# Soil Erosion Assessment using GIS and Revised Universal Soil Loss Equation (RUSLE).

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**CE 394K GIS in Water Resources - David R. Maidment.**

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# Table of Contents



# List of Figures

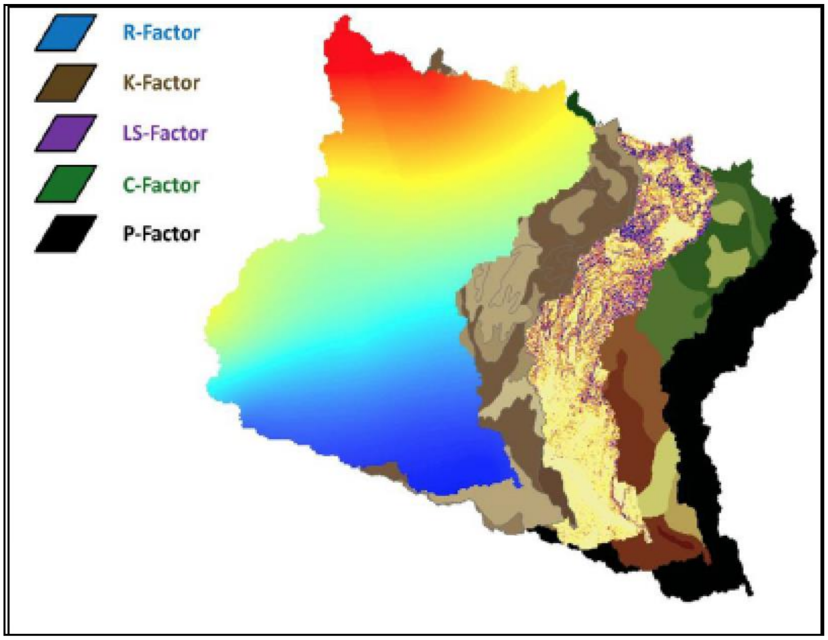
## Motivation and Objective

Sediments by soil erosion have been an important factor that affects the morphological changes of river beds and water quality in river systems. The sediments caused by erosion transport into the river systems and change the river bed morphologically through the settlement and the entrainment. The sediments, which accumulate on the river bed or on the bottom of reservoirs, cause the inundation by decreasing the cross section area of river stream and the reduction of storage capacity of reservoirs. The sediments caused by erosion are one of the leading sources of nonpoint source pollution. In particular, the increased fine silt and sands from nearby lands into river systems degrade the water quality by decreasing the depth of streams, increasing the turbidity, and increasing nutrient pollution. As a result, many of the previous research focused on the morphological changes of river beds and water quality changes in river systems caused by sediments, and at the same time there have been a lot of research estimating the amount of erosion on lands.

The exact estimation of the amount of soil erosion is the basic and essential step not only for the research of river morphology and water quality, but also for the appropriate management of sediments. The estimation and management of the amount of soil erosion is of particular interest to me because my research is focused on the facilities such as check dams to reduce sediments in the river channels. Therefore, the aim of this project is to calculate the amount of soil erosion more accurately using ArcGIS and Revised Universal Soil Loss Equation (RUSLE). This project would increase the understanding of the water-borne soil erosion directly related to river systems and the GIS combined RUSLE model. Based on the results of this estimation, the area which is vulnerable to erosion can be determined, and the best management plan to reduce soil erosion can be applied to that area.

**Revised Universal Soil Loss Equation(RUSLE)**

The Universal Soil Loss Equation (USLE) was first developed in the 1960s by Wischmeier and Smith of the United States Department of Agriculture as a field scale model [1]. It was later revised in 1997 in an effort to better estimate the values of the various parameters in the USLE [2]. There are five major factors that are used to calculate the soil loss for a given site. Each parameter is the arithmetic estimate of a specific condition that affects the severity of soil erosion at a particular location. The calculated erosion values reflected by this model can vary significantly due to fluctuating weather conditions. Thus, the erosion values obtained from the RUSLE (Revised Universal Soil Loss Equation) more accurately represents long-term averages. The RUSLE uses the simple equation (A = R x K x LS x C x P). Where ‘A’ is the average annual soil loss in tons/acre/year, ‘R’ is the rainfall-runoff erosivity factor, ‘K’ is the soil erodibility factor, ‘LS’ is the slope length and degree, ‘C’ is the land-cover management factor, and ‘P’ is the conservation practice factor[2]. Each parameter will be described in more detail in this report.



