Spring 2015

Mapping soil erosion risk and safety factors of the Massanutten Trail system

Joshua R. Foery
James Madison University

Philip V. Sturm
James Madison University

Mapping Soil Erosion Risk and Safety Factors of the Massanutten Trail System

---

An Honors Program Project Presented to

the Faculty of the Undergraduate

College of Integrated Science and Technology

James Madison University

In Partial Fulfillment of the Requirements

For the Degree of Bachelor of Science

by Joshua Foery and Philip Sturm

May 2015

Accepted by the faculty of the Department of Integrated Science and Technology, James Madison University, in partial fulfillment of the requirements for the Honors Program.

FACULTY COMMITTEE:

____
Project Advisor: Carole Nash, Ph.D.,
Assistant Professor, ISAT, GS

____
Project Advisor: Zachary Bortolot, Ph.D.,
Associate Professor, ISAT

____
Reader: Amy Goodall, Ph.D.
Associate Professor, Geographic Science

____
Reader: Helmut Kraenzle, Ph.D.,
Professor, Geographic Science

____
Reader: Wayne S. Teel, Ph.D.,
Professor, ISAT

HONORS PROGRAM APPROVAL:

____
Philip Frana, Ph.D.,
Interim Director, Honors Program

Abstract

Public mountain biking and hiking trails can pose challenges to trail-user safety. The purpose of this project is to improve the overall safety factors on the Massanutten Western Slope, in eastern Rockingham County, Virginia, where a 15-plus mile trail system has been made available to a broad range of users. Owned by Massanutten Resort, the trail system is in a remote, forested area frequented by local off-road cyclists, runners, hikers, as well as seasonal tourists and is maintained by the Shenandoah Valley Bicycle Coalition (SVBC). This multifaceted project, which integrates ESRI ArcGIS, Trimble Pathfinder, USDA Soil Survey Geographic (SSURGO) data, and the National Land Cover Database (NLCD), has the common goal of increasing the overall safety of the trail system through assessing both environmental impact in trail construction and use, as well as accessibility for first responders. Trail erosion risk was modeled in ArcGIS based on the variables outlined in the Revised Universal Soil Loss Equation (RUSLE). The factors of soil erodibility, slope, and vegetation cover type were used to assess erosion risk and identify areas where current trails are likely to erode and where future construction should be avoided by SVBC. Field collection of GPS locational data using a survey-grade field rover was undertaken to update trail marker signage, provide accurate locational maps for rescue efforts, and test the validity of the erosion model through ground-truthing. Cellular strength data was collected to identify areas along the trails where cellular coverage may be weak. Ultimately, first responders will be provided with maps of the trail system labeled with geographic coordinates and that identify access points.

Table of Contents

List of Figures and List of Tables

Acknowledgements

We would like to thank and acknowledge many people that helped in the completion of this project. Thomas Jenkins of the Shenandoah Valley Bicycle Coalition, for providing access to the Massanutten trail network, as well as for providing GIS files for our project. We would also like to extend thanks to Dr. Zachary Bortolot and Dr. Carole Nash for their guidance and support over the past three semesters. Lastly, we would like to thank our family and friends for their support throughout this project.

Introduction

Public mountain biking and hiking trails can pose challenges to trail-user safety. Accurate maps of mountain biking trails are not only useful to the users, but also to first responders who are in charge of responding quickly to emergency situations that may arise from trail accidents. The purpose of this project is to improve the overall safety factors on the Massanutten Western Slope Trail System, in eastern Rockingham County, Virginia, where15-plus miles of trail are available to a broad range of users (Figure 1).

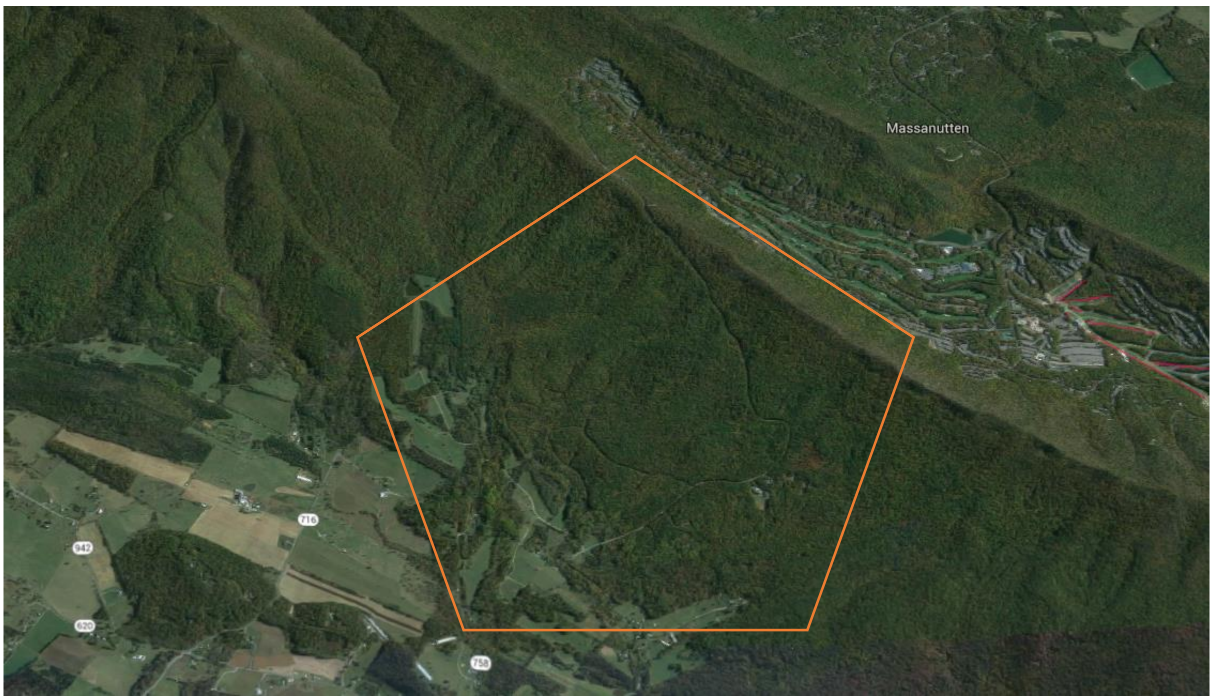

Figure 1: Close up of general area of trails location. This view is pivoted using the tools on Google Maps.

https://www.google.com/maps/@38.4282842,-78.7589159,10183m/data=!3m1!1e3

This trail system is owned by Massanutten Resort and built and maintained by the Shenandoah Valley Bicycle Coalition (SVBC). Users of the trail system, which is in use year-round, include SVBC mountain bikers and resort hikers. This multifaceted Honors project, which integrates ESRI ArcGIS, Trimble Pathfinder, PCI Geomatica, USDA SSURGO soils data, and the National Land Cover Database (NLCD), has the common goal of increasing the overall safety of the trail system through assessing both environmental impacts in trail construction and use, as well as accessibility for first responders. The overall goal of this project is to better assist future rescue efforts for local first responders along the trail system, as well as aid in future trail construction by the SVBC.

Both partners pursued this project for individual reasons. Phil Sturm's interest in mountain biking as well as his desire to complete a project that showcases a wide array of technical GIS skills led to his involvement. Josh Foery chose to undertake this project for a personal reason that occurred when he was in the tenth grade. While suffering from an emergency that required EMT response, the first responders got lost due to incorrect GPS data. In emergency response situations every second matters, and although Josh's situation was not life threatening, the slow response time due to incorrect GPS data highlights the need for accurate data, especially in remote areas such as those where mountain biking trails are developed Finally, both partners had the same goal: to complete a project that gave back to Harrisonburg and surrounding communities.

Literature Review

General Trail Safety Techniques and Injury Statistics

Although it seems like everyone in modern society owns a smart-phone and that virtually the entire continental United States supports cell phone coverage, this technology is useless in an emergency situation if those in need of rescue do not know their exact location. This situation is magnified even more when the emergency occurs in a remote location such as on the Western Slope Trails at Massanutten Mountain. How does one inform emergency service personnel where an injury has occurred so that these services can most efficiently respond to the need for rescue?

The research in regards to emergency rescues in remote areas is very limited, but that which does exist focuses on injury statistics and many of the causes of mountain biking accidents. Mountain biking in the United States has rapidly grown in popularity since its emergence in the late 1970s, both in terms of competitive and recreational mountain biking (Romanow, 2014). With the increase in popularity is also an increase in mountain bike-related injuries that often occur on remote trail locations. Chow (1993) reports the results of a survey of the members of two Southern California off-road bicycling organizations: “up to 84% of mountain bikers have reported being injured in the past year of activity. The most common forms are injuries to the extremities, such as the legs and arms. Of the injuries to the extremities, “injuries to the upper extremities and the torso were the most prevalent and were mild, ranging from abrasions, lacerations, and contusions.” The injuries that required more express care were fractures and dislocations, but often only involved the patient being treated and then released from an emergency care department. The rare incident of “extreme injuries to the head, such as concussions, neck injuries, and injuries that resulted in internal bleeding” were the only injuries that required immediate medical evacuation of patients from the trails, and extended stays in hospitals for treatment. (Chow, 1993).

Injuries from mountain biking are to be expected in remote areas, even for experienced riders. The same survey found that 84% of riders who had suffered from a crash in the previous year also revealed that their average amount of biking experience was 4.2 years (Chow, 1993). Even in competitive mountain biking, professional riders suffer from the same injuries as recreational riders. “Seventy percent of injuries to competitive riders were minor and involved their extremities, but of those injuries forward falls generated the most severe injuries often to the head, face, and upper portions of the body" (Burdick, 2005). Mountain bikers are also likely to suffer from multiple injuries from a single incident, such as a laceration, and abrasion to the arms and legs (Burdick, 2005).

Mountain biking-related injuries occur for a few simple reasons and range in severity. These injuries, especially those that were severe, occurred from "riding at speeds faster than normal and riding downhill, which, when combined, greatly increased odds of severe injury compared with flat and uphill riding" (Romanow, 2005). Other factors that contributed to accidents and injuries were collisions with moving and non-moving objects, and riding in unfamiliar areas. Riders wearing safety equipment were more likely to engage in risky behavior known as 'risk compensation,' leading to an increase in minor injuries (Romanow, 2005).

