and 4 are 92, 89, and 88, respectively. Standard CN calculations do not match those provided by the NEH chapter 9 (2004) (Table 4). In order to determine more accurate CNs for use in SWAT, the asymptotic method was also employed.

Asymptotic values for Thompson 1, 2, and 4 were 66, 66, and 74, respectively for λ = 0.20. Asymptotic CNs are shown to be substantially lower than those calculated by the standard method. Influences of the large events help to explain the dramatic decrease in CNs since calculated values are heavily controlled by the large storm events. Other studies, Hoomehr et al. (2013) and Hawkins (1993) show that decreases for CNs are typical for the method. The TR-55 manual, by Cronshey (1986), states that CN calculations are less accurate for smaller storms. Bonta (1997) reviews the history of the CN method and reiterates the assertion that CN method calculations are better for large storms since the original method was derived from maximum annual events based on field observations. Considering the accuracy of the asymptotic method with the published data and the evidence provided by Cronshey (1986) and Bonta (1997), values for SWAT input have been selected as those from the asymptotic method. An average of the asymptotic method CNs for λ=0.20 is calculated to be 69 (σ=3.33). Using this value as an average hydrologic condition will allow for wider application for SWAT modeling.

Seasonal averages for the CN are summarized below in Table 5. Seasonal values show the dual nature of switchgrass between growing seasons and dormant seasons. During the first growing season, spring, the added water demand reduces the CN from the values seen in the

summer and winter by infiltration and absorbance into the plant. Once the grass reached a height of about 1.5 meters, the grass was cut. A lack of canopy for evapotranspiration and a reduced water demand may attribute to the heightened CN for the summer months. The CN for fall is shown to be lowered again as the grass began its second period of growth to a height of about 3 meters into the fall. At the start of winter the grass was cut to a height of about 0.1 meter. During the winter the CN was shown to increase again due, in part, to the dormant plant nature. The cyclical nature of the grass should be considered for water quantity and quality models.

Table 4: Comparison of Published CNs

Selected CNs from NEH Chapter 9 - Hydrologic Soil Group B			
Cover Type	**Cover Description**	**Hydrologic Condition**	**CN**
Fallow	Crop residue cover (CR)	Good	83
Row Crops	Straight Row (SR)	Poor	81
Row Crops	Straight Row (SR)	Good	78
Row Crops	SR + CR	Poor	80
Pasture	grassland or rangeland	Poor	79
Pasture	grassland or rangeland	Fair	69
Pasture	grassland or rangeland	Good	61
Thompson Farm	Switchgrass	Standard	90
Thompson Farm	**Switchgrass**	**Asymptotic**	**69**

Table 5: Seasonal CN Summary

λ	Statistic	Spring	Summer	Fall	Winter
0.20	**Min**	63.61	44.91	47.88	70.74
	25th-Percentile	69.33	89.13	57.99	89.00
	Median	89.85	93.53	83.35	91.80
	75th-Percentile	97.84	97.75	98.56	97.95
	Max	99.88	99.99	99.20	99.55
	Mean	**84.59**	**91.18**	**77.83**	**90.10**
	STDEV	14.24	9.44	21.72	9.42

CONCLUSIONS

This study helps to link the SWAT modeling efforts to a reinforced CN so that a better model may be developed. Field studies were performed to determine data based CNs for switchgrass. ISCO samplers and bubblers were employed with an H flume to determine a rainfall runoff relationship for switchgrass. An average CN for switchgrass was calculated as 69 (σ=3.33) from the field data. For the purpose of SWAT modeling this study would recommend a CN of 69 for switchgrass land cover in East Tennessee.

Future field studies are needed to verify these average values for different regions of the United States and globally. Seasonal components as well as regional rainfall variability may play a large role in the rainfall runoff relationship of switchgrass. More in depth studies for the seasonal nature of switchgrass are needed to determine the impacts of switchgrass expansion on water quality.

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CHAPTER II
EROSION CROP MANAGEMENT FACTOR AND NUTRIENT EXPORT FOR SWITCHGRASS LAND COVER IN EAST TENNESSEE

A version of this chapter is planned to be published by Jordan A. Hayes, John S. Schwartz, Daniel C. Yoder, and Jon M. Hathaway in the *Transactions of the American Society of Agricultural and Biological Engineers* (ASABE). Co-authors, formed by the thesis committee, consisted of John S. Schwartz Ph.D., PE, Associate Professor in the Civil and Environmental Engineering Department at the University of Tennessee, Daniel C. Yoder Ph.D., Professor in the Biosystems Engineering and Soil Sciences Department at the University of Tennessee, and Jon M. Hathaway Ph.D., PE, Assistant Professor in the Civil and Environmental Engineering Department at the University of Tennessee.

Erosion Crop Management Factor and Nutrient Export for Switchgrass Land Cover in East Tennessee

Jordan A. Hayes; John S. Schwartz; Daniel C. Yoder; Jon M. Hathaway

ABSTRACT

A new biofuel refinery in Vonore, TN has created a demand for converting conventional crops to switchgrass in East Tennessee. The Soil and Water Assessment Tool (SWAT) was used to determine the water quality impacts derived from this conversion. The Revised Unified Soil Loss Equation (RUSLE) was used to determine the erosion reduction potential of converting traditional crops to switchgrass. SWAT models use the RUSLE cropping factor (C) to determine sediment export loads from a given crop. A RUSLE C factor for switchgrass in East Tennessee determined from field studies was necessary for proper erosion calibrations within SWAT. A C factor for switchgrass was determined by back calculating the RUSLE factors. A C factor was switchgrass was determined to be 0.0006, which is slightly lower than most published values, but provides only marginally better erosion protection than traditional grasses. Field collected nutrient export data was also needed to verify the output ranges for switchgrass nutrient export simulations. Total phosphorus and total nitrogen were selected as indicators of nutrient export for switchgrass in the study. Total phosphorus was collected on the range of 0.11 g/Ha to 400 g/Ha with an average load of 125 g/Ha. Total nitrogen was calculated on the range of 7.01E-4 g/Ha to 1519 g/Ha with a mean load of 358 g/Ha. Both values were shown to be within the typical ranges produced for switchgrass conversion in simulations.

