Soil Erosion Analysis using the USLE formula in Jasper County, Iowa

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Introduction

The environmental toll brought by the occurrence of soil erosion is one that is devastating and underappreciated. Its rapid undertaking can swiftly remove the topsoil that requires time on a geologic scale to accumulate. Erosion resulting in an inch of soil loss can take 100 to 200 years to replenish. Not surprisingly, the rate of loss has greatly outpaced the rate of formation; in many parts of the world, soil loss is occurring at the rate of an inch every 1 to 10 years. Clearly, the enormous discrepancies between loss and recharge rates in affect make soil a non-renewable resource. Nevertheless, the rate of change is often too slow to warrant reaction by most, and because the implications have in large part yet to be felt, the issue has often received little to no attention. However, wind and water erosion contribute 84 percent of the world's land degradation, with an annual loss of 75 billion tons per year (Blanco, Lal, 2010) (Zuazo, Pleguezuelo, 2009).

It is therefore essential that farmers and ranchers receive proper training in soil loss management, as the delay between practice and consequence can easily make for careless and inattentive thinking. This is perhaps particularly true in the Midwest, a land blessed with some of the most bountiful topsoil in the world, delivered from the advancement and retreat of glaciers of many years past. Healthy topsoil has long been taken for granted in the Midwest, and any thought of a barren, infertile land incapable of agricultural production is in large part inconceivable to those who are the benefactors of a multigenerational land operation. Yet the consequences may soon be felt; with much of the Midwest's topsoil averaging around six feet in depth, the root systems of some crops may begin to encounter the limitations of a soil profile that is incrementally diminishing. In fact, land does not need to reach exhaustion in order to diminish in fertility as a result of erosion. Many studies have indicated that soil erosion even before exhaustion can decrease the soil's productivity as root growth, water infiltration, and plow layer fertility is affected. Additionally, erosion can bring the development of rills and gullies, soil crusting, and greater rates of runoff from rainfalls (Environmental Protection Agency, 2012). Often, however, the reduction in soil fertility is concealed and the loss in yield is compensated through improved crop varieties and increased fertilization. As much as these practices have allowed relief, it has also deferred the problems and masked their severity. Additionally, it has continued to allow farmers to practice unsustainable farming methods to the detriment of their land and beyond.

The threat of topsoil exhaustion cannot be overstated. It has often been said that soil is the bedrock of civilization. A cursory look through human history tells us that this is in large part true. Jared Diamond, in his critically acclaimed book *Collapse: How Societies Choose to Fail or Succeed*, discussed the various factors involved in the collapse of past civilizations (2004). One of the principal factors of collapse stated time and time again, from the Easter Islanders to the Anasazi to the Nordic settlements of Greenland, was a miscalculation of the soil's capacity to regenerate from exhaustive agricultural practices. Too often, humans fail to address a problem that arises slowly until it is too late. Experiences from human history should be testimony to our vulnerabilities as a civilization, but such parables are rarely seen as applicable to our technologically hubristic society. There instead exists a certain level of paralysis that is the result of ignorance, political contention, and a reluctance to change.

Of course, erosion is not solely a result of human activity on the land. Its occurrence has preceded human history for as long as wind and rainfall has interacted with the earth's soil. However, with the onset of agriculture, an acceleration of the naturally occurring phenomenon has taken place. Overgrazing, tilling, deforestation, over-cultivation, mono-cropping, chemical fertilizer usage, surface irrigation and soil compaction have contributed to a rate of erosion that is outpacing soil's formation. These practices diminish a soil's structure, creating more vulnerability to the physical elements that naturally drive erosion. Top soil, the nutrient-rich loam composed of organic hummus that covers all of the world's fertile lands, can then easily dissipate, leaving behind barren landscapes inhospitable to most agricultural cultivation.

Considering the land's vulnerabilities, it is essential that users of the land pursue conservation practices that can sustain the soil for indefinite use. One useful erosion prevention technique is known as plant residue management. This can provide an effective soil cover after harvest, thereby limiting the surface runoff that is brought by rainfall activity. Creating a permanent surface cover of deep -root vegetation can also maintain soil cohesion. To ensure continuous soil cover, crop rotation, strip cropping and no-till practices should be strived for, and excessive tillage should be avoided. Crop rotation provides constant vegetation coverage without exhausting the soil's nutrients through the use of cover crops during fallow periods, while strip cropping uses vegetation strips along crop rows. Tillage is perhaps the number one culprit behind accelerated soil loss, as it not only removes the land's surface cover but also dehydrates the soil, leaving it more vulnerable to wind erosion. With the introduction of modern farm equipment, farmers have become capable of deep plowing, thus exacerbating the problem brought on by earlier forms of tillage. While no-till practices should be strived for, there are two tillage practices that are deemed acceptable but secondary to no-till; those being strip-till and ridge-till practices. Both strip-till and ridge-till are practices that require minimal tillage, with strip-till requiring tillage only in the portion of the soil that contains the seed row and ridge-till following the ridges built during cultivation from the previous year's crop. An overall avoidance of cultivation on sloped terrain can also be of importance. If flat land is not obtainable, terracing methods can minimize the toll brought by cultivation on sloped terrain. Sloped land can even be flattened using laser leveling techniques, thus ensuring a virtually perfect no-slope terrain that is less susceptible to erosion. Problems brought by sloped land can be minimized through the use of contour farming, which incorporates the slope formation in the row pattern, by planting along the slope instead of up and down it. A final soil conservation practice can utilize various natural buffers, such as grassed waterways, tree linings, terraces, windbreaks, and grass barriers. These buffers can block, mitigate, or redirect erosion forces in areas where land may otherwise be vulnerable to heavy amounts of wind or rainfall exposure.

