PUBLIC WORKS TECHNICAL BULLETIN 200-1-43
31 MARCH 2008

METHOD FOR IDENTIFYING ROADS AND TRAILS TO DETERMINE EROSION POTENTIALS ON U.S. ARMY INSTALLATIONS

Public Works Technical Bulletins are published by the U.S. Army Corps of Engineers, 441 G Street, NW, Washington, DC 20314-1000. They are intended to provide information on specific topics in areas of Facilities Engineering and Public Works. They are not intended to establish new DA policy.

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
441 G Street, NW
Washington, DC 20314-1000

CEMP-CE

Public Works Technical Bulletin 31 March 2008
No. 200-1-43

Facilities Engineering
Environmental

METHOD FOR IDENTIFYING ROADS AND TRAILS TO DETERMINE EROSION POTENTIALS ON U.S. ARMY INSTALLATIONS

1. Purpose.

a. This Public Works Technical Bulletin (PWTB) describes a Geographic Information System (GIS) software package for identifying unimproved roads and trails to determine erosion potential on U.S. Army installations. The GIS layers required for the software are elevation, vegetative cover, and soils which are standard GIS datasets available for most U.S. Army installations. In addition, users may wish to populate layers that allow site orientation within the program, such as roads, installation boundaries, county boundaries, bodies of water, and aerial photograph layers. Erosion potentials estimated by the software program are compared to on-site assessments at Camp Atterbury, IN, to validate the software calculations with field collected data. Appendix F gives a step-by-step procedure for using the software package.

b. All PWTBs are available electronically (in Adobe® Acrobat® portable document format [PDF]) through the World Wide Web (WWW) at the National Institute of Building Sciences' Whole Building Design Guide web page, which is accessible through URL:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB applies to all continental U.S. Army facilities.

3. References.

a. Army Regulation 200-1, “Environmental Protection and Enhancement,” 21 February 1997.

b. See additional references in Appendices E and H.

4. Discussion.

a. U.S. Army training facilities are experiencing significant erosion problems due to roads and trails created by vehicles deviating from established roadways during training exercises. Estimated costs for in-stream and off-stream impacts due to sedimentation in the United States exceed 11.6 billion dollars annually. Soil erosion may result in eutrophication, reduced water quality, increased fugitive dust, reduced vegetation and ground cover, reduced soil nutrients, altered infiltration patterns, and poor quality wildlife habitats.

b. The negative impacts from soil erosion can be controlled. However, the areas with the highest erosion potential must be identified in order to determine where rehabilitation efforts will be most effective. Often, the most practical and effective means of identification is with the use of a model. Although the validity of many of these models has been well documented, they have not been tested for conditions that exist on military training facilities.

c. The objective of this PWTB was to provide a GIS software package to identify roads and trails at a military training facility and estimate their erosion potential. This PWTB describes a simple to use web-based decision support program that identifies and calculates the length of unimproved roads and trails and classifies them into erosion potential categories without relying on labor-intensive on-site assessments. The use of the decision support program will result in improved decisions regarding the costs and benefits of rehabilitation or closure of unimproved roads and trails contributing to erosion potentials within affected watersheds. Land managers can compare different scenarios for rehabilitation of trails on an installation to determine the best way to reduce erosion potentials on heavily trafficked areas. In this way, rehabilitation funds can be used to maximize reductions in roads and trails erosion issues on an installation. The methods and results from a field validation study are provided in Appendix B in order to compare the results from the software package with results from on-site field calculations. The field methods described in Appendix B were used to validate the software calculations and are not needed for determining erosion potentials using the web-based decision support program developed for this project. Since the results from the software program are significantly correlated with the results from the on-site analysis, land managers can use the software program and avoid the costs of labor intensive field methods to estimate erosion potentials caused by roads and trails.

d. Appendix A contains background information. Appendix B contains project details and field data collection information from the field validation of the methodology. Appendix C contains results of the application of the technology at Camp Atterbury, IN. Appendix D contains summary information. Appendix E contains general references. Appendix F explains how the decision support system was used for classifying roads and trails at Camp Atterbury. Appendix G is a brief description of soil types at Camp Atterbury. Appendix H describes Geographic Information System processes to estimate erosion potentials using the Universal Soil Loss Equation. Appendix I contains field validation forms for calculating erosion potentials at Camp Atterbury. Appendix J contains field validation scores and results from Camp Atterbury.

5. Points of Contact (POCs). Headquarters, U.S. Army Corps of Engineers (HQUSACE) is the proponent for this document. The POC at HQUSACE is Malcolm E. McLeod, CEMP-II, 202-761-0632, or e-mail: malcolm.e.mcleod@usace.army.mil.

Questions and/or comments regarding this subject should be directed to the technical POC:

U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
ATTN: CEERD-CN-C (Michael Denight)
2902 Newmark Drive
Champaign, IL 61822-1072
Tel. (800) USA-CERL, x6749
FAX: (217) 373-7266
e-mail: Michael.L.Denight@usace.army.mil

FOR THE COMMANDER:

JAMES C. DALTON, P.E.
Chief, Engineering and Construction
Directorate of Civil Works

Appendix A

INTRODUCTION

U.S. Army training installations are experiencing significant erosion problems due to roads and trails created by vehicles deviating from established roadways during training exercises. Damage from erosion can be quite costly. Estimated costs for in-stream and off-stream impacts due to sedimentation in the United States exceed 11.6 billion dollars annually (Herzog et al. 2000). Soil erosion may result in eutrophication, reduced water quality, increased fugitive dust, reduced vegetation and ground cover, reduced soil nutrients, altered infiltration patterns, and poor quality wildlife habitats (Grace 2002; Gatewood 2002).

The negative impacts from soil erosion can be controlled. However, the areas with the highest erosion potential must be identified. Often, the most practical and effective means of identification is with the use of a model. Although the validity of many of these models has been well documented, they have not been tested for conditions that exist on military training facilities.

The objective of this PWTB was to develop a GIS software package to identify roads and trails and estimate their erosion potential at a military training facility. The goal was to provide a method to identify unimproved roads and trails on Army installations and classify them according to erosion potentials to improve management decisions regarding road closures or rehabilitation. The PWTB comprises several sections that contain the following information:

1. Appendix A: Introduction and Literature Review

This section discusses the problems with erosion from roads and trails, applicable erosion models, and published literature that address these topics.

2. Appendix B: Decision Support Software Program and Field Validation at Camp Atterbury, IN

This section discusses the factors and equations used to develop the model and the field validation methodologies.

3. Appendix C: Results

This section compares the results from the field validation efforts at Camp Atterbury, IN, with the model results.

4. Appendix D: Summary

This section summarizes the project and findings from the comparisons of field validation methodologies and model results.

5. Appendix E: References

This section lists the references cited in the body of the report.

6. Appendix F: Decision Support Web-Based Application

This section provides a step-by-step guide to the use of the decision support model for identifying roads and trails and estimating erosion potentials.

7. Appendix G: Camp Atterbury General Soil Descriptions

This section provides the soil classifications and descriptions at Camp Atterbury, IN.

8. Appendix H: GIS Process to Estimate Erosion with the USLE

This section discusses the use of GIS to add the K factor, to set minimum and maximum flow values, to calculate the LS factor, and to derive the slope for the USLE. These methods are given as background information only, so the reader can understand how the USLE factors were calculated for the model.

9. Appendix I: Field Validation Forms for Calculating Erosion Potential

This section provides the field validation forms in order to show what data were collected to estimate soil erosion from roads and trails to validate the model.

10. Appendix J: Camp Atterbury Field Validation Scores and Results

This section provides the raw data that were collected to validate the erosion potential model. These data were used to classify the selected roads and trails into the high, medium or low erosion potential categories.

Many military facilities experience significant soil erosion for various reasons. Training occurs on a daily basis on these facilities and creates conditions that can be quite erosive. Military vehicles disturb the soil and stunt or kill vegetation and form the roads and trails of concern on the military bases. These traffic ways are not constructed roads, but rather are trails that have formed from repeated use.

Geographic Information Systems (GIS) have had a profound effect on hydrologic modeling and model development (Xu et al. 2001). Hydrologic models often require extensive data preparation prior to model operation and, therefore, the data aspects of hydrologic models have often been a barrier to their use in solving watershed problems (Choi et al. 2002). A decision support system (DSS) is developed to assist decision makers with a well-structured provision to appropriately analyze or process data in lieu of having the decision maker perform the analysis (Choi et al. 2002). The basic consensus is that a DSS must be a helpful system for decision makers. The most useful DSS has feedback loops that allow the user to modify the initial query input as well as to support the exploratory nature of the process of scientific discovery. Along with the feedback, the DSS provides storage for evaluation of processes. Ariav and Ginsberg (1985) indicate the basic structure of a DSS as a computerized tool defined with three kinds of management parts including model management, data management, and interface management, with interactions involving internal and external data users.

A DSS can be useful in many vastly different applications. A common use for a DSS is to compare “before and after” scenarios. An example of this would be in the design report for a new residential development. The planners use the DSS to predict runoff pre-development and post-development, allowing for design of a properly sized retention pond. A very efficient DSS would recommend the retention pond size. Applied to this project, a DSS would acquire pre-vegetated and post-vegetated erosion estimates and recommend management practices for erosion reduction.

Literature Review

In recent years, the military has become sensitive to the potential environmental impacts from their activities. For example, Gatewood (2002) conducted a feasibility study of methods to construct environmentally friendly tank trails at the Fort Bliss military facility near El Paso, Texas. The project’s objectives were to improve trafficability and promote the Army’s four environmental pillars: compliance, prevention, restoration, and conservation. The major hazard due to tank trails in this region is wind erosion. At many other military facilities, including Camp Atterbury in central Indiana, erosion concerns are largely due to water erosion. The difference in erosion concerns between these two locations is primarily climate due to the differing geographic locations. However, both suffer the effects of bare soil caused by military vehicles.

A 1700-foot-long road on silt-dominated soils at Fort Bliss served as the study site for Gatewood (2002). Over time, the many bypass trails caused severe environmental degradation, including reduced vegetation and ground cover as well as reduced soil nutrients. Infiltration patterns were also altered and wildlife habitat reduced. Bypass trails were created from vehicles avoiding use of the main road that had already become denuded. These trails led to a proportionate increase in fugitive dust that had adverse effects in surrounding communities. Effects include increased respiratory illnesses, allergy problems, asthmatic inflammatory conditions, and wind blown bacteria leading to increased illnesses. During strong wind, visibility along the main road was dangerously reduced, increasing the potential for accidents.

In 1998, Fort Bliss acquired a few truckloads of the geosynthetic sand grid, or presto geoweb cellular confinement system. The repairs to trails using this geotextile worked well, and no trafficability problems occurred since the repairs were made. Geoweb is a cost-effective and functional answer to silt-dominated soil problems on Fort Bliss training-area roads.

Ayers (1994) studied environmental damage from tracked vehicles in the Pacific Northwest and found that bare soil exposed from track vehicle traffic had increased cone penetration resistance by 73 percent. More damage was caused by spring driving versus the driving done during the summer. This difference was attributed to higher soil moisture content in the spring. Other factors found to contribute to environmental damage from tracked military vehicles were contact area, surface pressure, total weight, track slip, track design, and vehicle speed. Surface conditions that affect the impact of tracked vehicle traffic include soil moisture content, plant species, soil type, plant growth stage, and climatic conditions. The adverse effects from these types of vehicles were greater on roads or trails with low turn radii. This effect was largely attributed to increased pivoting of the inner track as the turn radii decreased.

Many military facilities have uninhabited lands or lands that are seldom used. Often, these areas are forested and may contain many roads and trails within them. Additionally, other roads and trails on military training facilities are also similar to forested roads in that many of these traffic ways have no maintenance performed and are often left unattended after use. Forest roads actually have little erosion if left unaltered (Grace 2002). This can be attributed to increased surface cover from trees and forest litter providing better protection from raindrop impact. The heavy use of military training facilities often destroys this residue or decreases its effectiveness. In such instances, these forest roads can become major contributors of potentially detrimental environmental impacts (Binkley and Brown 1993). They account for as much as 90 percent of all erosion losses on forested lands (Anderson et al. 1976; McClelland et al. 1999; Megahan 1972; Megahan and Kidd 1972; Patric 1976). Forest floor disturbance can increase erosion rate by a hundredfold (Grace 2002). Several factors contribute to increased erosion potential of forest roads, among them: removal of surface cover, concentrated flow in ditches, interception of subsurface flow, destruction of the natural soil structure, increased slopes, and soil compaction.

A significant portion of the roads and trails at military training facilities, including Camp Atterbury, are graveled roads. Applying gravel to a forest road has many advantages such as reducing the amount of exposed surface soil, providing a firm road surface that resists rutting, and reducing the velocity of water on the road surface, thereby reducing its erosive force (Kochenderfer and Helvey 1987). Egan (1999) recommended various concepts to minimize erosion from forest roads. Reducing the overland flow momentum reduces the shear forces and thus reduces the total erosion. This is most often accomplished by diverting the flow to the surrounding forest floor or by installing drainage dips in the forest road. Avoidance is the term used to describe the prevention of surface water and channels. Channels concentrate flow and increase the flow’s ability to detach sediment. Adverse effects of channels are controlled by limiting the number of stream crossings and with the use of settling ponds, among other means.

On-site assessment of erosion potential is often not practical for an entire watershed or military facility. Additionally, erosion conditions may not be visible or evident due to vegetation, current weather patterns, or other extenuating circumstances. Computer models allow a land manager to readily identify areas of high erosion potential. Numerous soil erosion models have been developed including the Water Erosion Prediction Project (WEPP; Flanagan and Nearing 1995), the Universal Soil Loss Equation (USLE; Wischmeier and Smith 1978), the Revised Universal Soil Loss Equation (RUSLE; Renard et al. 1997), the Distributed Hydrology-Soil-Vegetation Model (DHSVM; Wigmosta et al. 1994), and many others.

Various studies have been conducted to test models for soil loss from forestlands and roads. For example, Elliott et al. (1999) used the Forest Service Water Erosion Prediction Program (FS WEPP) to predict erosion in forested areas. He also compared it to the original WEPP. The FS WEPP model utilizes inputs for conditions existing in forested areas and returns a predicted value of erosion. Elliott et al. (1999) indicated that the use of FS WEPP was quite low due to two factors: the user’s lack of time to devote to using the FS WEPP interface, and the complexity of the FS WEPP interface.

Rhee et al. (2004) conducted a study to assess the accuracy of erosion modeling on forest roads with the WEPP model using various levels of input: high, intermediate, and low for both the road traveled-way geometry and buffer geometry. For buffer modeling, sediment delivered to a stream was the measured result. This study concluded that high levels of detailed input are required to accurately predict sediment delivered to streams. However, for estimated detached sediment, the low levels of detail predicted similar levels as inputs with high levels of detail. In fact, the difference between all three levels of input detail was less than 5 percent.

In addition to the FS WEPP model, many other models exist for estimating soil erosion and its effects in forested areas. These models include SHETRAN/SHESED (Wicks and Bathurst 1996; Burton and Bathurst 1998), GEOTOP (Tamanini et al. 2003), and IDSSM (Dhakal and Sidle 2003), among many others. The SHETRAN/SHESED model is based upon the System Hydrologiuqe European (SHE) hydrology model. Like WEPP, all of these models are process-based. The Distributed Hydrology-Soil-Vegetation

Model (DHSVM), also process-based, was used by Doten et al. (2005) to conduct research in forested areas of the Pacific Northwest. The processes on which this model is based are considered by its authors to be the main sources of sediment generation in forested environments. The sources are mass wasting, hillslope erosion, and road surface erosion. This model is a complex, spatially distributed hydrological model that explicitly represents the effects that dissimilar elements of topography and subsurface attributes can have on the downslope redistribution of subsurface moisture.

The USLE is an empirical model developed with more than 10,000 plot-years of data (Wischmeier and Smith 1978). It was designed to compute long-term average annual soil losses from sheet and rill erosion for mainly agricultural applications. The long-term average annual soil loss is calculated by multiplying the six factors of the equation, making it a quite simple formula when compared with process-based models. Soil deposition can also be of concern, and the USLE does not account for this like models such as WEPP do.

The USLE remains the most widely used method for quickly obtaining erosion estimates (Yu 1999). Advantages of the USLE include the simplicity of the model, the data required are typically readily available, and the results are easily used within a DSS. The nature of military training allows for some roads and trails to revegetate naturally over time. All the while, many new roads and trails may be created. Using technology such as the FS WEPP model may be appropriate for the roads and trails that currently exist at a military installation but would be impractical to apply over the entire military facility. The military needs a simple estimation tool that does not require large time requirements or extensive training to operate.

Non-SI[*] units of measurement used in this report can be converted to SI units as follows:

Multiply	**By**	**To Obtain**
acres	4,046.873	square meters
acres	2.457	hectares
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1.609347	kilometers
tons (2,000 pounds, mass)	907.1847	kilograms

---

[*] *Système International d’Unités* (“International System of Measurement”), commonly known as the “metric system.”