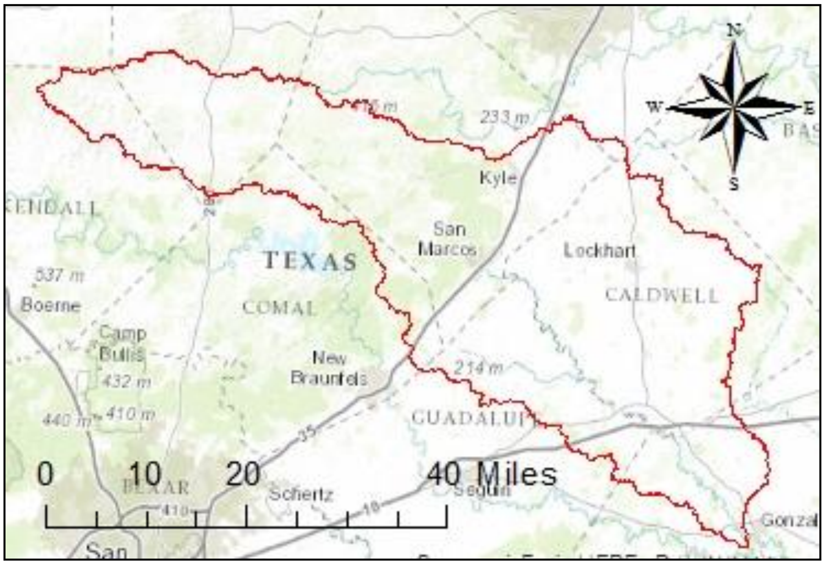

**< Figure 4. Overlay of the RUSLE Model >**

## Methodology

All data could be collected from the USDA, USGS, NRCS, and ESRI data services. Since their geographic coordinate system is WGS 1984 projection and datum, all maps are kept in this state. The projected coordinate system which is used for this project is North America Albers Equal Area Conic coordinate system. Since most of the parameters are in the vector form, they were converted into rasters with a cell size of 30m so that the model could accurately calculate the amount of soil loss.

## Study Area

In Central Texas, just south of the Austin area is the city of San Marcos. The watershed which comprises this city and some of its surrounding area is the San Marcos Subbasin. This subbasin was chosen for this study because it was used in previous exercises in Dr. David Maidment's Geographic Information Systems in Water Resources course at the University of Texas at Austin.




**< Figure 5. San Marcos Subbasin >**

**Analysis**

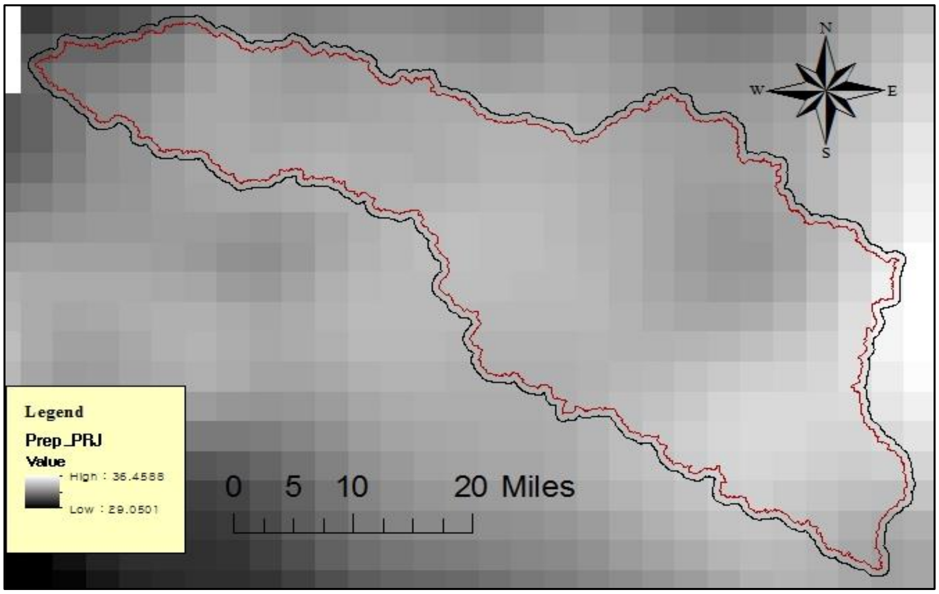
R-Factor: R-Factor is the rainfall erosivity parameter. This is highly affected by storm intensity, duration, and potential. Although the USDA created contours of the spatial variation of the R-Factor throughout the continental US during the revision of the USLE [3], these contours could not be used in GIS directly because the data were in the form of a pdf file. Therefore, to calculate R factor, another method, which uses an equation that has been developed to determine the relationships between rainfall intensity and energy, is considered. Among these equations, Kurt cooper's equation is adopted in this project.