Although the aforementioned conservation efforts are essential components to sustainable land practices, all lands differ in terms of quality and the kind of conservation efforts most needed. If a farmer with good intentions pursues a conservation practice that is not applicable to his or her land, it may be a wasteful use of resources that is the result of poor planning. To properly diagnose the soil's weaknesses, an assessment must first be made, to not only locate areas most in need of conservation but also to determine the kinds of conservation that is most needed. Doing a proper assessment of the land can help determine the type and the amount of remediation required, and also determine the areas where remediation is most in need. A soil erosion assessment can be accomplished through the use of soil erosion modeling.

There are two main types of erosion models; one that is process based and the other that is empirically based. Process based models create estimates of soil erosion rates through the use of mathematical equations using identified factors to approximate the rate of erosion. Empirical models weigh the rate of management and environmental factors to the rate of soil loss to determine the relationship.

The USLE formula

A number of erosion models have come about over the years, including ANSWERS, AGNPS, and WEPP. Perhaps the most well-known empirical soil erosion model is the Universal Soil Loss Equation (USLE), and its successor, Revised Universal Soil Loss Equation (RUSLE). USLE was developed in the 1930s by the USDA Soil Conservation Service, and first implemented by the same federal agency thirty years later. Its development began under a controlled experiment using a rainfall simulator and an erosion plot. The first iteration of the model was focused on slope steepness and length. A.W. Zingg first published the results of a study in 1940 which factored both using a constant of C, S for slope angle and L for slope length. A represented the average soil loss per unit area. Following Zingg's analysis came Dwight D. Smith's contribution in 1941, which took into account the cropping and support practice factor. Smith's input to the USLE equation was P, which was the ratio of soil loss with a mechanical conservation practice to soil loss without. Smith also introduced the rate of soil loss deemed allowable based on an annual limit. Further honing of the equation and its coefficients came with the introduction of the Agricultural Research Service in 1953 and the National Runoff and Soil Loss Data Center in 1954. Past data collected since the 1930s came to be used for testing and development of the USLE model (United States Department of Agriculture, 2009). The major breakthroughs that came about during this period of testing included determining the relationship between rainfall energy and soil loss, cropping management factor evaluation, and the formation of a rainfall erosion index. Today, USLE is considered an industry standard in erosion analysis, and has become a required tool in farm and ranch planning for qualification of USDA's assistance programs (National Soil Erosion Research Laboratory). USLE's equation has expanded since its introduction, and it now account for rainfall pattern, soil type, topography, crop system, and management practices (Stone, R.P., Hilborn, D., 2000). Despite its wide applicability, USLE is capable of determining soil loss rates from sheet or rill erosion alone. It is not capable of determining soil loss rates from gully, wind or tillage erosion. USLE has since been largely replaced by an improved version of the original formula, known as RUSLE. Although RUSLE uses the same formula as its predecessor, improvements were made in determining the individual factors. Among the improvements were revised isoerodent maps, using a time-varying approach for soil erodibility, a new subfactor for the cover-management factor, a new equation to account for slope angle and length, and new conservation-practice values (Institute of Water Research, 2002). The remainder of this section will use USLE to refer to both the USLE and RUSLE formulas, with clarification if a definition solely applies to one equation or the other.

There exist five factors that are used to determine soil loss using USLE. Estimates of the severity of each factor is used within the calculation and then multiplied. The USLE formula is the following:

$$A = R \times K \times LS \times C \times P$$

The A in the formula represents the average annual soil loss in tons per acre per year. Therefore, A is the result of the USLE calculation, often used to determine an area's fertile sustainability by comparing it to the area's tolerable soil loss, which is known as the T value.