Appendix B

DECISION SUPPORT SOFTWARE PROGRAM AND FIELD VALIDATION AT CAMP ATTERBURY, IN

This project identifies roads or trails that should be closed or upgraded due to their potential for creating erosion problems at military training facilities. Camp Atterbury was used to demonstrate and evaluate this method, which is broadly applicable and could be used at other installations as well.

In order to develop a DSS for roads and trails, erosion potentials were estimated by using a modified version of the Universal Soil Loss Equation (USLE) in a Geographic Information Systems (GIS) computer program. Data for each component of the USLE was acquired in the GIS software and applied over the entire site. The site-wide erosion potential data from the USLE estimates were overlain with the roads and trails of Camp Atterbury so that an estimated erosion potential for roads and trails could be acquired. Seventy-five points on roads and trails were then randomly selected so that qualitative validations could be made with erosion conditions at the Camp. The USLE site-wide erosion estimates were the basis for the creation of a prototype DSS (Appendix F).

Camp Atterbury, located approximately 35 miles south of Indianapolis, near Edinburgh, Indiana, served as the study location. The majority of the facility is within Bartholomew County. A small portion of the base along the northern edge is located in Johnson County, and a small portion along the western edge is located in Brown County, as shown in Figure B.1. Camp Atterbury is an Army National Guard (ARNG) installation, federalized in 2002 for the mobilization of ARNG and United States Army Reserve (USAR) units. Camp Atterbury offers its commanders the support required to function as a complete unit for mission training (http://www.campatterbury.org/welcome.htm).

Camp Atterbury is located on more than 33,000 acres in Central Indiana, and includes more than 145 live firing ranges that include 57 direct fire ranges, 10 mortar firing points, and more than 80 artillery firing positions. The artillery capabilities are designed to support training from both the air and ground, and the Indiana Air National Guard established an air to ground range in 1965. During the current mobilization, it is quite common to have 4,000 to 5,000 troops training simultaneously at the base.

Camp Atterbury soils are of four general soil classifications, as taken from the general soil map produced by the USDA-SCS (1990). These soils are of the Pekin-Chetwynd-Bartle, Hickory-Cincinnati-Rossmoyne, Crosby-Miami-Rensselaer, and Stonelick-Chagrin associations. From these four general classes, ten soil series were listed on the facility. The series name and brief descriptions are given in Appendix G. Seven of the soils are silt-loam, two are loam, and one is a silty-clay-loam.

The potential erosion levels were estimated over the entire facility, using a modified version of the USLE in a GIS software package. This process is significant and more easily accomplished when broken into smaller steps to obtain each component of the USLE. The USLE is shown in equation B.1 as it was applied to this study. Once each variable was obtained, equation B.1 was applied to the entire camp area, resulting in estimates of erosion potential site wide.

The rainfall-runoff erosivity factor, R, is a constant based on geographic location and climate (Wischmeier and Smith 1978). It is calculated from the annual summation of rainfall energy in every storm, times its maximum 30-minute intensity (Wischmeier and Smith 1978). The R factor varies with climate and geographic location. It is acceptable to consider only one R factor on this scale, because geographic, rainfall, and climatic patterns do not vary significantly for the area of concern for long periods of time. If the area of concern did, however, have mountainous terrain for example, more than one R factor may need to be considered. An R factor of 298 (megajoule centimeter / hectare / hour [MJ cm/ha/hr]), was acquired for Camp Atterbury from an R-Factor map obtained from Haan et al. (1994).

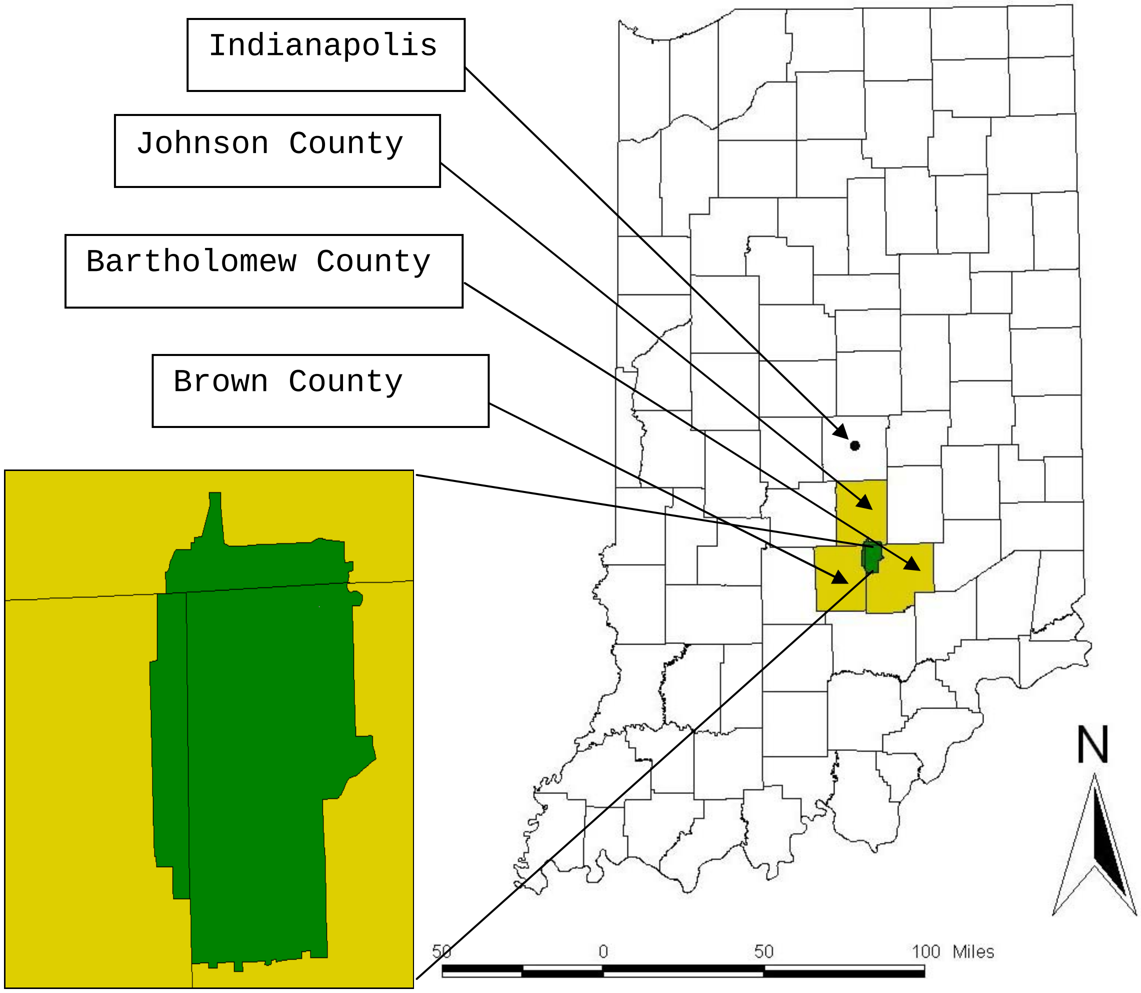


Figure B.1. Camp Atterbury location

$$A = R*K*LS*C*P \qquad \text{Eq. B.1}$$

Where A is defined as the average annual soil loss in metric tons per hectare per year (t/ha/y),

R is the rainfall-runoff erosivity factor ([MJ cm/ha hr]),

K is the soil erodibility factor ([t ha hr]/[MJ ha cm]),

LS is the slope and slope length factor (dimensionless),

C is the cropping management factor (dimensionless), and

P is the conservation management factor (dimensionless).

The soil erodibility factor, K, is based upon the soil type and properties. This was acquired from the State Soil Geographic Database (STATSGO) available through the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and the Soil Survey Geographic (SSURGO) Database, also available through the NRCS. Only Bartholomew County data were available in SSURGO format at the time of this study; therefore, the K factor for portions of Camp Atterbury in Brown and Johnson Counties were completed with the use of STATSGO data. The soil erodibility factor is defined as the soil loss rate per erosion index unit for a specified soil as measured on a standard plot (Haan et al. 1994). K values ranged from 0.03 to 0.72 (t ha hr / MJ ha cm). The K value is most typically not included in an attribute table to SSURGO or STATSGO maps. Procedures for adding K factor values are discussed in Appendix H.

The slope length factor, L, is a ratio of soil loss from a field slope length to soil loss from a 22.1 meter length under identical conditions. The slope length was estimated using the flow accumulation. The slope steepness factor, S, is a ratio of soil loss from the field slope gradient to soil loss from a 9 percent slope under otherwise identical conditions. The slope length and steepness were derived from a geographical information system (GIS) elevation map obtained from the U.S. Geological Survey (USGS).

The length and slope factors were computed using equation B.2 (Moore and Burch 1986). LS values ranged from 0 to 28.04. Appendix H includes a complete discussion of the methods to calculate the LS factor.

$$LS = \left(\frac{FlowAccumulation*CellSize}{22.13}\right)^{0.4} * \left(\frac{\sin\Theta}{0.0896}\right)^{1.3} \qquad \text{Eq. B.2}$$

where LS is the Length-Slope factor,

Flow Accumulation is the resultant GIS map with cell values for the number of cells flowing into that cell,

Cell Size is the length of each cell as set by the user (units in length are defined by the user), and

Theta (θ) is the slope angle in degrees.

The USLE estimates combined sheet and rill erosion. It does not predict ephemeral gully or classical gully erosion. This typically forces the user to modify the flow accumulation map by setting an upper limit on the quantity of flow accumulation, used in computing the LS factor. Appendix H shows the process to set an upper limit, which was not done in this study for two reasons. The first is to examine whether the USLE could be used in this manner, which is outside its validated use. The second is to ensure that the estimated erosion values were high to ensure that erosion potential would be more likely overpredicted than underpredicted, providing a built-in safety factor.

Cells where flow originated had a flow accumulation value of zero. When using this zero LS value in USLE, the erosion potential estimate becomes zero (all factors are multiplied). A minimum flow accumulation value of 1 was set for all cells where flow originated to prevent this (process described in Appendix H).

The USLE support practice factor, P, refers to support practices such as terracing, strip cropping, or contouring. It is a ratio of soil loss with this practice to soil loss without any practices at all. For this study, no support practice is used, so P was made to equal 1 (Tiwari et al. 2000).

The cover management factor, C, is the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow (Wischmeier and Smith 1978). To show the significant erosion that may be prevented from bare soils on the roads and trails of Camp Atterbury, erosion potentials with and without the cover factor have been computed and compared. The land-use cover was acquired from the Earth Remote Observation Systems (EROS) dataset from the USGS. The C factor values used for each land-use class in the land-use cover data are shown in Table B.1. To calculate erosion estimates with the USLE cover factor included, the erosion potential (without a cover included) was multiplied by the land-use cover map that used appropriate cover values for the land use. This calculation produced an additional GIS map of the potential erosion estimates including the cover factor.

The presence of gravel on roads also reduces erosion (Wu 2001; Egan 1999). To estimate the erosion potential on the graveled roads at Camp Atterbury, a C factor of 0.25 was applied for class 3 roads (also referred to as improved roads), and for class 4 roads (also referred to as semi-improved roads) a C factor of 0.50 was applied (Wu 2001).

Table B.1. Land use cover factors

Land Use	C Factor
Water	0.00
Low Density Residential	0.03
High Density Residential	0.03
Deciduous Forest	0.02
Evergreen Forest	0.02
Mixed Forest	0.02
Pasture / Grasses	0.05
Row Crops	0.18
Woody Wetlands	0.00
Herbaceous Wetlands	0.00
Class 3 road	0.25
Class 4 road	0.50

Road Classes

Five classes of roads were defined by Ayers et al. (2005). The classes are:

- Class 1 - Primary, all weather, hard surface (e.g., freeway, state highway)

- Class 2 – Secondary, all weather, hard surface (e.g., local thoroughfare, county road)

- Class 3 – Light duty, all weather, hard, or improved surface (e.g., residential street, rural road, or graveled road)

- Class 4 – Fair or dry weather, unimproved surface (e.g., improved road with no maintenance, unimproved dirt road; twin tracks; no tracks, but easily discerned vegetation change)

- Class 5 – Difficult to see (better seen across canyon than when driving), old fire break, or cow or motorcycle path

Class 1 and 2 roads at Camp Atterbury were not considered for this study since they are improved roads and would not suffer from erosion of the type estimated by the USLE. The roads and trails of interest at Camp Atterbury were divided into two categories: gravel and dirt. The gravel roads were often divided into subcategories according to their condition, improved and semi-improved.

The site-wide erosion estimates from the modified USLE were overlain with a map of the existing roads and trails of Camp Atterbury to obtain erosion estimates on the roads and trails of the Camp. Best case and worst case scenarios (with and without cover considered) of erosion estimates were made so that comparisons could be made to calculate potential erosion reduction.

Field Validation Data Collection and Analysis

The second objective of this study was to validate the erosion potential estimates using on-site qualitative measures. The erosion potential maps were divided into three categories: low, moderate, and high. Low erosion potential is assumed for 0 to 9 tons per hectare per year (t/ha/y), moderate erosion potential for greater than 9 to 24.2 t/ha/y, and high erosion potential for erosion greater than 24.2 t/ha/y.

Qualitative estimates of erosion were made at 75 randomly selected locations on roads and trails at Camp Atterbury. Figure B.2 shows these locations. Coordinates of each location were identified with a global positioning system (GPS). Attributes for vegetation, gullies, slope, and gravel road conditions were documented with photographs and on forms found in Appendix I. These factors were used to estimate the erosion severity. Each of the factors was given scores according to its conditions regarding potential erosion; a value of low (1), moderate (2), or high (3) was assigned. The method used to evaluate erosion potential on the roads and trails was based on work by Bracmort (2004) who evaluated the performance of various management practices. Unprotected earthen waterways and ephemeral gullies significantly contribute to the erosion process (Peterson et al. 2002). Soil losses increase at great rates with increasing slopes, even more so than runoff (Wischmeier and Smith 1978). For these reasons, vegetation, slope, and rill or gully presence were considered for erosion potential validation.

Vegetation scores were assigned by counting the number of anchored vegetation at 1-foot intervals in a 20-foot span across the road or trail. For traffic ways that are at least 20 feet wide, a tape was placed across the road perpendicular to the direction of travel with 10 feet on either side of the center. For traffic ways less than 20 feet wide, the transect was angled so that it spanned 20 feet across the road. The vegetation score was a low value if the number of anchored vegetation marks ranged between 15 and 20. Moderate scores were assigned for vegetation marks from 10 to 14. A high score was assigned for less than 10 marks.

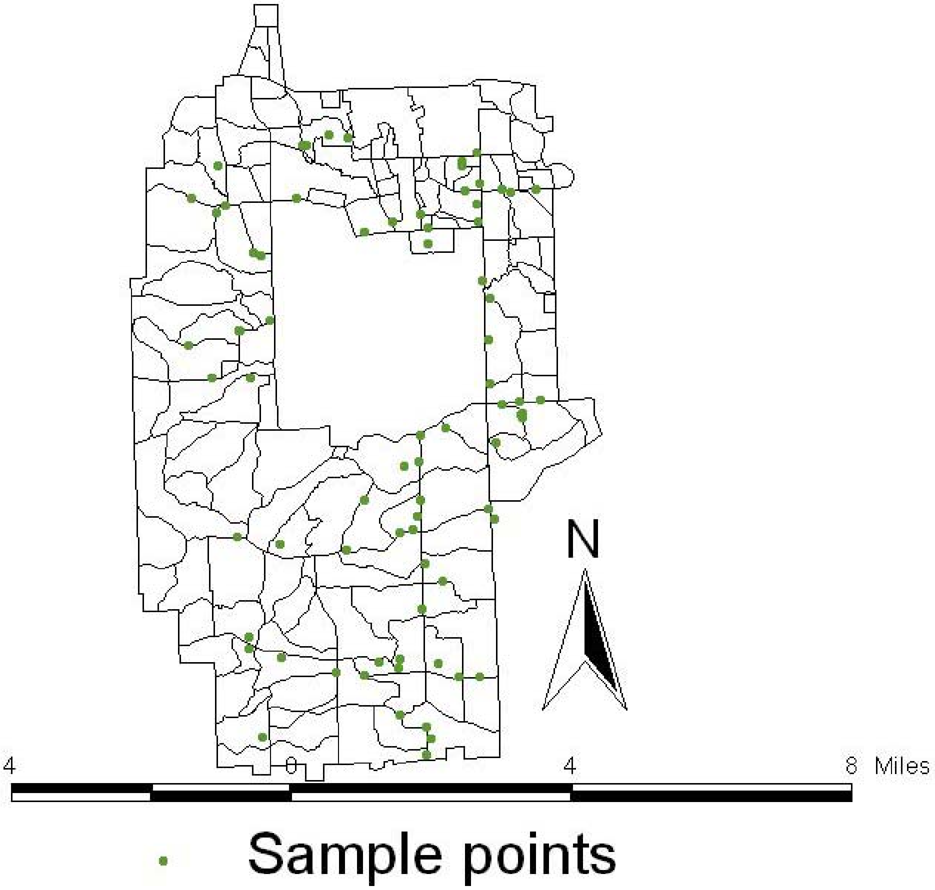


Figure B.2. Erosion validation sample locations at Camp Atterbury

Gravel road evaluations were treated as vegetation (Egan 1999; Wu 2001). A transect was placed across the road and gravel pieces greater than 2 mm were counted as gravel cover. Because gravel coverage results in Wu’s study (2001) were similar to the method used to validate vegetation in this research (25, 50, and 75 percent were compared to the results of a bare plot), scores for gravel roads were given in a like fashion to vegetation.