Kurt cooper suggested equations, which determine the relationships between mean annual precipitation and R factor, for the conterminous United States: Washington and Oregon, California, Western United States, and Eastern United States [4]. In this project, Kurt cooper's equation for Eastern United States is used to calculate R factors, and the equation is shown as

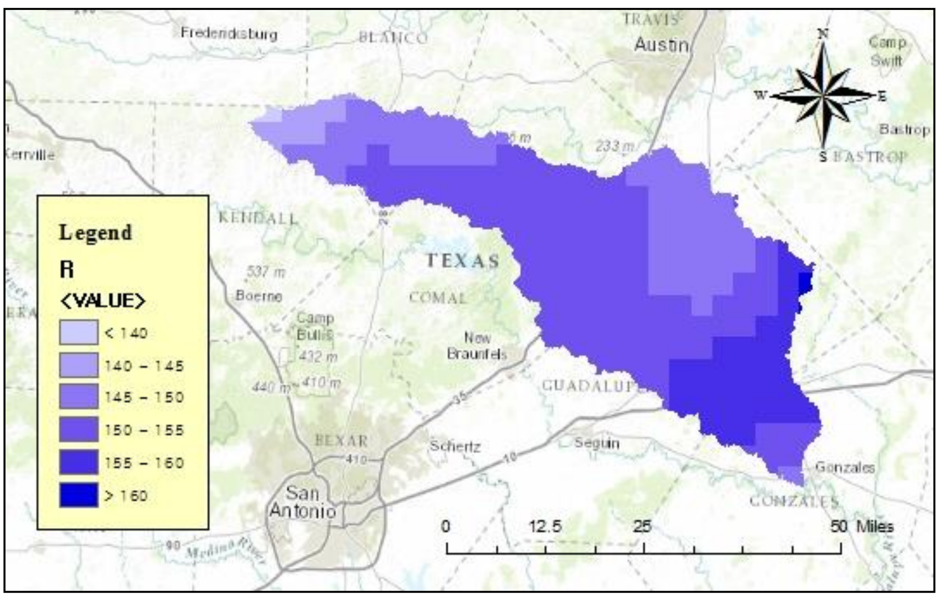
$$\mathrm{R} = 1.24 \times P^{1.36}, r^2 = 0.57 \tag{1}$$

where, R is rainfall erosivity (hundreds of foot-ton inches per acre per hour), and P is mean annual precipitation (inches). The data of mean annual precipitation of 1961~1990 for this target area is provided by USDA and NRCS.

Using the raster calculator function in GIS, the mean annual precipitation is converted into raster data of R factor (Figure 3, and Figure 4). The mean annual precipitation of the target area was between 29~36 inches and uniform over the basin area. Because of this uniform precipitation there is not so much variation in R factor over the basin area.



