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Application of the RUSLE erosion equation to the San Pedro Creek Watershed in Pacifica, California using ArcGIS 9.3.1

ABSTRACT

The purpose of this project was to apply the Revised Universal Soil Loss Equation (RUSLE) to the San Pedro Creek watershed in Pacifica, California using ArcGIS 9.3.1, and to compare the results with mapped landslides and gullies in the area as a way of testing the model. The RUSLE equation yielded the following erosion estimate: 130,838 tons hectare^{-1} per year $^{-1}$. Descriptive statistics indicate that the median RUSLE values for landslides and gullies were higher than the RUSLE sample (median being more appropriate because they were not Gaussian distributions), but this was not confirmed statistically.

Keywords: RUSLE, erosion, San Pedro Creek Watershed

I. Introduction

The purpose of this project was to apply the Revised Universal Soil Loss Equation (RUSLE) to the San Pedro Creek watershed in Pacifica, California using ArcGIS 9.3.1, and to compare the results with mapped landslides and gullies in the area as a way of testing the model. Although RUSLE is not intended to be a predictor of landslides or gullies, it seemed a reasonable assumption that areas with landslides or gullies may also be areas with higher levels of predicted erosion than areas without them.

The empirically-based RUSLE model is a revision of the United States Department of Agriculture's (USDAs) earlier USLE model. It is a soil detachment model designed to model sheet and rill erosion caused by overland flow on agricultural lands (Merritt et al 2003). RUSLE is widely used because it is easier to calculate than other models, particularly when using the free and downloadable RUSLE 1.06c or RUSLE2 computer programs. The equation is based on five factors: rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), crop and land management (C), and support practice (P). The predicted soil loss is given in tons per hectare^{-1} per year^{-1}. More information on each variable is in the section on methods.

$$A = R * K * LS * C * P$$

The decision to focus on the San Pedro Creek watershed was based on data availability; the author's familiarity with, and interest in the area; and the existence of mapped landslide and gully data that could be used to test the model results.

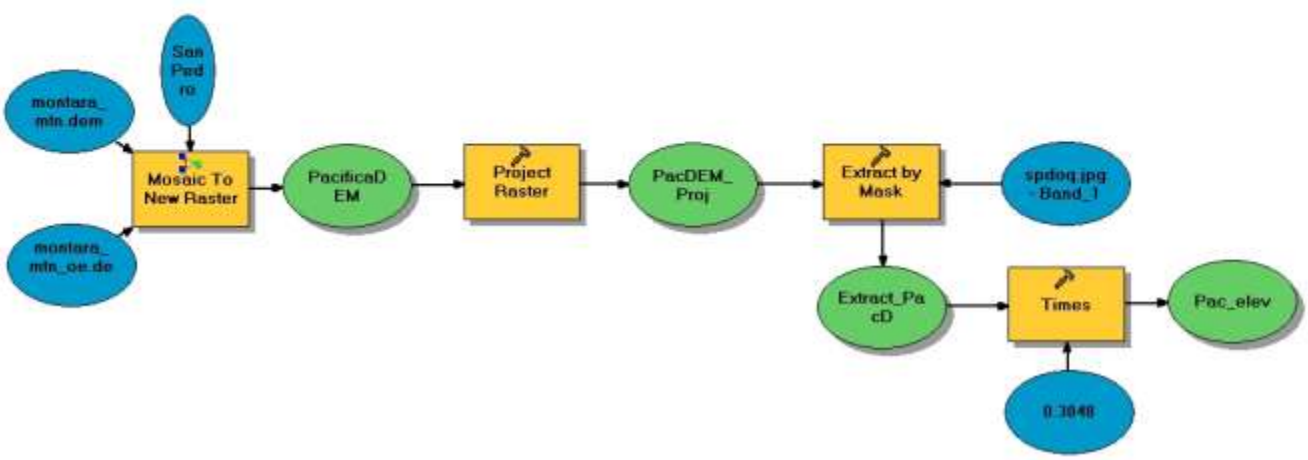
II. Methodology

The project began with a literature review to determine how to calculate the factors that make up the equation and how to apply it in ArcGIS 9.3.1. Although extensive literature exists on the application of USLE and RUSLE, the results of this literature review identified a limited number of articles focused on using GIS for the analysis, and even fewer that provided enough information with which to copy the procedures. No one article was found that included all of the required information for applying the equation, so information was used from a few separate publications that are identified below.