Rills and gullies were documented with their approximate dimensions, length, width, and depth. Gullies are significantly larger than rills (Peterson et al. 2002; Haan 1994). Rill erosion occurs if depth and slope is sufficient to cause channel incision in concentrated microrelief channels (Haan et al., 1994). Gullies occur where the location of channelized flow areas ceases to be controlled by microrelief and becomes controlled by macrorelief (Haan et al. 1994). In the on-site survey for this study, if no rills or gullies were present, a score of 1 (low) was assigned. For roads or trails with only rills present, a score of 2 (moderate) was assigned. Roads or trails with one or more gullies present were assigned a value of 3 (high).

Slope scores were acquired with a clinometer and scores were assigned accordingly. Low scores were assigned for slopes of 2 percent or less, moderate scores for slopes from 2 through 6 percent, and high scores for slopes greater than 6 percent.

The overall observed erosion score was obtained for each sample by averaging these scores and rounding to the nearest integer. A final validation score of low (1), moderate (2), or high (3) was then assigned to each location sampled. This score was then compared with the predicted score for the same location on the site-wide predictions. More details of the evaluation criteria and the forms are given in Appendix I.

Two additional analyses of the data were performed in order to further investigate the contribution of rills and gullies towards erosion potential. The observed score was changed to match the score of rills and gullies, regardless of the vegetative or slope scores, and the observed score was also calculated with the gully score given twice the weight of that given to vegetation or slope (equation B.3). Both of these validation observation scores were then compared with estimated erosion potential and computed with the same statistical analysis as the original method.

$$ObservedScore = (0.25 * VegetationScore) + (0.50 * GullyScore) + (0.25 * SlopeScore) \oplus \text{Eq.B.3}$$

Typical conditions of the sites that were sampled can be seen in Figures B.3, B.4, and B.5. The figures correspond to an improved road, semi-improved road, and trail, respectively. The validations were completed over 3 days (15, 16, and 24 March 2005). When beginning to acquire data at each location, the time, date, and coordinates were documented and photographs taken. The time to complete each sample location varied depending on road condition and location. Average time to complete one validation was approximately 10 minutes. When initially starting to acquire the data, the times were higher. Also, it was very advantageous to have a map of Camp Atterbury on hand for safety reasons, and to be able to identify the location on the facility at all times. The map also allowed for plotting coordinates of all points that were obtained during the day.

Figure B.3. Improved road with low erosion at Camp Atterbury

Figure B.4. Semi-improved road with moderate erosion at Camp Atterbury

Figure B.5. Camp Atterbury trail with high erosion

Spearman's rank correlation (Neter et al. 1996) was computed for the validation sample points. Although Pearson's correlation (Neter et al. 1996) is typically the standard statistical method used to identify correlations, it assumes a standard normal distribution, so it was not used in this case, because the datasets were categorized into erosion levels of low, moderate, and high; thus a normal distribution could not be assumed. The value of rho (ρ) obtained in Spearman's rank correlation was then compared with the critical value of ρ for a dataset with 75 samples and alpha (α) equal to 0.05 (a confidence level of 95 percent). The null hypothesis (H_O) states that there is no rank order correlation between predicted and observed erosion rates. The alternative hypothesis (H_a) states the opposite, that a rank order relationship is present between predicted and observed erosion potential. To reject H_O is to say that there is a rank order relationship between predicted and observed erosion at Camp Atterbury. H_O is rejected if the value obtained for ρ is greater than the critical value of ρ.

Appendix C

RESULTS

Decision Support Software Program

Erosion potential maps were generated for Camp Atterbury based on the modified Universal Soil Loss Equation (USLE) technique previously described. The first erosion potential map created did not consider vegetative cover and therefore represents the erosion potential for instances in which there is bare soil (Figure C.1). The second map created includes the cover factor (Figure C.2). As seen in these maps, the erosion potential decreases significantly with the addition of the cover factor.

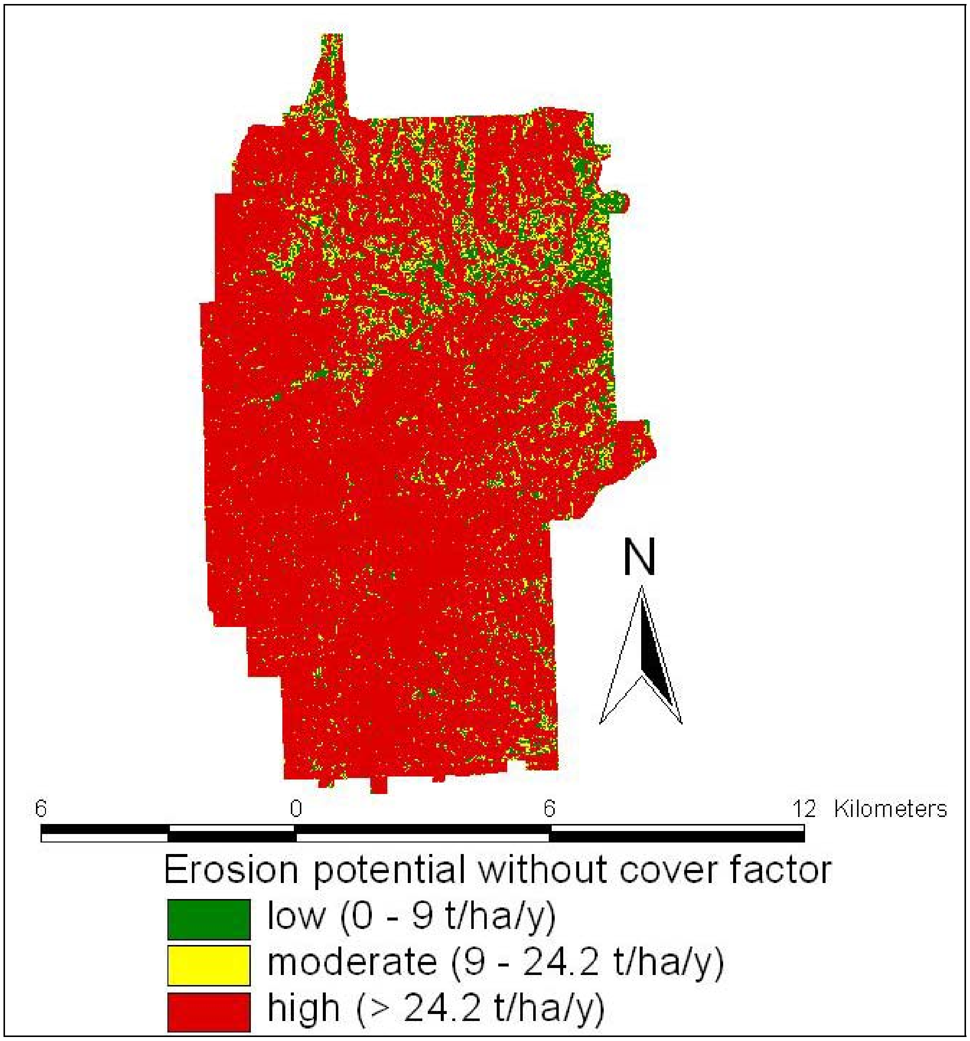


Figure C.1. Camp Atterbury modified USLE estimated erosion potential without cover factor

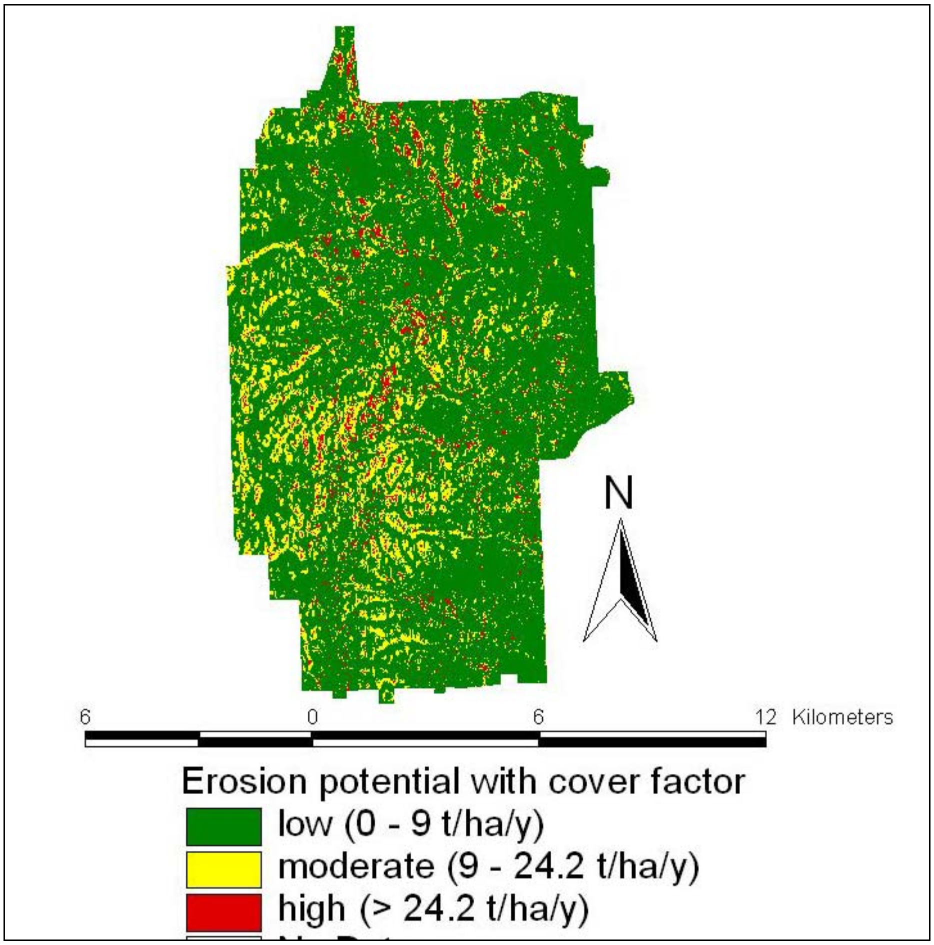


Figure C.2. Camp Atterbury modified USLE estimated erosion potential with cover factor

More than 11,000 hectares, or 88 percent of Camp Atterbury, is in the high erosion potential category without a cover factor. The moderate erosion potential category represents 8 percent, or just over 1000 hectares, while the low erosion potential category has the smallest area, representing 4 percent of the Camp, or just slightly less than 500 hectares. The percentage of Camp Atterbury’s area for erosion potential with C factor included are 5, 16, and 79 percent for the high, moderate, and low erosion classes, respectively. These are areas of approximately 600, 2000, and 10,700 hectares.

Once potential erosion levels were obtained for the entire facility, lengths of gravel and dirt roads in each category were obtained. Two road types, asphalt and driveway, were not considered because erosion would not occur on them in the manner estimated by these techniques. Erosion potential was estimated for the roads and trails of Camp Atterbury by overlaying the roads and trails map on the site-wide estimated erosion potential maps and extracting the erosion potential.

Tables C.1 and C.2 show the percentage of each type of road or trail in each estimated erosion potential category for the modified USLE method. Table C.1 was acquired from erosion estimates that did not have a cover factor included (C = 1 was assumed). Table C.2 utilized the appropriate C factor for each land use.

Table C.1. Percent of road and trail lengths at Camp Atterbury with estimated erosion potential in low, moderate, high, and deposition categories without a cover factor

Road Type	Erosion Level			
	Deposition	Low	Moderate	High
	Percent of Road Type in Category			
USLE estimated gravel	N/A	7.0	10.3	82.7
USLE estimated dirt	N/A	6.8	12.0	81.2

Table C.2. Percent of road and trail lengths at Camp Atterbury with estimated erosion potential when cover factors are considered in low, moderate, high, and deposition categories

Road Type	Erosion Level			
	Deposition	Low	Moderate	High
	Percent of Road Type in Category			
USLE estimated gravel	N/A	83.2	11.3	5.5
USLE estimated dirt	N/A	82.1	11.4	6.5

Analysis of these tables shows that, by having good cover, erosion can potentially be reduced significantly. Comparison of the percent erosion reduction in the road-segment lengths called dirt, show potential erosion reductions from 81.2 percent of the segment lengths in high potential erosion to 6.5 percent of the road lengths in that category for the modified USLE estimated method. This corresponds to lengths of approximately 160 kilometers and 12.9 kilometers of road, respectively.

After a cover factor has been considered, the road lengths change in each category. For the high categories, the length of roads and trails decreases, while the change is an increase for the roads and trails in the low potential erosion category. Table C.3 shows this in percent changes. The negative values shown in this table indicate an increase in the length of roads in these erosion level categories. This increase is encouraging since it means that the length of roads and trails for the high category has decreased, and more roads and trails are now in the moderate and low categories.

Table C.3. Percent reduction in road lengths at Camp Atterbury in erosion potential categories after cover factor has been considered (negative values indicate an increase)

Road Type	Erosion Level			
	Deposition	Low	Moderate	High
USLE estimated gravel	N/A	-76.2	-1.0	77.2
USLE estimated dirt	N/A	-75.3	0.6	74.6

Predicted vs. Observed Erosion Potentials on Roads and Trails

Seventy-five randomly selected locations on roads and trails at Camp Atterbury were used to validate the modified USLE erosion potential estimates. A map depicting these locations was shown previously in Figure B.2. Visual inspection of the erosion validation sample locations map shows two areas that were left unsampled in the central and southeastern portions of the facility. These are the impact and air ground areas, which are the focal areas for ordnances and the firing ranges and were unsafe to validate. Table C.4 contains sample distributions by road type, with gravel roads broken into two categories: improved and semi-improved roads. Improved roads are considered to be Class 3, and semi-improved roads are considered to be Class 4.

Table C.5 shows the results of predicted versus observed erosion with the modified USLE methods. The observed erosion data for the USLE estimates were obtained as discussed in Appendix B.

Table C.5 shows that 51 percent of the sample points were correctly predicted (38/75) for the modified USLE method. Twenty-nine total locations were overpredicted (39 percent). Of the overpredicted locations, 3 were predicted as having moderate erosion potential and observed as having low erosion, 7 were predicted in the high erosion potential category and observed as having low erosion, and 19 were predicted as having high erosion potential and observed in the moderate erosion category. Eight locations were underpredicted (11 percent). Seven of these locations were predicted in the low erosion potential erosion category and observed in the moderate erosion category. One location was predicted in the moderate erosion potential category and observed in the high erosion category. A table containing vegetation, gully, and slope score as well as all of the accompanying data for each validation sample location is given in Appendix J.

Table C.4. Validation sample distribution by road type

	Sample Distribution by Road Type		
Road Type	Dirt	Improved	Semi-Improved
Number of Samples	42	18	15

Table C.5. Modified USLE predicted versus observed erosion for roads and trails at Camp Atterbury

		Predicted Erosion Potential		
		Low	Moderate	High
Observed Erosion	Low	8	3	7
	Moderate	7	19	19
	High	0	1	11

Spearman’s rank correlation was computed for the validation sample points estimated with the USLE. The value of rho (ρ) obtained in this correlation was 0.50. The critical value of ρ for a dataset with 75 samples and alpha (α) equal to 0.05 is 0.19. Because the value obtained for ρ is greater than the critical value of ρ, the null hypothesis is rejected (Neter et al. 1996). The correlation between predicted erosion and observed erosion potential is significant, meaning that this procedure is a reliable method for predicting erosion potential.

The overpredicted sample points were attributed to two factors. The USLE does not estimate classical gully or ephemeral gully erosion. It is necessary, therefore, to limit slope lengths to approximately 150 meters when computing the LS factor in the USLE. This was not done for predicting erosion at Camp Atterbury. It was intended to over predict rather than under predict the erosion potential for any case where the estimated erosion potential did not match the observed erosion potential. This provides a built-in safety factor to the erosion estimation tool. The calculated results of the USLE are long-term average annual erosion potential. Likelihood is high that these roads and trails at Camp Atterbury were recently created. Although these locations were predicted in the low or moderate categories, they will likely be in the high erosion category if left unattended.

Data for points predicted to be more severe than observed values were examined to determine if reasons for this were consistent. The data examined included the LS factor, slope obtained in the GIS software, observed slope, vegetation score, and gully score (Appendix J). For the 29 points that were overpredicted by the USLE approach, no consistent reasons were found.

The eight points that were predicted by the USLE method to be less severe than observed had a very consistent reason for the missed predictions. For these sites, the GIS software estimated slopes were significantly lower than the slopes seen during on-site validation. The errors in slope were attributed to the Digital Elevation Model (DEM) data. This software uses an elevation value of one cell (30m x 30m) and compares it to the surrounding cell values to acquire the slope. It does not account for elevation changes that may occur within each cell. This error could be minimized by having more accurate input data (e.g., a DEM of better quality).