INTRODUCTION

Erosion affects the environment in a large number of ways. Erosion due to water processes has become a large environmental problem Fernandez et al. (2003). The Environmental Protection Agency (EPA) created the Pollution Control Act (1972) to combat pollution effects on the general populace. Many aspects of acts such as the Pollution Control Act (1972) focused on point source pollution as a major contributor to environmental pollution. Nonpoint source pollution was later emphasized as a potential threat to the environment. Lee et al. (2003) and Blanco-Canqui et al. (2004) define sediment, nitrogen, and phosphorus as major nonpoint pollutants even today. Cruse and Herndl (2009) suggest climate change as a potential threat to typical erosion control practices, accordingly, it is suggested that perennial grasses be used to combat soil and water resource loss. Blanco-Canqui (2010) determines that perennial grasses lack substantial environmental impact studies. Furthermore, Blanco-Canqui (2004) concludes that switchgrass reduced sediment export by up to 91% when compared to typical plowed plots.

Modeling efforts have begun to produce nutrient and sediment exports due to crop rotations. One example for modeling water quality and quantity is the Soil and Water Assessment Tool (SWAT) which daily values to simulate hydraulic and hydrologic processes associated with modeled watersheds Neitsch et al. (2002). SWAT uses the Revised Universal Soil Loss Equation (RUSLE) to determine erosion rates from a given watershed. The cropping management factor of RUSLE, the RUSLE C factor, relates erosion potential to a specific crop. Field studies are needed to better calibrate model inputs for switchgrass Rachman et al. (2008). Calibration has proven to increase Nash-Sutcliffe simulation efficiencies from 0.60 to 0.89 in some cases Sahu (2010). Furthermore, Khanal et al. (2013) concludes that switchgrass cropping management factors are not widely available even within large agency inventories such as the National Resources Inventory.

This study focused on determining a key erosion parameter for switchgrass, the RUSLE C factor. Determining this factor will allow more accurate measurements of sediment losses from fields converted to switchgrass. The objectives of the study were to 1) estimate the RUSLE C factor for switchgrass in East Tennessee from field measurements as an input to the SWAT

model, 2) summarize existing C factors relevant to switchgrass as a means to compare with the field measurements, 3) verify nutrient export simulations by comparison to field measurements.

MATERIALS AND METHODS

Study Area

The study site, Thompson Farm, is located in Monroe County in East Tennessee (Figure 6). Thompson farm experiences an average rainfall of 129 cm (50.8 in) per year NOAA (2014). Thompson farm consists mostly of Decatur Silty Clay Loams and Decatur Silt Loams with some Dewey Silty Clay Loams and Etowah Silt Loams within the study area (Figure 7) USDA NRCS Web Soil Survey (2013).

Four sites were installed on Thompson farm and numbered according to installation order. Thompson 3 was removed due to wildlife intrusion. Thompson 1, 2, and 4 are summarized in Table 6.

Table 6: Topographic Site Summary

Site	Lat	Long	Elev (ft)	L (ft)	S (°)	Soil Type	Hydrologic Group
T1	35.61205	84.36145	1009	211	5.06	Decatur Silty Clay Loam	B
T2	35.61432	84.35993	957	556	3.73	Decatur Silt Loam	B
T4	35.61098	84.35885	966	323	3.61	Etowah Silt Loam	B