The R factor represents the rate of rainfall and runoff by geographical location. There exists a positive correlation between a rainfall's duration and intensity and its erosion potential. The R factor uses average annual rainfall records for a normal year extended over a 22-year period. The erosion-index for R takes into account two variables in order to determine the erosion force of a given rainfall: the amount of rainfall and the peak intensity of the rainfall. Storm losses from rainfall represents the product of the total kinetic energy of a storm (E) multiplied by its maximum 30 minute intensity (I) (Institute of Water Research, 2002). If a storm is less than 0.5 inches, it is not accounted for as it likely contributes little to the total R value.

The K factor is the soil erodibility factor, which measures the susceptibility of the soil in becoming detached and transported by rainfall and runoff. The K factor specifically represents the average soil loss in tons per acre for a soil under normal conditions - in cultivated, continuous fallow with a slope length of 72.6 feet and a slope steepness of 9 percent (Stone, R.P., Hilborn, D., 2000). Soils are rated based mostly on their texture, but its structure, level of organic matter, and permeability are also contributing factors. Soils that are high in clay have low K values largely due to their high level of adhesion. Soils that are coarsely textured, such as sandy soils, also have low K values, but this is due to their low runoff rather than their level of adhesion. Soils with high silt content are the ones most vulnerable to erosion, as they are easily detached and produce high rates of runoff. The amount of organic matter in the soil can also have an impact on erodibility; high organic matter increases water infiltration, thereby reducing the rate of runoff. The K factor is intended to measure soil erodibility in its natural state. However, poor management can also increase soil erodibility if it results in heightened vulnerability by way of exposed subsoil, lost organic matter, or increased compaction.

The LS factor is the slope length-gradient factor, which represents the effect of slope angle and slope length on erosion. It is the ratio of soil loss from a field with a slope length of 72.6 feet and a slope steepness of 9 percent. Slope length represents the horizontal distance of a flow path from its origin to the location of concentration or deposition. The areas of concentration or deposition are typically at the base of concave slopes, but if there are no signs of deposition, it is generally assumed that deposition occurs where the steepness is half the average steepness of a slope (Institute of Water Research ,2002). A high degree of accuracy in determining a slope length for the USLE formula is generally unnecessary; inaccuracies of slope length of up to ten percent are likely acceptable, particularly in areas with flat terrain (Institute of Water Research, 2002). Determining an area's slope angle is more intuitive than that for slope length. Slope angle is also of greater importance to the LS factor than slope length; soil loss increases more rapidly with an increase in slope angle than it does with slope length.

The C factor is the cover-management factor, which uses a Soil Loss Ratio (SLR) of soil loss from land under a specific crop and management system to the soil loss from land under continuous fallow and tilled land. The C factor takes into account a number of subfactors, including surface cover, soil biomass, crop type, surface roughness, as well as soil disturbance from agricultural practices. Surface cover functions as barriers to disturbance from rainfall, by intercepting raindrops and thereby slowing surface runoff. Surface cover can include rocks, vegetation, and plant residue. Surface roughness affects the C factor as it accounts for depressions which capture water from rainfall, thereby reducing raindrop impact and the level of water flow. The level of soil disturbance affects the surface cover as well as the surface roughness.

The P factor is the support practice factor. It is the ratio of soil loss by a specified support practice to that of straight-row farming following the contours of a slope. Cross slope cultivation, contour farming, and strip-cropping are examples of practices that would be accounted for in the P factor. The P factor is only applicable to soils being used for agricultural purposes, and it accounts for differences between cropland, rangeland, and permanent pasture.

The T value is the soil loss tolerance expressed in tons per acre per year. Although the T value is not a contributing factor to the USLE formula, it is used for analysis along with the USLE result (A) to determine areas needing targeted conservation planning. The T value represents the maximum amount of tolerable soil loss which will continue to allow for a high level of crop production to be sustained indefinitely. Similar to the P factor, the T value is only applicable to soils being used for agricultural purposes.

The USLE formula, as well as its successor, RUSLE, are both useful models for soil loss detection and erosion vulnerability. The results can be used for analysis and conservation planning by farmers, ranchers, land managers, and conservationists. While there may not be a standard methodology in formulating many of USLE's factors, and some gaps may still exist in its level of validity, the USLE formula is an indispensable tool for those who are concerned about the health of our land and who wish to remediate the problems brought by erosion.

Methodology

The purpose of this research was to implement the USLE formula on a test area so to identify its feasibility using remote analysis via ArcGIS 10.0 mapping software. The test area chosen was Jasper County, Iowa, a location chosen largely for its data availability and its high level of agricultural land. The reference data was gathered from United States Geological Survey (USGS), the Soil Survey Geographic Database (SSURGO), the Iowa Department of Natural Resources (IDNR), the Multi-Resolution Land Characteristics Consortium (MRLC), and WorldClim. The data for the USLE formula was found to be obtainable without the use of on-site analysis for each factor with the exception of P, the support practice factor. There exists no map layers that identify the P factor in the area studied, and it is infeasible to determine P through the use of GIS analysis or remote sensing techniques alone. A more thorough study would have assessed the land in the county on-site in order to determine the P factor, through the use of a survey or roadside assessment. However, because the P factor is only applicable to agricultural lands, on-site analysis would have only been necessary for those areas within Jasper which are used for various forms of farming. The P factor was in turn left out of the analysis, and factors R, K, LS, and C were all determined through the use of various GIS and remote sensing methods, and were then multiplied to retrieve the USLE output, A.