Data Collection and Processing

The author benefited from the large data set on the San Pedro Creek watershed located on the San Francisco State University P: drive, created by Dr. Jerry Davis and previous students. Appendix I provides metadata for all GIS data used in the project. Soils, vegetation, and a streams feature file were borrowed for this analysis, as well as gully and landslide feature files for use in the testing. The elevation data was created from the two 10-m DEMS that cover the San Pedro Creek watershed, downloaded from the USGS Bay Area Regional Mapping website, along with a DRG file with a scanned topographic map of the area. As indicated in Diagram 1, the two DEMS were mosaiced together, the new raster projected, the study area extracted using the Pacifica DRG for extent, and the z-value was converted to meters. In addition, contours and a hillshade were created using the Spatial Analysis dropdown menu.

Diagram 1: Elevation Data Model



Defining the Watershed

Diagram 2 presents the model used for the remainder of the project. Starting with the elevation surface, the San Pedro watershed was defined following instructions for surface hydrologic modeling from the GEOG 642 Watershed GIScience course. The Fill tool was used to fill depressions in the elevation surface that would otherwise become artificial sinks in the stream channels, and that raster was input into the Flow Direction tool to determine the direction of flow, which was then fed into the Flow Accumulation tool. A stream network was created by connecting the Con tool to the Stream To Feature tool, with the expression “greater than 400,” however, after creating it, the result was mistakenly deleted from the model so it does not appear in the model diagram. The stream feature was used to identify “pour points” as described in the San Pedro Sub-watershed model. The pour points were fed into the Watershed tool and a new raster that delineated the San Pedro Watershed was the result.

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Diagram 2: RUSLE Model

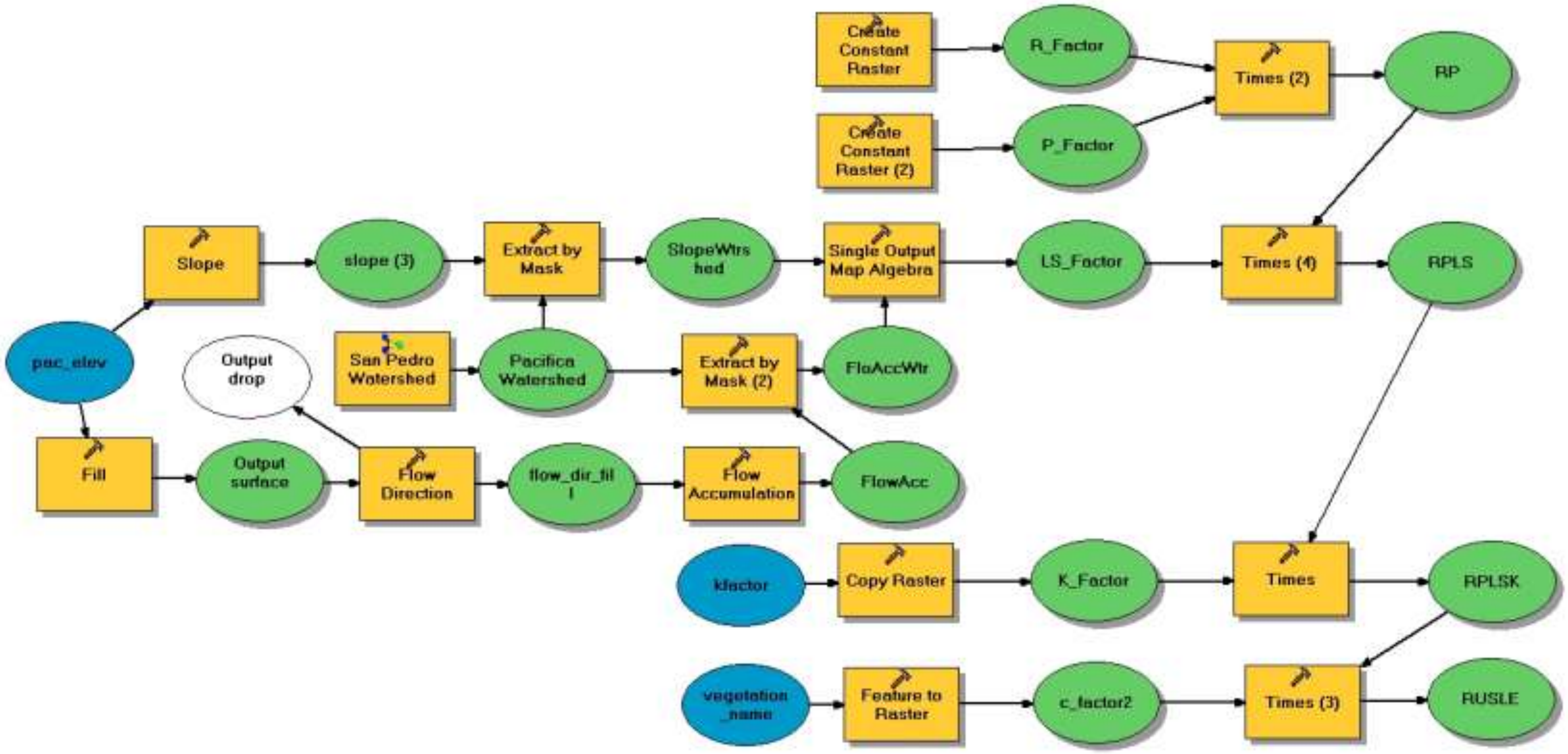
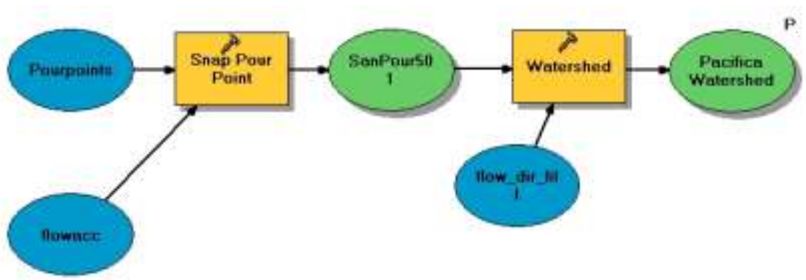