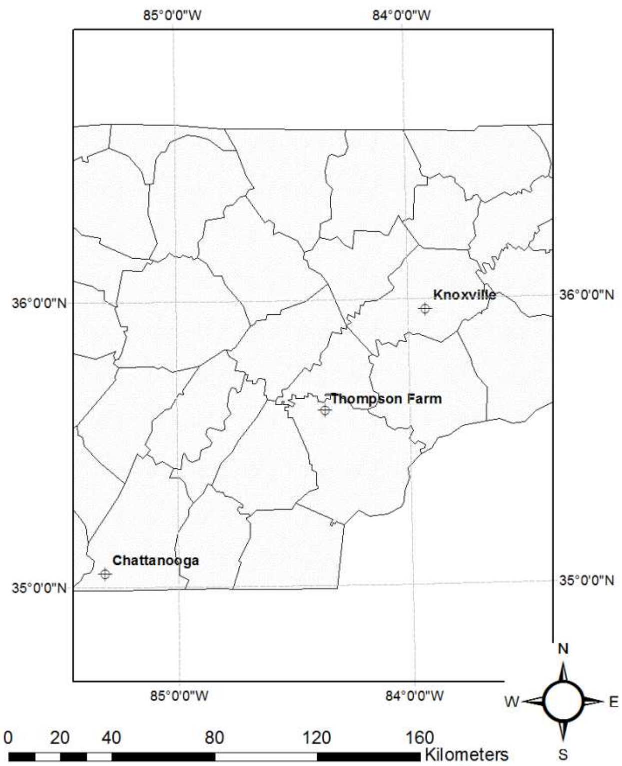

Figure 6: Thompson Farm State Location Map

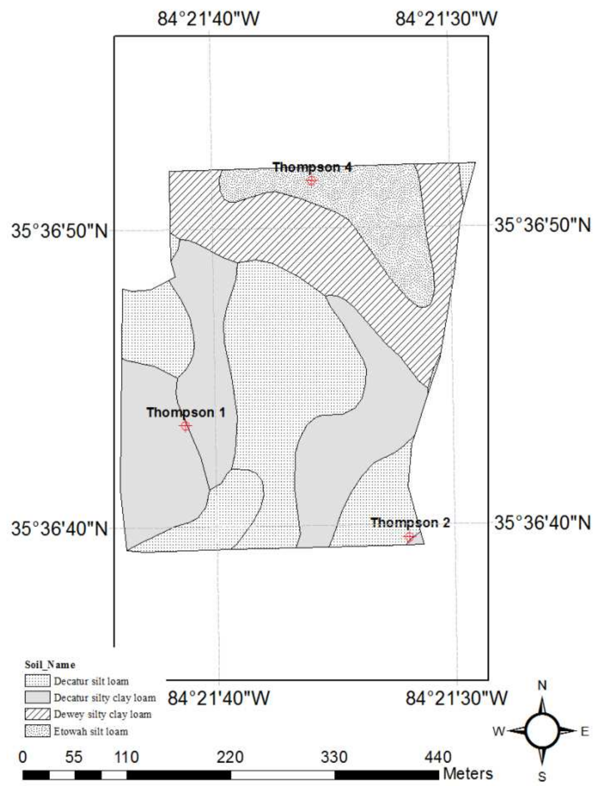

Figure 7: Thompson Farm Soil Distribution

Experimental Plot Design

Thompson 2 and 4 were outfitted with the following equipment: (1) ISCO 3700 Portable Sampler, (2) ISCO 4230 Flow Meter, (3) 45.75 cm (1.5 ft) TRACOM fiberglass H-Flume, and (4) 12 Volt 55-amp-hour all weather Power Sonic sealed rechargeable battery (Figure 8). Thompson 1 was setup with the same equipment as well as the addition of an ISCO tipping bucket rain gauge for all rainfall data collection. Plastic berms and a concrete pad were added to each site’s H-flume so that 0.1524 meter (6 inches) of runoff could be maintained during storm flows. Laboratory testing and calibration was performed on all equipment prior to implementation into the field.

An ISCO 3700 auto sampler and an ISCO 4230 bubbler type flow meter connected directly to each H-flume allowing for conditional sampling as well as simultaneous data collection. The

ISCO 4230 bubbler type flow meter provided runoff depths from hydrostatic pressure. Large bubble expulsion allow for debris clearing prior to sampling.

Figure 8: Typical Equipment Layout for Thompson 2 and 4

Rainfall and Runoff Measurements and Sampling efforts

The ISCO flow meter allowed for flow weighted sampling. Samples were collected at uniform flow increments once a minimum stage tolerance was maintained. Weekly routines included maintenance and sample collection. Data collection and processing was completed bi-weekly through ISCO Flowlink software and Microsoft Excel.

Thompson farm was selected for study in February 2013 and installed in March 2013. Data was collected from April 2013 to March 2014. 10 events were captured for sediment transportation and RUSLE C factor determination. 12 events were captured for nutrient export analysis in terms of total nitrogen and total phosphorus.

RUSLE Factors

The RUSLE equation is used to determine erosion rates from a given slope. RUSLE consists of 6 factors used to determine the annual sediment load. Factors are compared to the unit plot

condition, a worst case scenario erosion plot that is 22.1 m long, has a 9% slope, and is continuously tilled so that no vegetation may grow.

Equation 6: RUSLE

$$A = R * K * L * S * P * C$$

Where A is the annual erosion load ($kg*m^{-2}$); R is the rainfall erosivity factor ($MJ*mm*Ha^{-1}*hr^{-1}$); K is the soil erodibility factor; L is the slope length factor; S is the slope steepness factor; P is the practice factor; and C is the cropping management factor Agricultural Handbook (AH) 703 (1997).

The R-factor is comprised of two major components. The first component is the energy (E) of a given event. Total storm energy is calculated empirically from average storm raindrop diameter and falling velocity by the following equations outlined in AH 703 (1997):

Equation 7: Kinetic Energy Calculations

$$e_m = 0.119 + 0.0873 * \log_{10}(i_m) \ for\ all\ i_m \leq 76 \frac{mm}{hr}$$

$$e_m = 0.283\ for\ all\ i_m > 76 \frac{mm}{hr}$$

Where e_m is the kinetic energy per event with units of megajoule per hectare per millimeter of rainfall ($MJ*ha^{-1}*mm^{-1}$) and i_m is the storm intensity in millimeters per hour ($mm*hr^{-1}$). The second component of the R-factor is the maximum 30 minute storm intensity (I_{30}). These two components are then multiplied to calculate the total R-factor for one event Renard et al. (1997); Brown and Foster (1987); Renard and Freimund (1993).

K factors were determined from USDA NRCS Web Soil Survey (2013) soil properties and mapped to their respective soils using a method outlined by Yitatew et al. (1999) in ArcGIS (Figure 9). Values for sites were then determined by area weights of contributing soil areas Renard et al. (1997).

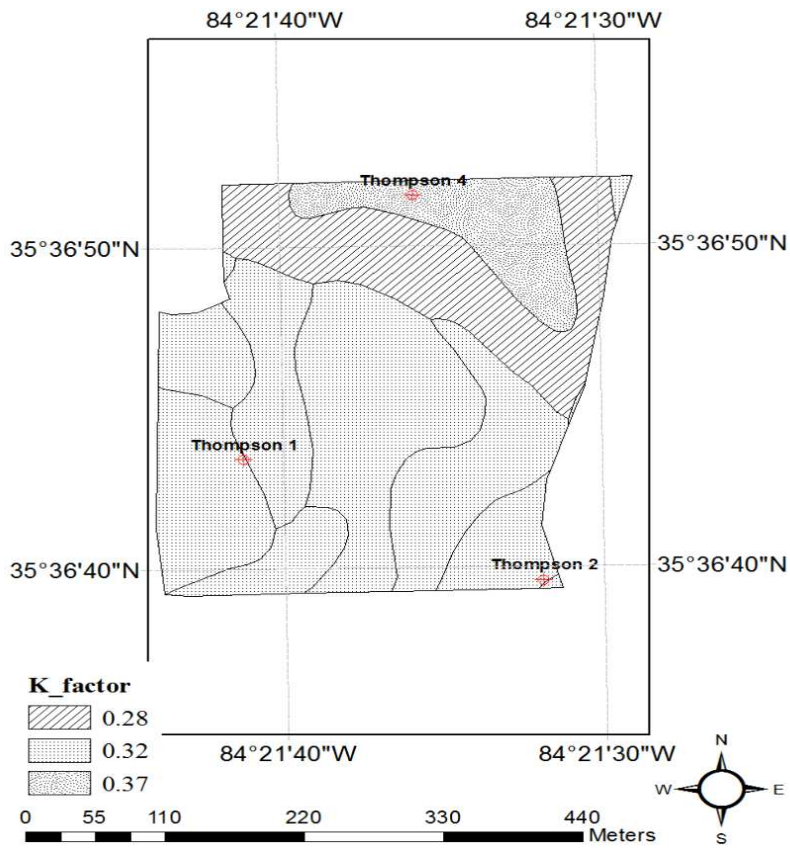

Figure 9: K Factors of Thompson Farm

The L factor was determined from the following equations outlined in AH 703 (1997):

