Estimated Cost for Protection of Bear Creek Sub-watershed Areas at High Risk to Soil Erosion.

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Keywords: Geographic Information Systems (GIS), Bear Creek Sub-watershed, Buffers, Slope Soils, Erosion, RUSLE, Flow, Land Cover, Conservation Practices

Abstract

The Bear Creek is a sub-watershed of the Zumbro watershed east of Rochester, Minnesota USA. As the population of Rochester continues to grow, it becomes increasingly important to protect highly erodible land through the use of conservation programs**.** Multiple layers of geographic information system (GIS) data are required to identify potential erosion sites within the Bear Creek sub-watershed and GIS analysis can help find those that are the most susceptible to soil loss. In the Sub-watershed, many are located on farmlands, and farmers are not always convinced to establish conservation practices and especially those practices that lack financial incentives. The goal of this project was to calculate an estimate of the cost of placing highly erodible lands within the Bear Creek sub-watershed under conservation practices. The creation of 120 foot buffer zones around potential area is proposed to identify areas with the highest risk. This analysis will assist in estimating budgets for Bear Creek sub-watershed conservation in the future. The Revised Universal Soil Loss Equation, or RUSLE, was used to find the erodible areas by multiplying a group of grid data factors together. Various GIS analysis tools were used to assist in calculating the acreage of high risk areas. The result using RUSLE shows an area of 28.95 acres within the sub-watershed was identified as high risk for soil erosion. When including the buffer zones, the total area increased to 130.53 acres. The total cost of conservation for the area including the buffer zone was estimated to be $12,139.48 at a cost of $93 per acre.

Introduction

The Zumbro Watershed Partnership, along with the United States Fish and Wildlife Service, are looking to acquire land use and soil loss information about the Zumbro Watershed and each targeted sub-watershed. The Bear Creek sub-watershed is located east of Rochester, Minnesota USA in an area of increasing population growth. Soil erosion data on the sub-watershed is needed to develop a plan for future use of the area, such as usage towards industrial and/or residential housing. Financial budgeting information is also needed to evaluate conservation practices and their cost effectiveness. This paper describes the process used to estimate costs of installing

Zellers, Drew P. 2009. Estimated Cost for Protection of Bear Creek Sub-watershed Areas at High Risk to Soil Erosion. Volume 12, Papers in Resource Analysis. 10 pp. Saint Mary's University of Minnesota Central Services Press. Winona, MN. Retrieved (date) from http://www.gis.smumn.edu.

conservation practices throughout the highly erodible areas of the Bear Creek sub-watershed.

Methods

The RUSLE model was used throughout the Zumbro watershed. RUSLE can predict erosion potential of a grid on a cell-by-cell basis. By using the RUSLE model and applying it to GIS, it is possible to find target areas, query those locations and give value to them (Jones et al., 1998). There are six elements that comprise the RUSLE model. These elements are used to find the output identified as A (Eqn 1).

$$A = R * K * L * S * C * P \qquad \text{(Eqn 1)}$$

Where:
A = Calculated soil loss in tons/acre/year
R = Rainfall factor
K = Soil erodibility factor
L = Slope length factor
S = Slope steepness factor
C = Cover management factor
P = Erosion-control practice factor

R-Factor

The R-factor is the rainfall-runoff erosivity factor (figure 1), which is an average annual summation value for the area's normal year's rainfall.

The erosion-index (erosivity factor) (Eqn 2) is a measure of the erosion of a specific rainfall. When other factors are constant, soil losses from rainfall are proportional to the product of the total kinetic energy of the storm (E) times its maximum 30-minute intensity (I) (Anonymous, 1998).

$$R=\sum EI_{30}(10^{-2}) \qquad (2)$$

Where:
R = Rainfall-runoff erosivity
E = Total storm kinetic energy
I_{30} = Maximum 30-min. rainfall intensity

R-factor represents the average storm EI_{30} values over a 22-year record. R is an indication of the two most important characteristics of a storm: amount of rainfall and peak intensity sustained over an extended period. The value for this is area is 140 bases on the formula previously stated.