The reference data for the first factor, R, was retrieved from a nationwide rainfall dataset obtained from WorldClim, and clipped to only encompass Jasper County. Because the dataset was in raster format, the clip operation used the Extract by Mask tool with a boundary layer of Jasper County as the feature mask data. The rainfall dataset gathered from WorldClim was generated through the use of interpolation methods of average monthly climate data from weather stations on a 30 arc-second resolution grid (Hijmans, Cameron, Parra, Jones, Jarvis, (2005). The data came in 12 raster layers, each one capturing monthly precipitation averages over the course of thirty to fifty years, depending on data availability for each given location. The raster calculator in the Spatial Analyst toolbox was used to aggregate the monthly data into an annual average. This was accomplished by simply adding the individual layers together and dividing by the total number of layers, in this case twelve.

A hindrance in using the WorldClim data was that it did not fully satisfy the requirements of the USLE formula, as R is intended to incorporate both the energy of a storm (E) as well as its maximum 30 minute intensity (I). Ordinarily, this can be obtained through the use of breakpoint rainfall intensity data calculated from graphical charts generated by rain gauges. With this information, a storm erosion index can be developed in order to give a numerical value for the R factor using the following formula:

$$Storm\ EI_{30} = \{\sum 1099 \times [1 - 0.72 \times \mathrm{Exp}(-1.27 \times I_{\mathrm{r}})] \times R_{\mathrm{r}}\} \times I_{30}$$

Where I_r is the rainfall intensity in a given storm's time interval and R_r is the rainfall amount during the same time interval. These values are calculated for every time interval of the storm and then summed to extract the storm energy (E). The E value is multiplied by the I_{30}, which is the maximum 30 minute intensity during the storm, thus resulting in storm EI_{30}. The average annual total of the storm EI_{30} values represent the rainfall erosion index, or R factor, for a particular area (Khosrowpanah, Heitz, 2001).

Because the breakpoint rainfall intensity data was very hard to come by, this study substituted the EI_{30} value with monthly precipitation averages. Such substitution has been defended as sufficient for obtaining a usable R factor given little data availability. The researchers of the study *Using monthly precipitation data to estimate the R-factor in the revised USLE* found that there is a strong level of correlation between the EI_{30} values and monthly precipitation rates, suggesting that the latter can be used as a sufficient proxy for the former in the event of insufficient data for a full R factor calculation (Renard, Freimund, 1994).

The reference data for the second factor, K, was retrieved from the SSURGO dataset available from its website, http://soils.usda.gov/survey/geography/ssurgo/. The spatial extent of the data encompassed Jasper County, and came in a shapefile format. The SSURGO data contained a K factor field available "out of the box", thus allowing for ease of use to the user. The only step that was necessary to take was a conversion from shapefile format to raster, so as to allow for compatibility with the other factor layers upon doing the USLE calculation.

Had the K factor field been not provided in the SSURGO data, a manual calculation would have been required. The following formula can determine the surface layer erodibility, or K factor, of a soil dataset:

$$K = (27.66 \times m^{1.14} \times 10^{-8} \times (12-a)) + (0.0043 \times (b-2)) + (0.0033 \times (c-3))$$

Where m is the percent silt added to the percent of very fine sand, which is multiplied by the percent clay subtracted by 100; i.e. (silt (%) + very fine sand (%))(100-clay (%)), a is the percent of organic matter, b is the structure code (1 being very structured, 2 being fairly structured, 3 being slightly structured, and 4 being solid), and c is the profile permeability code (1 being rapid, 2 being moderate to rapid, 3 being moderate, 4 being moderate to slow, 5 being slow, and 6 being very slow) (Agriculture and Agri-Foods Canada, 2012).

The reference data for the third factor, LS, was retrieved from the USGS online user tool Earth Explorer, available at http://earthexplorer.usgs.gov/. The data came in raster format as a Digital Elevation Model grid (DEM) in 30-meter resolution. Similar to the R factor, the layer was clipped by way of the Extract by Mask tool using the boundary layer of Jasper County as the feature mask data. As mentioned in *The USLE formula* section, the LS factor contains two subfactors – L for slope length and S for slope gradient. Both subfactors required a preprocessing step to ensure that all depressions within the DEM were filled, thereby preventing any real or manufactured sinks from distorting the results. This preprocessing step used the Fill tool in the Spatial Analyst toolbox.