Diagram 3: San Pedro Watershed Sub-Model



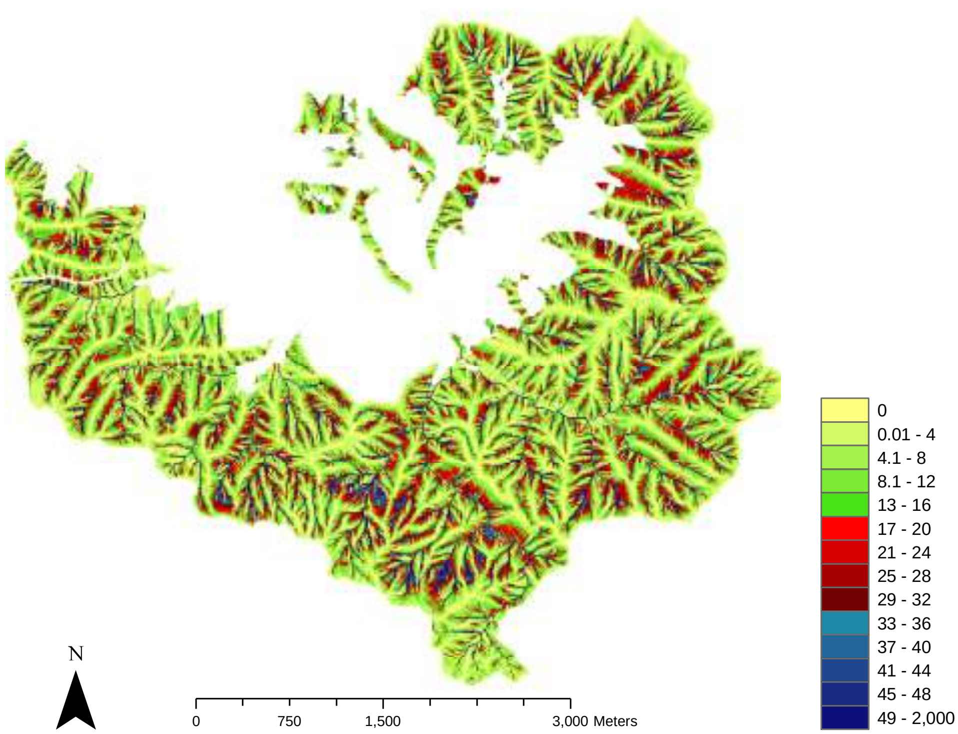
Creating the RUSLE Factors

The LS Factor was created first. It defines the effect of slope angle and slope length on sheet and rill erosion and is based on USDA experiments in which test plots of 22.1 m and 9% slopes were used to measure erosion (Tehran 2002). More than one method for determining this equation is described in the literature and the powers used vary in different applications from 0.4-0.6 for flow accumulation and 1.0-1.4 for the slope (Hudson 2005, Lewis et al 2005, Sims et al 2003, Tehran 2002). I chose the version offered by Sims because it made sense and was the easiest to use. As described in Sims (2005), the LS equation is: $T = (A/22.13)^{0.6} (\text{Sin } B/0.0896)^{1.3}$. For use in ArcGIS, Sims used the following Map Algebra expression:

Pow ([flow accumulation] * cell size / 22.13, 0.6) * Pow (Sin ([Slope of DEM] * 0.01745) / 0.0896, 1.3)

A slope raster was derived from the elevation model, and I used a Mask tool with the watershed raster as input to limit the slope of the watershed raster to the study area, and did the same with the flow accumulation raster created earlier. These two rasters were used in the Map Algebra equation, along with the cell size of "10." The resulting raster is presented in Diagram 3. The LS factor ranged from 0-2000, mean = 14, standard deviation = 39.

Diagram 3: LS Factor