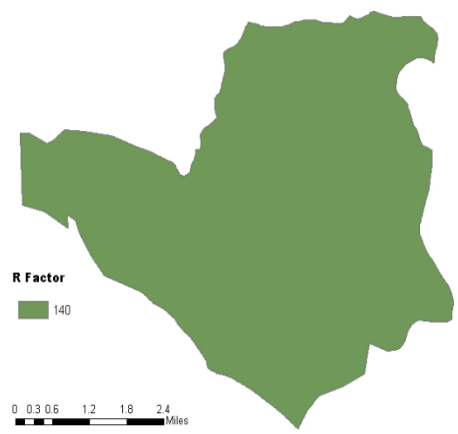

Figure 1. Rainfall, R-factor.

The complete formula for the R-factor can be found in the USDA Agriculture Handbook Number 537. It is a complex formula and has been calculated for all areas of the United States. A single value can be applied for most counties in the United States. Factors that can lead to multiple values occurring in a county are the presence of mountains, size of county and large bodies of water (Jones et al., 1998).

K-Factor

The K-factor is the soil-erodibility factor (figure 2). The K-factor represents both susceptibility of soil to erosion and the amount and rate of runoff. The K-factor takes into account soil texture, organic matter, structure, and permeability to determine the erodibility of a particular soil (Jones et al., 1998). Soils high in clay, for example, have low K-values, about 0.05 to 0.15, due to resistance to detachment. Course textured soils, such as sandy soils; also have a low K-value. Medium textured soils, such as silt loam, have a K-value between 0.25 and 0.40. Soils having a high silt content are the most erodible of all soils with a K-value greater than 0.40.

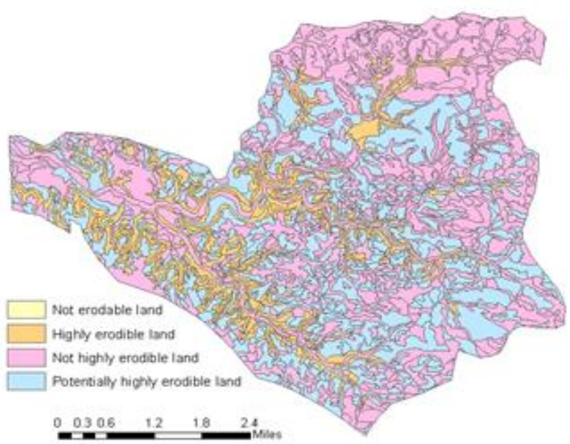

Figure 2. Soils, K-factor.

Although a K-factor was selected to represent a soil in its natural condition, past management or misuse was not taken into account in this study and could change the actual realized outcomes from the findings suggested.

L-Factor or Flow Accumulation

The L-factor is the slope length factor. The L-factor represents the effect of slope length on erosion. The longer the slope the greater potential for erosion exists. Figure 3 shows that the slope length is the distance from the origin of the overland water flow along its flow

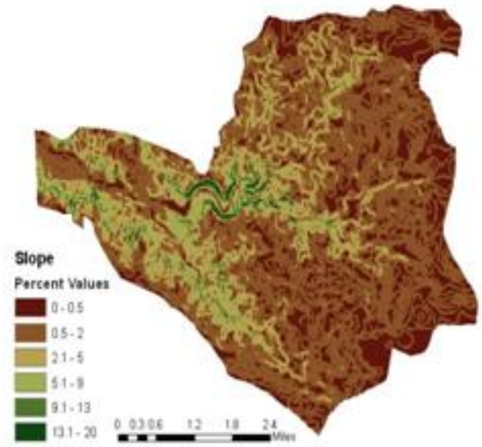

Figure 3. Flow Values, L-factor.

path to the location of either a concentrated flow or deposition.