Out of the two subfactors, the L subfactor proved to be the most challenging one to generate, as ArcGIS 10.0 does not offer a tool that is intended specifically for this purpose. The literature did however contain some workaround solutions. In *Slope Angle and Slope Length Solutions for GIS*, there contained a solution that was rather complex, but entirely useful. It first calculates the maximum downhill slope and the flow direction of the DEM. High points within defined watersheds are then determined by locating the cells that have no flow entering them. A non-cumulative slope length can then be determined based on the cell's status; if it is a high point cell it is determined by 0.5 multiplied by the cell resolution, if it is a cell with a cardinal direction of N, S, E, or W, then it is just the cell resolution, otherwise, all other cells are 1.412 multiplied by the cell resolution. A cumulative slope length can then be determined by summing the non-cumulative slope length cells along the flow direction starting at the high point cells (Hickey, 2000). An easier method proposed by Desmet and Govers (1995) determined slope length via a flow accumulation raster. This was the route that was decided upon for this study. The flow accumulation raster was derived by first determining the flow direction via the Flow Direction tool, and then using the Flow Direction output as an input for the Flow Accumulation tool.

The S subfactor was determined using the Slope tool in the Spatial Analyst toolbox. This tool uses a quadratic surface algorithm which determines the slope across a cell based upon at least four of the neighboring cells, thus calculating an average slope based upon a 3x3 neighborhood (Hickey, 2000). The output raster generated from the slope calculation was highly distorted; the majority of cells contained a slope of 85 to 90 percent, an obvious miscalculation. The explanation behind this grievous distortion was due to the DEM itself. The elevation raster came in a geographic coordinate system, where x and y coordinates were stored in latitude and longitude while the elevation values were stored in linear units (in this case, meters). Because latitude and longitude are angular units while meters are linear units, they are incompatible with each other for any kind of surface analysis. Degrees of longitude represent much greater lengths compared to meters, with the exception of areas in close proximity to the poles. Additionally, degrees of longitude are of variable length depending on the latitude, thereby requiring adjustment depending on the location of the analysis. With this in mind, it is best to first use a projected coordinate system so that all units of measurement are in the same unit. The formula used to allow for compatibility between the angular units and the linear units (in meters) within a geographic coordinate system is the following:

$$\text{Z-Factor} = 1 / 111320 \times \cos(L)$$

Where L is the mid-latitude of the dataset, and 111320 is the number of meters in one degree, in radians, at the equator. The calculation comes out to roughly 0.00001, which can be used as the Z-factor input for the slope calculation. With this weight provided, the extreme level of distortion seen in the original slope grid is eliminated.

With the two subfactors in place, the LS factor was then determined. The formula used for the LS factor is the following:

$$\text{LS Factor} = (\text{FA} \times \text{Cell Size} / 22.13)^{0.4} \times (\sin S / 0.0896)^{1.3}$$

Where FA is the Flow Accumulation raster, cell size is the length in meters of the DEM cell (resolution), and S is the slope gradient expressed in radians. This formula was calculated using the Raster Calculator in the Spatial Analyst toolbox.

The reference data for the fourth factor, C, was retrieved from the USGS online user tool Earth Explorer, available at http://earthexplorer.usgs.gov/. The data was from LANDSAT 7 Thematic Mapper and came in a multiband image raster, which was clipped by way of the Extract by Mask tool using the boundary layer of Jasper County as the feature mask data. The date of the image gathered was from May 7, 2004, which is an ideal time of year for the purposes of this project, as the C factor attempts to detect the level of crop residue during a fallow period. Because most seed plantings do not begin until May, the beginning of May is the ideal timeframe for crop residue detection.

There exist a number of spectral models for measuring the levels of crop residue and identifying tillage practices. These models combine the low reflectance of the visible with the high reflectance of the near infrared in order to identify the level of vegetation. Among the various models which utilize the green vegetation spectrum in determining the C factor are the Normalized Difference Tillage Index (NDTI), Simple Vegetation Index (SVI), Normalized Difference Index (NDI), and Normalized Difference Vegetation Index (NDVI). These indices determine the relative difference in reflectance from soil and vegetation. The model chosen for this research was the Normalized Difference Vegetation Index, which is the difference of a near infrared band and a red band divided by the sum of the same near infrared band and red band. The NDVI is considered one of the oldest and most popular of the Vegetation Index models, as it is applicable to a wide range of environments. The value of the index ranges from -1 to 1, and the majority of green vegetation fit within the range from 0.2 to 0.8 (ENVI User's Guide, 2005).