The R Factor, generally referred to as the EI_{30}, in System International (SI) units (M J.mm/ha.h.yr), is a product of storm kinetic energy and maximum 30 minute intensity (Sims et al 2003). It would have been preferable to compute this figure using rain gauge intensity data for the Pacifica watershed or average rainfall following the procedures offered by Millward or Lorito (Millward et al 1999, Lorito et al 2002), but it was not possible to do so within the time constraints of the project. Instead, the California Isoerodent Map (EPA 2001) was used; it is a map prepared specifically for use in USLE and RUSLE. However, the isolines (in increments of 20) are generalized over the state of California; the map is small, making it difficult to determine exactly where Pacifica is; and in the general location of Pacifica, the lines are very close together – all of these factors making the choice of the best number to use a guess at best. The Constant Raster tool was used to create an R Factor raster with the value "80."

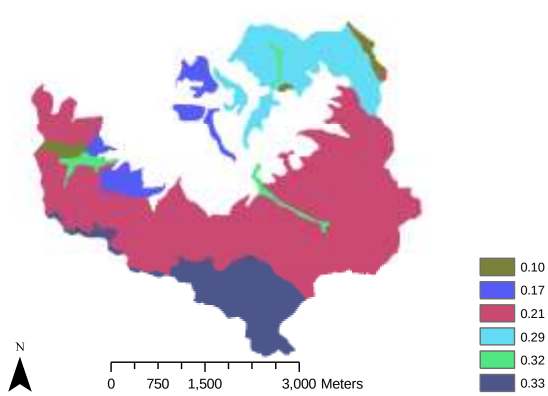
The soil erodibility K Factor measures soil resistance to detachment (Hudson 2005). Rather than downloading new data from the USDAs National Resource Conservation Service Soils Soil Survey Geographic Database (SSURGO), I used the existing K Factor raster in the San Pedro Creek Watershed GIS files. Table 1 identifies the values used and the values are presented in Diagram 4.

Table 1: K Factor Values

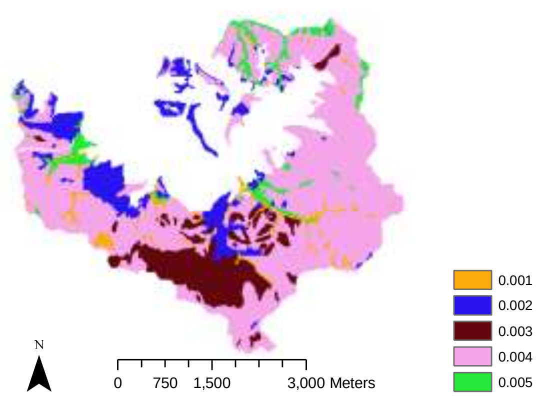
Rock and Slope Type	K-Factor
Barnabe-Rock outcrop complex; 15 to 75% slopes	0.10
Candlestick-Barnabe complex; 30 to 50% slopes	0.17
Barnabe-Candlestick complex; 30 to 75% slopes	0.21
Candlestick-Kron-Buriburi complex;30 to 75%	0.29
Candlestick variant loam; 2 to 15% slopes	0.32
Scarper-Miramar complex; 30 to 75% slopes	0.33