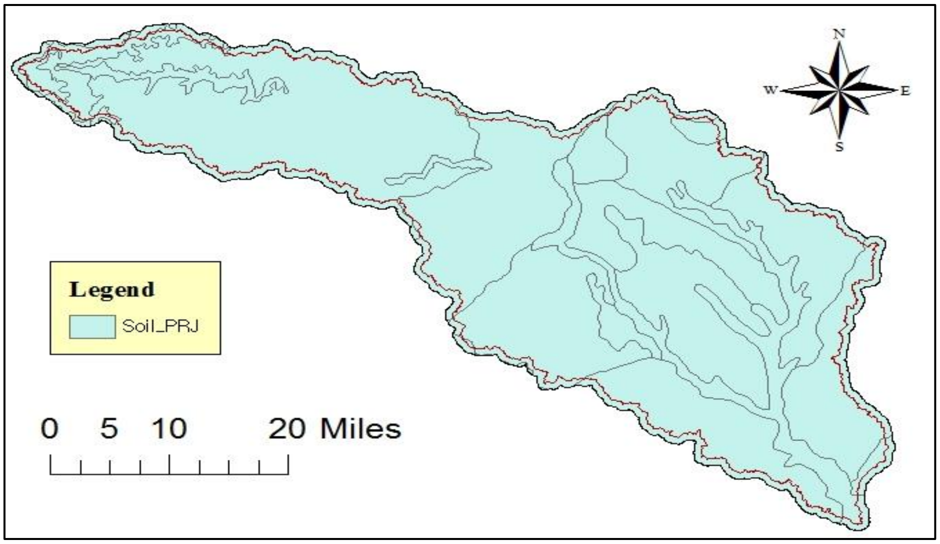

**< Figure 6. Mean Annual Precipitation(1961~1990) >**




**< Figure 4. Raster data of R factor >**

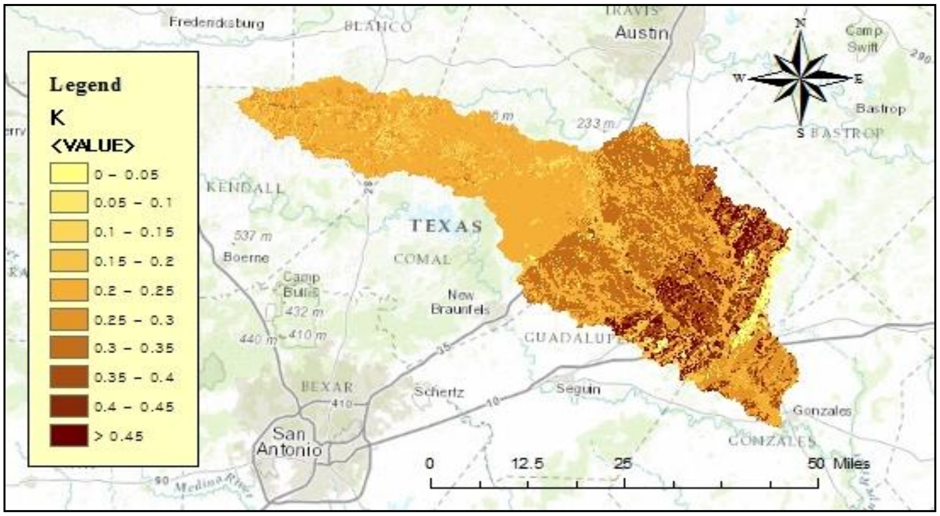
<u>K-Factor</u>: The soil erodibility parameter is based on the soil texture, structure, organic matter, and even permeability. The NRCS conducts soil surveys throughout the country, and these surveys contain GIS shapefiles with tabular data including the K-Factor for each soil type.

After obtaining the K-factor from soil survey data of NRCS, the GIS shapefile(Figure 5) of soil type is converted into raster data of K factor by the feature to raster function of GIS.




**< Figure 5. Soil Survey Shapefile >**

Soils high in clays tend to have low K values (0.05-0.15) because they are more resistant to detachment. Figure 6 shows the raster created for the K factor. Note that most of the high K values are in the southeast area. It can be assumed that the result is caused by the flat topography and alluvial accumulation in south east area.




**< Figure 6. Raster data of K factor >**

LS-Factor: The $L$ and $S$ factors represent the effects of slope length ($L$) and slope steepness ($S$) on the erosion of a slope. In general RUSLE model calculation, the L and S factor are calculated by different equations. The L factor(slope length factor) is the ratio of soil loss from a slope length relative to the standard erosion plot length of 22.1m. The actual slope length is the horizontal distance (excludes slopes) of the plot being modeled and is converted to the slope length factor by the following equation (*2*):

$$L = \left(\frac{\lambda}{22.1}\right)^{m} \quad (2)$$

where λ is the actual slope length and m is the slope length exponent that is the ratio of rill to interill erosion.