Literature on emergency rescue techniques in remote areas is very limited because the specificity of conditions of each location and rescue situation are different and difficult to universalize. Depending on the location, rescue crews have specific tools and training for rescue missions in remote areas. Besides common knowledge of carrying a first aid kit, informing people where one is riding, carrying a cell phone, and wearing protective equipment, many riders take for granted safety measures that can aid in a quicker response in the event of an emergency. Based on the work of Newman (1998), the potential of a locational technology to assist injured persons in remote areas is great. One technology that can aid in the quicker location of injured riders relies on a Personal Communication Service (PCS) and is utilized by some emergency response stations within the United States. This emergency system is small enough to be held or worn by an individual mountain biker or hiker and is the critical starting point for the emergency response process after an injury occurs. The PCS enables a user to transmit his or her location in latitude and longitudinal coordinates with pinpoint accuracy, utilizing the Global Positioning System. When the device is in operation, it obtains its location from at least three of the twenty-four operational GPS satellites orbiting the Earth and can produce precise locations to within ten meters of the user. The device sends location information either on-demand to a concerned inquirer via a voice-processing unit or automatically to emergency services, such as police, medical ambulances, and rescue squad personnel. As long as the PCS device is turned on, it periodically receives coordinates from the GPS satellites and sends its location information to the computer via the PCS network. One of the most advanced features possessed by a PCS unit is the ability to change the frequency of transmissions received from the orbiting satellites. In the event of an accident such as a mountain bike crash, the next scheduled transmission of the location information can be overridden by pressing an emergency distress button, generating a distress signal with the exact coordinates at that precise moment (Newman, 1998).

Erosion Modeling with GIS and RUSLE

Construction of new trail systems in an area has the potential for environmental impacts that can compromise the existing topographical features through erosion (Newsome 2009) and also affect the safety of riders. By identifying potential areas of excessive erosion, trail construction techniques may be implemented to address these impacts before they occur (Newsome 2009). A GIS model with the ability to identify these areas can be a valuable tool for future trail construction best practices (Wachal and Banks 2007). In this case, Massanutten Resort owns the land but the Shenandoah Valley Bicycle Coalition (SVBC) constructs and manages the trails through the use of volunteers (SVBC 2013) who would benefit from guidance concerning good trail construction practices. Excessive erosion along the trails may also pose a threat to trail riders who may be unfamiliar with the area.

A number of studies have used GIS in the past for identifying soil erosion (C. Fernandez, et al. 2003). ArcMap supports the use of the Revised Universal Soil Loss Equation (RUSLE) (Wachal and Banks 2007). Because of its history and volume of research available for review, components of the RUSLE procedure will be utilized to calculate erosion risk in the area of interest. This equation (A = R x K x LS x C x P) was first developed in the 1960s and revised in 1997 and uses five major factors to calculate soil loss. In the equation, 'A' is the average annual potential soil loss in tons/acre/year, 'R' is the rainfall-runoff erosivity factor, 'K' is the soil erodibility factor, 'LS' is the slope length and degree, 'C' is the land-cover management factor, and 'P' is the conservation practice factor (Page 2012). While this procedure was designed primarily to assess soil loss in agricultural situations, GIS and remote sensing technology make it possible to apply this formula to study larger areas (Fernandez, et al. 2003).

Trail Factors Applied to Massanutten Mountain

For the purposes of this study, the Conservation Practices or "P" factor will not be used when assessing erosion risk. For the purpose of identifying erosion potential on the trails, our assumption is that the forested area is not being managed to combat erosion. The rainfall erosivity layer will not be created but the value from the Virginia Isoerodent map will be utilized to calculate soil losses in order to interpret relationships of erosion potential within the area (Fletcher et al 1977). An isoerodent map shows the rainfall erosivity factor over an area. The R factor is the quantitative expression of the erosivity of local annual average rainfall and runoff causing soil erosion. R values are affected by volume of precipitation, intensity, duration, and pattern of rainfall (Farhan et al, 2013).

In order to further isolate the trail system from the surrounding study area, a 'Trail Factor' was applied to the RUSLE calculation. A single trail factor value represents the entire trail system, allowing erosion potential to be calculated and relationships between low medium and high erosion potential mapped. By applying a single factor, we are assuming the entire trail system has the same volume and type of use. Such assumptions are important for modeling, which provides differing scenarios based on the variables chosen and their associated values.

Testing the Model

In the course of mapping the trail system for safety access, we wanted to collect accurate coordinates of those areas that appeared to be eroded more than what we considered normal. Although this is highly subjective, we wanted points that could be used to check ('truth') the validity of the erosion model. In the course of mapping the trail features we collected only three points where erosion seemed excessive. These observed points were added to the trail erosion maps. The lack of excessively eroded areas was unexpected, but we attributed it to the ongoing efforts of the Shenandoah Valley Bicycle Coalition's volunteer trail maintenance efforts (SVBC). Also, as our data collection occurred in the late fall and early winter months, leaf litter was in evidence and may have been covering some eroded areas.

The significance of this work is underscored by the fact that the SVBC is in the process of trail expansion in the Western Slope area, specifically in the area between Del Webb Drive and the property boundary, south of Del Webb Drive (Figure 2). Application of a spatial model identifying potential erosion areas would be very useful so that erosional problems can be avoided. The area of future expansion is shown above in the blue rectangle.

Figure 2: Close up the SVBC trail expansion area.

https://www.google.com/maps/@38.4282842,-78.7589159,10183m/data=!3m1!1e3

Objectives

The objectives for this project are to use components of the Revised Universal Soil Loss Equation (RUSLE) to assess erosion risk on the Western Slope Trail system of Massanutten Mountain. By examining the soil erodability factor, slope length, degree, and land-cover factors, areas of low, medium and high erosion risk will be identified. Maps that depict these areas were produced and distributed to trail managers. Accuracy of the trail erosion model was assessed by comparing erosion point data collected on the ground to the maps produced.

Secondly, we collected accurate coordinates of trail intersections, trail posts, access points, and natural or human-made landmarks. Signage and marked trail information were included as attributes within the GPS data dictionary during field data collection. The goal was to produce a map displaying trail posts labeled with accurate coordinates that can be utilized by first responders in an emergency situation. The third objective was to provide detailed trail maps to local first responders to aid in future rescue efforts along the Western Slope trail system. It is our hope that rescue response times will be reduced when first responders can use GPS technology to locate the nearest trail intersection where an injured person may be.

The final objective was to collect cellular signal strength data at various points of the trail system to identify areas of poor cellular reception. These points were interpolated into an isoline map displaying cellular signal strength throughout the trail system. Prior knowledge of cellular signal gaps in the area is useful information to trail users who may need to call for help.

Methodology

The study area, Massanutten Mountain, is located approximately 7 miles Southeast of Harrisonburg, Virginia. Massanutten Mountain Resort is nestled within a “bowl” on the southern end of the mountain ridge. The study area owned by the resort is located on the southwestern slope of Massanutten Mountain in a relatively rural area outside of Harrisonburg. The upper slope is mostly deciduous forest with much of the lower slope containing smaller hardwood trees, shrubs and grass pasture. The Shenandoah Valley Bicycle Coalition constructed the recreational trail system. SVBC utilizes volunteers to maintain the trail system on the Western Slope of Massanutten Mountain (SVBC). The current trail system is approximately 15-18 miles in length consisting of open fields, single-track, older access trails and fire roads.

The Western Slope area was surveyed by GPS and a trail map was produced by Applied Trails Research, Inc. (SVBC, 2014). The trail feature files were made available to us by the SVBC. This project required the collection of additional GPS coordinates to confirm locations of trail features, access roads, and intersections for safety enhancement analysis.

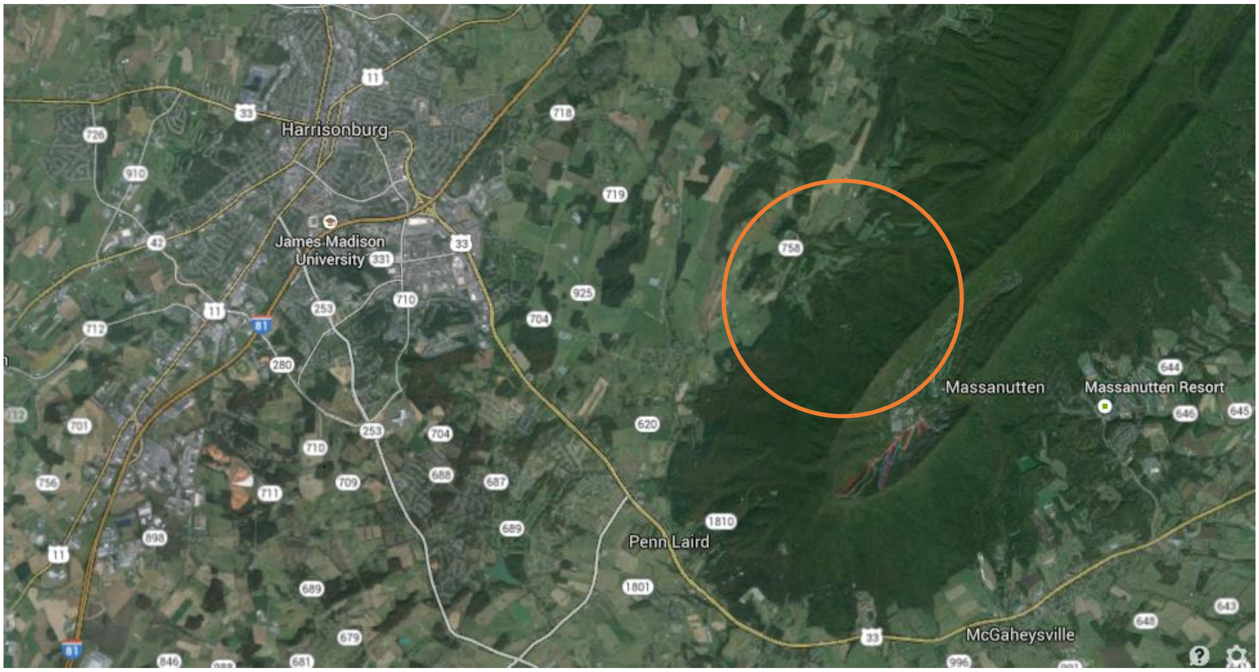

Figure 3: General area of trails in the orange circle.

https://www.google.com/maps/@38.4282842,-78.7589159,10183m/data=!3m1!1e3

GPS data collected in this study was post-processed for the best accuracy. Prior studies have demonstrated that post-processed data is more reliable than both uncorrected data and real time corrected data (Trimble 2004).