The observed erosion data were further investigated by assigning validation scores based only on the score for rills and gullies (Table C.6), which resulted in little change from the original analysis. The calculated value of ρ for assigning observed erosion scores according to the presence of rills and gullies was 0.47, indicating a significant correlation between predicted and observed erosion potential when the observed erosion is based solely on the presence of rills and gullies. As shown in Table C.6, 49 percent of the locations were correctly predicted by the modified USLE process (37/75), 37 percent of the locations were overpredicted (28/75), and 13 percent of the locations were underpredicted (10/75). The locations that were underpredicted again had significantly lower slopes for GIS-predicted slopes compared with the observed slopes (Appendix J).

Table C.6. Modified USLE predicted versus observed erosion for roads and trails at Camp Atterbury for rill and gully scores

		Predicted Erosion Potential		
		Low	Moderate	High
Observed Erosion	Low	8	3	6
	Moderate	7	17	19
	High	0	3	12

The results of the validations show that the modified USLE method for predicting erosion potential on roads and trails is reliable for the particular use planned by the military. The predicted erosion estimates matched the observed erosion for more than 50 percent of the locations sampled. For the predictions that were incorrect, 29 out of 37 were predicted in a more severe erosion condition than observed (overpredicted), which is more desirable than predicting erosion potential less than observed (underpredicting). Typically, the overpredicted cases were overpredicted by a single category. The eight locations with underpredictions were a result of poor DEM slope data.

The military needs a simple method to estimate soil erosion due to unimproved roads and trails. The generalized categories obtained with the modified USLE were sufficient to accomplish this. Based on the performance of the USLE approach and its simplicity, it was selected for use in the DSS. Appendix F gives the procedure for using the web-based GIS software program to identify roads and trails and estimate erosion potentials on military lands.

Appendix D

SUMMARY

U.S. Army installations experience negative environmental impacts from soil erosion caused by the repeated use of graveled and unimproved roads and trails by military vehicles. The erosion potential at Camp Atterbury was estimated using a modified version of the USLE. The erosion potential was calculated with and without a vegetation cover factor included. The estimated erosion on the roads and trails at Camp Atterbury was extracted from those results. Potential erosion reduction due to revegetation was calculated for the Camp’s roads and trails.

Seventy-five points on roads and trails were randomly sampled for validating the erosion potential model for Camp Atterbury. Data were collected for each location to identify the erosion category according to the conditions for vegetation, slope, and presence of rills and gullies. The observed erosion results were compared with the modified USLE predictions at those locations. Of the 75 points, 38 were correctly predicted from the USLE methodology. The USLE predicted 29 points to have a higher erosion potential than the observed erosion. This is not unexpected because the data inputs were conservative in order to minimize under prediction of erosion. A total of eight points were predicted with less severe erosion potential than observed.

Additional analyses were run by assigning observed scores according to the rill and gully score and also by weighting the rill and gully score. The USLE method performed similarly to the analyses presented previously for these modifications in observed erosion scores. For the points that were not correctly predicted, it was a much more desirable result to predict a more severe erosion condition than observed, rather than predict a less severe erosion condition than observed. This would allow the land manager to be prepared for the negative impacts from erosion. Sites that are predicted less severe than observed may go undetected until a severe condition exists.

Spearman’s rank correlation showed with 95 percent confidence that a significant correlation exists between predicted and observed erosion potential and the modified USLE method. Therefore, the processes used to obtain these results can be used to estimate erosion potential of roads and trails at Camp Atterbury and other U.S. Army training facilities.

Appendix E

REFERENCES

Literature Cited for Appendix H

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. Forest and water: effects of forest management on floods, sedimentation, and water Supply. General Technical Report PSW-18. San Francisco, Cal: USDA Forest Service.

Ayers, P.D. 1994. Environmental damage from tracked vehicle operation. *Journal of Terramechanics* 31(3): 173-183.

Ayers, P.D., A.B. Anderson, and C. Wu. 2005. Analysis of vehicle patterns during field Training Exercises to identify potential roads. *Journal of Terramechanics*, In Press.

Ariav, G., and M.J. Ginzberg. 1985. DSS Design: A systemic view of decision support. *Communications of the ACM* 28(10): 1045-1052.

Bennett, S.J., J. Casalf, K.M. Robinson, and K.C. Kadavy. 2000. Characteristics of Actively Eroding Ephemeral Gullies in an Experimental Channel. *Transactions of the ASAE* 43(3):641-649.

Binkley, D., and T.C. Brown. 1993. Forest practices as non-point sources of pollution in North America. *Water Resources Bulletin* 29(5): 729-740.

Bracmort, K.S. 2004. An evaluation of structural best management practices 20 years after installation. PhD. Thesis. Agricultural and Biological Engineering, Purdue University, West Lafayette, IN.

Burton, A., and J.C. Bathurst. 1998. Field variability of landslide model parameters. *Environmental Geology* 35: 110 – 115.

Choi, J.Y., B.A. Engel, and J. Harbor. 2002. Integrated DSS of Web-GIS and Online Watershed Delineation for Hydrologic Impact Evaluation. ASAE Paper Number 023038. American Society of Agricultural Engineers, St. Joseph, MI.

Dhakal, A.S., and R.C. Sidle. 2003. Long-term modeling of landslides for different forest management practices. *Earth Surf. Process. Landforms* 28: 853-868.

Doten, C.O., L.C. Bowling, E.P. Maurer, J.S. Lanini, and D.P. Lettenmaier. 2005. A spatially distributed model for the dynamic prediction of sediment erosion and transport in mountainous forested watersheds. *Water Resources Research*, In Press: http://www.hydro.washington.edu/SurfaceWaterGroup/Publications/dhsvm_sediment.pdf

Egan, A.F. 1999. Forest roads: where soil and water don’t mix. *Journal of Forestry*. 98(8): 18-21.

Elliot, W.J., D.E. Hall, and S.R. Graves. 1999. Predicting sedimentation from forest roads. *Journal of Forestry* 97(8):23-28.

Flanagan, D.C., and M.A. Nearing, eds. 1995. USDA-Water Erosion Prediction Project Hillslope Profile and Watershed Model Documentation. NSERL Report Number 10, USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN.

Flanagan, D.C., J.R. Frankenberger, and B.A. Engel. 2004. Web-based GIS application of the WEPP model. ASAE Paper Number 042024. American Society of Agricultural Engineers, St. Joseph, MI.

Gatewood, R. 2002. Environmentally friendly army tank trails. http://www.forester.net/ecm_0211_environmentally.html.

Grace, J. M. III. 2002. Effectiveness of vegetation in erosion control from forest road sideslopes. *Transactions of the ASAE*. 45(3):681–685.

Haan, C.T., B.J. Barfield, and J.C. Hayes. 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press, San Diego, CA.

Herzog, M., J. Harbor, K. McClintock, J. Law, and K. Bennett. 2000. Are green lots worth more than brown lots? An economic incentive for erosion control on residential developments. *Journal of Soil and Water Conservation* 55(1):43-49.

Kochenderfer, J.N., and J.D. Helvey. 1987. Using gravel to reduce soil losses from minimum-standard forest roads. *Journal of Soil and Water Conservation* 42(1): 46-50.

McClelland, D.E., R.B. Foltz, C.M. Falter, W.D. Wilson, T. Cundy, R.L. Schuster, J. Saurbier, C. Rabe, and R. Heinemann. 1999. Relative effects on a low-volume road system of landslides resulting from episodic storms in northern Idaho. *In* Seventh International Conference on Low-Volume Roads: Vol. 2. Transportation Research Record 1652, 235-243. Washington, D.C.: National Research Council, Transportation Research Board.

Megahan, W.F. 1972. Logging, erosion, sedimentation: are they dirty words? *Journal of Forestry* 70(5):403-407.

Megahan, W.F., and W.J. Kidd. 1972. Effect of logging roads on sediment production rates in the Idaho Batholith. Research Paper INT-123. Ogden, Utah: USDA Forest Service, Intermountain Forest and Range Experiment Station.

Moore, I.D., and G.J. Burch. 1986. Physical basis of the length-slope factor in the universal soil loss equation. *Soil Science Society of America Journal* 50:1294-1298.

Neter, J., M.H. Kutner, C.J. Nachtsheim, and W. Wasserman. 1996. Applied Linear Statistical Models, Fourth Edition. Irwin Publishing, Chicago, IL.

Patric, J.H. 1976. Soil erosion in the eastern forest. *Journal of Forestry* 74(10):671-677.

Peterson, J.R., D.C. Flanagan, and K.M. Robinson. 2002. Channel evolution and erosion in PAM-treated and untreated experimental waterways. Paper presented at 2002 ASAE Annual Internation Meeting / CIGR XVth World Congress. July 28-31, 2002, Chicago, IL.

Renard, K.G., G.R. Foster, G.A. Weesies, K.K. McCool, and D.C. Yoder. 1997. Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703. U.S. Gov. Print. Office, Washington, D.C.

Rhee, H., J.L. Fridley, and R.B. Foltz. 2004. Modeling erosion from unpaved forest roads at various levels of geometric detail using the WEPP model. *Transactions of the ASAE* 47(3): 961-968.

Tamanini, D., G. Bertoldi, R. Rigon 2003. GEOTOP: A model for simulating the terrain-vegetation-atmosphere continuum. Geophysical Research Abstracts, Vol. 5, # 12353.

Tiwari, A.K., L.M. Risse, and M.A. Nearing. 2000. Evaluation of WEPP and Its comparison with USLE and RUSLE. *Transactions of the ASAE* 43(5):1129-1135.

USDA-SCS. 1990. Soil Survey of Brown County and Part of Bartholomew County Indiana. Washington, D.C.

Vandekerckhove, K., J. Poesen, D. Oostwood Wijdenes, and T. de Figueiredo. 1998. Topographical thresholds for ephemeral gully initiation in intensively cultivated areas of the Mediterranean. *Catena* 33:271-292.

Wicks, J.M., and J.C. Bathurst. 1996. SHESED: a physically based, distributed erosion and sediment yield component for the SHE hydrological modeling system. *Journal of Hydrology* 175:213 – 238.

Wigmosta, M.S., L.W. Vail, and D.P. Lettenmaier. 1994. A distributed hydrology-vegetation model for complex terrain. *Water Resources Research* 30:1665–1669.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall erosion losses; A guide to conservation planning. USDA Agricultural Handbook 537. U.S. Gov. Print. Office, Washington, D.C.

Wu, C-C. 2001. Surface-cover subfactor for gravel-rich surfaces. ASAE Paper Number 701P0007 presented at Soil Erosion Research for the 21st Century, Proc. Int. Conf. January 3-5, 2001. Honolulu, Hawaii.

Xu, Z.X., K. Ito, G.A. Schultz, and J.Y. Li. 2001. Integrated hydrologic modeling and GIS in water resources management. *Journal of Computing in Civil Engineering, ASCE* 15(3): 217-223.

Yu, B. 1999. A comparison of the R factor in the universal soil loss equation and revised universal soil loss equation. *Transactions of the ASAE* 42(6):1615-1620.

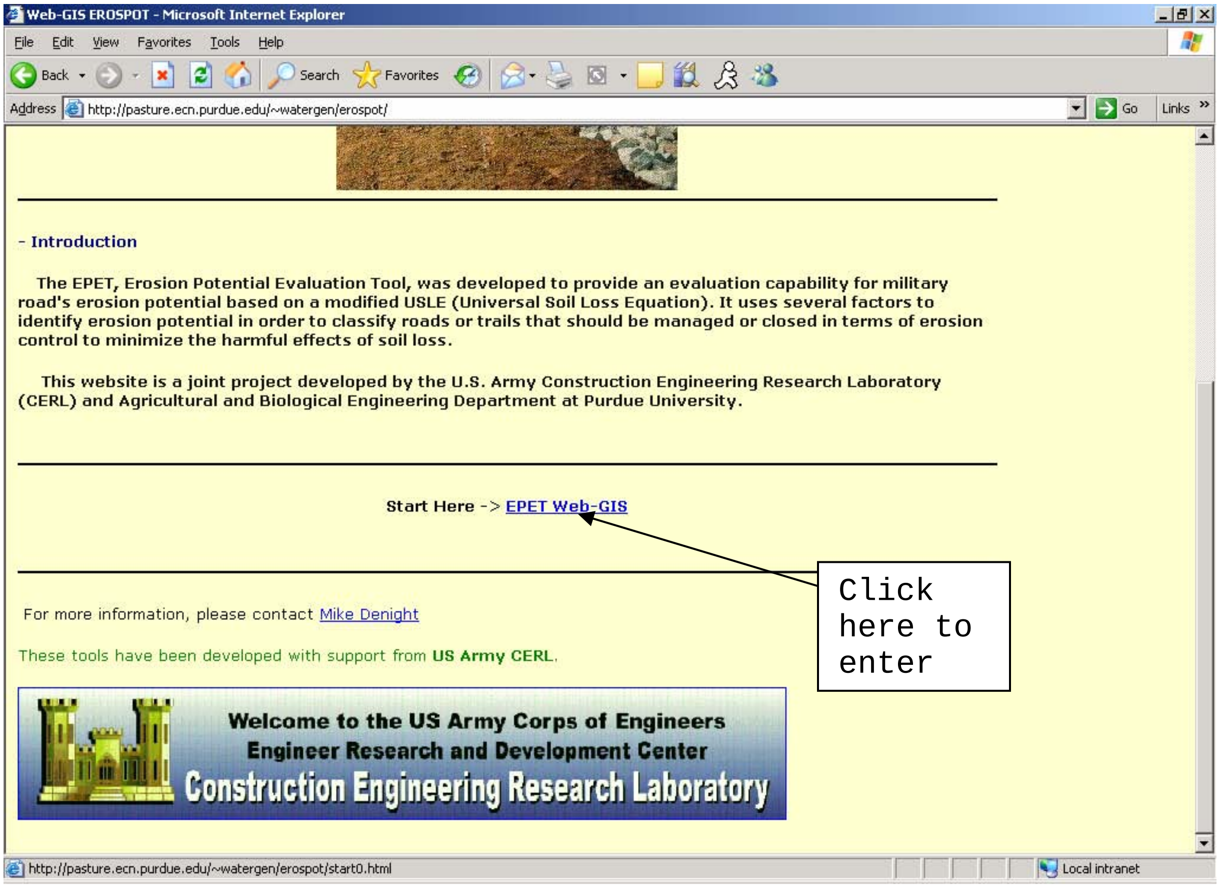
Appendix F

DECISION SUPPORT WEB-BASED APPLICATION

The Erosion Potential Evaluation Tool for Military Training Roads is used for estimating erosion on the trails and roads of military training facilities. A short demonstration of the basic operations to obtain an estimate of erosion for trails and roads follows.

The URL is http://pasture.ecn.purdue.edu/~watergen/erospot. The first step is to enter the Web-GIS page from the introduction page. This is shown in Figure F.1 and accomplished by clicking the "Start Here" link.

Once inside the Web-GIS site, the help button on the bottom left of the screen gives instructions on the different tools that may be used. The link that appears after clicking the help button is shown in Figure F.2.



- Introduction

The EPET, Erosion Potential Evaluation Tool, was developed to provide an evaluation capability for military road's erosion potential based on a modified USLE (Universal Soil Loss Equation). It uses several factors to identify erosion potential in order to classify roads or trails that should be managed or closed in terms of erosion control to minimize the harmful effects of soil loss.

This website is a joint project developed by the U.S. Army Construction Engineering Research Laboratory (CERL) and Agricultural and Biological Engineering Department at Purdue University.

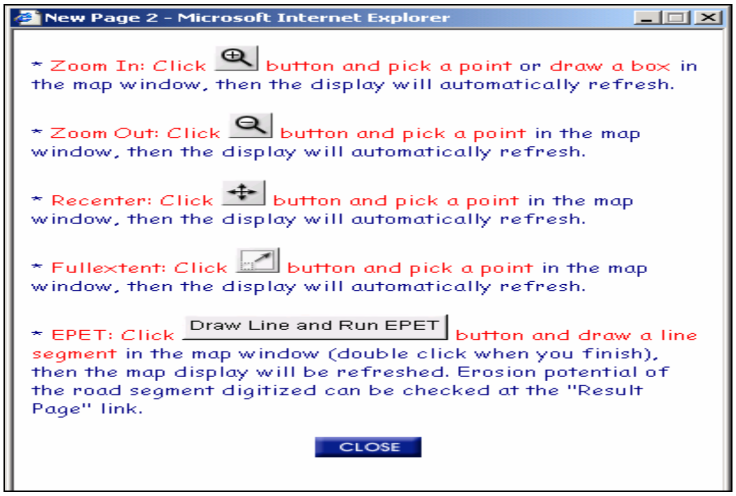
Start Here -> EPET Web-GIS

For more information, please contact Mike Denight

These tools have been developed with support from **US Army CERL**.