The S factor(slope steepness factor) is the ratio of soil loss relative to a 9% slope, which is the standard slope that experiment plots use. The slope steepness factor is calculated as a function of slope as shown below:

$$S = 10.8 \sin\theta + 0.03, \ \text{slope gradient} \leq 9\% \quad (3)$$

$$S = 16.8 \sin\theta - 0.50, \qquad \text{slope gradient} > 9\%$$

where $S$ is the slope factor, and $\theta$ is the slope angle. Depending on the measured slope gradient, a different equation for $S$ must be used. Choosing $S$ allows the RUSLE to be more finely tuned for different terrains. This is important because the topographic factor (and the RUSLE entirely) is very sensitive to the slope factor $S$.

In this project, LS is calculated by the USPED(Unit Stream Power Erosion and Deposition) method, which is using the raster calculation between flow accumulation and slope of watershed, because it is obvious that it can be done with the tools included in a normal GIS ArcMap installation [5].

In comparison to the RUSLE, the USPED is a physically based model that incorporates a spatial component. In the RUSLE, $L$ is dependent on linear distance $\lambda_i$, which is the horizontal length from the start of sediment transport to point $i$ on the slope. Thus, they are inherently a single dimensional function. The USPED instead uses the area of upland contributing flow at distance $i$. In the USPED model, the area is substituted in place of the former slope length. The L calculation for point $i$ on a slope is shown in Equation (*1*).

$$L = (m+1)\left(\frac{\lambda_A}{22.1}\right)^m \tag{1}$$

where, $L$ is the slope length factor at some point on the landscape, $\lambda_A$ is the area of upland flow, $m$ is an adjustable value depending on the soil's susceptibility to erosion, and $22.1$ is the unit plot length.

The calculation of S value is shown in Equation (*2*).

$$S = \left(\frac{\sin(0.01745 \times \theta_{deg})}{0.09}\right)^n \tag{2}$$

where, $\theta$ is the slope in degrees, $0.09$ is the slope gradient constant, and $n$ is an adjustable value depending on the soil's susceptibility to erosion. Designations for exponents $m$ and $n$ values can be found in the literature. In this project, *m=0.4* and *n=1.4* is used, which is typical of farm and rangeland with low susceptibility to rill erosion.

Using USPED method, the LS factor is calculated in the GIS program according to the following steps:

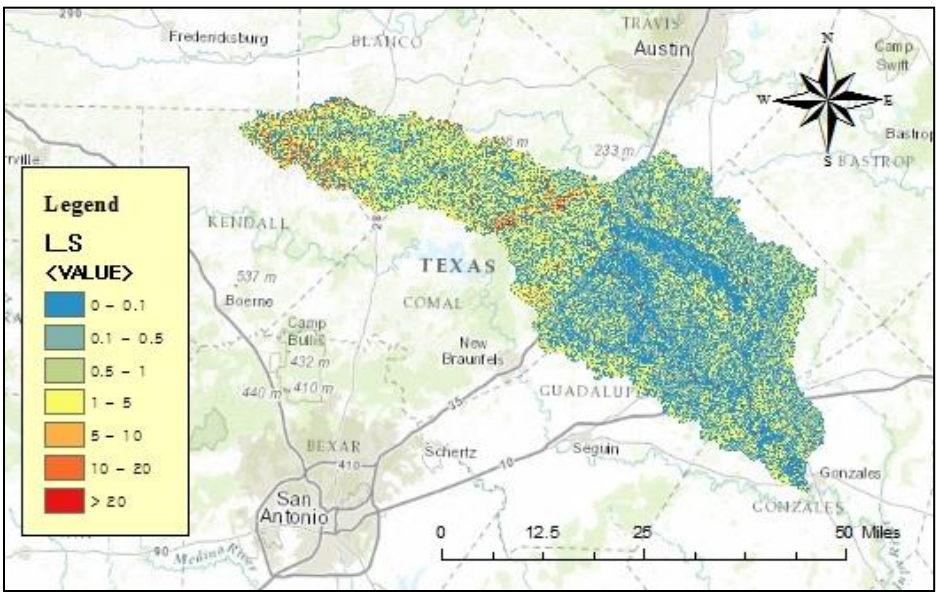
(Step 1) Calculate Flow Direction from clipped Watershed DEM layer Using Flow Direction Tool, (Step 2) Calculate Flow Accumulation with Flow Accumulation Tool using flow direction data as the input raster,