Layers Produced to Compute Erosion Risk

The creation of the GIS raster layers for the erosion model took the most time in this project. A raster in its simplest form is a matrix of cells (or pixels) organized into rows and columns (or a grid), where each cell contains a value representing information, such as elevation or slope (ArcGIS Desktop, 2013). The RUSLE calculation uses rainfall erosivity, soil erodibility, topographic factors, land cover, and conservation practices combined to measure soil loss in agricultural settings (Simms et al, 2003). To model erosion potential in the Massanutten Western Slope area, K factor, LS factor, C factor and an experimental Trail factor are created. The techniques for creating these GIS layers are outlined below.

Digital Elevation Model (DEM)

The digital elevation model (DEM) is a layer that provides the elevation of the study area for computation of the slope degree and length of slope factors (LS) in the RUSLE model. For this project, Rockingham County data from the NRCS Virginia LiDAR Project, completed in February of 2012, was utilized (NRCS). Grid tiles were selected that cover the extent of the study area and LiDAR data tiles were merged in ArcGis to produce a single DEM layer of the study area (Figure 4). The DEM is used to extract raster layers to compute the LS factor explained below.

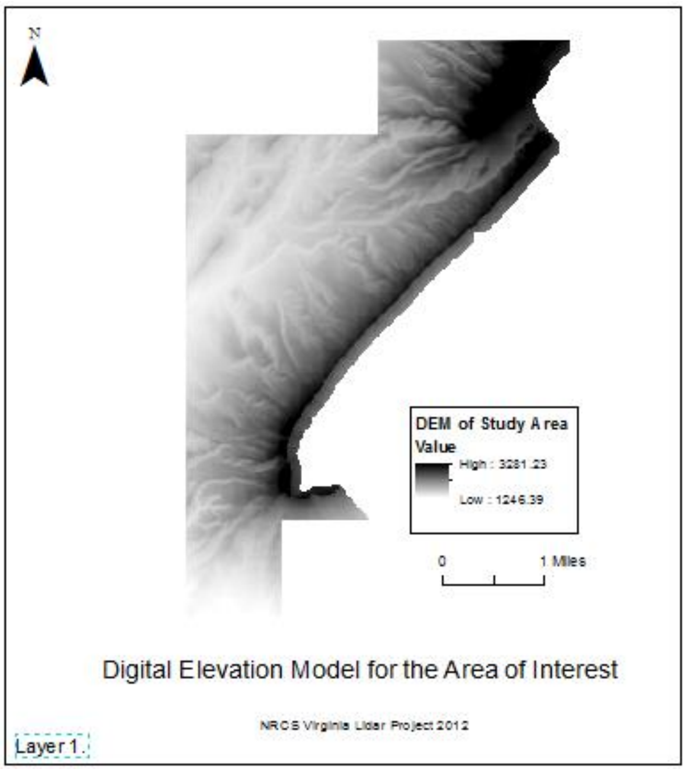

Figure 4: Digital Elevation Model

K factor Layer (Soils Erodibility)

The amount of energy needed to dislodge and transport soils varies with the soil type (Tirkey, et al 2013). The K factor indicates the susceptibility of soil to sheet and rill erosion (USDA). The USDA Soil Survey Geographic (SSURGO) database depicts information about the kinds and distribution of soils on the landscape. This dataset is generally the most detailed available for soil geographic data in the U.S. The SSURGO Soils database includes RUSLE K factor values for soil polygons needed to compute the erosion risk in the study area (USDA 2014).

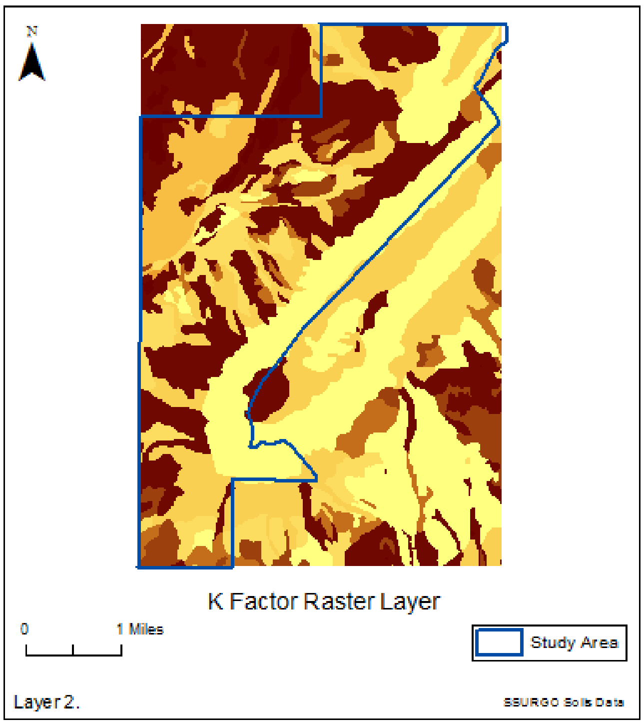

Figure 5: K Factor Raster Layer

Soil Data Viewer is a tool built by the NRCS as an extension to Esri ArcMap and is used for extraction of values from the Soil Survey Geographic (SSURGO) database. Soil Data Viewer Version 6.1 was utilized to run a Dominant Condition Aggregation of soil components to produce a table (see appendix II) assigning a single Kfactor value for each soil polygon. For instance, a soil sample may contain 40% clay and 60% silt loam. The aggregation will compute a single soil type and value based on the proportions of soil types within the soil polygon. Variables can be adjusted in this report for individual research needs (See Appendix II for aggregation report and explanation of how it works). For this study, the top surface layer of soil was examined and the Kw field within the SSURGO data tables, indicating "K factor whole soil including rock fragments" was used (USDA 2014). The Soil Data Viewer tool could not be run within our version of ArcMap 10.2.2, but it was able to generate the aggradation table of the values (see Appendix II). This table was then exported to excel and joined in ArcMap with the SSURGO soil polygons layer using the "Map Symbol" field. Once the map soil polygon layer had the aggregated Kfactor values included, the ArcMap Polygon to Raster tool was used to convert the polygons to a new raster layer called Kfactor (Figure 5). The Kfactor value in the study area ranges from 0.10 to 0.49. Generally the higher the value the more susceptible the soil is to erosion by water (USDA 2014).

LS factor (Length of Slope and Slope Steepness)

The L and S factors of the RUSLE model are related to the topographical effects of land on erosion. "S" represents the degree of slope and "L" represents the length of slope. Length of slope is defined as the distance from the source of runoff to the point where deposition begins, or runoff becomes focused into a defined channel (Simms et al 2003). Slope shape, length, and the interaction of steepness has an effect on the magnitude of erosion. As slope steepness increases, soil erosion increases due to higher velocity and the erosivity of runoff. Similarly, as slope length increases, erosion also increases due to a progressive accumulation of runoff in the down slope (Farhan et al 2013). As a result, slope angle and length should always be considered together (Simms et al 2003). In the original USLE and RUSLE equations, slope length was a subjective measurement based on human judgment. Therefore calculating slope and slope length using a DEM in a GIS program provides a much more accurate LS factor (Simms et al 2003).

The LS factor layer was computed in ArcMap using the Raster Calculator function applied to raster layers derived from the digital elevation model. Using the “Slope” tool in Esri Spatial Analyst, a raster with values in degrees of slope was created from the DEM. Next, the DEM itself was modified with the “Fill” tool from the “Hydrology” toolset. Using the filled DEM, another raster, “Flow Direction,” was created as an interim step for the final calculation of the LS factor. Finally, using the flow direction raster as an input, a Flow Accumulation raster was produced. The LS factor (Figure 6) is computed using Raster Calculator to build an expression using the Flow Accumulation and Slope Steepness raster layers (Simms et al 2003).

The expression is:

Pow([flow accumulation]*DEM Resolution/22.1,0.6) * Pow((Sin[Slope of DEM]*0.01745)/0.09, 1.3)

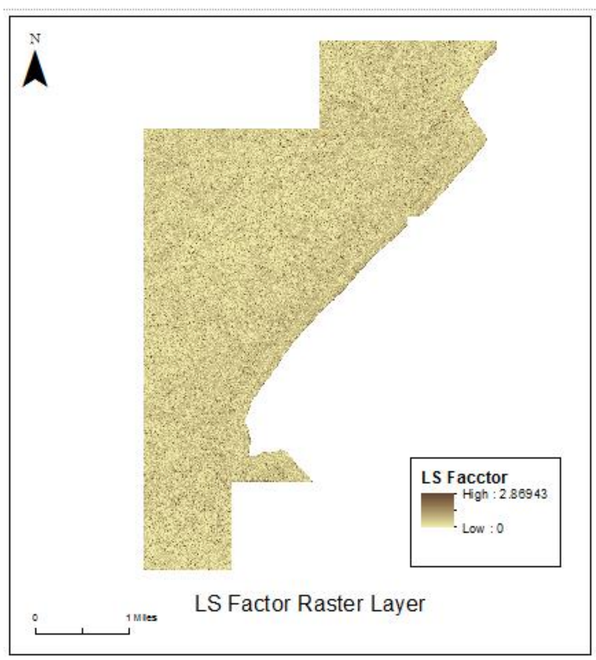

Figure 6: LS Factor Raster Layer

C Factor (Land Cover Management Factor)

In the RUSLE model, the Crop Management or Cover factor represents the effects of cropping and soil management practices on the rate of soil erosion (Farhan 2013). C Factor is defined as the ratio of soil loss from land maintained under specified conditions to the corresponding loss from continuous tilled bare fallow (Simms et al 2003). The RUSLE was originally developed for agricultural fields; however, cover factor can be adapted for use in other conditions. In our study area, the C factor represents the protection of the soil surface from raindrop energy by various canopy vegetation above the soil, as well as the protection of overland flow by land cover in contact with the soil (Simms et al 2003). Using remotely sensed imagery, a C Factor layer was created using Spectral Mixture Analysis in PCI Geomatica to estimate the values based on fraction images from spectral mixture analysis. The assumption is that abundant vegetation cover results in less soil erosion and less vegetation or higher soil fraction results in more soil erosion (Lu et al 2002).