Diagram 4

K-Factor Values



C-Factor Values



The crop and land use management C Factor derives a measure of sediment sources (Trahan 2002). It is based on land use type, and can be further broken down into sub-features that include previous land use, canopy cover, ground surface cover, surface roughness, and soil moisture. Most of the study area is public land used primarily for recreational purposes. I used the single factor of vegetative land cover, based on a vegetation classification shapefile in the San Pedro Watershed GIS dataset, and followed the classification system used by Trahan.

Table 2: C Factor Values

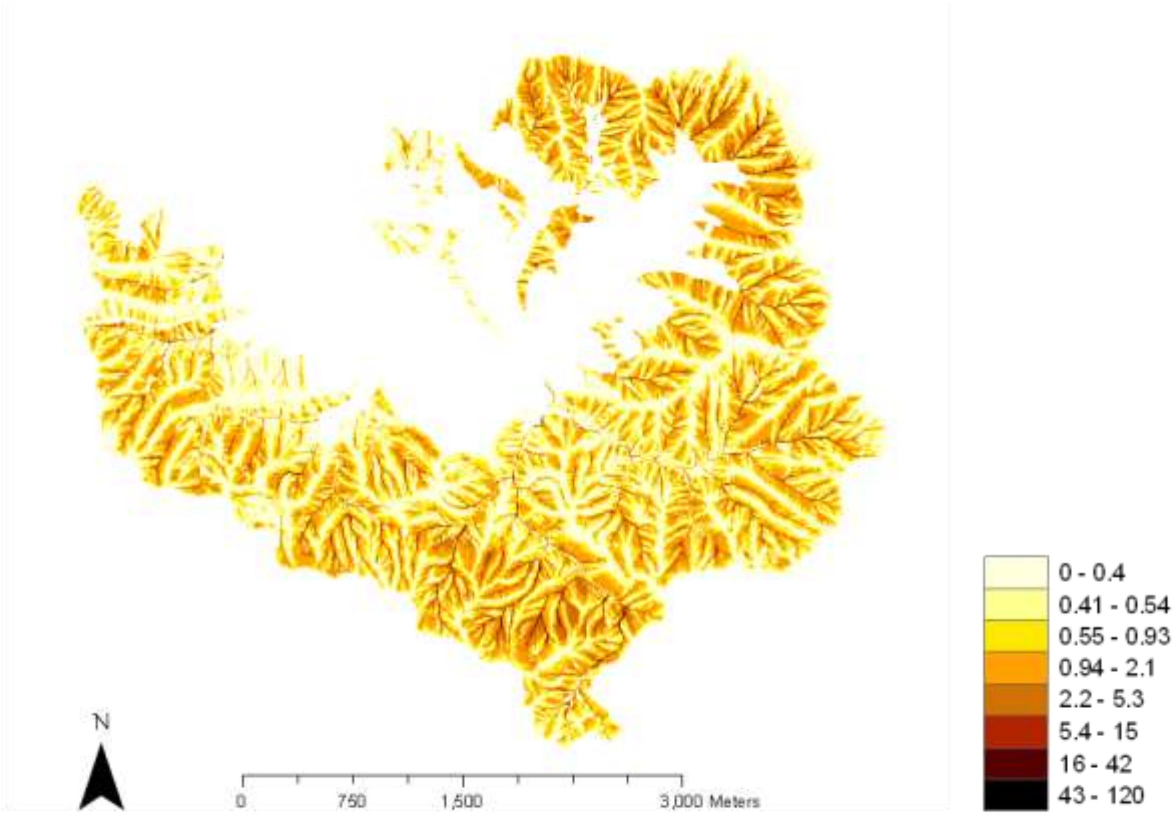
Vegetation Classification	C-Factor
Wetland scrub, Marsh, Riparian Forest	0.001
Forest, Woodlands	0.002
Scrub	0.003
Chaparral	0.004
Grassland	0.005

Finally, the P Factor covers land management practices meant to keep erosion for occurring. Because it is primarily applicable for agricultural uses, I created a Constant Raster with the value "1" for this factor. To run the model, four Times tools were added and the factors were multiplied two at a time.