Click here to enter

Figure F.1. Erosion potential introduction page



* Zoom In: Click button and pick a point or draw a box in the map window, then the display will automatically refresh.

* Zoom Out: Click button and pick a point in the map window, then the display will automatically refresh.

* Recenter: Click button and pick a point in the map window, then the display will automatically refresh.

* Fullextent: Click button and pick a point in the map window, then the display will automatically refresh.

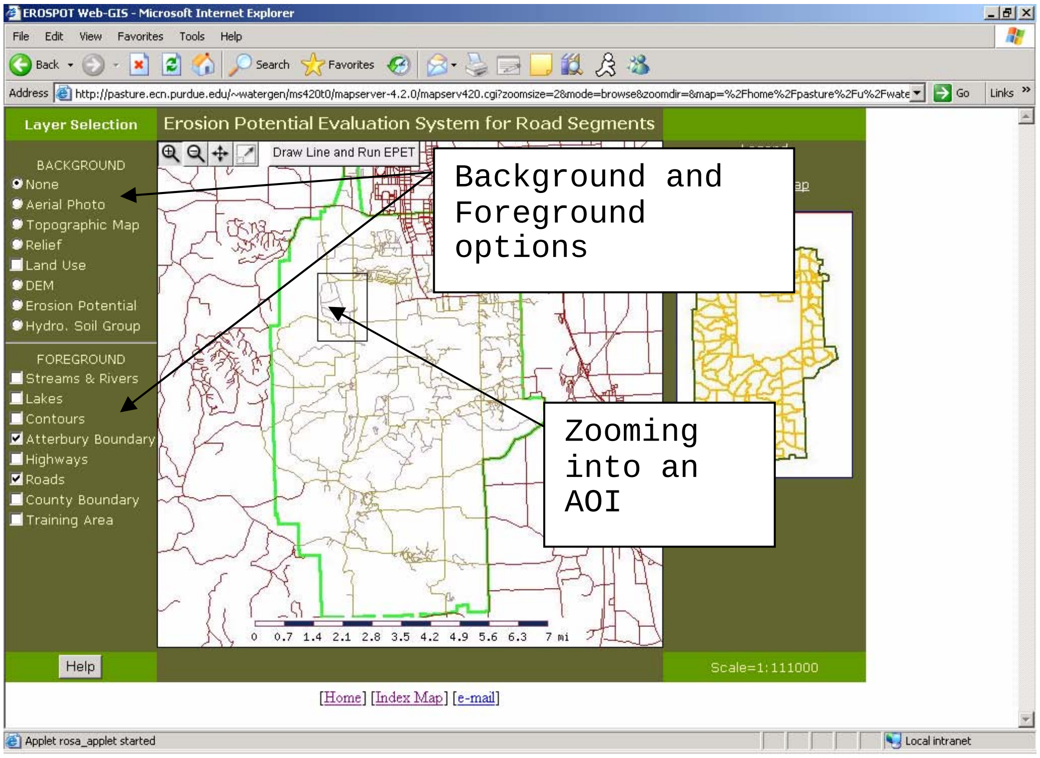
* EPET: Click Draw Line and Run EPET button and draw a line segment in the map window (double click when you finish), then the map display will be refreshed. Erosion potential of the road segment digitized can be checked at the "Result Page" link.

Figure F.2. Help page

In addition to the explanations given in Figure F.2, the tools have the following functions. For any of the buttons, the tool can be used only once. That is, once a tool is used, the button becomes unselected and must be selected again before the feature can be used again. The recenter tool refreshes the map, making the point selected the center of the screen. The map scale remains the same. When the Full Extent button is used, the map automatically refreshes to view the entire Camp Atterbury area that the user saw upon originally entering the Web-GIS page.

The data displayed can be altered by using the options available under “layer selection” on the left side of the screen. The options under the background layer are None, Aerial Photo, Topographic Map, Relief, Land Use, DEM, Erosion Potential, and Hydrologic Soil Group. Only one of these options can be selected at a time. The foreground options are Streams & Rivers, Lakes, Contours, Atterbury Boundary, Highways, Roads, County Boundary, and Training Area. Any of the options can be selected as the user desires, from none to all, and any combination. These options can be seen in Figure F.3.

The user is now ready to begin estimating erosion potential. The first step is for the user to zoom into an area of interest (AOI), such as shown in Figure F.3. The page resulting from this action is shown in Figure F.4.



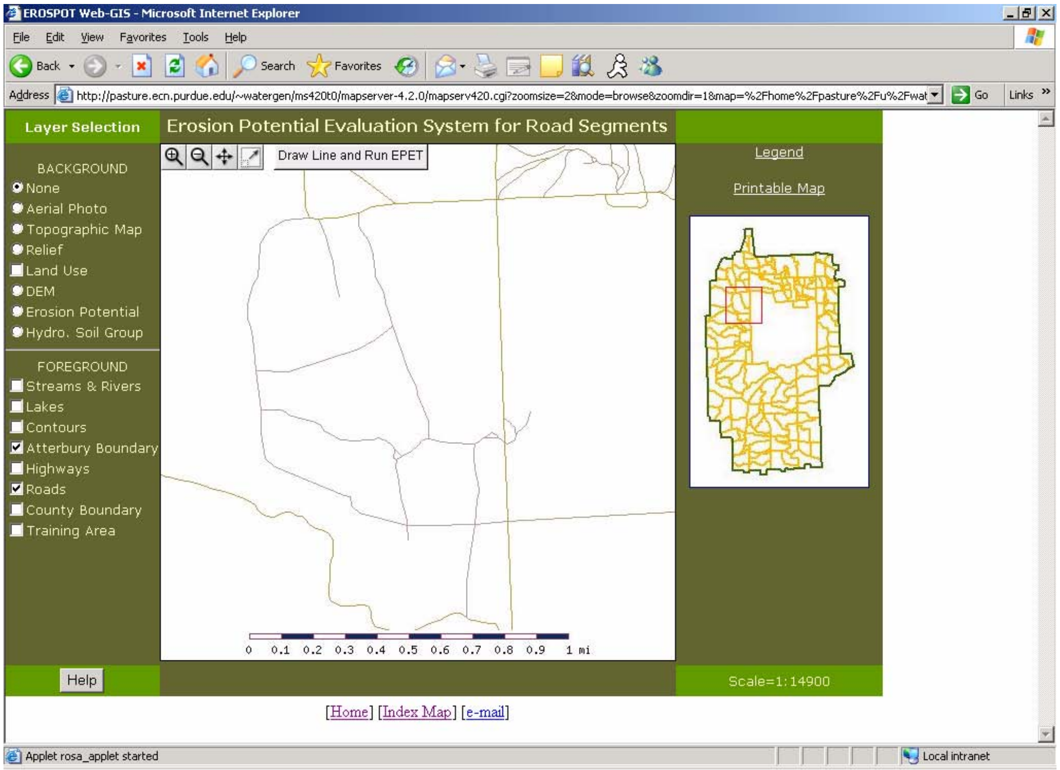
BACKGROUND
● None
○ Aerial Photo
○ Topographic Map
○ Relief
○ Land Use
○ DEM
○ Erosion Potential
○ Hydro. Soil Group

FOREGROUND
☐ Streams & Rivers
☐ Lakes
☐ Contours
☑ Atterbury Boundary
☐ Highways
☑ Roads
☐ County Boundary
☐ Training Area

Background and Foreground options

Zooming into an AOI

Figure F.3. Background, foreground options, and zooming into AOI.

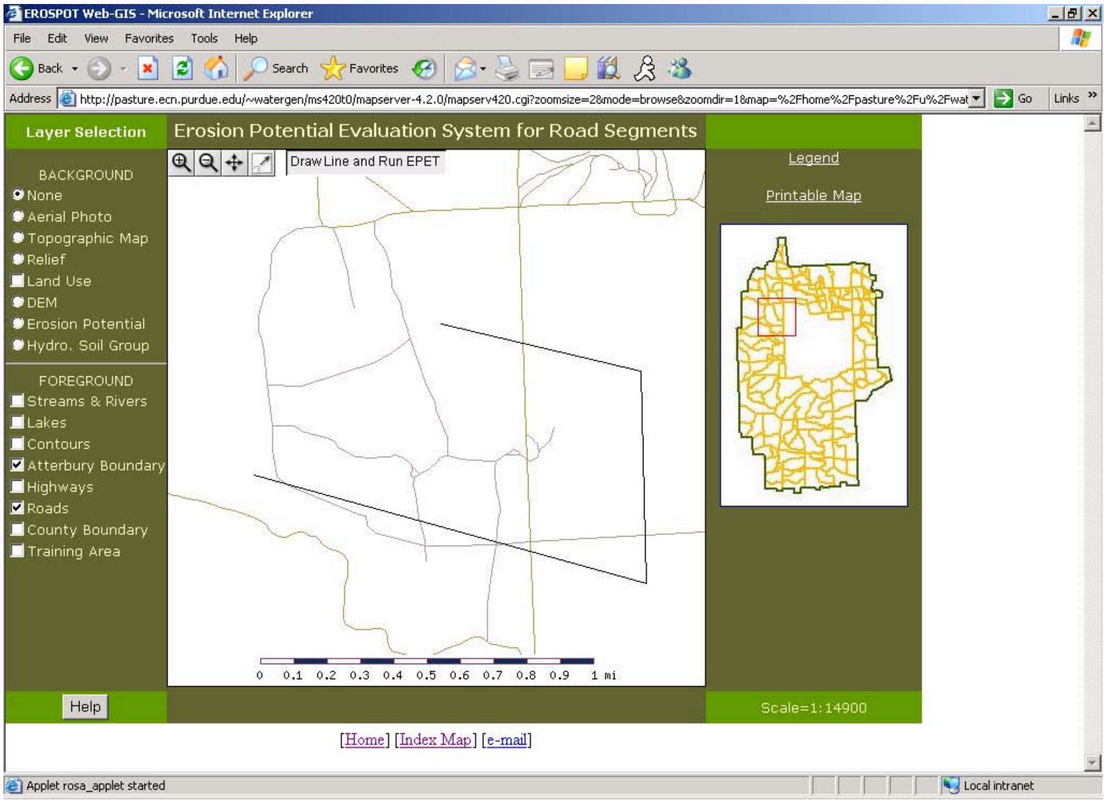


BACKGROUND
● None
○ Aerial Photo
○ Topographic Map
○ Relief
○ Land Use
○ DEM
○ Erosion Potential
○ Hydro. Soil Group

FOREGROUND
☐ Streams & Rivers
☐ Lakes
☐ Contours
☑ Atterbury Boundary
☐ Highways
☑ Roads
☐ County Boundary
☐ Training Area

Figure F.4. Resulting page from zoom.

Assuming that the zoom covers the desired AOI, the user can now select the “Draw Line and Run EPET” tool. This selection allows the user to choose road segments by left clicking at the beginning of the segment and each time a change in direction is desired. When the entire segment is selected as shown in Figure F.5, the user double clicks on the end of the segment.



http://pasture.ecn.purdue.edu/~watergen/ms420t0/mapserver-4.2.0/mapserv420.cgi?zoomsize=2&mode=browse&zoomdir=1&map=%2Fhome%2Fpasture%2Fu%2Fwat

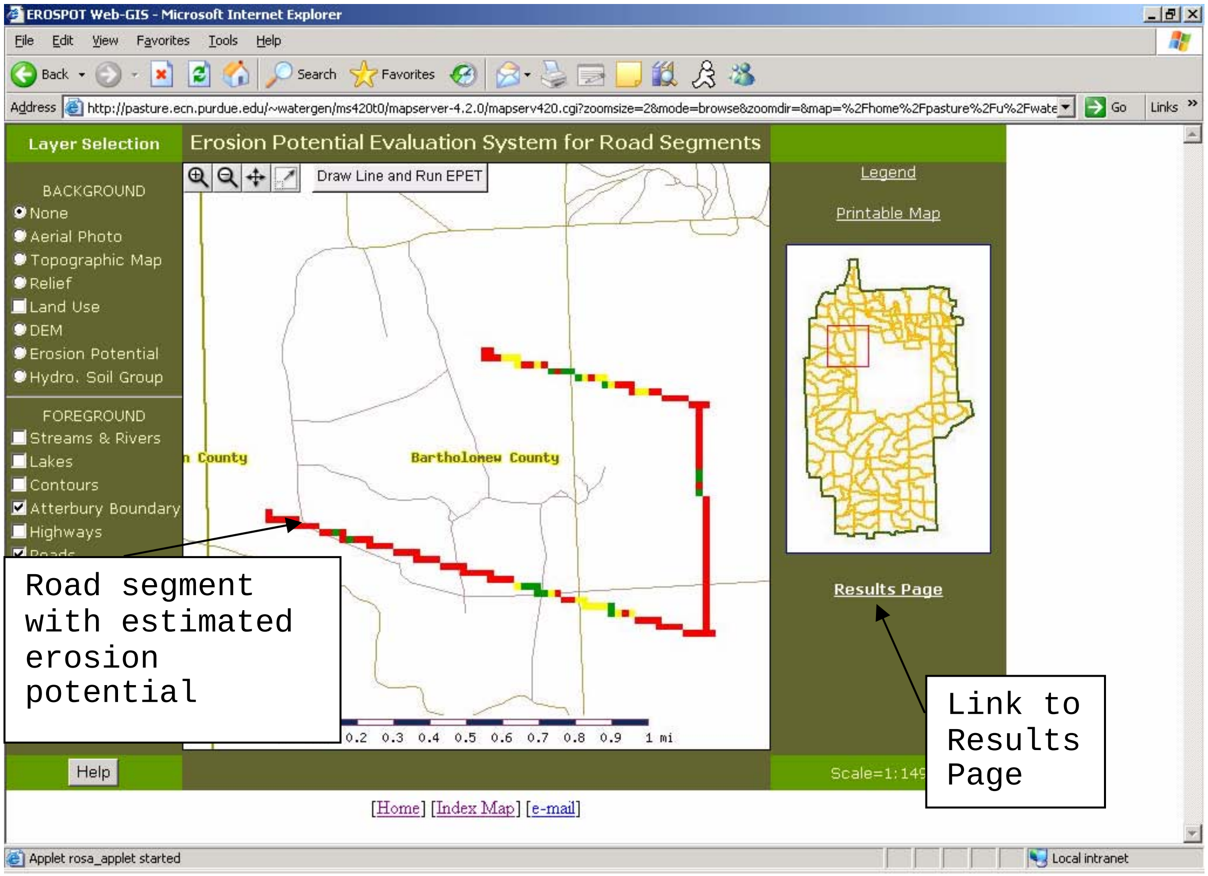
BACKGROUND
● None
○ Aerial Photo
○ Topographic Map
○ Relief
☐ Land Use
○ DEM
○ Erosion Potential
○ Hydro. Soil Group

FOREGROUND
☐ Streams & Rivers
☐ Lakes
☐ Contours
☑ Atterbury Boundary
☐ Highways
☑ Roads
☐ County Boundary
☐ Training Area

Figure F.5. Selecting a road segment.

It should be noted that estimating erosion potential is not necessarily for existing trails or roads only. Since trails may have been revegetated or created after the roads file was made and aerial photograph taken, any location is available for erosion potential estimation.

After the road has been selected, it appears in green, yellow, red, or any combination of those colors. This road segment shows the maximum erosion potential for the worst-case scenario. Green indicates low erosion potential (0–4 tons per acre per year (T/A/Y)). Yellow indicates moderate erosion potential (4–10 T/A/Y). Red indicates the most severe case of erosion potential (> 10 T/A/Y). Also a link called “Results Page” now appears on the right-hand side of the screen, as shown in Figure F.6.