We acquired a Landsat 5 thirty-meter resolution image (September 2013) that included he study area and imported it into PCI Geomatica (Version 2014, PCI Geomatics Enterprises) for processing. First, the bands were merged together creating an image we could run with the PCI "Endmem" tool to find five endmembers. Endmembers represent spectrally pure features (no mixed pixels). Next the image was spectrally unmixed (Spunmix in PCI) for the five endmembers. We compare the endmembers to the original image to determine what each endmember represented. Five endmembers were identified: green vegetation, shade, and 3 different soil types. The three soil fractional endmembers were added together in raster calculator, resulting in three fractions for C Factor computation: soil, green vegetation, and shade (Figure 7).

The formula for C Factor computation is: C= Soil / (1+Gv + Shade x Shade), where soil, green vegetation and shade are normalized to add up to 1 with values ranging from zero to 1 (Lu et al 2002).

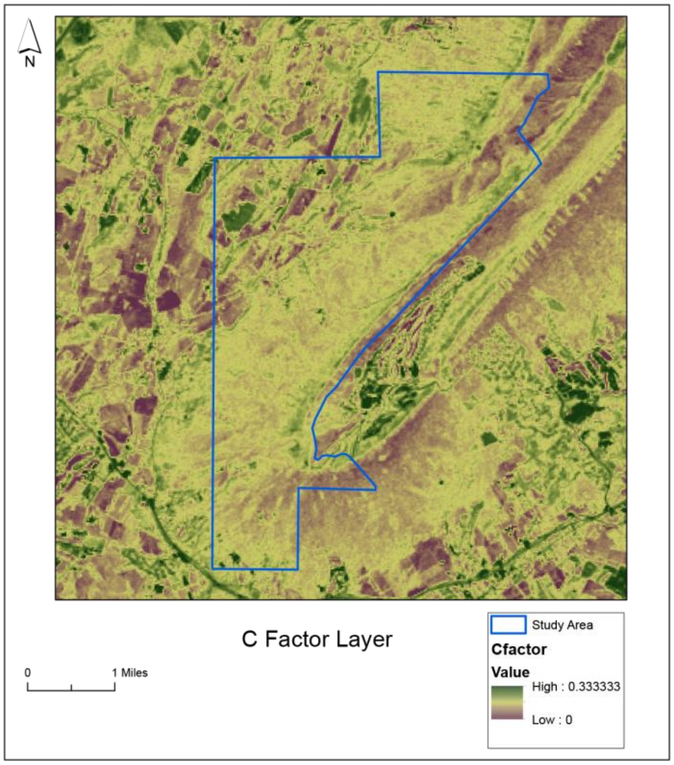

Figure 7: C Factor Raster Layer

Trail Factor

The conservation practice or P Factor is not applied in this model to adjust erosion values. Instead we applied what we named a Trail Factor. By assigning a multiplier to the trail itself and calculating the effects with our previous erosion model, we are able to assess trail erosion relationships and identify areas that will be more prone to erosion than others. In essence we are multiplying areas on the Western Slope touched by a trail by 0.3 in order to isolate the trail itself. Since our C factor layer (Figure 7) has values between 0 and .33, we chose to assign a similar value to the trail. We now have the necessary layers created to run the model (see results and discussion). Using the trail features layer provided to us by SVBC, in ArcGIS a new field was added to the attribute table and each trail was assigned a trail factor value of 1.3. Next, the edited trail layer was transformed from feature to raster using ArcGIS conversion tools. The selected cell size matched the other layers of the RUSLE model. The new layer effectively assigns each cell coinciding with the trail a factor value of 1.3. The remaining cells in the raster contained no data (Figure 8).

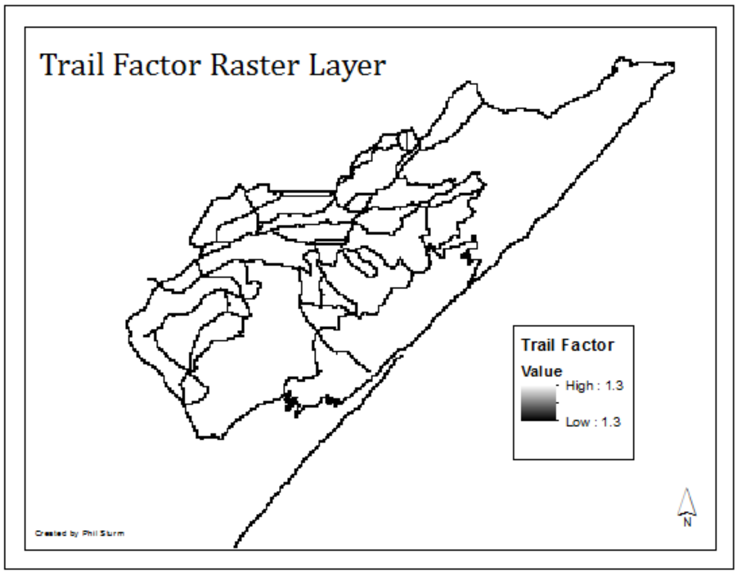

Figure 8: Trail Factor Raster Layer

GPS Data Collection Methodology

Collecting features along a fifteen-plus mile trail system was a challenge. Mountain bicycles were utilized to get from feature to feature, which greatly reduced time spent in the field. GPS data collection was performed using Trimble GeoXH handheld GPS Receivers running TerraSync 5.4 and Trimble Pathfinder Office Version 5.60. Since the data collection took place during winter months, satellite reception in the forest was acceptable for this collection with PDOP values fluctuating between 2 and 4. Occasionally GPS signal was lost due to the receiver being placed in a pocket or backpack during transport to the next feature.

A data dictionary was created in Pathfinder Office to collect attributes for the following features (see appendix).

1. Trail posts
2. Trail markers
3. Unmarked trail intersection
4. Natural features or landmarks
5. Gates
6. Roads
7. Trail signage
8. Points of erosion along the trail
9. Cellular signal strength (Bars) for AT&T and Verizon

(See Appendix III for complete data dictionary)

To field-test the erosion model described above, GPS coordinates were collected for visible signs of erosion that seemed excessive along the trails.

Cellular signal strength (number of bars) was recorded at every trail intersection and post during the three separate field visits, for both Verizon and AT&T carriers Points were interpolated using ArcMap 10.2.2. We utilized the Inverse Distance Weighted Tool for each cellular carrier to produce the coverage maps over the trail system. The Inverse Distance Weighted Tool is a statistical process in ArcMap. This is a technique that estimates cell values in a raster from a set of sample points that have been weighted so that the farther a sampled point is from the cell being evaluated, the less weight it has in the calculation of the cell's value (ArcGIS Desktop, 2013).

After data collection was complete, GPS rover files were differentially corrected using base station data from an NOAA Continuously Operating Reference Station (CORS). This station, Loyola A Coop, is approximately 10 kilometers from the study area. Files were exported as shapefiles to be used in conjunction with the trail shapefiles received from SVBC and integrated into new maps.

Interview with Massanutten Rescue/Security Team

On February 20, 2015 we conducted an interview with the Keith Dean, Manager of Special Services and Security of the Massanutten Resort. We wanted to learn how quickly rescuers can be on-site to an injured rider on the trail system. We were also interested in lso how many employees work on the security team, what sort of rescue equipment are available, and how many accidents they respond to each year.

We learned that the rescue/security team at Massanutten has 12 full time members, and five part time members, each of whom possesses EMS backgrounds and are required to maintain training courses in EMS and rescue techniques. Rescue members are often told during their first week to hike the trail system to familiarize themselves. Rescue members have many modes of transport available during a rescue operation: ATV's, rescue vehicles (SUV's), and equipment such as mountain climbing gear and first aid kits. In the event of extreme emergencies, Massanutten can call for tactical response teams from Rockingham County volunteer rescue squads. In addition, a helicopter rescue can be called if deemed necessary.

Mr. Dean informed us that a large number of calls to the trail system are for lost hikers, rather than mountain biking injuries. However, he reported that the rescue team responds to roughly two mountain biking injuries per year that require assistance from the trails. Injuries are believed to occur frequently on the trail but are often not reported due to their lack of severity. The accidents that require assistance occur most frequently from early spring to the beginning of fall, the peak season of trail use.

Mr. Dean reported that he response time to injured riders on the trail system varies between thirty minutes and one hour. This time difference exists because of the vast size of the trail system and the exact location of the injured rider. The rescue team has to navigate to the trail system, which may include unlocking two to three gates along the access road. It may take first responders twenty minutes to reach the parking lot at the base of the trails after receiving a call for help. Once the team reaches the trail system it can take up to twenty to forty minutes to establish a base camp and hike in and locate the injured rider. Depending on where the rider is on the system, and whether he/she has fallen in a location that requires climbing to access, response times can be even longer (Dean 2015).

Results and Discussion

Erosion Model Calculation

Using Raster Calculator in ArcGIS Spatial Analyst Tools, the RUSLE layers were combined to form the erosion potential image for the study area (Figure 9). The R Factor value of 150 from the Virginia Isoerodent map was used in the calculation (Fletcher et al 1977). When the calculated values are classified using natural breaks, areas with more or less erosion are identified (Figure 10).