For larger land areas, the slope length can be determined with the use of a Digital Elevation Model (DEM). With smaller land areas, the slope length can be determined by conducting field site visits to make manual calculations (Anonymous, 1998).

One limitation of the use of RUSLE that should be noted is the decrease of accuracy with the use of slope lengths longer than 1000 ft (Anonymous, 1998).

S-Factor or Slope

The S-factor is the slope steepness and it represents the effect that the slope angle and grade have on erosion (Figure 4). The steeper the slope the greater the potential for erosion.

The numbers in the legend represent the magnitude of the slope potential for erosion. This was based on the factors developed by the United States Geological Survey (USGS).

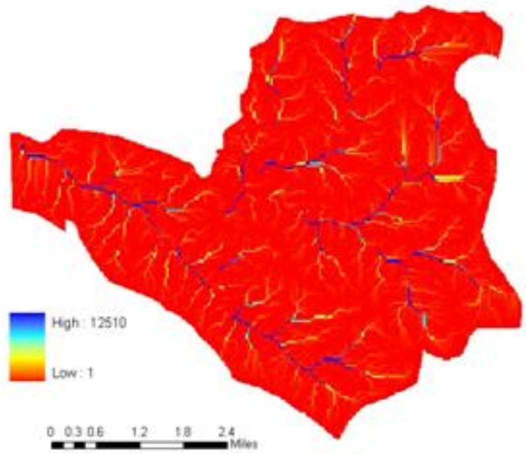

Figure 4. Slope, S-factor.

Soil loss increases more rapidly with increasing slope steepness than it does with slope length (Van Remortel et al., 2001).

The relationship of soil loss to gradient is also influenced by the density of vegetative cover and soil particle size (Anonymous, 1998). When calculating RUSLE, the S- and L-factors are combined.

C-Factor

The C-factor is the cover-management factor (Figure 5). The C-factor represents the effect of plants, soil cover, below-ground biomass, and soil-disturbing activities on soil erosion (Jones et al., 1998). The C-factor is used to reflect the effect of cropping and management practice on erosion rates**.** This factor is primarily used in the comparison of possible impacts that management scenarios have on conservation plans.

The C-factor value ranges from 0 to 1, with zero representing no erosivity (e.g. concrete), while a value of 1 represents the highest erosivity possible (e.g. barren, fallow land). Figure 5 highlights the variation in land cover and associated C factor values for the Bear Creek sub-watershed. A majority of the landcover is under agricultural production and the differing shades of yellow define different farming practices and crops. The other colors represent a variety of other land covers from densely populated forest to grasslands, pasture and urban landscapes.

Land cover influences the degree to which water is retained, infiltrates the soil or run off. As such land cover plays a significant role in erosion potential and soil loss.

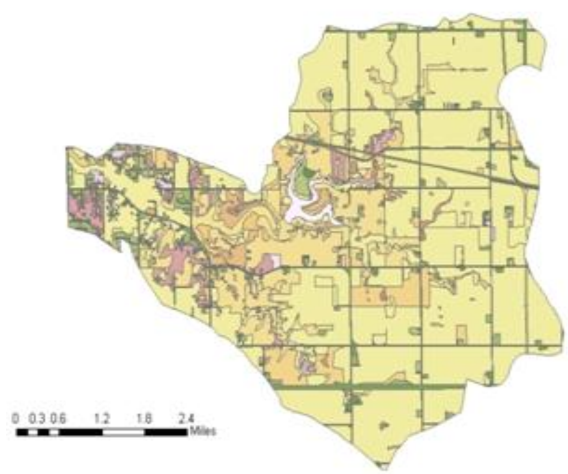

Figure 5. Landcover, C-factor.