<u>Running the model</u>

The model result is presented in Diagram 3. The RUSLE equation yielded the following erosion estimate: 130,838 tons hectare^{-1} per year $^{-1}$. Erosion varied from 0 to 118.7 per 10 m cell, with a mean of 0.94 and standard deviation of 2.45. An analysis of the data indicates that the highest levels of erosion are predicted to occur in stream channels, and along the steepest slopes.

Diagram 3: RUSLE Erosion Prediction



III. Data Analysis

The first question asked was, "Do these results make sense?" With the help of Dr. Jerry Davis, an estimate was made of the average amount of erosion occurring throughout the tested part of the watershed per year. The result of 130,838 tons hectare $^{-1}$ per year^{-1} was converted to volume in kg and divided by the average density of rock (2.7 g/cm^3). Average erosion was estimated to be 0.35 mm/year.

Ideally, it would be best to vary all model inputs to test its sensitivity to variation in each of the factors. However, there was not enough time to do so. The model was re-run with an increase in the R factor from 80 to 81. Doing so added 1,324.74 tons hectare $^{-1}$ per year^{-1} (0.01%). Most of the analysis centered on testing the results of the model against mapped landslides and gullies that had been digitized by Stephanie Sims in 2003. Two polygon shape files were used; one with 600 mapped landslides, the other with 50 mapped gullies. Because most of the conversion of the data could not be done with ArcGIS tools, the process is not included in a model diagram.

1. The two shapefiles were converted from polygons to points using instructions obtained from the online ArcGIS Resource Center (2009). The process included adding two new fields to each attribute table to hold the X and Y values, using "Calculate Geometry" to set the parameters for the centroid points, displaying the new XY data, exporting the tables, and creating a new feature file.
2. The gulley and landslide feature files were input into the Sample tool to add a field with the RUSLE values for each point. Because many of the points were outside of the study area, the files were exported into Excel to delete points with a value of "0." The edited Excel files were imported back into ArcGIS and a new feature file was created for each; the gully file had 15 points and landslides, 479.
3. Both features were checked for independence using the Spatial Autocorrelation tool. Moran's I Index for the gullies was 0.31 with a Z-Score of 2.16 and landslides 0.17 with a Z-Score of 3.27, both of which are considered clustered.
4. A random sample of 100 was drawn from the landslide data in SPSS, it was exported back into ArcGIS, a new feature was created, and it was checked for independence. The result was a random sample, with Moran's I Index of 0.3 and a Z-Score of 0.87.
5. To create points with which to test the sample, the Create Random Points tool was used to create 500 points from the RUSLE raster (500 was used after first trying 100 and finding only 20 points within the measured area). The new random point feature was input into the Extract Values to Points tool along with the RUSLE raster value and a new feature of 149 random sample points was created. This feature was exported to SPSS and a random sample of 100 was picked.

Statistical Analysis

Table 3 summarizes the descriptive statistics and Table 4 the statistical test results. Gullies are included for descriptive purposes, even though no test statistics were done because the sample was found to be spatially autocorrelated as noted above.

Table 3: Sample Statistics

	N	Min	Max	Mean	Median	Std. Dev	Variance	Skewness	Kurtosis
RUSLE Sample	100	.02	18.74	1.7293	.8182	2.937	8.627	3.798	16.191
Landslide Sample	99	.15	9.52	1.4259	.9577	1.735	3.010	2.968	9.597
Gully Sample	15	.18	8.28	1.6094	.9863	2.074	4.302	2.735	8.226

Levene's F Test $F = \frac{s_1^2}{s_2^2}$ was used to determine which T-Test to use, based on the following hypothesis:

H$_o$: $\sigma_A^2 = \sigma_B^2$ **H$_a$:** $\sigma_A^2 \neq \sigma_B^2$

F = .349 with a two-tailed P-value of 0.999 > 0.05, therefore the null hypothesis could not be rejected. The Two-Sample T-Test for Equal Variances was used to test the following hypothesis:

H$_o$: $\mu_A = \mu_B$ **H$_a$:** $\mu_A \neq \mu_B$

$$t_{test} = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{s_p^2}{n_1} + \frac{s_p^2}{n_2}}}$$

T = 0.888 with a two-tailed P-value of 0.375 > 0.05, therefore the null hypothesis could not be rejected. Based on this finding, there is evidence of a difference between the RUSLE values for landslides as compared with the overall RUSLE sample values. However, the mean RUSLE value for the landslide samples (1.42) is less than the mean for the area sample (1.72).