(Step 3) Calculate slope of watershed in degrees using Slope Tool using clipped watershed DEM as the input layer, and

(Step 4) Copy and paste the LS-factor formula below into Raster Calculator:

*Power("flow accumulation"*[cell resolution]/22.1,0.4)*Power(Sin("slope of degree"*0.01745))/0.09, 1.4)*1.4.*

Using these processes, the LS factor is calculated for the target area, and Fig.7 shows the raster data created for the LS factor. LS factor is higher in northwest area due to the effect of steep slope in that area.

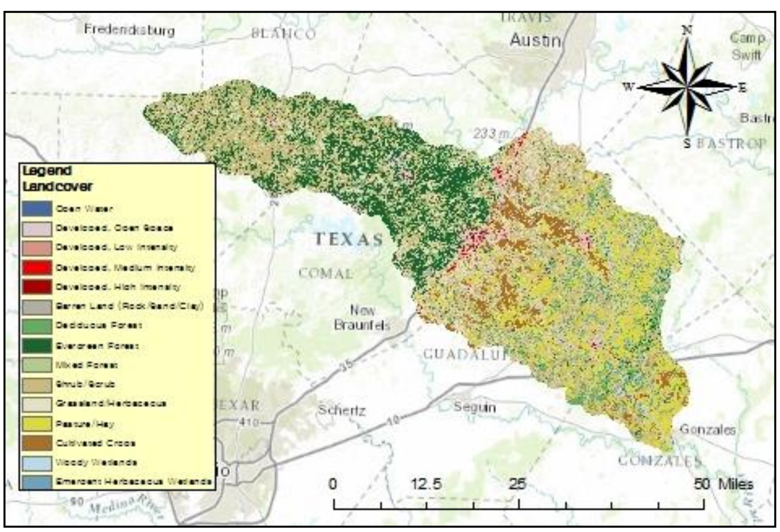



**< Figure 7. Raster data of LS factor >**

C-Factor: the land-cover management factor is a ratio comparing the soil loss from a specific type of vegetation cover. It is used to determine the effectiveness a crop/vegetation management system has on preventing soil loss. In this project the land-cover data of shapefile came from USGS seamless server (Figure 8). The table of C values is used in coordination with the land cover classifications to determine the values of C for each land classification [6]. Using Figure 8 and Table 1, the C-Factor raster (Figure 9) was created.

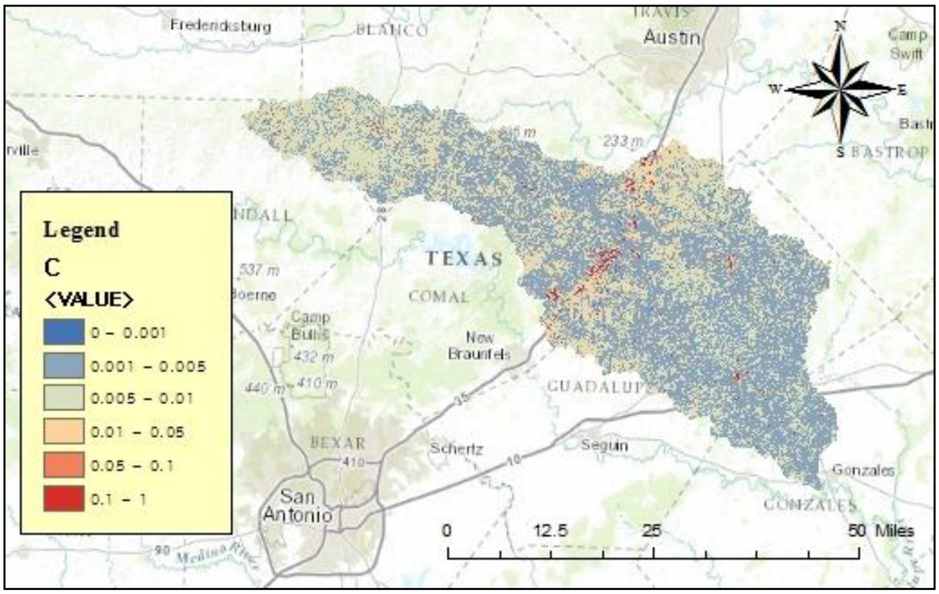
**Table 2. C Values for each Land Cover Classification**