P-Factor

The P-factor is the effect of conservation practices such as contouring, strip cropping, and terraces on soil erosion. Most often this variable is set to equal 1 if looking at a large area of land**.** If looking at a specific land parcel the variable for the conservation practice will be what is being done to the land, such as no till, strip till, etc.

Various P-factor scenarios can be run to predict the effects of different management options on soil loss estimates (Jones et al., 1998). The P-factor is set to 1 if a conservation practice is not known (Figure 6).

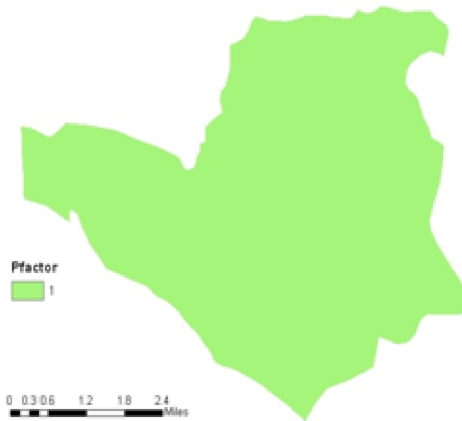

Figure 6. Conservation Practice, P- factor.

Why RUSLE is commonly used?

RUSLE is widely used because the equation is believed to be applicable wherever factor values are available (Kelsey, 2003). According to the National Sedimentation Laboratory, RUSLE is the best available tool for erosion prediction from specific field sites to watersheds (Kelsey, 2003).

Problems with RUSLE

Assessments of the accuracy of RUSLE are dependent on many factors. In addition field studies are costly, labor intensive, and time consuming, the result, which may lead to accepting what is produced either by hand or computer as the final answer rather than field validating. Also the variability in data caused by difference in plot preparation or soil characteristics can result in misleading conclusions (Foster et al., 1999).

Data Acquisition

The initial steps of this project included becoming familiar with RUSLE and the factors that comprised the model. The next step was to find the data for each factor.

The R-factor formula was found in the Agriculture Handbook. The R-factor value for the sub-watershed, 140, was acquired from the Olmsted County NRCS office. The value is based on the formula in Eqn. 1.

As a reminder, the K-factor is based on soil erodibility and has values between zero and one. In this project, soils were divided into four categories. These included non-erodible land, not highly erodible land, potentially highly erodible land, and highly erodible land. The values used for this project were the averages of the many soil types in each category. For not highly erodible land areas the factor was 0.1, for potentially highly erodible it was 0.35, and for highly erodible the factor was 0.55. The data was acquired from the Department of Forest Services at Colorado State University.

The L-factor was calculated from the DEM and that number was imbedded in the gridcode and was viewed in the attribute table for this project. A value of 1.0 represents low flow. This number would increase based on slope length. This data was acquired from (Fox, 2006).

The S-factors were determined from a DEM and the slope was in a percentage that ranged from zero to twenty (Fox, 2006).

The C-factors came from an old paper copy of C-factors that is very hard to locate today with the advent of RUSLE II. The C-factor values are given a value from zero to one. The values in this project were acquired from a couple of sources. The Rochester NRCS office gave values for crops of 0.32 (Svine, 2006). This was a worst case scenario for crops. The rest of the values were estimated from data acquired from Justus-Liebig Universitat Giessen in the Netherlands (Erencin, 2000).

The P-factor for this project was 1.0 because running RUSLE over a large area can provide mixed results. If RUSLE was run on one specific land parcel and the knowledge of those specific farm practices were implemented, then a more descriptive value could be used.

The question will arise of "Why are there estimates and assumptions in the project while using RUSLE?" When running RUSLE over a large area the results will be a general fit for the whole area. That is opposed to running the program on a small area or a single farm; where specific information is known. A general fit was acceptable for this project. The time and labor to run RUSLE on each farm or parcel in the Bear Creek sub-watershed would be ideal for increased accuracy, but not realistic for this study.