BACKGROUND
● None
○ Aerial Photo
○ Topographic Map
○ Relief
☐ Land Use
○ DEM
○ Erosion Potential
○ Hydro. Soil Group

FOREGROUND
☐ Streams & Rivers
☐ Lakes
☐ Contours
☑ Atterbury Boundary
☐ Highways
☑ Roads

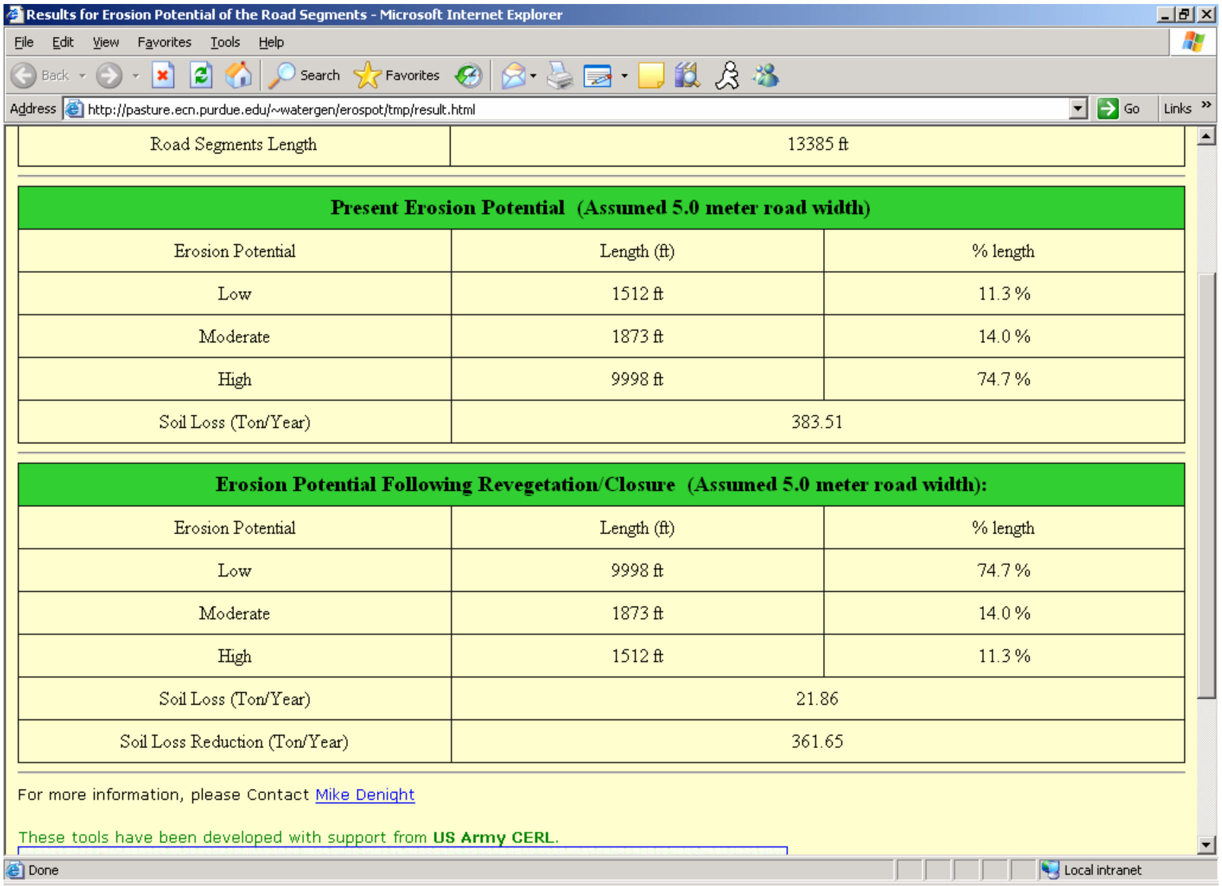
Road segment with estimated erosion potential

Link to Results Page

Figure F.6. Road segment with Results Page link.

Clicking the Results Page link brings up a new window, shown in Figure F.7. In the “Present Erosion Potential” table shown in Figure F.7, the total lengths of the selected road in each erosion potential category are shown when a cover factor has not been considered. This section of the figure also shows total erosion from the selected road. The section titled “Erosion Potential Following Revegetation/Closure” shows the erosion potential for the selected road after a cover factor has been considered. Also shown is the total potential erosion reduction.

On the Web-GIS page, two links are located on the right side of the screen just above the Camp Atterbury map locator. These links are Legend and Printable Map. Clicking either link will open a new page. The Legend page simply shows the legend for all of the options selected in both the background and foreground Layer Selections. The Printable Map page correlates the AOI, the legend, and the scale into one page, which may be useful to include with any reports recommending the closure or revegetation of any trails or roads.



Road Segments Length	13385 ft

Present Erosion Potential (Assumed 5.0 meter road width)

Erosion Potential	Length (ft)	% length
Low	1512 ft	11.3 %
Moderate	1873 ft	14.0 %
High	9998 ft	74.7 %
Soil Loss (Ton/Year)	383.51	

Erosion Potential Following Revegetation/Closure (Assumed 5.0 meter road width):

Erosion Potential	Length (ft)	% length
Low	9998 ft	74.7 %
Moderate	1873 ft	14.0 %
High	1512 ft	11.3 %
Soil Loss (Ton/Year)	21.86	
Soil Loss Reduction (Ton/Year)	361.65	

For more information, please Contact Mike Denight

These tools have been developed with support from **US Army CERL**.

Figure F.7. Erosion potential results page for the road or trail segment digitized.

Appendix G

CAMP ATTERBURY GENERAL SOIL DESCRIPTIONS

Soil at Camp Atterbury is classified in four general types, as taken from the general soil map produced by the USDA-SCS (1990). These soils are of the Pekin-Chetwynd-Bartle, Hickory-Cincinnati-Rossmoyne, Crosby-Miami-Rensselaer, and Stonelick-Chagrin associations. The descriptions of each soil type are as follows:

- PEKIN-CHETWYND-BARTLE – Deep, nearly level to very steep, somewhat poorly drained to well drained soils formed in silty and loamy deposits; on terraces.

- HICKORY-CINCINNATI-ROSSMOYNE – Deep, gently sloping to very steep, well drained and moderately well drained soils formed in loess and in the underlying loamy and silty glacial drift and till; on uplands.

- CROSBY-MIAMI-RENSSELAER – Deep, nearly level to strongly sloping, somewhat poorly drained, well drained, and very poorly drained soils formed in loess and the underlying loamy glacial till, in glacial till, and in stratified loamy sediments; on uplands and terraces.

- STONELICK-CHAGRIN – Deep, nearly level, well drained soils formed in loamy alluvial deposits; on flood plains.

From these general soil types, there are 10 soil series. Their names and brief descriptions are also produced by the USDA-SCS (1990).

- Berks – The Berks series consists of moderately deep, well drained, moderately rapidly permeable soils on uplands. These soils formed in material weathered from interbedded siltstone, sandstone, and shale bedrock. Slopes range from 6 to 70 percent. The surface texture is silt-loam. The classification to the family level is Loamy-skeletal, mixed, mesic, Typic Dystrochrept.

- Cincinnati – The Cincinnati series consists of deep, well drained soils on uplands. These soils formed in loess and in the underlying glacial drift. They have a fragipan permeability is moderate above the fragipan and slow in the fragipan. Slopes range from 6 to 12 percent. The surface texture is silt-loam. The classification to the family level is Fine-silty, mixed, mesic Typic Fragiudalf.

- Crosby – The Crosby series consists of deep somewhat poorly drained, slowly permeable soils on till plains. These soils formed in a thin layer of loess and in the underlying glacial till. Slopes range from 1 to 5 percent. The surface texture is silt-loam. The classification to the family level is Fine, mixed, mesic Aeric Ochraqualf.

- Dubois – The Dubois series consists of deep, somewhat poorly drained, nearly level soils on terraces. These soils formed in about 2 to 4 feet of loess and the underlying lacustrine deposits. They have a firm and brittle fragipan at a depth of about 2 to 3 feet. Slopes range from 0 to 2 percent. The surface texture is silt-loam. The classification to the family level is Fine-silty, mixed, mesic Aeric Fragiaqualf.

- Hennepin – The Hennepin series consists of deep, well drained, moderately steep to very steep soils on uplands. These soils formed in loamy glacial till. Slopes range from 18 to 40 percent. The surface texture is loam. The classification to the family level is Fine-loamy, mixed, mesic Typic Eutrochrept.

- Hickory – The Hickory series consists of deep, well drained, moderately permeable soils on uplands. These soils formed in a thin mantle of loess and in the underlying glacial till. Slopes range from 12 to 70 percent. The surface texture is silt-loam. The classification to the family level is Fine-loamy, mixed, mesic Typic Hapludalf.

- Miami – The Miami series consists of deep, well drained soils on till plains, formed in glacial till. The permeability is moderate in the solum and moderately slow in the substratum. Slopes range from 6 to 15 percent. The surface texture is silt-loam. The classification to the family level is Fine-loamy, mixed, mesic Typic Hapludalf.

- Rensselaer – The Rensselaer series consists of deep, very poorly drained, nearly level soils on terraces. These soils are slightly depressional. They formed in loamy outwash material that overlies stratified sand and silt at a depth of about 42 to 60 inches. Slopes range from 0 to 2 percent. The surface texture is loam. The classification to the family level is Fine-loamy, mixed, mesic Typic Argiaquoll.

- Stendal – The Stendal series consists of deep, somewhat poorly drained soils on bottom lands. These soils formed in silty acid alluvium. Slopes range from 0 to 2 percent. The surface texture is silt-loam. The classification to the family level is Fine-silty, mixed, acid, mesic Aeric Fluvaquent.

Appendix H

GIS PROCESSES TO ESTIMATE EROSION WITH THE USLE

Adding K Factor to GIS Attribute Table

The USLE soil erodiblility factor, K, is a soil property that varies by soil type. A soil survey map of the applicable area is needed and can be obtained from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). If the soil erodibility factor, K, is not already part of the attribute of the soil map, it will need to be added to the attributes table. Figure H.1 is a depiction of the soil survey of Bartholomew County, IN. A USDA website allows soil survey attributes to be added to the attribute tables of the soil survey (http://nasis.nrcs.usda.gov/downloads). At this website, a Microsoft™ Access database is available for importing the soil attribute data. Detailed instructions on how to use this database are also available. This is discussed here in order to have the soil erodibility factor (USLE K) added to the attributes.

Three tables from the nasis website are required to do this. These three tables are:

1. Report – MANU – Table K2 – Soil Features
2. Component
3. Chorizon

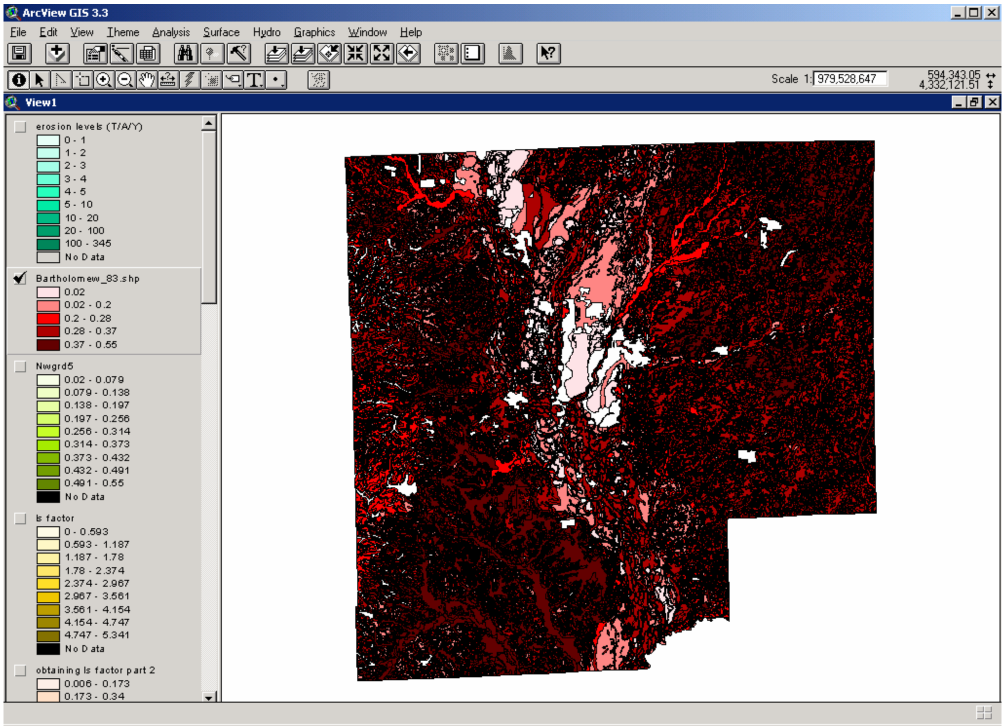


Figure H.1. ArcView presentation of soil survey in Bartholomew County, IN

The component table has the data map unit key and component key, abbreviated in the table as mukey and cokey, respectively. The Chorizon table has the data component key and the k-factor data, abbreviated as cokey and kwfact in the table. Lastly, the attribute table in the GIS software for the soil survey has the data map unit key, or once again mukey. These tables can be joined in the GIS software so that the k-factor can now be part of the attribute table associated with the soil map, by joining the component table to the attribute table and then joining the chorizon table to the attribute table. To join database tables to an ArcView table, the following steps are performed in the ArcView software:

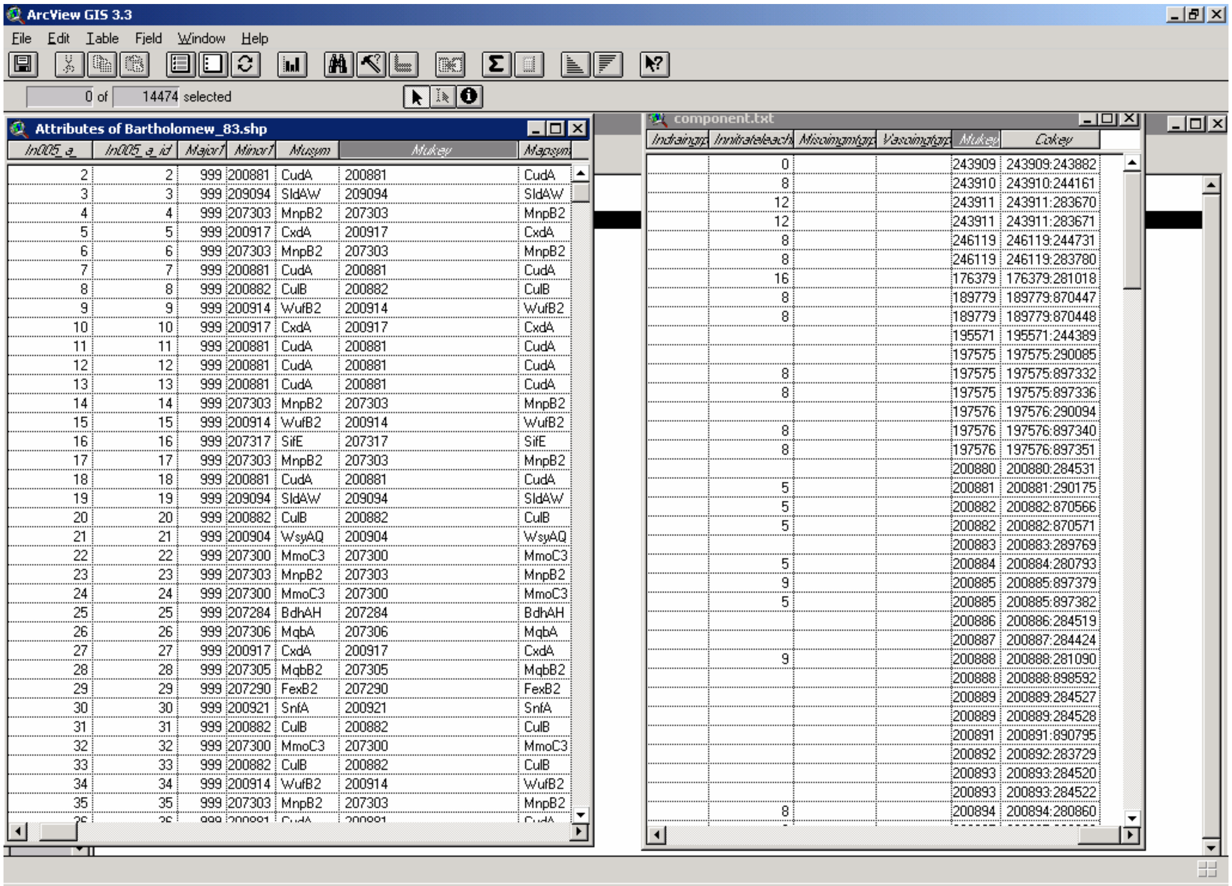
a. Open the database table; if the table's window is already open, make it active.

b. Click on both of the common field's names in the database tables to make the fields active.

c. Open the ArcView table; if the table's window is already open, make it active.

d. Click the Join button.

The contents of the ArcView table change to include the joined attributes from the database table while the database table remains open and unchanged. Figure H.2 shows the component table being joined with the attribute table. Notice that the mukey field in both tables is made active.



