

# Modeling Soil Erosion Risk in Los Maribios Volcanic Chain, Nicaragua

by Richard Chávez, MF 2003

## Introduction

Nicaragua is a country heavily affected by natural disasters, many of which are linked to land degradation and anthropogenic pressure on its natural resources, especially forests. On the Pacific side of Nicaragua, land transformation in rural areas is most prevalent where the expansion of agriculture practices is contributing to an unprecedented rate of land use change. Conversion of land from forest to agriculture has created both on and off site problems for rural people living in these watersheds. One of the most visible problems is soil erosion (Landa et al. 1997). Deforestation and land transformation have exposed soils to water erosion, increasing their susceptibility to natural disasters such as the landslides caused by Hurricane Mitch in 1998.

Land transformation, deforestation, and lack of soil conservation practices have made the Los Maribios volcanic chain one of the most degraded landscapes in the country; agribusinesses, subsistence farming, and cattle ranching have contributed to the increased soil erosion risk.

This research aimed to develop a tool that can be used to both model and monitor the effect of land use on soil erosion potential,

given the physical conditions within the Los Maribios volcanic chain. The applied model is based upon the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and is integrated with GIS.

The objectives for this study were: (1) to analyze existing rainfall data to generate a soil erosivity map; (2) to collect and analyze existing geographic information to develop a soil erodibility map; (3) to assess land cover and land use through both field visits (ground truthing) and satellite imagery analysis, in order to develop a land cover map; and (4) to analyze collected and processed information to identify areas of soil erosion risk.

## Study Site

Research took place in four micro watersheds: Casitas, Cristo Rey, Las Marias, and Las Quemadas in the Volcanic Chain of Los Maribios. Most of the soils of this region are of volcanic origin and have textures varying from very sandy to sandy loam, with depths from superficial to greater than 90 cm (MAGFOR 1971).

Land use and land cover patterns in this region are the result of both natural and socio-economic factors. In general, the top organic layer of these soils has been eroded, resulting in low productivity levels (Sharma 1990). Most families who inhabit the area rely on subsistence agriculture. The lack of available low elevation lands forces subsistence and marginal farmers to move to higher altitudes on the slopes of Los Maribios; this, in turn, results in further soil degradation.

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Agriculture in lowlands and highlands. Cordillera Los Maribos, Nicaragua. Photograph by R. Chávez

## Methods

### Data sources

This research integrates the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) with the Arc Geographic Information System (GIS) to model soil erosion risk within the Los Maribos Volcanic Chain. The data used was obtained from weather stations, vegetation surveys, and topographic maps. GIS files were created for each factor of the USLE – precipitation, soil type, landcover, and slope – and combined by cell-grid modeling procedures in ArcGIS to predict soil erosion risk. Resolution was set to 30 meters by 30 meters.

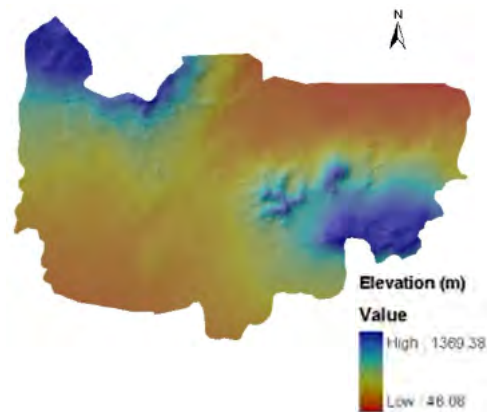
### Digital Elevation Model (DEM)

In many developing countries, spatial information data is limited or non-existent. It is therefore necessary to create digital spatial information, such as elevation models (DEM), by digitizing contour lines from topographic maps.

The DEM for this research was developed from vector contour lines using a topographic map scale 1:50,000 with Wise Image Pro5 software package. Interpolation of the elevation

points to create the DEM was achieved using ArcGIS v8.2.; the interpolation method used was Kriging (Figure 1).

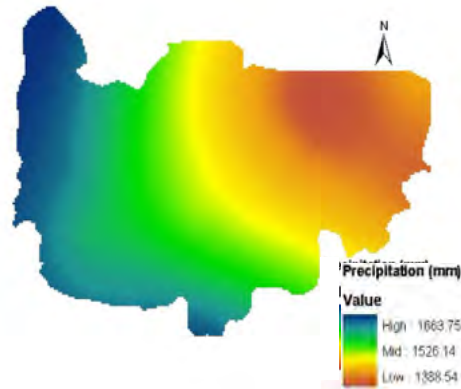
**Figure 1.** The Digital Elevation Model (DEM)



### Rainfall

The precipitation surface was obtained by interpolating average rainfall during a 10-year period for twelve observation points within the study area. The interpolation method used was Kriging (Figure 2).