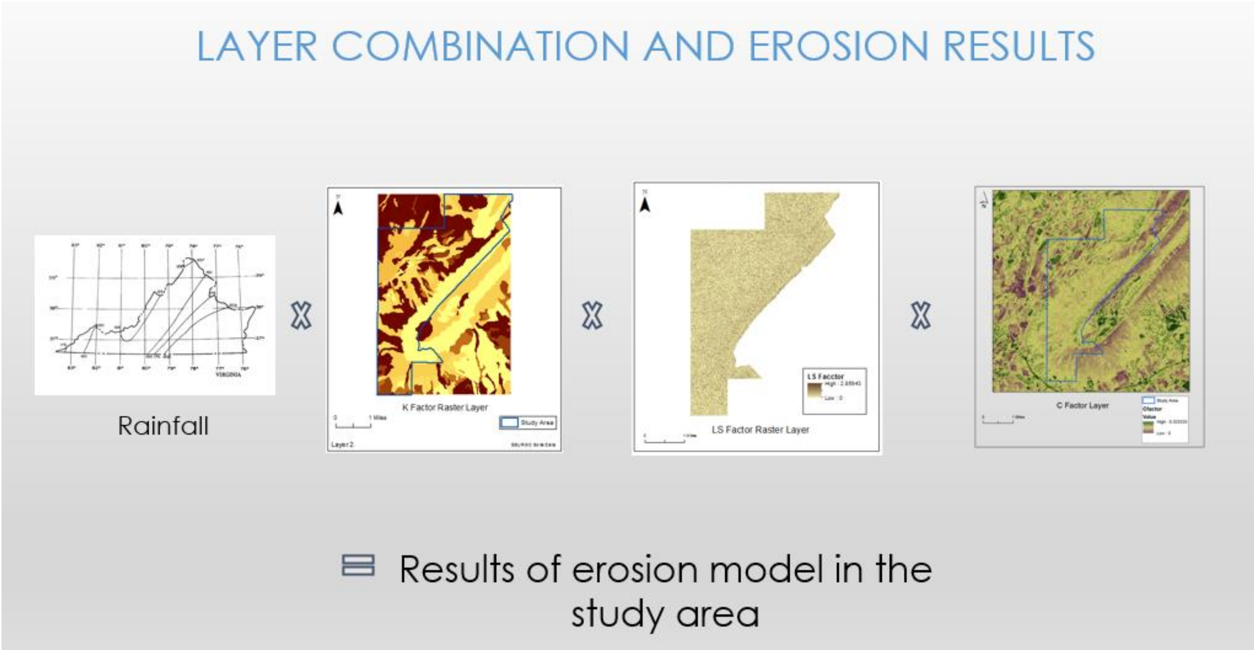

Figure 9: Layer Combination Image. RUSLE: R x K x LS x C

Soil Erosion Maps and Images

Figure 10 shows the RUSLE model applied to the study region. Areas of higher potential erosion appear to be on the lower slopes in and around agricultural fields. This erosion model shows the relationships between erosion potential across the study area. RUSLE values are classified using natural breaks to display relevant relationships. These results are not attempting to quantify total soil losses, only identify areas of the study area where more erosion is likely to occur.

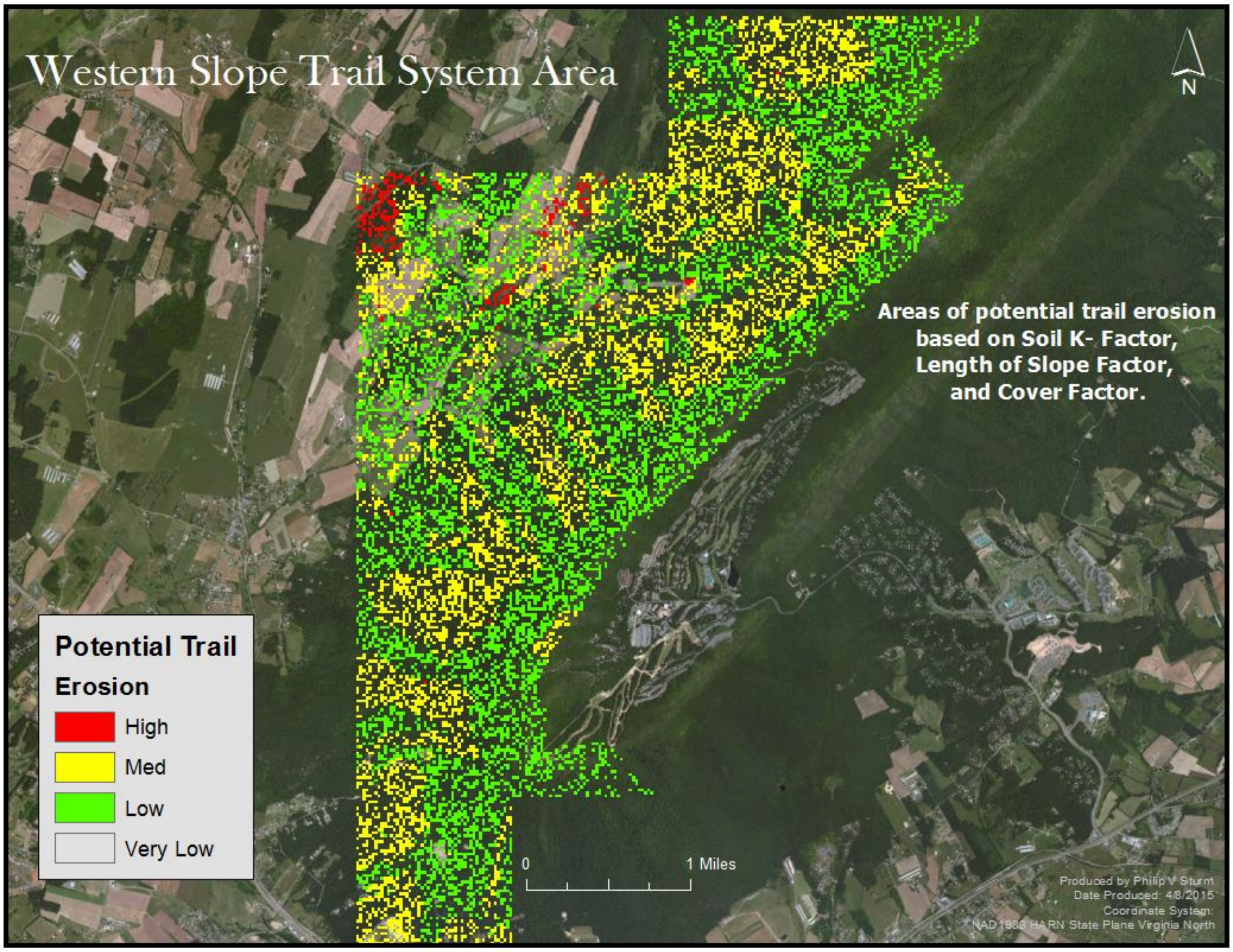

Figure 10: RUSLE Result based on R value of 150 x K Factor x LS Factor x C Factor

When we apply the Trail Factor to the above erosion model and reclassify the values, relationships of erosion potential along the trail itself are identified (Figure 11).

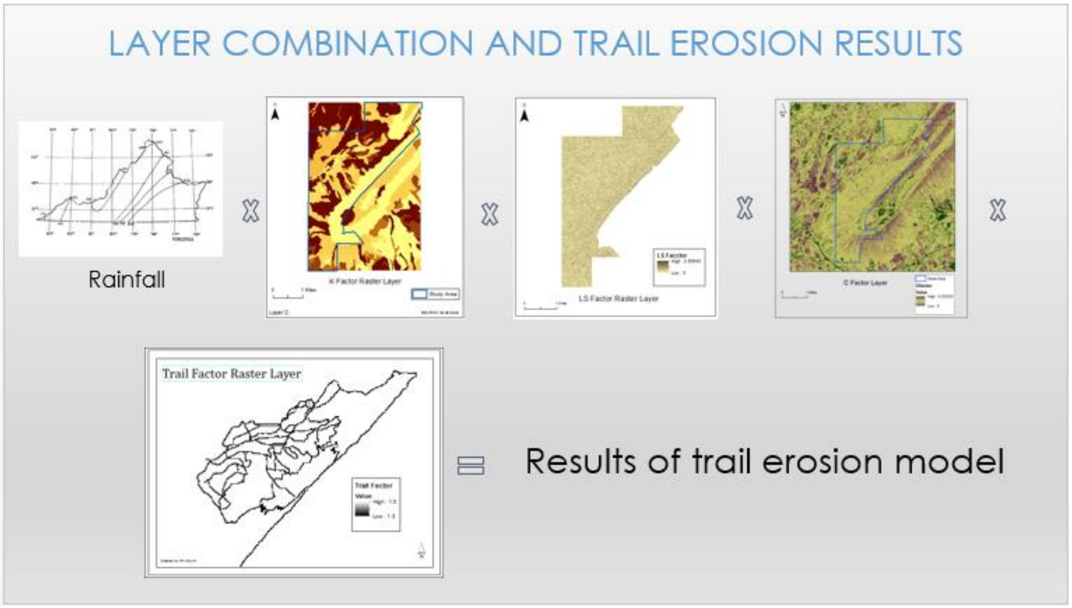

Figure 11: Layer Combination with Trail factor. RUSLE: R value of 150 x K x LS x C x Trail 1.3

Figure 12 shows the entire trail system at Massanutten Western Slope with the trail Factor applied to highlight the individual trails and the potential erosion areas.

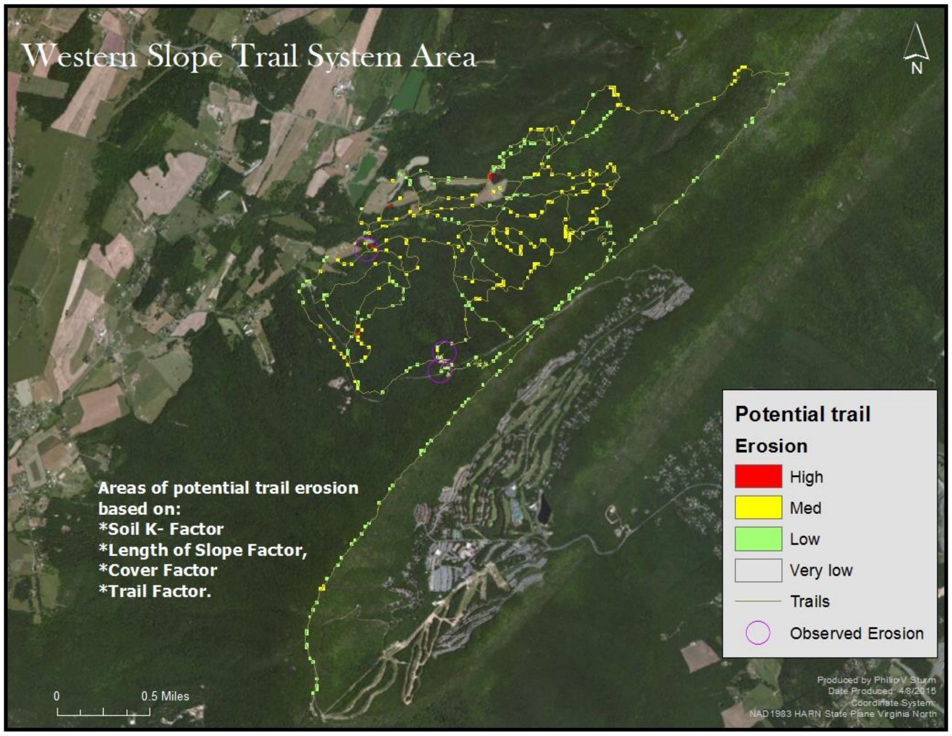

Figure 12: RUSLE Result based on K Factor, LS Factor, C Factor, and Trail Factor

The SVBC does not maintain records of trail use in terms of numbers of users and type of user on the trails. This lack of information could be limitation to the study in reducing the overall accuracy of the erosion model because high traffic areas could not be incorporated into the calculations. The trail system itself has much less erosion than we expected. We also realized that many different trail users visit the trail system. We saw mountain bicycles, runners, and hikers using the trails even in the winter months when we were collecting data. The erosion model showed a few areas of high erosion potential, one of which coincided with one of our observed ground erosion points, but most of the trail system seemed to be in good condition.