Equation 8: L-factor Determination

$$L = \left(\frac{\lambda}{72.6}\right)^m$$

Equation 9: Slope Length Exponent (m) Calculation

$$m = \frac{\beta}{(1+\beta)}$$

Equation 10: Ratio (β) of rill to interrill conditions

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

Where L is the length factor, λ is the horizontal projection of the slope length (ft), m is the slope length exponent, β is the ratio of rill to interrill conditions, and θ is the slope angle.

Equation 11: Deposition to Erosion Ratio

$$Slope\ Ratio = \frac{Final\ Segment\ Slope}{Deposition\ Slope}$$

Equation 12: Deposition length calculation

$$L_{Dep\ end} = L_{Dep\ begin} + (1 - slope\ ratio) * (L_{total} - L_{Dep\ end})$$

Total deposition length subtracted from the total length yields total erosion length. Length factors are calculated from the erosion lengths.

The slope steepness factor is derived from the angle of the slope and compared to unit plot slopes by the following methods outlined in AH 703 (1997):

Equation 13: Murphree Mutchler fit for slopes below 9%

$$S = 10.8 * \sin(\theta) + 0.03$$

Equation 14: Normalized Lacrosse fit for slopes equal or greater than 9%

$$S = 16.8 * \sin(\theta) - 0.50$$

Length and slope calculations were determined using a Trimble 3600 total station and a 300ft engineer's tape.

For the purposes of this study the P will be simplified and designated as equal to 1.

Sediment loads were collected by the ISCO monitoring equipment outlined above on a flow weighted basis throughout each monitored storm event. After each storm event, the samples were collected and returned to the lab. Samples were then analyzed for total suspended solids (TSS)

according to EPA ESS method 340.2 (1993). Event mean concentrations of TSS were utilized as equivalent event based A values. Total flow during the storm is multiplied by the sediment (TSS) per flow volume to achieve a total sediment load (g/Ha).

Crop management factors were back calculated from the RUSLE equation. EI_{30} values and A values are summed across all events to provide an annual C factor. The value is then calculated by dividing the Annual A value by the product of the summed EI_{30} factor and the determined K, L, S, and P factors. Calculated C factors are then used as input for SWAT modeling of switchgrass in East Tennessee.

Nutrient Analyses

Total phosphorus and total nitrogen were also analyzed. Samples were preserved by adding 1 mL nitric acid for each 500mL of sample to achieve a pH of 2, fixing nitrogen and phosphorus concentrations. Samples were collected from study locations after each storm and transported back to the lab where they were then stored under refrigeration (5°C).

Total phosphorus and total nitrogen analyses were completed using Hach testing kits. Total phosphorus tests were completed using the US EPA Method 8190: PhosVer3 with acid persulfate digestion method. The combination of Hach digesters and reagents convert orthophosphates to molybdate complexes and then into blue colors. The results for total phosphorus are then determined by measurements at 880nm with the use of a spectrophotometer. Total nitrogen tests were completed under the guidance of US EPA method 10071. Under this method nitrogen is converted to nitrate and then reacts with chromotropic acid to form a yellow complex. The results for total nitrogen are then determined by measurements at 410nm with the use of a ThermoSpectronic 20D+ spectrophotometer. Determined concentrations are then converted into total nutrient loads (g/Ha).

RESULTS

C Factor

Ten rainfall events were monitored for sediment transport. From these 10 events, the annual C factor was calculated as 0.0006. RUSLE factors determined for calculation of the C factor are summarized below in Table 7.

Table 7: RUSLE Factor Summary

Site	Storm Date	Duration	P	Q	E*I30	K	LS	A
Thompson 1	04/11/2013	9.25	29.21	5.49	54.90	0.32	1.59	7.71E-03
	01/02/2014	10.25	12.95	0.84	18.33	0.32	1.59	1.23E-02
	2/4/2014	10.25	3.70	0.30	2.10	0.32	1.59	5.72E-03
Thompson 2	4/19/2013	7.00	33.53	0.13	3.61	0.32	2.44	7.21E-06
	4/27/2013	41.50	82.30	13.21	8.21	0.32	2.44	4.63E-04
	7/6/2013	32.75	82.04	0.00	23.64	0.32	2.44	3.97E-09
	12/6/2013	23.00	46.74	72.36	6.77	0.32	2.44	1.49E-02
	1/5/2014	5.00	5.84	0.02	0.18	0.32	2.44	3.13E-04
	2/2/2014	78.00	25.70	0.18	0.67	0.32	2.44	3.21E-03
Thompson 4	06/01/2013	23.25	78.49	36.88	10.43	0.37	1.33	4.25E-03
All	**C Factor**	**6.16E-04**						

Where duration is total storm duration (HH.hh); P is total storm precipitation (mm); Q is total storm flow (mm); EI_{30} is the R factor ($MJ*mm*ha^{-1}*hr^{-1}$); K is the soil erodibility factor; LS is the topographic factor; and A is the sediment yield ($kg*m^{-2}$)

Total Nitrogen and Total Phosphorus

Nutrient values ranged from 0.108 mg/L to 8.930 mg/L for total phosphorus with a mean of 8.930 mg/L (σ=1.529). Total nitrogen ranged from 0.159 mg/L to 18.635 mg/L with a mean value of 5.889 (σ=3.681). Bar graphs for each site are shown in Figure 10 below.