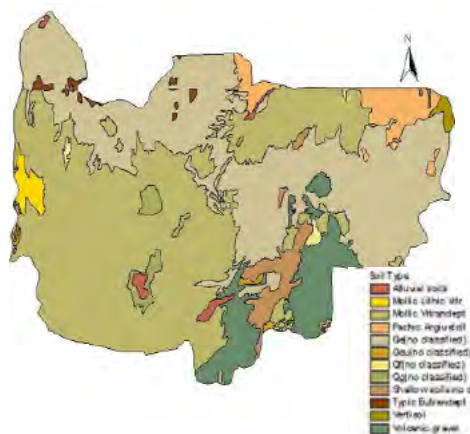
**Figure 2.** Precipitation surface (mean annual precipitation in mm)



**Soil**

Soil data was digitized from a map with scale 1:50,000 produced by MAGFOR (1987).

**Figure 3.** Soil type



Some of the soil types shown in the soil classification map (Figure 3) have not yet been classified using the USDA system. A nomenclature was therefore developed based on their physical characteristics (Catastro e Inventario de Recursos Naturales 1971). For instance:

1. Qe (Lands with moderately steep slopes) includes soils with slopes between 15–30% that have not been classified in a specific class because they lack uniformity in their profile. However, these soils' type has been characterized based on deepness, texture, and gravel content.

2. Qeu (Lands with moderately steep slopes, very shallow soils, and slopes between 15–30%) are soils that vary in their textural

characteristics, are very permeable, and have very low organic matter content. The soil profile is not well defined.

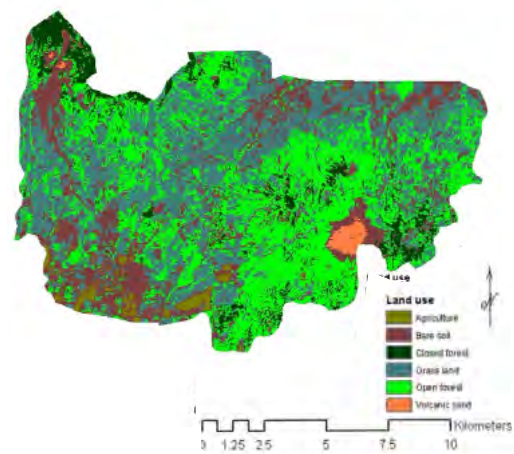
3. Qf (Steepest slopes) includes soils with slopes between 30–75% that have not been formally classified.

4. Qg are very shallow soils located in very steep slopes (greater than 75%).

**Land cover**

The land cover data used was derived from satellite imagery (Landsat-7 Thematic Mapper (TM) image, Path 017 Row 51, July 15, 2001) and classified using a supervised classification with the ERMapper software package. First, six different land use types were defined: (i) agriculture, (ii) open forest, (iii) closed forest, (iv) grass land, (v) bare soil, and (vi) volcanic sand. The training regions were defined using ground truth data collected during the summer of 2002 as well as other ground truth data, such as aerial photo land use classifications (MAGFOR 1999). An aerial photo of land use was used to assess the accuracy of the classifications (Figure 4).

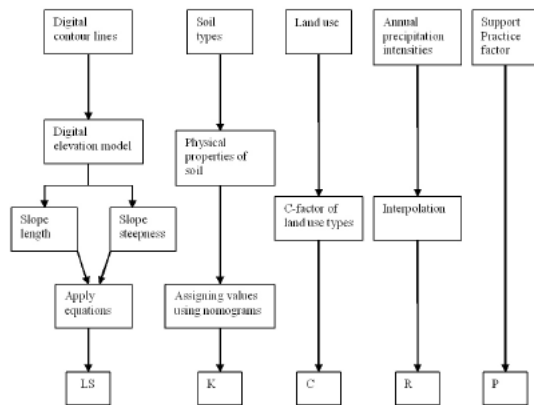
**Figure 4.** Land cover



**The Model**

The four data layers and the subsequent derivation of the LS-, R-, K-, C-, and P-factors from these layers were created using the following technique (Figure 5):

**Figure 5.** GIS procedure for creating coverage for each USLE factor



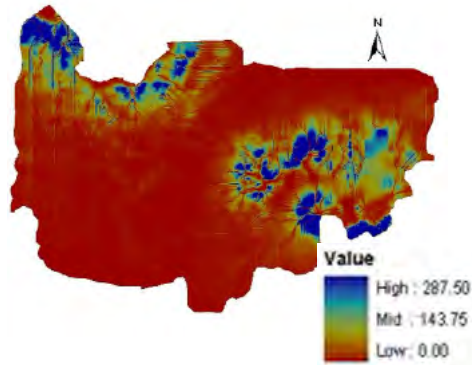
**Slope length and Steepness factor (LS)**