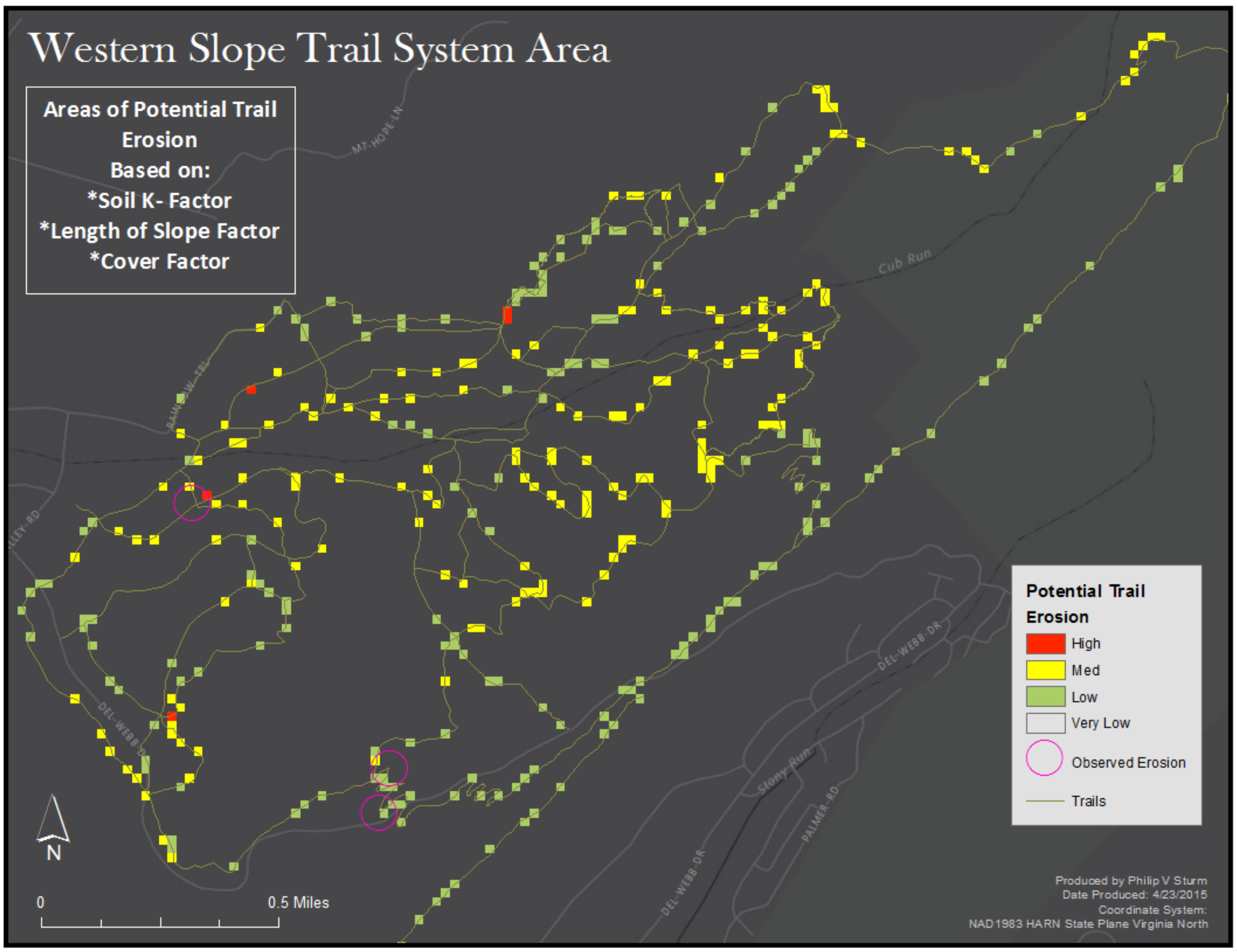

Figure 13: RUSLE Result based on K Factor, LS Factor, C Factor, and trail factor zoomed into the trails

Figure 13 is a closer view of the Western Slope Trails Potential Erosion Map with Trail Factor Applied (without base imagery). It shows the areas of the Massanutten Mountain bike trails where erosion is likely to occur. The small pink circles are the locations of visible trail erosion that were collected during GPS surveying of the trail markers. These points were applied to the erosion maps to see if the observed erosion coincided with the modeled areas of higher erosion potential. As previously stated, we only collected three points where erosion seemed excessive. There were no measurements between points and erosion areas on the map in this study. We simply wanted to see if the model and the observed points were close. One of our observed points appeared very close to an area of high erosion potential and the other two coincided with areas of medium erosion potential.

GPS Results: Coordinate Map

Trail Post Coordinates

Trail Letter	Latitude	Longitude
AA	38.435797	-78.747519
A	38.428759	-78.768547
B	38.431114	-78.764543
C	38.419852	-78.756743
D	38.432287	-78.758701
E	38.43503	-78.760821
F	38.434604	-78.752852
G	38.44067	-78.739627
H	38.427958	-78.741491
J	38.434578	-78.74947
K	38.43279	-78.751475
K	38.432705	-78.751364
L	38.430915	-78.752278
L	38.430813	-78.752315
M	38.429535	-78.746405
N	38.430414	-78.744872
O	38.429212	-78.754075
Q	38.437358	-78.746534
R	38.429158	-78.7648
S	38.430147	-78.761052
T	38.427644	-78.761246
U	38.422722	-78.766118
UM-1	38.432074	-78.75994
UM-2	38.4378	-78.747033
UM-3	38.42658	-78.754275
UM-4	38.427024	-78.75171
UM-5	38.423913	-78756997
UM-6	38.423791	-78.747625
UM-7	38.422351	-78.750244
V	38.425586	-78.769034
V	38.427292	-78.756313
W	38.420355	-78.766479
X	38.420873	-78.757828
Y	38.425149	-78.754661
Z	38.426452	-78.751792

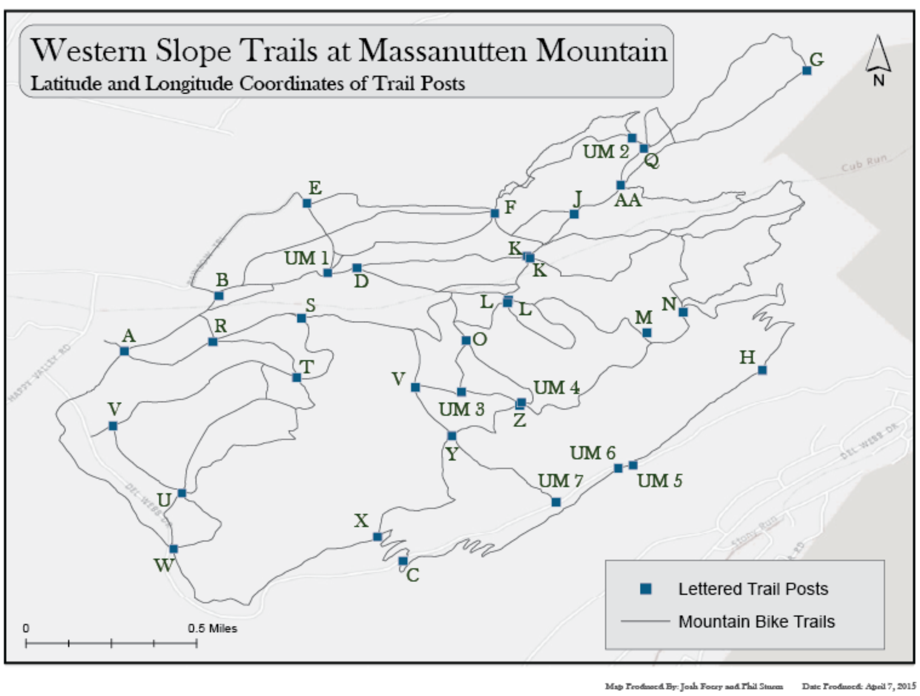

Figure 14: Map for rescue response members showing latitude and longitude coordinates of trails posts and trail intersections

Figure 14 the trail system map designed for the rescue responders. The design of this map was kept simple. A minimal number of colors were utilized, we focused on the use of gray scale for the main map body, and the use of dark hues of green and blue for the lettering and trail post markers. The main feature of the map is the addition of the table with latitude and longitude coordinates shown. The table is arranged in alphabetical order, and the letters correspond to pre-existing trail maps produced by the SVBC. During data collection we noticed several posts without markings. We collected latitude and longitude coordinates for these posts, and labeled them as UM (un-marked) on the map. These un-marked posts may be labeled in the future by the SVBC trail maintenance volunteers, and this map can easily be updated to accommodate the new labels.

The purpose of this map is to decrease rescue response times to injured trail users. Our hope is that in the event of an emergency situation a rescue official can use this map to navigate to the trail user, or a location very close to the injured person. This map will most likely be used in conjunction with other tools that the rescue squads already possess, but we hope that this map will further enhance rescue capabilities. On the coordinate map there are two instances of double lettering of the trail posts. The SVBC labeled the posts in this fashion in their overall trail map, and for the coordinate map we matched the pre-existing labeling. Some of the limitations of this map are that it can quickly become out of date. If the SVBC builds new trails, or re-labels the trail system, this map will need to be updated to match maintenance by the SVBC. This map will be distributed electronically to the SVBC and the Massanutten Rescue Team, and then printed as they see fit.