0 of 14474 selected

Attributes of Bartholomew_83.shp

In005_a_	In005_a_id	Major1	Minor1	Musym	Mukey	Mapsym
2	2	999	200881	CudA	200881	CudA
3	3	999	209094	SldAW	209094	SldAW
4	4	999	207303	MnpB2	207303	MnpB2
5	5	999	200917	CxdA	200917	CxdA
6	6	999	207303	MnpB2	207303	MnpB2
7	7	999	200881	CudA	200881	CudA
8	8	999	200882	CulB	200882	CulB
9	9	999	200914	WufB2	200914	WufB2
10	10	999	200917	CxdA	200917	CxdA
11	11	999	200881	CudA	200881	CudA
12	12	999	200881	CudA	200881	CudA
13	13	999	200881	CudA	200881	CudA
14	14	999	207303	MnpB2	207303	MnpB2
15	15	999	200914	WufB2	200914	WufB2
16	16	999	207317	SifE	207317	SifE
17	17	999	207303	MnpB2	207303	MnpB2
18	18	999	200881	CudA	200881	CudA
19	19	999	209094	SldAW	209094	SldAW
20	20	999	200882	CulB	200882	CulB
21	21	999	200904	WsyAQ	200904	WsyAQ
22	22	999	207300	MmoC3	207300	MmoC3
23	23	999	207303	MnpB2	207303	MnpB2
24	24	999	207300	MmoC3	207300	MmoC3
25	25	999	207284	BdhAH	207284	BdhAH
26	26	999	207306	MqbA	207306	MqbA
27	27	999	200917	CxdA	200917	CxdA
28	28	999	207305	MqbB2	207305	MqbB2
29	29	999	207290	FexB2	207290	FexB2
30	30	999	200921	SnfA	200921	SnfA
31	31	999	200882	CulB	200882	CulB
32	32	999	207300	MmoC3	207300	MmoC3
33	33	999	200882	CulB	200882	CulB
34	34	999	200914	WufB2	200914	WufB2
35	35	999	207303	MnpB2	207303	MnpB2

component.txt

Indraingr	Innitrateleach	Misoimgmtgr	Vasoimgtgr	Mukey	Cokey
	0			243909	243909:243882
	8			243910	243910:244161
	12			243911	243911:283670
	12			243911	243911:283671
	8			246119	246119:244731
	8			246119	246119:283780
	16			176379	176379:281018
	8			189779	189779:870447
	8			189779	189779:870448
				195571	195571:244389
				197575	197575:290085
	8			197575	197575:897332
	8			197575	197575:897336
				197576	197576:290094
	8			197576	197576:897340
	8			197576	197576:897351
				200880	200880:284531
	5			200881	200881:290175
	5			200882	200882:870566
	5			200882	200882:870571
				200883	200883:289769
	5			200884	200884:280793
	9			200885	200885:897379
	5			200885	200885:897382
				200886	200886:284519
				200887	200887:284424
	9			200888	200888:281090
				200888	200888:898592
				200889	200889:284527
				200889	200889:284528
				200891	200891:890795
				200892	200892:283729
				200893	200893:284520
				200893	200893:284522
	8			200894	200894:280860

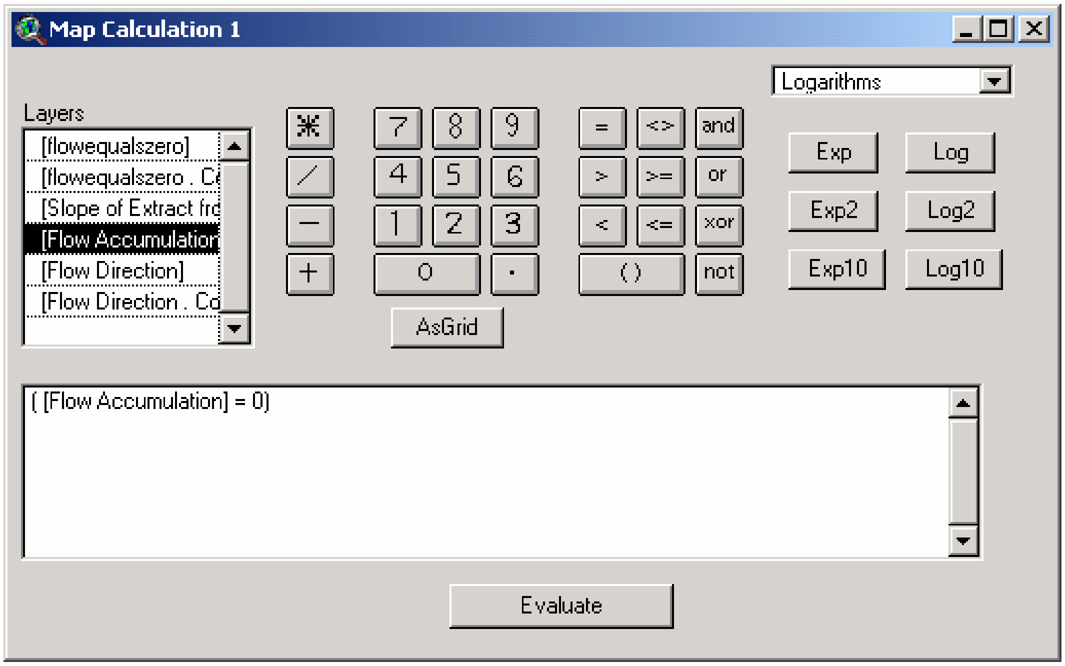
Figure H.2. ArcView presentation of component table being joined to the attribute table

Setting Minimum and Maximum Flow

The USLE estimates combined sheet and rill erosion. It does not predict ephemeral gully or classical gully erosion. This typically forces the user to modify the flow accumulation map by setting an upper limit on the quantity of flow accumulation, used in computing the LS factor (this is the equivalent to setting a maximum slope length).

Flow accumulation cells that have a value of zero indicate areas that are higher in elevation than the surrounding cells, meaning no flow accumulates in these cells. Since the USLE results are obtained by multiplying all factors together, the calculated erosion estimate would be zero for these cells. This means that because there is no accumulation of flow, erosion potential is also zero. In order to correct this, the cells with a flow accumulation value of zero are set to one. Once the flow direction and flow accumulation maps have been obtained from the DEM, it is necessary to set minimum and maximum flows to one and five cells, respectively. Five cells were chosen in this case because the cell size was 30 meters by 30 meters. The number of cells should be chosen so that cell size times the number of cells equals approximately 150 meters. Slope lengths beyond this length have not been considered by the USLE so the USLE is not considered valid.

With the flow accumulation theme active in ArcView, use the map calculator to find all cells with flow equal to zero (Figure H.3). The result is a map with a value of one for all of the cells that previously were zero and a value of zero for all cells that previously had any value other than zero. A resulting map is shown in Figure H.4.



([Flow Accumulation] = 0)

Figure H.3. Finding flow accumulation cells equal to zero

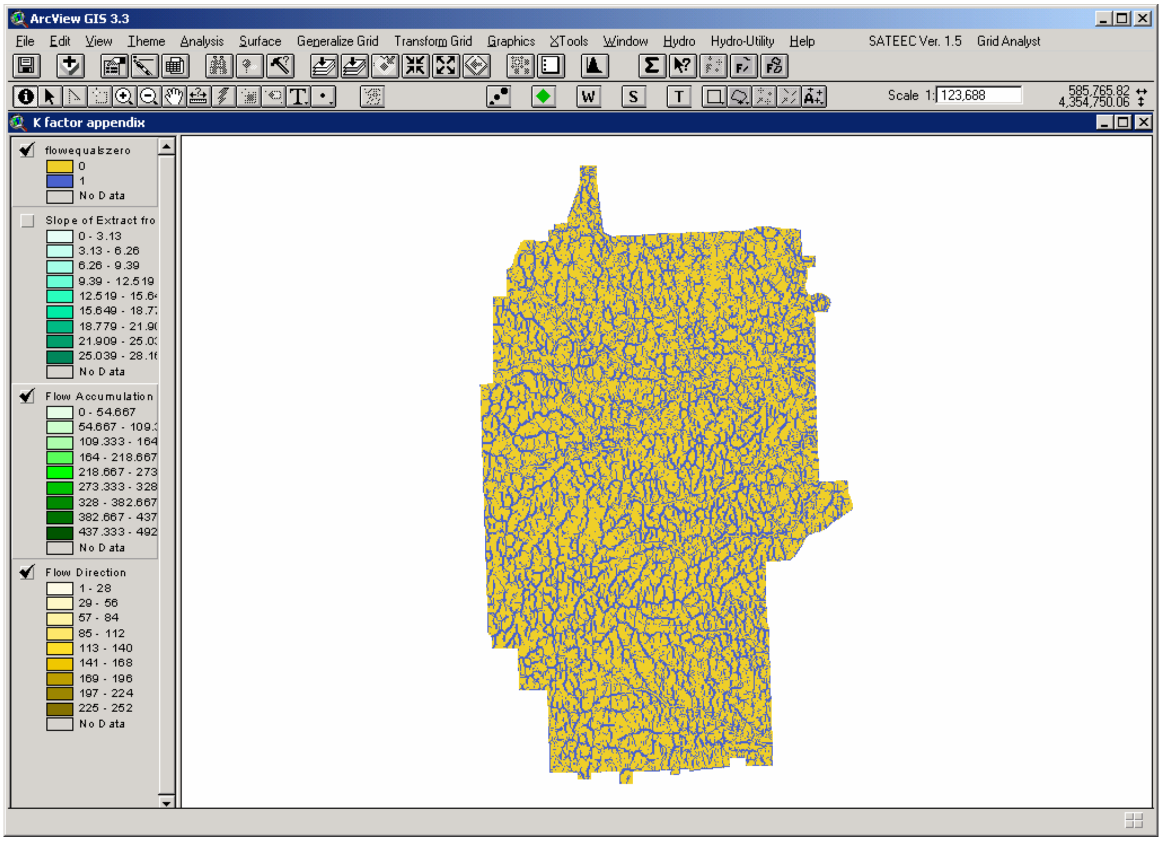


Figure H.4. ArcView map of cells with flow accumulation equal to zero

After exchanging a value of one for all zero cells, use the map calculator tool to add the original flow accumulation map to this map. This sets the minimum flow accumulation to one. This map should then be used for setting maximum flow accumulation to five cells.

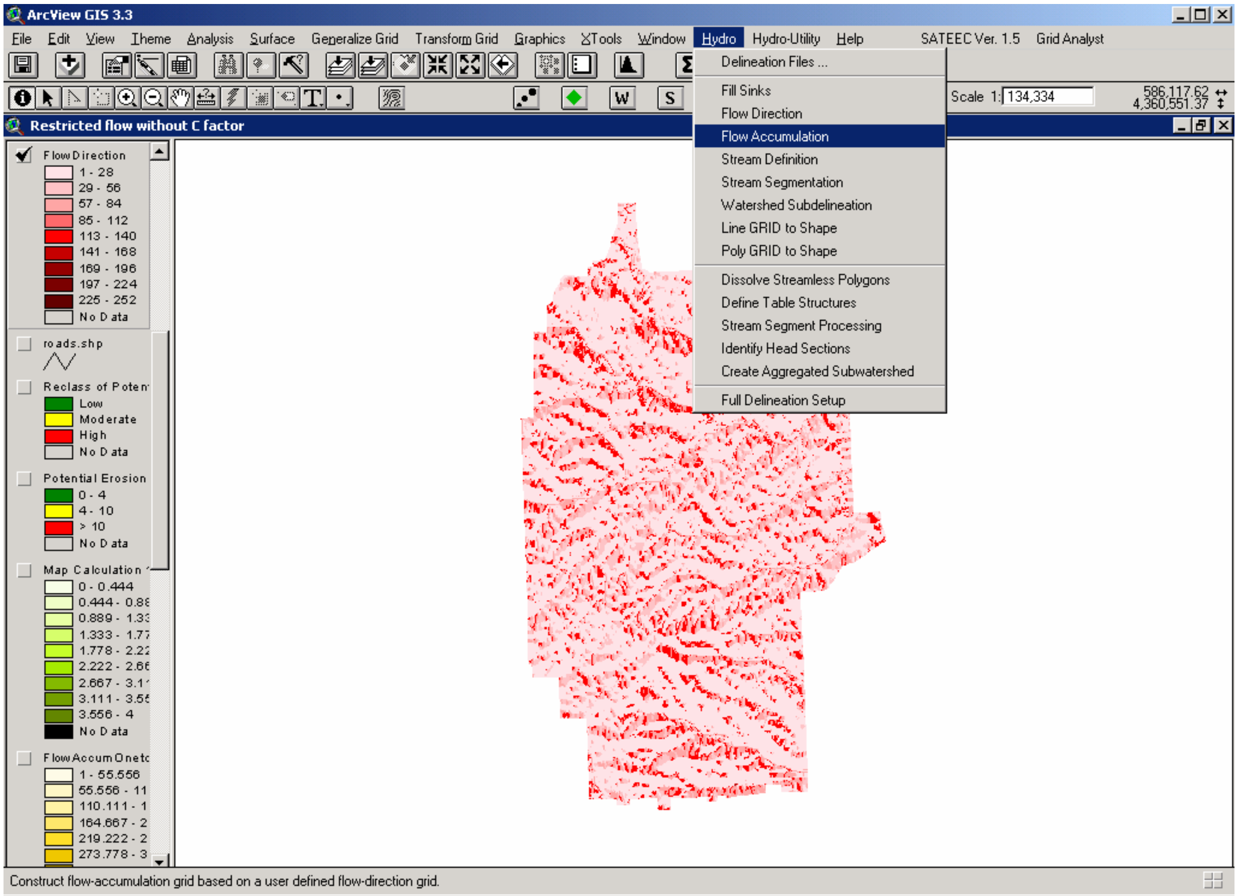
Using the map calculator similarly to the above process, the maximum flow accumulation can be set so that the length factor is approximately equal to 150 meters. The first step for setting the maximum flow accumulation is to use the map calculator to find all cells with a flow accumulation greater than five. The result is a map with values of zero for cells that were five or less and a value of one for cells that were greater than five. This map should then be multiplied by five so that all cells five or less still have a value of zero and cells greater than five are now given a value of five. Call this “map one.”

The next step is to identify cells with values less than or equal to five. The result of this map calculation is a map with cells that have a value of one for all cells that were five or less and cells that have a value of zero where they previously had a value greater than five. Multiplying this map with the original map in map calculator results with a map that has the original values for cells that were previously less than five, and a cell value of zero for the cells that had a value greater than five. The final step is to add this map with “map one.” The final map has values ranging from one to five.

Calculating LS Factor

Two components of the USLE, L and S, may be combined into one term and estimated using flow accumulation. Flow accumulation is derived from the Digital Elevation Model (DEM) of Camp Atterbury. The process to estimate the LS factor is described below.

Obtain a DEM of the applicable area. Using the ArcView hydro extensions, derive the flow accumulation map. In order to determine flow accumulation, flow direction must first be calculated. This can be accomplished by using the flow direction tool shown in Figure H.5, just one tool above the highlighted flow accumulation tool.



Construct flow-accumulation grid based on a user defined flow-direction grid.

Figure H.5. Obtaining flow accumulation in ArcView

Get an identical DEM to that used in the beginning of this procedure. With this DEM, derive the slope by using the derive slope under the ArcView surface toolbar. If the surface toolbar is not visible, make sure the surface extensions are turned on in the extensions field of the file toolbar. The slope map is shown in Figure H.6.