Calculating slope length presents the largest problem when using USLE as a model to predict soil loss within GIS. Schmidt (2001) created an extension for Arc-View 3x to calculate the slope length factor. The S factor was calculated using the DEM and Nearing’s equation (1997) (Figure 6).

$$S = -1.5 + \frac{17}{1 + \exp(2.3 - 6.1 \sin \theta)}$$

where  $\theta$  is the slope angle in degrees. Nearing’s equation (1997)

**Figure 6.** Slope Length and Steepness factor (LS)



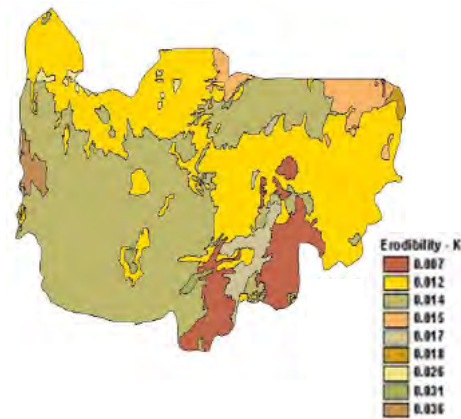
**Soil erodibility factor (K)**

The soil erodibility factor (K) is the soil’s resistance to erosion by water in units of ton MJ<sup>-1</sup>mm<sup>-1</sup>hr. A digital map of ecological regions developed by MAGFOR (not pub-

lished) was used to identify the soil series in the study area.

K-factor values were estimated using the soil-erodibility nomograph (Wischmeier and Smith 1978). Since soil samples were not taken, the K values presented in this paper are estimations based on the physical characteristics of the soils described in the internal 1971 MAGFOR document (Figure 7).

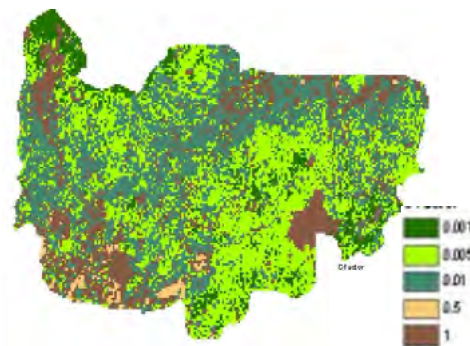
**Figure 7.** Soil erodibility ton MJ<sup>-1</sup> mm<sup>-1</sup> hr



**Cover-management factor (C)**

The C-factor models the effect of cropping and management practices on erosion rates. C factor values were applied to five cover types identified in the study area. The USLE’s cover and management factors (C-factors) corresponding to each land cover condition were estimated from the USLE guide tables (Morgan 1995; Wischmeier and Smith 1978). These values were used to reclassify the land cover map to obtain the C-factor map of the study area.

**Figure 8.** Cover Management Factor Map



**Rainfall and runoff factor (R)**

The rainfall and runoff factor (R) represents the energy available to erode land in units of MJ mm ha<sup>-1</sup>h<sup>-1</sup>y<sup>-1</sup> (Wishmeier and Smith 1978).

The rainfall erosivity factor was determined by calculating storm erosivity indices using data from three weather stations (Leon, Chinandega, and Posoltega) [INETER 2002] over a four-year period. The index was calculated for the winter season only (May to November). The sum of monthly EI<sub>30</sub> is the annual R-factor (Dissmeyer and Foster 1980; Renard and Freimund 1993; Yu et al. 2001).

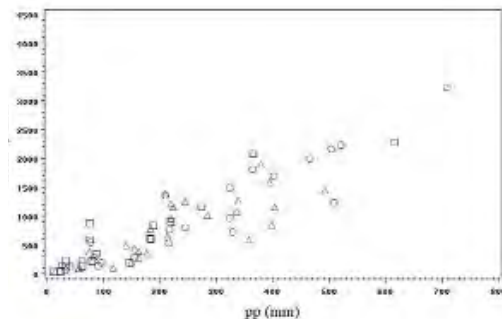
$$R = \sum EI_{30}$$

Where:

R is the Erosivity factor

EI<sub>30</sub> is the Erosion index

**Figure 9.** Linear relationship between monthly precipitation and the monthly erosion index



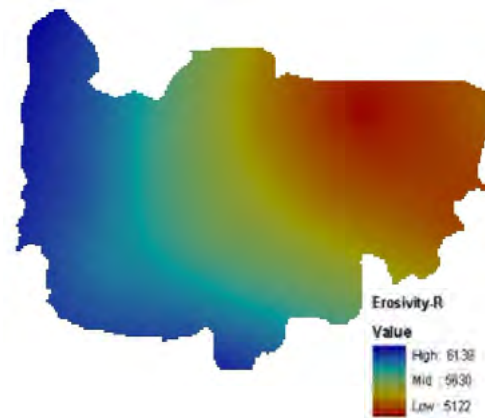
The regression equation to predict monthly EI<sub>30</sub>, given monthly precipitation in millimeters, is:

$$EI_{30} = 3.88pp - 37.23 \quad R^2 = 0.802$$

**Support practice factor (P)**

Because no information in regard to the P-factor is available for this area, a value of 1 was assigned to the model presented in this study. A P-factor value of 1.00 represents no land-use influence.

**Figure 10.** Soil Erosivity factor map MJ ha<sup>-1</sup> mm h<sup>-1</sup> yr<sup>-1</sup>



**Results and Discussion**

Soil erosion risk was modeled within Los Maribios volcanic chain, integrating the Universal Soil Loss Equation (USLE) with GIS. The quantitative data of predicted soil loss in each map (LS, R, K, C) was reclassified into qualitative data to identify areas that are the most susceptible to soil erosion within the study area.

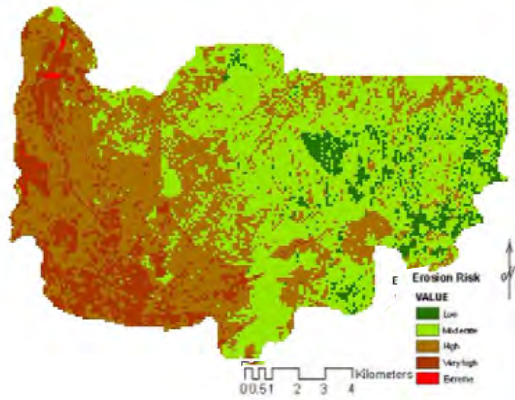
The model included only LS, R, K, and C factors. More research is necessary to characterize the effect of contouring and tillage practice as well as other soil conservation practices needed to develop a P-index.

Figure 11 shows erosion hazard in the upper and lower parts of the study area, which is expressed in five classes, ranging from low risk to extreme erosion risk.

Bare soils with clay contents ranging from moderate to high were estimated to have extreme to very high erosion. They showed higher values in slope-length and steepness. Some areas of lower elevation showed high erosion risk. This is because there is bare soil, high erosivity values, and high indices of erodibility. These areas of high risk in lower elevations are frequently cultivated areas.

More than 50% of the study area was considered to be at high to extreme risk of erosion (Table 1). Most of these lands were situated in the casitas site and were used extensively for cul-

**Figure 11.** Soil erosion risk map



tivated agriculture. In contrast, the moderate to low erosion risk areas were generally covered by grass, shrubs, and open forest.

**Table 1.** Area and Percentage Erosion Hazard

Erosion Risk	Area (ha)	Percent (%)
Low	1116.54	5.73
Moderate	8210.79	42.0
High	7766.64	39.74
Very High	2412.45	12.34
Extreme	39.51	0.20

Some of the maps used in this model might lack accuracy due to the insufficient information used in the interpolation. Accuracy of the precipitation surface would have improved if more data points were used in the interpolation.

Figure 11, depicting erosion risk is a qualitative description of erosion potential in the study area. Because the USLE/RUSLE requires a series of complex algorithms, the model makes it difficult to quantitatively characterize the area in terms of erosion risk while using GIS.

The characterization of the erosion risk map demonstrated the utility of the model as a conservation management tool where the relative comparison among land areas is more important than the absolute soil loss in any single cell.

## Conclusions

This project developed and applied a simple methodology to predict a qualitative estimate of soil erosion risk in a format that can be understood and interpreted by any land manager.

This study further demonstrated the compatibility of integrating GIS with USLE to predict soil erosion risk. Although it was not possible to quantify soil loss in the study area, the classification of soil erosion risk used in the final map can help identify where alternative soil conservation practices would be best applied.

There were limitations in determining the P-factor when using USLE in this model. There were limitations in this study due to the lack of information on the P-factor in the USLE model. Further research is necessary to determine the appropriate P-factor for local soil conservation practices.

## Acknowledgements

This work would not have been possible without the help of the following people and institutions: Professors Dana Tomlin and Timothy Gregoire, Abraham Parrish for his guidance, the Compton Fellowship Program, Latin American Association of Yale, the National University of Nicaragua-Leon, the Ministry of Agriculture and Forestry of Nicaragua, and the Tropical Resource Institute at the Yale School of Forestry and Environmental Studies.

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