In order to implement the NDVI, only bands 1 and 5 were used. Before the NDVI formula could be implemented, four preprocessing steps were first required. First, all data in the raster that read as 0 values had to be reclassified as null using the Reclassification tool. Second, because the LANDSAT 7 data is formatted as a digital number (DN) which allows everything to fit in an 8-bit number ranging from 0 to 255, the data is not suitable for processing. Before continuing, the DN data first had be converted to reflectance data, which is the actual physical measurement of the satellite imagery. This is done by using the following formula:

$$L_\lambda = (\text{gain}_\lambda \times DN7) ++ \text{bias}_\lambda$$

Where L_λ is the calculated radiance [in Watts / (sq. meter × µm × ster)], DN7 is the LANDSAT 7 ETM + DN data, and the gain and bias are band-specific values. The gain and bias for Band 1 is 0.778740 and -6.98, respectively, and the gain and bias for Band 5 is 0.126220 and -1.13, respectively. The following formulas were put into raster calculator to determine the radiance for bands 1 and 5:

Band 1 Radiance: (0.778740 * "Band1") -6.98
Band 5 Radiance: (0.126220 * "Band5") -1.13

The third step was to convert the radiance data to reflectance data. This step is necessary to allow for better comparison among scenes, as it removes any differences brought by the position of the sun, and more importantly, the differing amounts of energy output for each band.

The level of reflectance is in essence the level of albedo on the earth's surface registered from the sun. The following formula converts radiance data to reflectance data:

$$R_\lambda = (\pi \times L_\lambda \times d^2) / E_{sun\lambda} \times \sin(\theta_{SE})$$

Where R_λ is the reflectance, L_λ is the radiance calculated from the last step, d is the distance of the area to the sun in astronomical units, $E_{sun\lambda}$ is the band-specific radiance emitted by the sun, and θ_{SE} is the angle of the solar elevation. The solar elevation angle can be found within the header file of the raster's metadata, while the other pieces of information were retrieved from http://ibis.colostate.edu/WebContent/WS/ColoradoView/TutorialsDownloads/CO_RS_Tutorial10.pdf. It should be noted that the sine function in the raster calculator requires the solar elevation angle to be in radians instead of degrees. The following formula performs the conversion:

$$\text{radians} = (\text{degrees} \times \pi)/180°$$

The radian conversion was embedded into the reflectance data conversion. The following formulas were put into raster calculator to determine the reflectance for bands 1 and 5:

(3.141592654 * "Band1" * SquareRoot(1.00904)) /
(1997 * Sin(59.6168067 * 3.141592654 / 180))

(3.141592654 * "Band5" * SquareRoot(1.00904)) /
(230.8 * Sin(59.6168067 * 3.141592654 / 180)

The fourth step was to enforce positive reflectances. Any negative values are the result of the conversion process from DN data to reflectance, and are not actually physically present. Any negative values that do exist from the conversion process should appear to be relatively small. The formula for enforcing positive reflectances in the raster calculator is:

Corrected Reflectance = CON("Input_Raster"<0.0, 0.0, "Input_Raster)

The CON statement within raster calculator functions as a conditional, where any cells that fit the condition of being less than 0.0 in value are replaced by a value of 0.0. With all the preprocessing steps finished, the NDVI can now be calculated in the raster calculator:

NDVI = (Band 5 – Band 1) / (Band 5 + Band 1)

The output of the NDVI formula functions as the C factor.

As was previously mentioned, the fifth and final factor, P, was not calculated due to insufficient resources. However, because the support practice factor only applies to agricultural lands, and because tillage methods are inferred by the plant residue cover extracted from C, it may be fair to assume that the P factor is of less importance in performing the USLE formula. Of course, this is not to say that the P factor is an entirely frivolous component of the USLE formula, but rather that its requirement of on-site field work makes it virtually unobtainable for the purposes of this project.

With all of the input factors calculated , the USLE formula can now be performed. There is however, one preprocessing step necessary before the USLE can be calculated. Many of the input rasters contain differing cell sizes. When any map algebra is performed on the rasters, the lowest resolution of the four rasters is the one used as the output resolution. To prevent this, lower resolution rasters must be adjusted to match their higher resolution counterparts, so that all input rasters contain equally high resolution. Raster layers that do not contain linear measurement units must go through an initial step using the Project Raster tool, and setting the Linear Measurement to Meters. The rasters can then be resampled using the Resample tool in the Data Management toolbox.

The calculation typically performed in the USLE formula, i.e., A = R x K x LS x C x P, could not be applied because of the bias potential if all factors were given equal weight. The issue stems from the fact that the R factor was determined through alternative means, thus making its values inappropriate as raw input for the USLE formula. To accommodate for the relatively high values of the R factor, an indexing formula which adjusted for relative inaccuracies was used instead. The following is the USLE formula, adjusted:

0+((("C" - C Mean) / C St. Dev.) * 1) + ((("K" - K Mean) / K St. Dev.) * 1) + ((("R" - R Mean / R St. Dev.) * 1) + ((("LS" - LS Mean) / LS St. Dev) * 1)

The following is the same USLE formula, with the actual figures in place:

0+((("C_Factor" - 1.47) / 0.22) * 1) + ((("K_Factor" - 0.3) / 0.06) * 1) + ((("R_Factor" - 73.52) / 1.30) * 1) + ((("LS_Factor" - 0.83) / 6.86) * 1)

Conclusion

The USLE formula is an erosion model with many useful purposes. Although it requires a number of steps to compile, the end result is an accurate and useful representation of an area’s susceptibility to erosion. Its application to Jasper County, Iowa, revealed an area with a dynamic variation of erosive features. Through this compiled map, farmers and rural planners within the county can now determine areas most in need of soil conservation practices. The use of USLE is therefore an indispensable component to analyses of agricultural health practices and to those who care about the health of topsoil.