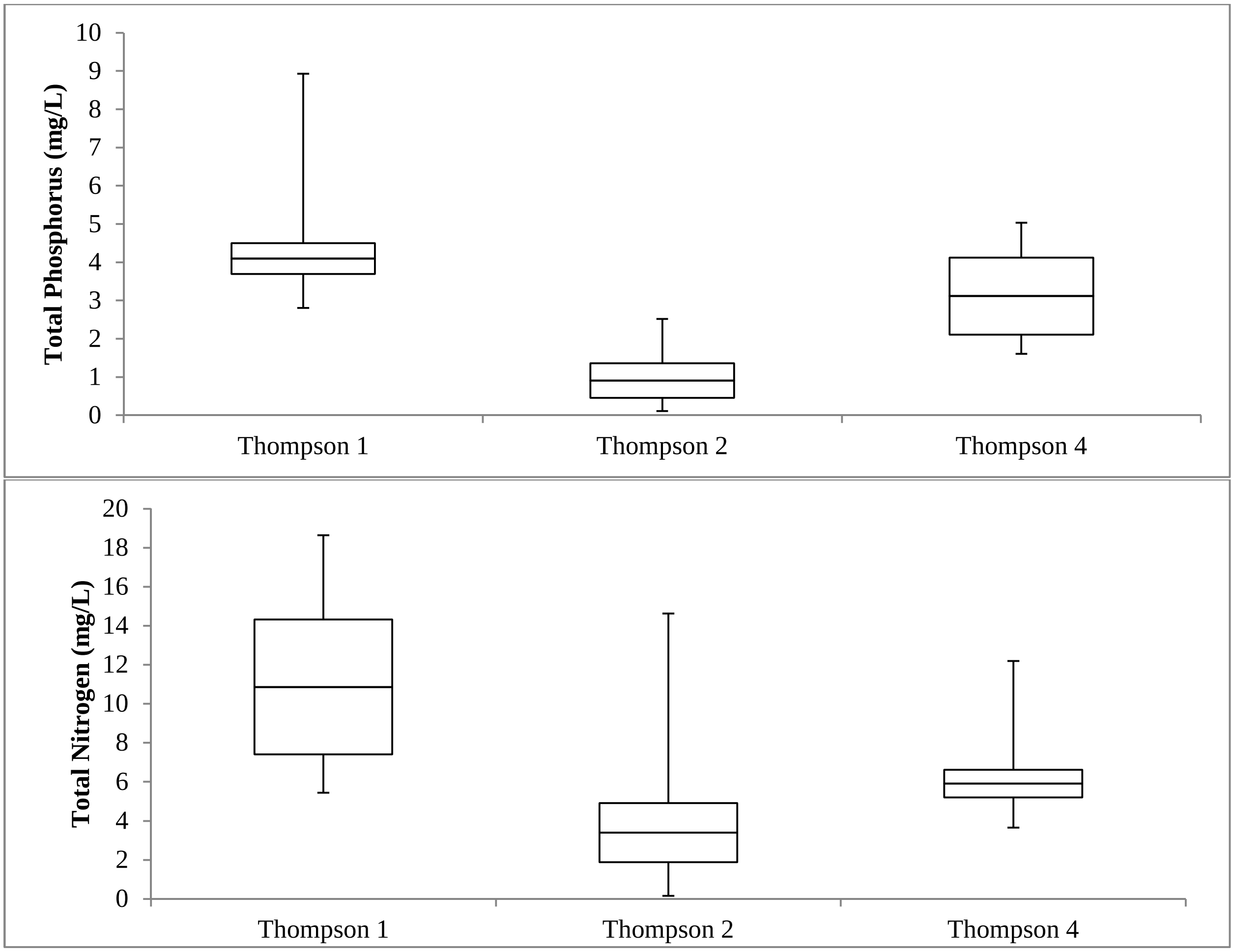

Figure 10: Nutrient Export Summaries

DISCUSSION

A C factor of 0.0006 was calculated for use as SWAT input. Comparing these values to published values (Table 9) provides understanding into the meaning of the calculated value. When comparing the published values with the calculated values it is important to understand the significance of the C factor. At first glance it may appear that a difference in C factor between 0.04 and 0.0006 is a significant change in erosion prevention. Both values, however, are compared to erosion reduction from the unit plot condition AH 703 (1997). A C factor of 0.04 is equivalent to a reduction in erosion of 96% from the unit plot condition, whereas the C factor of 0.0006 is a reduction in erosion of 99.94%. When comparing the two values in terms of

improvement over unit plot conditions a more reasonable relationship becomes apparent. Selection of C factors between typical grasslands and switchgrass provide very little overall change in erosion prevention.

Switchgrass provides an erosion reduction of drastic proportions. The major source of erosion protection is the canopy of the switchgrass. Trocsanyi et al. (2008) indicates that during the summer light penetration may be reduced by up to 95%. Rainfall impact plays a major role in initial sediment motion Kinnell (2005); Hairsine and Rose (1991). Sharma et al. (1995) even indicates that "interrill erosion is detachment limited". With such a dense canopy it is evident that the influence of rainfall impact is severely reduced. The other major driver in sediment transport is overland flow Kinnell (2005). Switchgrass has a very deep and extensive root system that infiltrates large amounts of runoff Kort et al. (1998) as well as Mclaughlin and Walsh (1997). Switchgrass has the ability to further reduce erosion by breaking up overland flow Meyer et al. (2001). The ability to reduce the impacts of rainfall runoff provides support for switchgrass as an ideal crop for water quality improvement.

Nutrient export is another metric for determining the water quality improvement potential of switchgrass. Total phosphorus and total nitrogen were analyzed to determine key nutrient export relationships and are summarized below in Table 10. Total phosphorus loads ranged from 0.11 g/Ha to 400 g/Ha with a mean load of 125 g/Ha. Total nitrogen loads ranged from $7.01*10^{-4}$ g/Ha to 1519 g/Ha with a mean load of 358 g/Ha. Lee et al. (2003) directly compares the improved water quality potential of switchgrass by comparing nutrient export from a control site as well as on a switchgrass plot. Values were shown to drastically improve nutrient runoff between the control site and the site cropped with switchgrass Lee et al. (2003). Lee et al. (2000) provides simulation results for switchgrass plots compared with control sites. All studies showed an improvement in nutrient export with the switchgrass plots when contrasted against the control sites. Values obtained in the study reinforce the simulation outputs and field measurements. Nutrient analyses indicate Thompson farm switchgrass nutrient output fall within the range provided for the control plot and the switchgrass plot. Thompson farm matches the simulation output from Lee et al. (2000) providing evidence that simulation output accurately models nutrient export from switchgrass plots, especially in regard to the improvement of water quality under the shift to switchgrass land cover.