After conducting both tests, and questioning the conclusions, I went back and looked more carefully at both samples. Neither was Gaussian; in fact, both were positively skewed and had peaked kurtosis ranging from 9.5 for the landslide sample to 19.2 for the RUSLE sample. Given this situation, the assumptions for the T-Test were not met and it is not appropriate. I believe that the Mann-Whitney test could be used; however, I did not conduct it because I have no familiarity with this test.

IV. Conclusion

The RUSLE model predicted erosion of 130,838 tons hectare $^{-1}$ per year^{-1} in the study area; an average of 0.35 mm throughout the study area per year. Without further research, it is impossible to ascertain whether this result is reasonable. In addition, the descriptive statistics indicate that the median

RUSLE values were higher for both the landslides and gullies than the RUSLE sample, and given that the distributions are not normal, the median seems to be a better indicator than the mean. However, I was not able to confirm the results through statistical tests for this analysis.

There are many possible explanations, both for the overall prediction, as well as for the results related to landslide values. In terms of the overall prediction, more research should be conducted on inputs for the R, LS, and C factors and the model re-tested. In addition, the results could be compared with results from predictions made by other researchers in the area. Specifically,

1. With more time available, it would be possible to measure R specifically for the watershed rather than relying on the generalized Isoerodent Map.
2. Some researchers have commented that the LS factor does not work as well in areas with steep topography and suggest replacing the slope length with the upslope area only (Millward et al1999, Mitosova and Mitas 2004, Terranova et al 2009). It would be useful to try to implement the variations of the equation that have been developed to do this.
3. Additional inputs could be included in the C factor, including the presence of roads and trails and previous human alterations to the landscape.

In terms of the comparison between the RUSLE sample and landslide and gully values, it would be useful to run the Mann Whitney test. It is also possible that given that the RUSLE model is a soil detachment model based on sheet and rill erosion, the assumption that landslide and gully areas would have higher RUSLE values than other areas may not be appropriate because they are caused by other mass wasting processes.

Data	Source	Spatial Reference	Process to Create data	Extent	Units	Cell Size	Attributes Used
Montara.mtn.Dem	USGS DEMS downloaded from BARD.	*1	Mosaic to New Raster Project Raster Mask SPDOQ.jpeg Times * 0.3048 Contours Hillshade	Top: 4164195 Left: 544125 Right: 555245 Bottom: 4150245	Linear: meters Z units: feet	10	elevation
Montara.mtn.oe.Dem	Same as above	*1	Same as above	Top: 4164135 Left: 533095 Right: 544195 Bottom: 4150195	Linear: meters Z units: feet	10	elevation
San Mateo County DRG	USGS, downloaded from BARD			San Mateo County			Image
SPDOQ.jpeg	Davis SFCW GIS folder: DOQ	*2		Top: 4162500 Left: 541800 Right: 549200 Bottom: 4156500	Linear: meters	1	extent for mask
Streams	Davis SFCW GIS folder: Streams	*2					Stream feature
K_factor	Davis SFCW GIS folder : Soils	*2		Top: 4162846 Left: 542489 Right: 549359 Bottom: 4155836	Linear: meters	10	K_factor
Vegetation_name.shp	Davis SFCW GIS folder: Vegetation	*2	Add field: C_factor Edit field to enter C_factor Calculate field Project Feature to Raster		Linear: meters	10	Class
Gullies.shp	Sims SFCW GIS folder: Landslides	*2	Converted to Centroid Point feature files.				Gully polygons
Landslides.shp	Sims SFCW GIS folder : Landslides	*2					Landslide polygons

*1: NAD_1927_Zone_10N and datum D_North_America_ 1927

*2: NAD_1983_Zone_10N and datum D_North_America_1983

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