Cellular Coverage Map

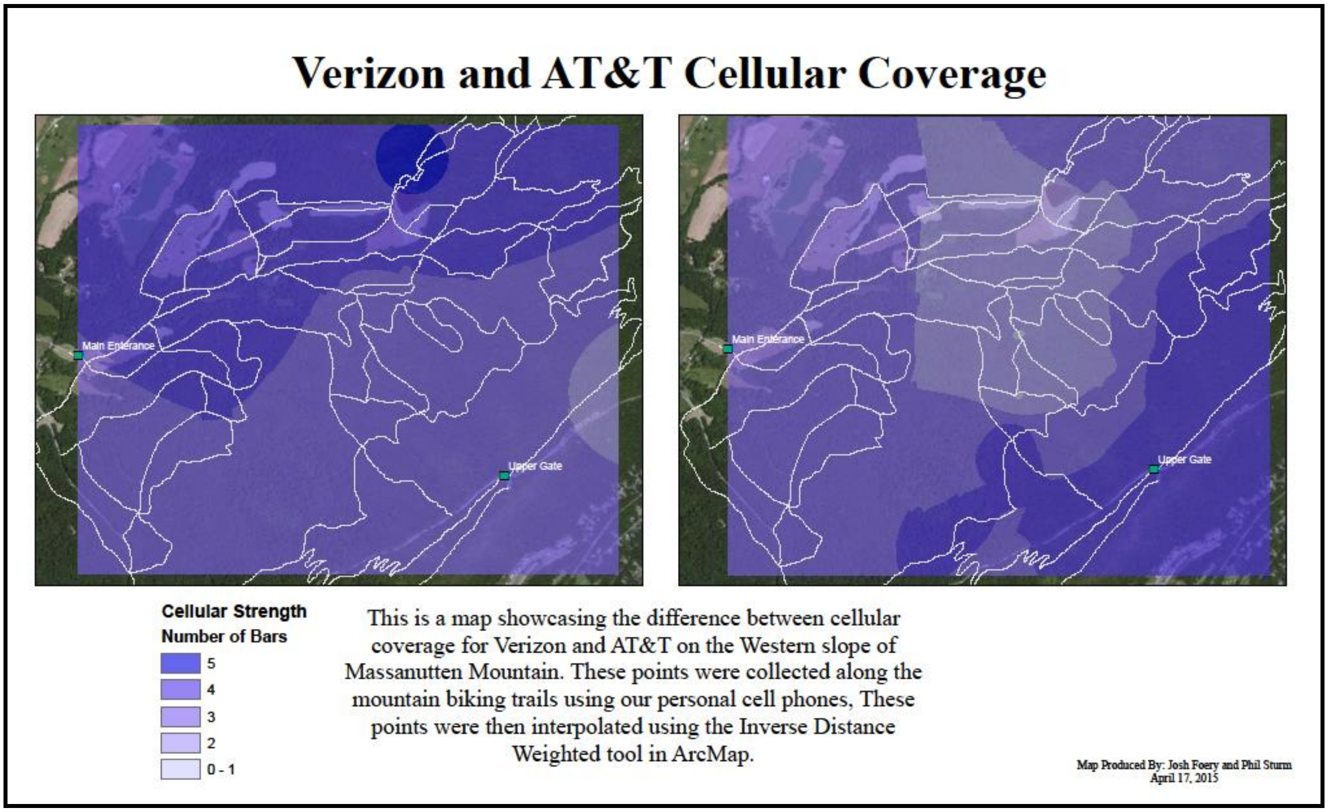

Figure 15: Cellular coverage comparison map for Verizon and AT&T

Figure 15displays the cellular coverage strength of Verizon and AT&T based on the points collected from the field visits. Verizon coverage is depicted on the left and AT&T coverage on the right. Cellular coverage was collected based on the number of bars indicating cellular strength, ranging from 0 (light purple) up to 5 (dark purple). Both cell phones used for collection were Apple iPhones.

Verizon seems to have better coverage (in number of bars) on the lower and middle portions of the trails, and fewer bars towards the upper portion of the trails. AT&T, on the other hand, has better coverage on the upper portion of the trails, and lower numbers of bars on the middle and lower sections of the trails. Both cellular carriers had adequate coverage across the entire study area throughout the collection time frame (December to March). Neither carrier ever lost cell phone signal, and we were both able to receive and send texts and emails while on the trails. In our opinion, both carriers have enough coverage on the trails for an injured rider or trail user to send a call or text in the event of an emergency.

Conclusion

The combination of components of the Revised Universal Soil Loss Equation (RUSLE) and GIS technology proved effective for analyzing erosion potential in a large, mountainous or forested area used for recreational activities. Areas of high, medium and low erosion potential on trails in the study area were identified using the RUSLE components of R factor, K factor, C factor, and LS factor. When applying an experimental Trail Factor, areas of erosion potential and their relationships were identified along the Massanutten Western Slope trail system. These maps may be used by trail maintenance personnel to plan trail erosion mitigation strategies or shift planned trail locations to minimize erosion.

Although most injuries that occur on mountain biking trails are minor, in the instances where severe injuries occur, especially from “riding downhill, and at speeds faster than normal”, quickly locating injured riders is paramount to a successful rescue operation (Romanow, 2005). According to the Massanutten Rescue Squad, the average response time to injured riders along the Massanutten Trail System ranges from thirty to sixty minutes. By having exact latitude and longitude coordinates of trail posts and trail intersections, response times to emergency rescues on the trail system may be reduced. Utilizing these coordinates can assist in emergency planning and locating stranded or injured trail users. The coordinate map that was produced can be distributed to not only rescue personnel, but also to trail users through their SVBC membership. In theory, an injured trail user could utilize the coordinate map to communicate their coordinates directly to an emergency dispatch worker to further reduce the time a rescue operation would take.

In the event of a crash along the trail system, the injured riders cell phone becomes one of the most important tools to assist in a rescue operation. Knowing the cellular coverage of a trail system is valuable for trail users and rescue personnel to know in advance. The cellular signal strength (number of bars) of Verizon and AT&T was collected along the Massanutten Trail system. Both the cellular coverage of Verizon and AT&T was adequate over the entire trail system. Neither carrier had any losses in cellular coverage along any point of the trail system during data collection. Although there were slight differences between the two providers, there was sufficient cellular strength to make a call in an emergency situation. The ability to call for help in the event of an emergency can greatly reduce the time it takes to complete a rescue operation for an injured trail user.

The combination of the RUSLE erosion model, the coordinate map, and the cellular coverage map all serve to increase the overall safety of the Massanutten Trail system. By identifying areas of potential erosion, the SVBC can better focus their maintenance efforts to reduce the risk to trail users. The SVBC can also use this model to avoid building new trail sections in areas of excessive erosion, and consequently avoid potential accident-prone areas. In the event of an injury, the coordinate map can decrease the response time to injured trail users, by allowing the injured user to communicate their location directly, or allowing the rescue personnel to use a GPS to locate the nearest trail intersection or post to the user. Lastly, knowing the mountain has adequate cellular coverage permits riders to directly communicate their position in the event of an emergency. Communication is vital in an emergency situation, and the ability to make a cellular call from the trails improves the safety of the trail system.

Future Work

Maps produced during this study will be provided to local rescue squads to assist with locating any possible injured or lost trail users. The maps will be distributed to the Massanutten Security and Rescue Team, as well as Rockingham County and Harrisonburg City emergency response personnel. Erosion maps and the coordinate map will also be made available to the Shenandoah Valley Bicycle Coalition to help with future trail planning and trail maintenance. Other future projects could arrange for the physical labeling of all trail posts with the GPS coordinates so that an injured cyclist could relay those coordinates to first responders. It would also be very beneficial for the SVBC to create an interactive, on-line trail map using the existing files which, combined with our trail data and intersection and feature attributes, would provide an important tool available to all users that could be placed on their web page. The responsibility to update the maps will be up to the Shenandoah Valley Bicycle Coalition (SVBC). Since the SVBC maintains a relationship with JMU's Geographic Science Program, assistance can be given to the SVBC if needed to update these maps.

Future trail planning could include analysis of erosion potential before a single trail is cut. If trail builders collect GPS lines while trail blazing, those features could easily be assigned a trail factor and applied to the RUSLE model to identify erosion potential. By avoiding areas of higher potential erosion, trail maintenance costs can be reduced and safety enhanced. Another future project is the improvement of the soil erosion model through employing different trail factors depending on trail user or trail type; for instance, future mappers could assign different trail factors for horse riding, trail running, or ATV use on trails. Lastly, future cellular signal strength studies could focus on collecting data during the summer when leaves are on the trees, or examining coverage from other cellular providers and other phone types.

Unintended Consequences

There are no indications of unintended consequences during this project. Care was taken during trail surveys to insure no damage was done to trails, or other property.

Appendices

Appendix I: LIDAR Data

NRCS Lidar Data Information

Data produced for the project were delivered in the following reference system

Horizontal Datum: The horizontal datum for the soil erosion project is North American Datum of 1983 (NAD 83) HARN

Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)

Coordinate System: Virginia State Plane Coordinate System, North Zone

Units: Horizontal units are in US Survey Feet, Vertical units are in Feet

Geiod Model: Geoid09 (Geoid 09 was used to convert ellipsoid heights to orthometric heights)

NRCS Lidar tiles selected for this project:

DEM_N16_4803_40	DEM_N16_4803_10	DEM_N16_4813_10
DEM_N16_4802_30	DEM_N16_4803_30	DEM_N16_4803_20
DEM_N16_4802_20	DEM_N16_4813_20	DEM_N16_4804_40
DEM_N16_4804_10	DEM_N16_4814_10	DEM_N16_4802_10

Appendix II: USDA SSURGO K Factor Aggregation Report

Attribute Name: K Factor, Whole Soil From SSURGO Soils, generated with Soil Data Viewer 6.1 on February 18, 2015. Erosion factor K indicates the susceptibility of a soil to sheet and rill erosion by water. Factor K is one of six factors used in the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) to predict the average annual rate of soil loss by sheet and rill erosion in tons per acre per year. The estimates are based primarily on percentage of silt, sand, and organic matter and on soil structure and saturated hydraulic conductivity (Ksat). Values of K range from 0.02 to 0.69. Other factors being equal, the higher the value, the more susceptible the soil is to sheet and rill erosion by water.