Table 8: C Factor Publication Comparison

Summary Table for C Factors					
Source	**Location**	**Crop**	**Min**	**Max**	**Mean**
USDA NRCS Ohio 2000	Ohio	permanent pasture	0.0010	0.1640	0.0402
Bolstad et al. - 2008	Carolinas	pasture	--	--	0.0050
		forest	--	--	0.0030
GaSWCC - 1995	Georgia	corn	--	--	0.0700
		corn and small grain	--	--	0.0400
		undisturbed forest	0.0001	0.0090	0.0030
Orange Grove Energy 2008	California	native grasses	--	--	0.0300
Fernandez et al. - 2003	Idaho	forest	--	--	0.0010
		grass	--	--	0.0030
Doucet-Beer et al. 2011	Minnesota	grassland	--	--	0.0050
Cruse and Herndl 2009	Iowa	Switchgrass	--	--	0.0200
LAWAL et al. 2004	Benin, Africa	Alamo Switchgrass	--	--	0.0040
Thompson Farm	**Tennessee**	**Switchgrass**	**--**	**--**	**0.0006**

Table 9: Nutrient Export Publication Comparison

		TP (g/Ha)			TN (g/Ha)		
Source	**Crop**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Lee et al. 2003	none	84.00	726.00	363.00	105.00	2453.00	951.17
Lee et al. 2003	switchgrass	22.00	160.00	73.17	30.00	872.00	262.67
Lee et al. 2000	none-a	--	--	100.00	--	--	820.00
Lee et al. 2000	switchgrass-a	--	--	50.00	--	--	520.00
Lee et al. 2000	none-b	--	--	420.00	--	--	2270.00
Lee et al. 2000	switchgrass-b	--	--	190.00	--	--	1380.00
Nyakatawa et al. 2006	switchgrass	--	--	2100.00	--	--	--
Thompson	**switchgrass**	**0.11**	**400.57**	**124.92**	**0.00**	**1518.64**	**357.99**

Where a denotes a simulation for a 2hr storm at an intensity of 25mm/hr and b denotes a simulation for a 1hr storm at an intensity of 69mm/hr.

CONCLUSIONS

Field testing was needed to calibrate SWAT models for East Tennessee. Switchgrass was chosen for a biofuel rotation model within SWAT. Two relationships were monitored for this study. The first relationship to be determined was the erosion potential associated with switchgrass. RUSLE was employed to back calculate the C factor associated with switchgrass in East Tennessee as an input to SWAT. The C factor for switchgrass in East Tennessee was calculated to be 0.0006. This C factor represents an improvement in erosion prevention compared to the unit plot condition of 99.94%. Furthermore, water quality is improved in regards to nutrient export when comparing switchgrass to traditional crops. The second relationship to be explored was the typical range of nutrient export for total phosphorus and total nitrogen from switchgrass plots. Expected loads for total phosphorus and nitrogen range from 0.11 g/Ha to 400 g/Ha and from $7.01*10^{-4}$ g/Ha to 1519 g/Ha, respectively. This range is substantially lower than that seen in traditional crops. Sanderson et al. (1996) estimates nutrient export values of 60,000 g/Ha and 135,000 g/Ha for total phosphorus and total nitrogen, respectively.

In general, percent area of contribution of switchgrass land cover is directly proportional to water quality. Erosion is reduced in comparison to the unit plot condition as well as other traditional crops. Nutrient export is also reduced by the increase of switchgrass percent area. Further field studies may be needed to determine the applicability of the calculated C factor and nutrient export ranges to other regions.

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CONCLUSION

Energy concerns globally have spurred a large interest in the biofuel movement. It is important to understand the benefits and tradeoffs due to switchgrass conversion. Regional Models such as BLOSM Parish et al. (2012) allow a more holistic understanding of these burgeoning new fuel sources by balancing the transportation needs, the environmental needs, and the feasibility of the issue. Water quantity and water quality play a large role in the biofuel movement. Blanco-Canqui and others (2004) present the argument that unseen pollution is taking place every day with non-point source pollutants such as Nitrogen and Phosphorus. The NRCS CN method was used to determine the rainfall-runoff relationship of switchgrass for input to SWAT. Erosion predictions and nutrient export ranges were chosen to determine water quality effects associated with switchgrass conversions in SWAT.

Runoff potential, erosion potential, and nutrient export have all been analyzed so that a better understanding of switchgrass may be presented to SWAT modeling. Using the asymptotic curve number method a CN for switchgrass in East Tennessee was calculated to be 69. The C factor for switchgrass in East Tennessee has been determined as C = 0.0006. Nutrient export ranges were analyzed to determine the accuracy of nutrient export models associated with switchgrass. These ranges fell within the values presented between traditional crops and those shown for switchgrass. Switchgrass presents an ideal land cover that balances the needs of the energy movement, the increase in water quality, and the decrease in agricultural runoff.