When the data was collected, the RUSLE equation was implemented as per equation 1 and repeated here.

$$A = R * K * (L * S) * C * P \quad (1)$$

Acreage Calculation

The second part of this project was to calculate the acreage of land that was considered at high risk for soil erosion. This was determined from the output of the RUSLE model.

Acreage was calculated by creating buffer zones along areas that were at high risk. These buffers were set at a distance of 120 feet. The distance was provided by the Olmsted County Minnesota Soil and Water Conservation Department (Langer, 2006).

It is also possible to look at the different buffer types individually to determine the best fit for a specific area but this was not done here. For example, if the slope was steep, a filter strip might be applied. Or, if the area was along a stream, a riparian buffer might apply with trees and shrubs to filter out pollutants and provide habitat for wildlife.

In some cases buffers had overlap areas that had have minimal erosion potential because good land practices were currently in use. These areas were not factored into the acreage and were removed by Onscreen digitizing.

X Tools Pro was used to calculate the highly erodible and buffer areas. The data was then converted by Data East to the ESRI ArcGIS for environment high level work with simple tools.

Conservation Cost

A cost estimate was created from the acreage (value) that was calculated by creating the buffers and the execution of X Tools. The cost estimate came from two types of conservation practices, CRP and CREP.

CRP

The Conservation Reserve Program

(CRP) is a voluntary program available to farmers to help protect environmentally sensitive land. Farmers sign up for CRP for a period of 10 to 15 years to improve water quality, control soil erosion, and improve wildlife habitat. In return, the USDA Farm Service Agency (FSA) helps participants with rental payments and cost-share assistants (Anonymous, 2003).

CREP

The Conservation Reserve Enhancement Program (CREP) is also a voluntary land retirement program. The program is a partnership among producers, tribal, state, and federal governments; and in some cases private groups. CREP is an offshoot of CRP and is also overseen by the FSA.

CREP addresses high priority conservation issues such as water supplies, loss of habitat for wildlife species, soil erosion, and limited habitat for fish population. CREP is a community-based program with local communities identifying the target areas. CREP and CRP utilize conservation practices such as filter strips, wetland restoration, field windbreaks and riparian buffers. Grass planting was the conservation practice that this project used (Anonymous, 2003). Grass planting is planting buffer strips of grass, both native and introduced, to reduce erosion.

Each county has a monetary value that is given for each acre of land placed under a conservation practice. For this project an average of the cost per acre was factored in at $93 per acre (Langer, 2006).

Results

Data Processing Steps

With the data collected, the RUSLE equation was exercised.

A = R * K * (L * S) * C * P (Eqn 1)

The L and S factors first were joined so they could be used. This was done using the raster calculator (Engel, 2003). The equation used to join them was:

((([Flow Grid] * Cell size/22.13) Pow(0.4)) * (((([Slope Grid] * 3.14/ 180) Sin) / 0.0896) Pow(1.3))

The R, K, C, P and LS factors were then multiplied together. The soil loss predicted results (A) produced the RUSLE map shown in Figure 7.

A, the calculated soil loss, ranged in value for this project from 0 to 14,385.392 tons/acre/year (Svine, 2006). The high risk area values ranged from 3,554.037 to14,385.392.

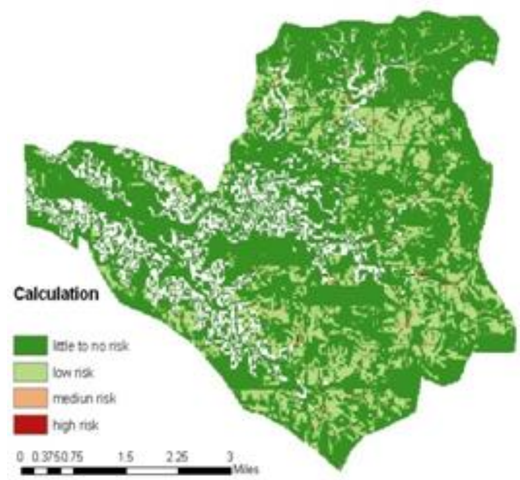

Figure 7. RUSLE Output (A).