| Value | C | Cdescription |
|---|---|---|
| 11 | 0 | Open Water |
| 21 | 0.003 | Developed, Open Space |
| 22 | 0.013 | Developed, Low Intensity |
| 23 | 0.2 | Developed, Medium Intensity |
| 24 | 0.45 | Developed, High Intensity |
| 31 | 1 | Barren Land |
| 41 | 0.003 | Deciduous Forest |
| 42 | 0.003 | Evergreen Forest |
| 43 | 0.003 | Mixed Forest |
| 52 | 0.009 | Shrub/Scrub |
| 71 | 0.013 | Grassland/Herbaceous |
| 81 | 0.003 | Pasture/Hay |
| 82 | 0.003 | Cultivated Crops |
| 90 | 0.001 | Woody Wetlands |
| 95 | 0.003 | Emergent Herbaceous Wetlands |




**< Figure 8. USGS Shapefile Representing Vegetation Communities >**

The shapefile is converted into a raster using the feature to raster function of GIS based on the C value and the output is C values throughout the studied area. There is not much variation in C factor over the target area except some points in the middle of the area.

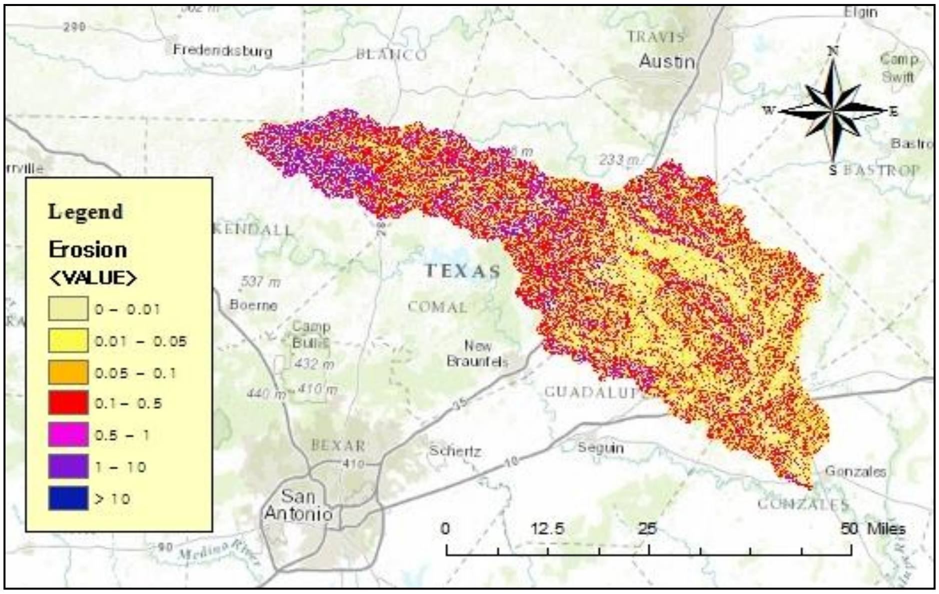



**< Figure 9. Raster data of C factor >**

<u>P-Factor</u>: The conservation practice represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. For this project, the ratio is kept at 1, indicating straight-row farming.

## Results

From these five 30m rasters, a simple raster calculation was computed to get the soil loss for each 30m x 30m cell. Figure 10 shows the raster output from the RUSLE model. The results make sense, seeing how the most soil loss is in the northwest part of the watershed which is the area that has a steeper slope. The locations with no soil loss are areas of either no slope, or water bodies.




**< Figure 10. Average Annual Soil Loss >**

## Conclusion

The RUSLE model combined with GIS is effective to estimate the potential of soil erosion for the target watershed. From basic overlays of the 5 variables and the raster calculator, the model was accurately depicted. For a more precise calculation the P factors will need to be more exact, since this project assumed P factor as the constant value of 1 over the target area. Although this RUSLE model combined with GIS is effective tool for the estimation of soil loss, caution is needed when interpreting the results considering the assumptions made to create each variable and errors of an empirical equation for the RUSLE model.

**Acknowledgement**

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