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APPENDIX

Table 10: Curve Number Dataset

	Site	Storm Date	Rainfall Duration (HH.hh)	I30 (mm/hr)	Rainfall Depth (mm)	Flow Depth (mm)	CN (λ=0.05)	CN (λ=0.20)
1	Thompson 1	04/11/2013	9.25	19.30	29.21	5.49	74.37	83.80
2	Thompson 1	04/14/2013	4.00	2.03	1.27	0.01	93.69	98.00
3	Thompson 1	04/17/2013	3.75	1.02	0.51	0.26	99.84	99.88
4	Thompson 1	04/19/2013	8.00	41.66	33.53	0.77	42.79	68.27
5	Thompson 1	04/24/2013	4.75	9.14	3.81	0.21	90.56	95.89
6	Thompson 1	06/10/2013	6.75	1.02	0.25	0.23	99.99	99.99
7	Thompson 1	06/18/2013	11.25	29.46	22.35	0.07	42.40	72.14
8	Thompson 1	06/23/2013	2.25	5.08	1.52	0.01	91.55	97.44
9	Thompson 1	06/24/2013	2.25	4.06	1.02	0.01	95.02	98.41
10	Thompson 1	06/25/2013	1.25	4.06	1.27	0.00	92.17	97.75
11	Thompson 1	06/26/2013	2.00	5.08	1.27	0.01	93.01	97.88
12	Thompson 1	06/27/2013	1.50	7.11	1.78	0.00	89.47	96.89
13	Thompson 1	06/28/2013	2.75	4.06	1.78	0.01	91.00	97.15
14	Thompson 1	06/30/2013	17.00	47.75	17.02	0.93	67.95	83.84
15	Thompson 1	07/02/2013	11.75	16.26	8.13	0.76	85.84	92.89
16	Thompson 1	07/21/2013	2.50	26.42	6.86	0.03	71.67	89.66
17	Thompson 1	07/22/2013	1.25	19.30	4.83	0.01	77.04	92.25
18	Thompson 1	07/27/2013	2.00	14.22	4.57	0.23	88.37	94.97
19	Thompson 1	07/31/2013	2.50	3.05	1.78	0.01	91.08	97.16
20	Thompson 1	08/07/2013	7.75	36.58	15.49	0.46	63.99	83.05
21	Thompson 1	08/08/2013	3.25	2.03	1.02	0.15	98.56	99.24
22	Thompson 1	08/09/2013	2.00	2.03	0.76	0.03	97.57	99.06
23	Thompson 1	08/10/2013	2.50	11.18	6.86	0.10	76.03	90.70
24	Thompson 1	08/11/2013	1.00	26.42	6.60	0.03	72.61	90.05
25	Thompson 1	08/12/2013	11.00	2.03	1.27	0.44	99.23	99.48
26	Thompson 1	08/17/2013	5.00	13.21	11.18	0.57	75.69	88.56
27	Thompson 1	08/21/2013	17.50	7.11	2.29	0.08	92.83	97.19
28	Thompson 1	09/21/2013	26.75	55.88	65.28	11.20	54.48	68.65
29	Thompson 1	12/14/2013	5.25	7.11	11.68	7.96	98.07	98.45
30	Thompson 1	02/04/2014	10.25	4.40	3.70	0.30	92.37	96.44
31	Thompson 2	04/19/2013	7.00	1.40	33.53	0.13	33.46	63.61
32	Thompson 2	06/01/2013	23.25	1.71	78.49	37.12	77.05	82.16
33	Thompson 2	06/05/2013	23.75	0.19	8.13	0.96	87.69	93.53
34	Thompson 2	06/07/2013	1.50	0.32	2.79	0.00	82.93	94.95
35	Thompson 2	06/09/2013	9.50	1.27	9.91	0.45	76.94	89.45

Table 10. Continued.

	Site	Storm Date	Rainfall Duration (HH.hh)	I30 (mm/hr)	Rainfall Depth (mm)	Flow Depth (mm)	CN (λ=0.05)	CN (λ=0.20)
36	Thompson 2	06/18/2013	13.75	1.84	22.35	0.81	57.15	78.01
37	Thompson 2	06/25/2013	26.25	0.32	2.54	0.93	98.60	99.04
38	Thompson 2	07/02/2013	1.75	1.02	4.06	0.00	76.03	92.64
39	Thompson 2	07/03/2013	36.05	1.27	21.59	0.16	46.30	74.07
40	Thompson 2	07/13/2013	17.75	2.67	13.21	1.38	80.07	89.38
41	Thompson 2	07/21/2013	14.50	1.65	6.86	0.51	86.20	93.44
42	Thompson 2	07/22/2013	16.28	1.07	4.83	0.49	91.49	95.78
43	Thompson 2	07/27/2013	2.75	0.89	4.57	0.01	77.50	92.53
44	Thompson 2	07/31/2013	5.25	0.19	1.78	0.01	90.74	97.10
45	Thompson 2	08/07/2013	8.50	2.29	15.49	0.03	49.55	78.22
46	Thompson 2	08/08/2013	5.25	0.13	1.02	0.02	95.85	98.56
47	Thompson 2	08/09/2013	4.00	0.13	0.76	0.01	96.48	98.85
48	Thompson 2	08/10/2013	4.50	0.89	6.86	0.02	70.73	89.44
49	Thompson 2	08/11/2013	6.50	1.65	6.60	0.07	75.36	90.69
50	Thompson 2	08/12/2013	14.00	0.19	1.27	0.08	96.89	98.65
51	Thompson 2	08/17/2013	18.50	1.08	11.18	0.26	69.38	86.65
52	Thompson 2	08/21/2013	9.00	0.44	2.29	0.02	89.41	96.49
53	Thompson 2	09/21/2013	27.00	3.49	65.28	0.35	21.27	47.88
54	Thompson 2	12/05/2013	1.50	0.06	0.25	0.00	98.36	99.55
55	Thompson 2	12/09/2013	11.50	0.64	11.68	2.09	87.40	92.61
56	Thompson 2	12/14/2013	5.75	0.83	11.68	0.79	77.62	88.99
57	Thompson 2	12/22/2013	7.75	0.06	0.76	0.03	97.59	99.07
58	Thompson 2	01/02/2014	10.00	0.57	12.95	1.18	78.94	89.04
59	Thompson 2	01/05/2014	5.00	0.64	5.84	0.02	74.46	90.98
60	Thompson 4	04/19/2013	6.50	2.03	33.53	1.84	51.88	72.50
61	Thompson 4	04/27/2013	19.00	0.89	37.59	1.42	44.65	68.04
62	Thompson 4	04/28/2013	14.50	1.33	44.70	37.41	96.89	97.37
63	Thompson 4	05/02/2013	1.00	0.13	0.76	0.00	94.80	98.59
64	Thompson 4	06/01/2013	23.25	1.71	78.49	36.88	76.86	82.03
65	Thompson 4	06/05/2013	23.50	0.19	8.13	0.01	65.17	87.25
66	Thompson 4	06/09/2013	3.00	2.22	19.05	0.00	41.17	73.21
67	Thompson 4	06/16/2013	7.75	0.19	1.02	0.00	92.88	98.08
68	Thompson 4	06/23/2013	10.50	0.32	2.54	0.01	87.31	95.92
69	Thompson 4	06/25/2013	1.25	0.25	1.27	0.00	91.21	97.60
70	Thompson 4	06/26/2013	1.00	0.32	1.27	0.00	91.09	97.59
71	Thompson 4	06/27/2013	0.75	0.44	1.78	0.00	87.86	96.64