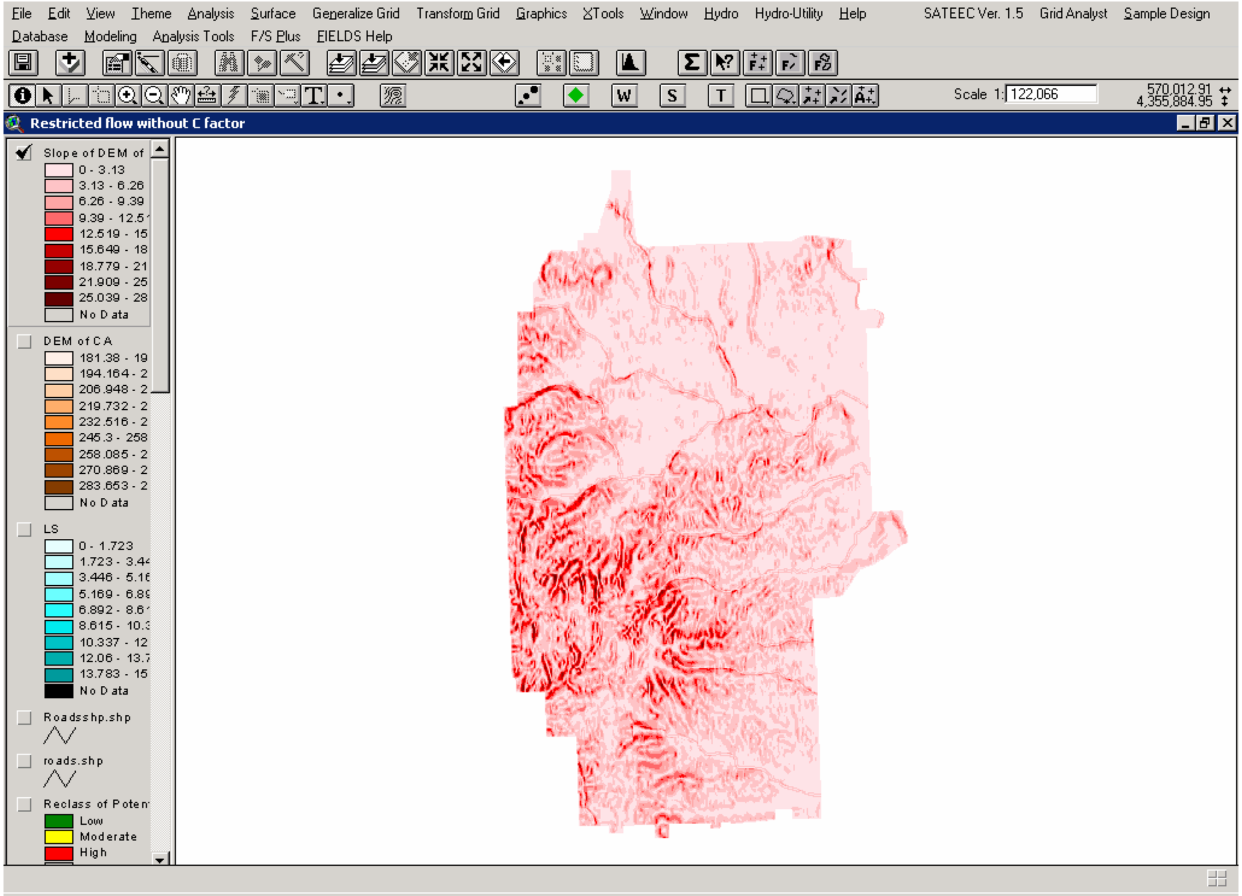
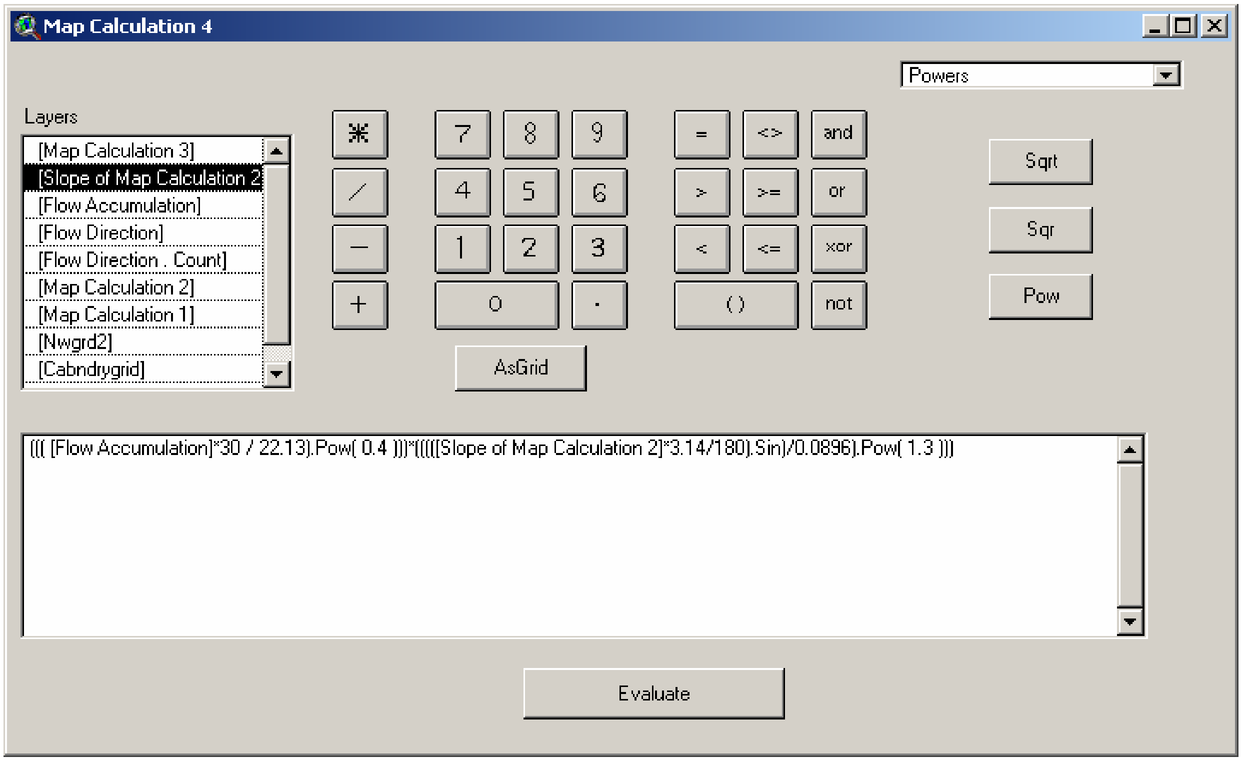


Figure H.6. Slope at Camp Atterbury

In order to compute slope, a DEM map must first be obtained. A DEM of the entire state of Indiana is available as part of the USGS National Elevation Dataset (NED). This DEM was cut to the boundaries of the area of interest with the ArcView software. Additionally, 1000-meter buffers were added to the boundary to ensure the slope derivation would be correct around the borders. Under the surface tab in the ArcView software, derive slope is selected while the DEM theme is active. The result is the slope map of Camp Atterbury in degrees. Caution must be used here to ensure the proper units are used. If Universal Transverse Mercator (UTM) coordinates are used for the DEM, the elevation units should also be meters.

Once the slope map is available, use the map calculator tool to compute the LS factor, as shown in Figure H.7.



```
((( [Flow Accumulation]*30 / 22.13).Pow( 0.4 )))*((((([Slope of Map Calculation 2]*3.14/180).Sin)/0.0896).Pow( 1.3 )))
```

Figure H.7. Map calculator showing the equation used to obtain LS factor

Obtain the average annual estimate of soil loss potential through the use of the map calculator tool, calculating the USLE as discussed. This calculation is accomplished using equation H.1 in the map calculator.

$$A = K*LS*175 \qquad \text{Eq. H.1}$$

Where K is the K factor map obtained in step 1,

LS is the length-slope factor, and

175 is the rainfall factor.

This process calculates erosion potential when land use is not considered (C factor equals one). To obtain erosion potential including the C factor, multiply equation H.1 by the land-use map.

Appendix I

FIELD VALIDATION FORMS FOR CALCULATING EROSION POTENTIAL

A process was developed to qualitatively estimate erosion and erosion potential at observed locations on the roads and trails at Camp Atterbury. Bracmort (2004) used a similar process to evaluate the performance of various management practices including earthen waterways. The procedures described here are based on the Bracmort process. Three factors were evaluated to assess erosion conditions: vegetation, slope, and the presence of rills or gullies. Slope is a contributor to erosion rates (Moore and Burch 1986) so it was included in the validation process. Unprotected earthen concentrated flow areas such as grassed waterways prior to vegetation and ephemeral gullies are prone to severe erosion (Peterson et al. 2002). Wu (2001) studied the effects of gravel on erosion rates by treating it similarly to vegetation. For this reason, gravel and vegetation scores were treated in a like manner. Each condition was given a score of 1, 2, or 3. Scores of 1 were assigned when erosion conditions were low, 2 were assigned for moderate vegetation conditions, and 3 for high erosion potential conditions. The following materials were required to complete a validation; evaluation form, measuring tape, slope meter (clinometer), GPS logger, camera, and writing utensil.

The averages of these scores, rounded to the nearest integer, were the final observed erosion conditions. Vegetation provides protection against soil erosion by reducing rainfall impact effects. Gravel was treated in the same manner as vegetation. The more vegetation or gravel that is present on a road or trail, a lower score will be assigned for vegetation. As slope increases, runoff velocity also increases. Erosion rates increase with slope. Therefore, lower slopes were assigned a low erosion potential score and higher slopes were assigned higher scores. Rills and gullies concentrate runoff flow. This also increases runoff velocity, and increases erosion rates. A generic distinction between rills and gullies is that gullies are significantly larger than rills (Peterson et al. 2002). Roads and trails without the presence of rills or gullies were given a score of 1. A road or trail with only rills present was given a score of 2. A score of 3 was given to the roads and trails with any number of gullies present.

Vegetation scores were given for each location with a minimum value of 1 and a maximum value of 3. A score of 1 indicates that vegetation is in good condition and erosion potential from vegetative conditions is low. Attributes constituting good vegetative conditions are described in the following manner. For a road or trail section more than 20-feet wide, a transect perpendicular to the direction of the trail with 10 feet on either side of the center of the trail should be used. For a road or trail that is less than 20-feet wide, the transect should be placed diagonally across the trail so that it is 20 feet from one edge of the trail to the other. Record the number of marks that can be classified as having anchored vegetative cover. Note the marks may or may not be 1-foot apart. A score of 1 was given to transects that had 15 or more marks of anchored cover. A score of 2 was given to those transects that have 10 to 14 marks of anchored cover. A score of 3 was given to those transects that had 9 or less marks of anchored cover. Additionally, comments as to the condition of vegetation, noting the type of vegetation if known (grass, weeds, etc.) and characteristics (height, presence of canopy, stunted or killed, etc), were also noted on the survey sheet.

When rill or gully erosion occurs, sediment levels increase drastically. A gully is defined by Peterson et al. (2002) as channelized flow areas that are generally formed downslope of a rill network, and by Bennett et al. (2000) as small erosional channels caused by the concentration of overland flow. It was suggested by Vandekerckhove et al. (1998) that ephemeral gullies are approximately 1 square foot or larger and rills are smaller than this in size. Gully scores also ranged from 1 to 3. A score of 1 was given for a road or trail without the presence of any rills or gullies. A score of 2 indicates that only rills have formed. A score of 3 was given for a trail that had ephemeral gullies present.

The topography of an area has significant effects erosion rates. As slope increases, overland flow velocity increases, which will increase erosion rates. Again, scores ranged from 1 to 3. The slope was obtained using a slope meter. Although slopes sometimes varied significantly over each section of the roads and trails, the slope score was assigned for the section with the highest slope. A score of 1 was given for slopes of 2 percent or less. Slopes from 2 to 6 percent are considered moderate and were given a score of 2. Any slope greater than 6 percent was given a score of 3.

In any of the above conditions, it may be necessary to take measurements in more than one location for the road segment. Each measurement will be treated individually, and a road segment will be given a composite score. This composite is the result of adding the scores of the road segment together and dividing by the number of instances the measure was taken. For example, a 60-meter road segment with no rills or gullies on a two percent slope has a 20-meter segment of good vegetation followed by a 20-meter segment of bare soil. This segment is followed by a 20-meter portion that is sporadically vegetated. The vegetation scores for each segment are 1, 3, and 2, respectively. The sum of these scores is 6. Since no rill or ephemeral gullies are present, the gully score is 1. The low slope is also given a value of 1. The composite score is 8/5, or 1.6. This score will be rounded to the nearest integer, making the road segment validation score 2. An overall validation score of 1 indicates low actual erosion, 2 indicates moderate actual erosion, and 3 indicates high actual erosion. This would put the actual validation in the moderate erosion category and can now be compared with the predicted results.

Wu (2001) measured gravel surfaces in the same manner as described previously for vegetative cover. Wu’s study (2001) developed an equation for a soil loss ratio for bare soil to gravel covered soil. If the road in question at Camp Atterbury is a gravel road, an additional validation category will be applied to the previous criteria. For a gravel road with approximately 0 to 50 percent cover, a score of 3 was given. A score of 2 was given for roads with between 50 and 75 percent gravel cover. Roads with greater than 75 percent cover were assigned a score of 1.

Erosion Estimation Validation Form

Slope

Date: __________
Time: __________
Location Number: __________
Location (Coordinates): ______________________________
Width of trail segment: __________ ft / m
Length of trail segment: __________ ft / m
% Slope: __________
Slope score: 1
2
3

Comments

Erosion Estimation Validation Form
Gully

Date: __________
Time: __________
Location Number: __________
Are gullies present? Y N
If yes, how many on this road segment? __________
Are rills present? Y N
If yes, how many on this road segment? __________

Rill or Gully Number (Indicate which)	Width (ft / m)	Length (ft / m)
1		
2		
3		
4		
5		

If more than five gullies or rill, use additional sheet or space on back of this sheet

Gully score: 1 2 3

(Clearly show calculations in comments section)

Comments

Erosion Estimation Validation Form
Vegetation

Date: __________
Time: __________
Location Number: __________

If vegetation is uniform, only one transect is required. If vegetation is not uniform, a transect is required in each section of vegetation.

Number of transects made: __________
Number of marks: __________

Transect score:	1 2 3

Repeat as necessary

Overall vegetation score:	1 2 3

(Clearly show calculations in comments section)

Is this a gravel road?	Y N

If yes, treat gravel as cover and conduct additional evaluation.

Number of transects made: __________
Number of marks: __________

Transect score:	1 2 3

OVERALL EROSION POTENTIAL SCORE:	1 2 3

(Clearly show calculations in comments section)

Comments

Appendix J

CAMP ATTERBURY FIELD VALIDATION SCORES AND RESULTS

Note: the X and Y coordinates are given in UTM NAD 83.

Table J.1. Validation results

ID	X (m)*	Y (m)*	Type	Veg Score	Veg Score	Veg Score	Gully Score	Slope Score	Gravel Score	Obs Score	USLE Predicted Score
1	585266	4354082	Trail			2	1	1		1	1
2	585316	4354954	Improved				1	2	1	1	1
3	585815	4354824	Improved				1	2	1	1	1
4	586583	4354848	Semi-improved				1	2	1	1	2
5	586008	4354769	Trail			1	1	1		1	3
6	581222	4355859	Semi-improved				1	3	3	2	2
7	580274	4353322	Trail			3	1	1		1	1
8	579241	4354307	Trail			2	1	3		2	3
9	583285	4354071	Tank Trail			3	3	3		3	3
10	582268	4356034	Trail			2	2	1		2	3
11	581847	4356086	trail			1	1	2		1	2
12	581345	4355856	trail		1	3	3	3		3	3
13	581076	4354634	Trail			1	1	1		1	1
14	579451	4354453	Trail			2	2	3		2	1
15	578665	4354646	Semi-improved				1	3	3	2	2
16	579278	4355392	Trail			1	1	3		2	3
17	580105	4353377	Trail			3	2	2		2	1
18	580311	4342194	Trail			3	2	2		2	3
19	580488	4351815	Trail			2	3	2		2	3
20	580047	4351600	Improved				2	3	1	2	3
21	579797	4351278	Trail			3	3	2		3	3
22	578602	4351234	Improved				1	3	1	2	1
23	579168	4350475	Improved				1	1	1	1	3
24	579773	4351577	Trail			2	2	1		2	3
25	582671	4353852	Improved				1	1	1	1	1
26	585377	4352712	Improved				1	3	2	2	2

Table J.1.Validation results (continued)

ID	X (m)*	Y (m)*	Type	Veg Score	Veg Score	Veg Score	Gully Score	Slope Score	Gravel Score	Obs Score	USLE Predicted Score
27	585557	4352309	Trail			3	3	2		3	3
28	585516	4351366	Trail			2	1	1		1	2
29	585528	4350333	Trail			2	2	3		2	3
30	585673	4348996	Trail			3	3	3		3	3
31	584651	4347229	Improved				2	2	3	2	1
32	583894	4347291	Trail			1	2	3		2	2
33	583939	4347649	Semi-improved			1	1	3		2	2
34	583575	4348439	Trail			3	3	3		3	3
35	584056	4346216	Trail			2	1	1		1	3
36	584455	4345788	Semi-improved				1	2	2	2	2
37	583986	4345148	Improved				2	3	1	2	2
38	583475	4342705	Trail	1	3	1	1	2		2	1
39	584082	4342425	Trail			2	2	3		2	2
40	584080	4341782	Improved				1	3	1	2	2
41	584190	4342174	Trail			2	2	2		2	3
42	584365	4343883	Trail			3	2	2		2	2
43	583786	4346973	Trail			3	2	3		3	3
44	585499	4347465	Semi-Improved				1	2	3	2	2
45	585253	4354503	Trail			1	2	1		1	3
46	584954	4354803	Trail		1	3	3	1		2	3
47	584913	4355368	Trail			1	1	1		1	3
48	585238	4355686	Trail			1	1	2		1	3
49	584890	4355481	Trail			3	1	2		2	1
50	583958	4354270	Tank Trail			3	2	2	2	2	2
51	584119	4353952	Semi-improved				1	1	2	1	1
52	586699	4349973	Improved				1	3	1	2	2
53	586260	4349650	Trail			3	3	3		3	2
54	586287	4349565	Trail			1	1	1		1	3
55	584537	4349345	Improved			1	1	2		1	1

Table J.1. Validation results (continued)

ID	X (m)	Y (m)	Type	Veg Score	Veg Score	Veg Score	Gully Score	Slope Score	Gravel Score	Obs Score	USLE Predicted Score
56	583946	4349165	Semi-improved				2	2	3	2	2
57	583919	4348549	Semi-improved				1	3	2	2	3
58	583456	4346909	Semi-improved				1	3	3	2	3
59	582252	4346501	Semi-improved				1	1	3	2	2
60	580716	4346638	Improved				1	3	1	2	3
61	579747	4346819	Trail			3	3	3		3	3
62	585313	4343592	Trail			3	1	3		2	3
63	584842	4343584	Improved				1	3	1	2	2
64	584163	4343693	Semi-improved				3	1	2	2	2
65	582000	4344000	Semi-improved				2	1	3	2	3
66	583483	4347660	Semi-improved				3	3	2	3	3
67	582652	4343633	Semi-improved				1	2	2	2	3
68	580755	4344019	Improved				1	3	1	2	3
69	579930	4344225	Trail				1	3	1	2	3
70	579993	4344506	Trail			2	3	3		3	3
71	582990	4343927	Improved				1	3	1	2	3
72	583446	4343798	Trail			2	2	3		2	2
73	585831	4349868	Improved			1	2	3		2	1
74	586211	4349938	Improved				3	3	1	2	2
75	586282	4349566	Trail			2	3	3		3	3