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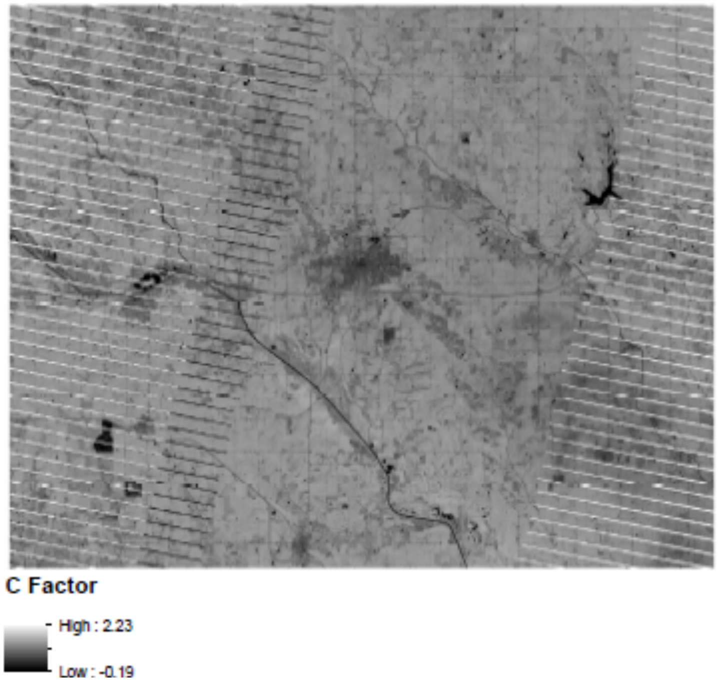
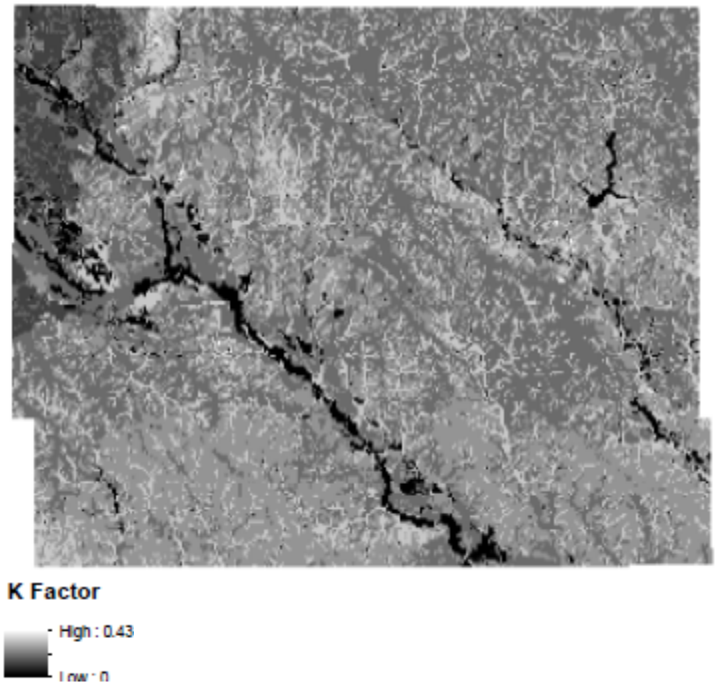
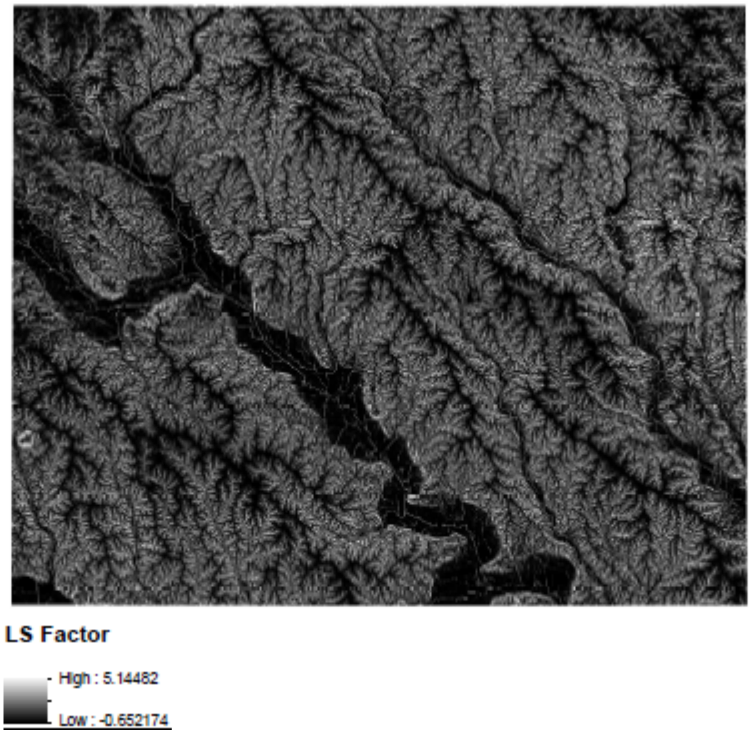
Appendix 1: C Factor