Table 10. Continued

	Site	Storm Date	Rainfall Duration (HH.hh)	I30 (mm/hr)	Rainfall Depth (mm)	Flow Depth (mm)	CN (λ=0.05)	CN (λ=0.20)
72	Thompson 4	06/28/2013	5.25	0.25	1.78	0.00	88.22	96.69
73	Thompson 4	06/30/2013	1.50	2.98	11.94	0.00	52.40	81.23
74	Thompson 4	07/01/2013	1.00	1.21	5.08	0.00	71.91	91.01
75	Thompson 4	07/02/2013	69.50	1.02	24.89	0.05	38.43	69.31
76	Thompson 4	07/06/2013	27.75	1.57	79.76	0.92	20.53	44.91
77	Thompson 4	07/10/2013	8.25	2.98	12.95	0.03	54.90	81.39
78	Thompson 4	07/13/2013	2.75	2.67	12.95	0.03	54.67	81.32
79	Thompson 4	07/21/2013	2.50	1.65	6.86	0.03	70.97	89.50
80	Thompson 4	07/22/2013	6.25	0.08	4.83	0.06	81.08	93.10
81	Thompson 4	07/27/2013	2.50	0.51	4.57	0.30	89.78	95.36
82	Thompson 4	07/31/2013	3.75	0.19	1.78	0.44	98.43	99.04
83	Thompson 4	07/31/2013	4.25	0.06	0.25	0.09	99.84	99.90
84	Thompson 4	08/07/2013	14.00	0.76	17.78	3.15	81.90	89.13
85	Thompson 4	08/08/2013	2.25	0.04	1.02	0.20	98.88	99.36
86	Thompson 4	08/09/2013	9.75	0.08	0.76	0.29	99.60	99.72
87	Thompson 4	08/10/2013	3.75	0.57	6.86	0.07	74.64	90.36
88	Thompson 4	08/17/2013	19.50	0.74	11.18	6.96	97.65	98.15
89	Thompson 4	08/21/2013	5.50	0.08	2.03	0.17	95.71	98.03
90	Thompson 4	09/01/2013	1.25	0.19	0.76	0.00	95.74	98.73
91	Thompson 4	09/09/2013	1.25	0.13	0.51	0.00	97.46	99.20
92	Thompson 4	09/10/2013	1.75	0.19	1.27	0.01	94.05	98.06
93	Thompson 4	09/21/2013	32.25	3.49	65.53	2.25	30.78	54.44
94	Thompson 4	02/02/2014	12.00	0.58	22.00	0.01	38.75	70.74
95	Thompson 4	02/03/2014	28.00	0.58	19.22	0.07	46.30	75.14

Table 11: Total Phosphorus Dataset

TP				
Date	**Site**	**EMC (mg/L)**	**Min (mg/L)**	**Max (mg/L)**
12/13/2013	T1	4.185	2.805	8.930
1/9/2014	T1	4.541	4.247	4.922
1/23/2014	T1	3.559	3.365	3.797
4/15/2013	T2	0.356	0.113	0.649
4/22/2013	T2	0.296	0.108	0.573
7/8/2013	T2	0.937	0.886	0.995
12/13/2013	T2	1.548	1.110	2.282
12/20/2013	T2	1.023	0.299	2.513
1/9/2014	T2	1.271	1.250	1.300
6/4/2009	T4	2.369	2.189	2.469
12/13/2009	T4	2.436	1.607	5.032
1/9/2010	T4	4.537	4.247	4.982

Table 12: Total Nitrogen Dataset

TN				
Date	**Site**	**EMC (mg/L)**	**Min (mg/L)**	**Max (mg/L)**
12/13/2013	T1	14.109	10.288	18.635
1/9/2014	T1	12.395	11.913	13.359
1/23/2014	T1	6.073	5.449	6.531
4/15/2013	T2	2.352	0.794	3.341
4/22/2013	T2	2.021	0.659	5.087
7/8/2013	T2	2.415	2.073	2.865
12/13/2013	T2	5.870	3.340	14.621
12/20/2013	T2	2.568	0.159	9.879
1/9/2014	T2	5.143	3.598	6.311
6/4/2013	T4	4.917	3.658	6.166
12/13/2013	T4	6.575	4.798	12.201
1/9/2014	T4	6.228	5.520	7.501

VITA

Jordan Avery Hayes was born on December 26th, 1989 in Palm Springs, California. He spent the first ten years of his life in Twenty-Nine Palms, California in the Mojave Desert. Scarcity of water in the desert led Mr. Hayes to become fascinated with water. Consequently, he developed a yearning to learn as much as possible about water. In 2000 he moved to Clarksville, Tennessee. With vegetation and water abound, the stark difference in biome further reinforced the need to learn all things water resources related. He graduated from Rossview High School in the fall of 2008. Upon graduation he decided to stay for an extra year in Clarksville to help rehabilitate his mother while he attended the local university, Austin Peay State University. He transferred to the University of Tennessee in Fall of 2009 where he received his Bachelor of Science in Civil Engineering with specialties in water resources and environmental engineering in December of 2012. He became employed by his major professor in the fall of 2011 for the purpose of completing undergraduate research in the water resources field. This research led to a master degree funding opportunity presented jointly by IBSS, USDA, and ORNL. Mr. Hayes plans to complete his Master of Science in Environmental Engineering in May of 2014. Becoming the first in his immediate family to graduate college, he plans to continue to achieve by obtaining professional licensure and a doctoral degree.