The project's next step was to find the acreage of areas of high risk to soil erosion. This was done by onscreen digitizing polygons over the high risk areas, and using X Tools to calculate the acreage (Figure 8).

The next task was to create a 120 foot buffer zone around all of the high risk areas. These newly created buffer zones overlapped areas that did not need to be included because of currently employed good land practices and as such were excluded in the financial equation for cost calculation. This correction of areas was the next step in the process of this project. This manipulation of the area can be the difference of thousands of dollars in costs if done correctly.

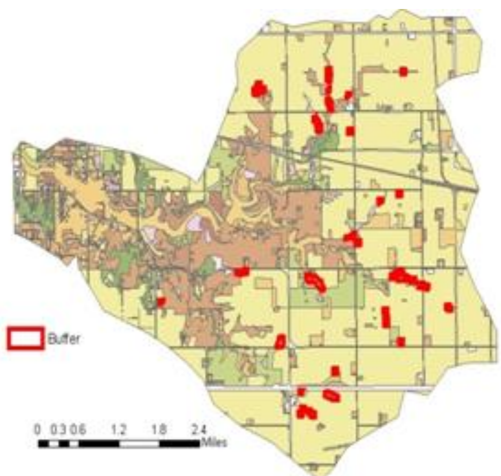

Figure 8. Buffer Zones.

The calculation of the land areas at high risk for soil erosion was determined to be 28.95 acres. After including the area of the buffer zones but editing so as to not overlap, the calculated amount of area was 130.53 acres.

If the removal of areas within the buffer zones that already had good conservation practices employed had not been done, the total area calculation would have been 144.26 acres.

The final step of this project was to find the average cost per acre that Olmsted County pays, which was $93**.** This cost was then multiplied by the total number of acres that were located within high risk soil loss areas in the Bear Creek sub-watershed.

The result was that the estimated cost of putting the high risk areas under a conservation practice and was $12,139.48.

Project Constraints

This project had many limitations, starting with the RUSLE model; there were other models that could have been used such as RUSLE II, USLE, and WIPP, but do to the cost and technology constraints these were not available to me.

The next constraint was the size of the area that was being targeted. If the target area was just one parcel of land, more accurate values could have been obtained through manual field calculations. For example, the P-factor could be given a value based on the conservation practice that a particular farm or land parcel was using.

The final constraint was getting data for the RUSLE model. This proved to be the most difficult part of the process as much of the data needed was unavailable, as well as the decreased usage of RUSLE since the advent of RUSLE II. Some estimates had to be given to some of the data so the validity of this project might come into question.

Conclusion

In the Bear Creek sub-watershed, there were a number of possible places that were at high risk for soil erosion. These areas (28.95 acres) need to be targeted for some type of conservation practice. These areas need some type of buffer zone around them and 120 feet is the average value suggested by in Olmsted County. The high risk zone and the buffers bring the acreage total to 130.53.

Olmsted County on average pays $93 per acre, which leads to a conservation plan for the Bear Creek sub-watershed estimated at a total cost of $12,139.48.

Acknowledgements

I would like to thank Dr. David McConville, John Ebert, and Patrick Thorsell and all the staff and students in the Department of Resource Analysis at Saint Mary's University for their support during my studies.

I would also like to thank Tex Hawkins at the U.S. Fish and Wildlife Service for his encouragement and help with the creation of a project. Also during my employment for him I learned valuable knowledge that will lead me far.

Thank you to Skip Langer and Jennifer Ronnenberg from the Zumbro Watershed Partnership for their support and data, and Laurie Sphine of the Rochester NRCS office who was kind enough to copy the C-factor data for this project.

Finally, I would like to thank my friends and family for their support and financial contributions to make my education possible.

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