"Erosion factor Kw (whole soil)" indicates the erodibility of the whole soil. The estimates are modified by the presence of rock fragments.

Layer Option: Surface Layer

Aggregation Method: Dominant Condition

Aggregation is the process by which a set of component attribute values is reduced to a single value to represent the map unit as a whole.

A map unit is typically composed of one or more "components". A component is either some type of soil or some nonsoil entity, e.g., rock outcrop. The components in the map unit name represent the major soils within a map unit delineation. Minor components make up the balance of the map unit. Great differences in soil properties can occur between map unit components and within short distances. Minor components may be very different from the major components. Such differences could significantly affect use and management of the map unit. Minor components may or may not be documented in the database. The results of aggregation do not reflect the presence or absence of limitations of the components which are not listed in the database. An on-site investigation is required to identify the location of individual map unit components.

For each of a map unit's components, a corresponding percent composition is recorded. A percent composition of 60 indicates that the corresponding component typically makes up approximately 60% of the map unit. Percent composition is a critical factor in some, but not all, aggregation methods.

For the attribute being aggregated, the first step of the aggregation process is to derive one attribute value for each of a map unit's components. From this set of component attributes, the next step of the aggregation process derives a single value that represents the map unit as a whole. Once a single value for each map unit is derived, a thematic map for soil map units can be generated. Aggregation must be done because, on any soil map, map units are delineated but components are not.

The aggregation method "Dominant Condition" first groups like attribute values for the components in a map unit. For each group, percent composition is set to the sum of the percent composition of all components participating in that group. These groups now represent "conditions" rather than components. The attribute value associated with the group with the highest cumulative percent composition is returned. If more than one group shares the highest cumulative percent composition, the corresponding "tie-break" rule determines which value should be returned. The "tie-break" rule indicates whether the lower or higher group value should be returned in the case of a percent composition tie. The result returned by this aggregation method represents the dominant condition throughout the map unit only when no tie has occurred.

Tie-break Rule: Higher. The tie-break rule indicates which value should be selected from a set of multiple candidate values, or which value should be selected in the event of a percent composition tie.

End of Report.

Appendix III: Trimble Data Dictionary for GPS Feature Collection

```
E:\SeniorProject\GPS_Stuff\Massanutten Trails.ddf                                                    4/20/2015
Massanutten Trails
Western Slope of Massanutten mountain

Signage                 Point Feature, Label 1 = Type, Label 2 = Other/ Notes
   Type                 Menu, Normal, Normal, Type of sign or marker
      Trail Marker
      Direction Arrow
      Sign
      Other
   Other/ Notes         Text, Maximum Length = 100, Notes
                        Normal, Normal

Trail Posts             Point Feature, Label 1 = Type of Post, Label 2 = Trail Color
                        posts along the trail
   Type of Post         Menu, Normal, Normal
      Marked
      Unmarked
      Other
   Trail Color          Menu, Normal, Normal
      Red
      Blue
      Green
      Black
      Other
   Notes                Text, Maximum Length = 50
                        Normal, Normal

Trail Intersection      Point Feature, Label 1 = Intersections, Label 2 = Number of trails in
   Intersections        Menu, Normal, Normal, number of trails
      Multiple
      Single
   Number of trails in        Numeric, Decimal Places = 2
                        Minimum = 0, Maximum = 10, Default Value = 0
                        Normal, Normal
   Cell Signal Strength       Menu, Normal, Normal, Number of Bars (Cell)
      5
      4
      3
      2
      1
   Cell Signal          Menu, Normal, Normal
      ATT Cellular [Yes] [No]
      Verizon [Yes] [No]
   Notes                Text, Maximum Length = 50
                        Normal, Normal

Stream Crossings        Point Feature, Label 1 = Bridge / NO Bridge, Label 2 = Other
                        trail crossing stream
   Bridge / NO Bridge Menu, Normal, Normal
      Bridge
      No Bridge
   Other                Text, Maximum Length = 50
                        Normal, Normal

Landmark                Point Feature, Label 1 = Landmark Type, Label 2 = Descrption
   Landmark Type        Menu, Normal, Normal
      Natural
      Cultural
      Other
   Descrption           Text, Maximum Length = 50
                        Normal, Normal

Erosion Areas           Area Feature, Label 1 = Causes, Label 2 = Soil Type?
   Causes               Menu, Normal, Normal, Apparent cause
      Stream
      Trail Use    Default
      Flood
      Other
   Soil Type?           Text, Maximum Length = 50
                        Normal, Normal
   Description          Text, Maximum Length = 100
                        Normal, Normal

Erosion Point           Point Feature, Label 1 = Notes
```

E:\SeniorProject\GPS_Stuff\Massanutten Trails.ddf 4/20/2015

	Point of Erosion
Notes	Text, Maximum Length = 100
	Normal, Normal

Works Cited

An Approach to Evaluating the Impacts of Mountain Bike Activity in Natural Areas: The Case of John Forrest National Park, Western Australia. APAC 2008, 2008. OAIster; OCLC. Web.

Applied Trails Research. 2014. Massanutten Western Slope Trail Map. Design by Stealth Ink.com. Feb 2014.

ArcGIS Desktop. 1 Jan. 2013. Web. 28 Apr. 2015. <http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//009z0000006m000000.htm>.

Burdick, Timothy. "Wildnerness Event Medicine: Planning for Mass Gatherings in Remote Areas." *Travel Medicine and Infectious Disease* 3.4 (2005): 249+. Web. 27 Mar. 2015.

Chow, T K, M D Bracker, and K Patrick. “Acute Injuries from Mountain Biking.”*Western Journal of Medicine* 159.2 (1993): 145–148. Print.

Farhan Yahya, Dalal Zregat, Farhan Ibrahim. Spatial Estimation of Soil Erosion Risk Using RUSLE Approach, RS, and GIS Techniques: A CAse Study of Kufranja Watershed, Northern Jordan. 2013. *Journal of Water Resource and Protection,* 2013, 5, 1247-1261. Published Online December 2013 (http://scrip.org/journal/jwarp.

Ferguson, Janet Y.1998. *Location and Design of recreational Trails: Application of GIS Technology*. Virginia Polytechnic Institute and State University. 1998. Blacksburg V.A.

C. Fernandez, J.Q.Wu, D.K. McCool, and C.O. Stockle. *Estimating Water Erosion and Sediment Yield with GIS, RUSLE, and SEDD*. Journal of Soil and Water Conservation 58(3):128-136. www.swsc.org. 2003 Web.

Fletcher, Joel E.; Huber, A. Leon; Haws, Frank W.; and Clyde, Calvin G., "Runoff Estimates for Small Rural Watersheds and Development of a Sound Design method. Volume II, Recommendations for Preparing Design Manuals and Appendices B, C, D, E, F, G, & H" (1977). Reports. Paper 474.http://digitalcommons.usu.edu/water_rep/474.

"History." *International Mountain Bicycle Association*. Web. 16 April, 2014. https://www.imba.com/about/history

Lowell James, Rulon Rahl, assignee. Patent US6292687 B1. 18 Sept. 2001. Print.

LU D., Li G., Valladares G. S., Batistella M. Mapping Erosion Risk in Rondonia, Brazillian Amazonia: Using RUSLE, Remote Sensing and GIS. 2003. Land Degradation and Development, 15:499-512. 2004. Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/Idr.634

Natural Resources Conservation Service (NRCS). NRCS Virginia LiDAR Project, Florida: Dewberry, 2012. (USGS Contract G10PC00013, Task Order Number G11PD00336).

Newman, Brian. Emergency PCS System for Identification and Notification of a Subscriber's Location. Mci Communications Corporation, assignee. Patent US5835907 A. 11 Nov. 1998. Print.

Newsome, David, and Claire Davies. "A Case Study in Estimating the Area of Informal Trail Development and Associated Impacts Caused by Mountain Bike Activity in John Forrest National Park, Western Australia." *Journal of Ecotourism* 8.3 (2009): 237-53. Web.

Nicole T.R. Romanow , Brent E. Hagel , Michelle Nguyen , Tania Embree & Brian H. Rowe (2014) Mountain bike terrain park-related injuries: an emerging cause of morbidity, International Journal of Injury Control and Safety Promotion, 21:1, 29-46, DOI: 10.1080/17457300.2012.749918

Page, Josh. Developing a GIS Based Soil Erosion Potential Model for the Jemez Watershed – Using the Revised Universal Soil Loss Equation (RUSLE). 2012. Web.

Shenandoah Valley Bicycle Coalition. Trail Work. Wordpress, 2013. Web. 16 April, 2014. http://svbcoalition.org/our-riding/mountain-biking/massanutten/

http://svbcoalition.org/our-riding/mountain-biking/massanutten/attachment/nutmap1/

Simms A. D., Woodroffe C. D., Jones B. G. Application of RUSLE for Erosion Management in a Coastal Catchment, Southern NSW. 2003. Proceedings of MODSIM 2003:International Congress on Modelling and Simulation. Vol 2, Integrative Modelling of Biophysical, Social and Economic Systems for Resource Management Solutions. Townsville, Queensland. 14-17 July 2003, 678-683.

Tirkey, Pandey, Nathawat. Use of Satellite Data, GIS and RUSLE for Estimation of Average Annual Soil Loss in Daltonganj Watershed of Jharkhand (India). Journal of Remote Sensing Technology, May 2013, Vol. 1 Iss 1, PP.20-30. Print.

Trimble Navigation Limited. *Why Postprocess GPS Data?* Westminster, 2004.

U.S. Department of Agriculture, Natural Resources Conservation Service. Soil Survey Geographic (SSURGO) database for Rockingham County, Virginia. Fort Worth, Texas, U.S. Department of Agriculture, Natural Resources Conservation Service, December, 2013. (Details: va165, Online_Linkage: http://websoilsurvey.nrcs.usda.gov).

Webel, Suzanne. *Wildlife and Environmental Issues: Two Views on the Environmental Impacts of Trails*. American Trails.org. http://www.americantrails.org/resources/wildlife/WildTwoViews.html.