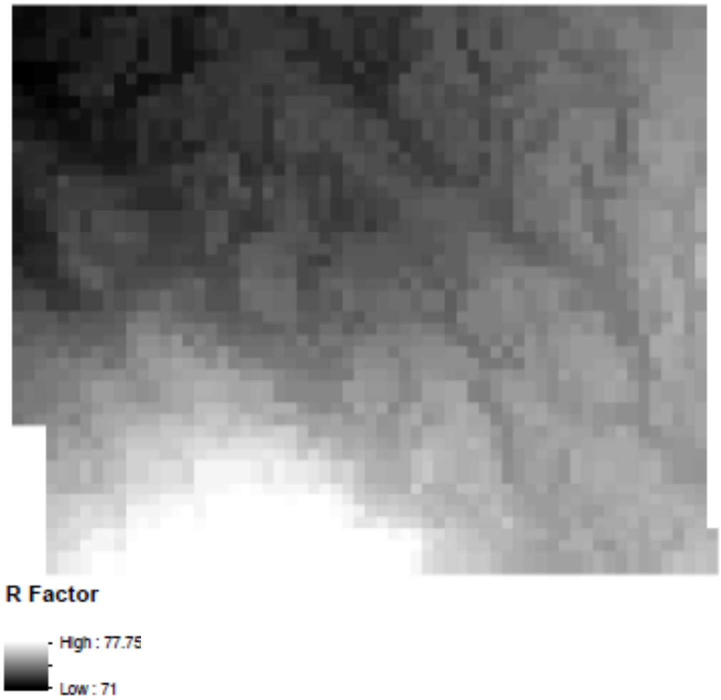
Appendix 2: K Factor



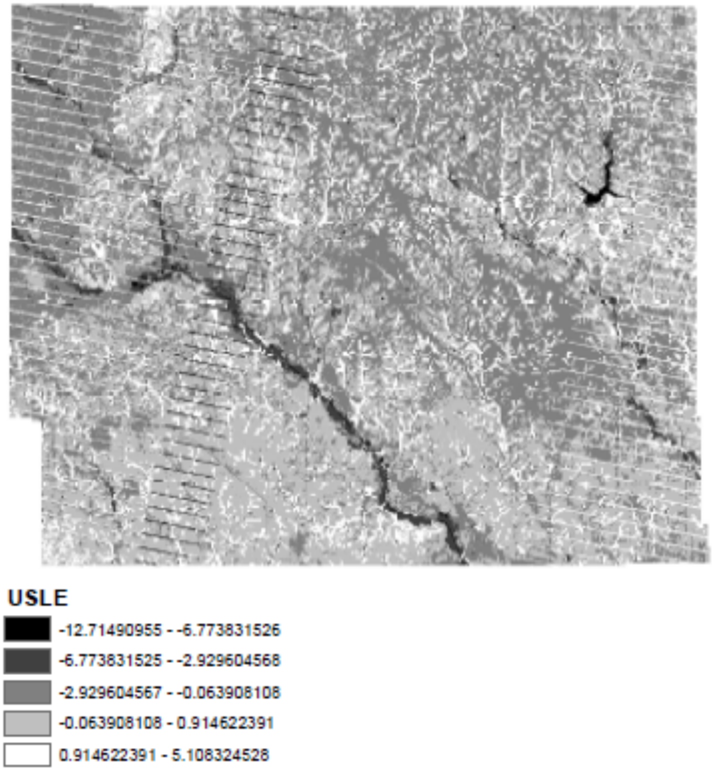
Appendix 3: LS Factor



Appendix 4: R Factor



Appendix 5: USLE


USLE
■ -12.71490955 - -6.773831526
■ -6.773831525 - -2.929604568
■ -2.929604567 - -0.063908108
■ -0.063908108 - 0.914622391
□ 0.914622391 - 5.108324528