RESOURCE NOTES

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SOILS/GEOLOGY

Estimating Watershed Runoff and Sediment Yield Using a GIS Interface to Curve Number and MUSLE Models

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Background

Increased sediment yield from a watershed is usually a sign that the condition of the watershed is degrading. Geographic information systems (GIS) offer a unique opportunity to generate otherwise difficult-to-obtain data that can be utilized in various models of natural processes that occur throughout large areas of landscape. It can perform some of the mathematical operations of the existing models using spatial data processing algorithms and can help test the models' effectiveness for describing and predicting the actual situation. It also allows us to visualize the results of modeling as maps rather than mere columns of numbers.

A relatively simple GIS procedure can be used to generate input and output data for the Modified Universal Soil Loss Equation (MUSLE) model to calculate sediment yield. The GIS methods permit the generation of detailed information from digital maps about the many environmental parameters required to run MUSLE. Using GIS enables easier derivation of difficult-to-obtain key data for large areas which, when used with the MUSLE model, can provide estimates of sediment yield for a storm. These estimates, provided in tabular and map format, can be used to locate and design sediment yield control methods that include the building of structures such as dams and spreaders, the digging of pits, contour plowing, and revegetation.

Calculating Sediment Yield Using the MUSLE/GIS Interface

Two steps are used to calculate sediment yield by using the MUSLE/GIS interface:

• The calculation of a runoff hydrograph for a particular storm using rainfall and watershed characteristics data such as the average slopes, areas of the hydrologic response units, and lengths of the longest channels in subwatersheds; and

• The calculation of sediment yield using the MUSLE with the runoff factor calculated from the runoff hydrograph.

The Modified Universal Soil Loss Equation follows the structure of the Universal Soil Loss Equation (USLE), with the exception that the rainfall factor is replaced with the runoff factor. The equation calculates sediment yield for a storm within a watershed that does not exceed 5 square miles. The structure of the MUSLE is

$$SY = R * K * L * S * C * P$$

where

$$R = a(Q * _{qp})b$$

therefore

$$SY = a(Q * _{qp})b * K * L * S * C * P.$$

SY is the sediment yield per calculation unit (watershed) in tons, *a* is a constant, *b* is a constant, *Q* is the volume of runoff in acre-feet, and *qp* is the peak flow rate in cubic feet per second. The other factors are precisely the same as the Revised Universal Soil Loss Equation (RUSLE) factors and include *K*, which is the the soil erodibility factor—the soil loss rate per erosion index unit for a specified soil, as measured on a unit plot, which is defined as a 72.6-foot length of uniform 9% slope continuously in clean, tilled fallow; *L* is the slope-length factor—the ratio of soil loss from the field slope length to that of a 72.6-foot length under identical conditions; *S* is the slope gradient factor—the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions; *C* is the cover and management factor—the ratio of soil loss from an area with specified cover and management to that of an identical area in tilled continuous fallow; and *P* is the support practice factor—the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to that with straight-row farming up and down the slope.

Discussion

The function of GIS in the modeling procedure is to obtain input data on subwatershed characteristics for calculation of a storm hydrograph from watershed and storm data. GIS capabilities allow for calculation per subwatershed of average slope gradients, determination of the length of the longest channel in each subwatershed, integration of soil and vegetation information to develop hydrologic response units (HRUs), and estimation of the areas of the HRUs. This information is used as input to develop a runoff hydrograph using hydrograph software. From the hydrograph, data can be obtained that permit derivation of the runoff *(R)* factor. A map of the *R* factors can be generated and then combined with maps of other relevant environmental parameters to develop a sediment yield map for the storm. Sediment yield maps show the modeled distribution of sediment output from various locations and can be used to estimate sediment yield for each subwatershed, and then for the entire watershed. A sediment yield map can also be calculated for each cell, and this map will show the areas of the greatest likely runoff. Potentially, a series of sediment yield maps for a sequence of storms can be used to derive locations of areas with highest contributions of sediment over a time period and for a variety of different types of storms. Since MUSLE permits calculation of sediment yield based on curve number model runoff estimates for a single storm only, it would also be useful to get an annual perspective of the project area's response to rainfall. We can get an understanding of the type of storms on the landscape over the duration of a year by applying basic statistics and modeling the biggest storm, the smallest storm, the mean storm, and the median storm. These storms also have a frequency associated with them, which will tell us how often they occur over several years of time.

The versions of the National Resource Conservation Service (NRCS) runoff hydrograph generation program and of the Modified Universal Soil Loss Equation sediment yield calculation program on which this discussion is based consist of two programs used at the center: WILDCAT4 for NRCS runoff hydrograph calculation, and the RUSLE (which also contains calculations for MUSLE) program. The runoff hydrograph program WILDCAT4 was based on the SCS "Curve Number" method using triangular unit hydrographs, as outlined in the SCS National Engineering Handbook, Section 4, Hydrology ("NEH-4"). The sediment yield program is the combined Revised Universal Soil Loss Equation and the Modified Universal Soil Loss Equation package prepared by Richard Moore. This program is based on the work of K. G. Renard, D. K. McCool, and G. R. Foster, which can be referenced in Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation, and J. R. Simanton from the U.S. Agricultural Research Service.

Values for the constants *a* and *b* can vary depending on sources and areas of application. I used the constants provided in the BLM MUSLE DOS program, in which $a = 11.8$ and $b = 0.56$. These constants were originally derived on the basis of individual storm data from 18 basins in Texas and Nebraska and validated on 102 basins throughout the United States. One of the benefits of using the GIS/MUSLE methodology is that it is flexible in adjustment of the constant values used in calculation if scientists believe that they have better estimates from previous research into the MUSLE in their areas. The *K, L, S, C,* and *P* factors can be obtained by looking up their values in the soil surveys for the area of study, generating them by using GIS processes, or calculating them by using the instructions in the DOS RUSLE/MUSLE program.

A list of steps of the MUSLE/GIS procedure for generating sediment yield maps is as follows:

• Prepare a map of subwatersheds from the Digital Elevation Model for the area of study using GIS hydrologic terrain analysis capabilities.

• Generate a vector map of line segments representing the longest stream or channel courses for each subwatershed and determine the total length of the stream.

• Intersect raster maps of soil hydrologic groups and range condition units from the soil or vegetation surveys for the project area to create a map of Hydrologic Response Units (HRUs).

• Intersect the HRU map with the subwatershed map to obtain a map of HRUs for each of the subwatersheds.

• Produce an area listing for each of the HRUs for each subwatershed.

• Prepare a listing of the average slopes for each subwatershed.

• Prepare a table that contains all the information you just generated. The table should include, for each subwatershed: average slope, length of the longest channel, number of HRUs, area of each HRU in square miles, and the curve number of each HRU.

• Input this information into the WILDCAT4 runoff hydrograph program together with storm data, generating a unique watershed file for each subwatershed, and a unique storm file for each storm. Generate a hydrograph for each subwatershed, which will give you the volume of runoff *(Q)* and peak flow *(qp)* data.

• Generate a volume of runoff *(Q)* and peak flow *(qp)* maps, and relate them mathematically to produce a runoff *(R)* factor map for each subwatershed.

• Prepare maps of other factors, namely the soil erodibility *(K)*, the terrain *(LS)*, surface cover factor *(C)* and erosion control practice *(P)* factor maps (these factors are the same as the Revised Universal Soil Loss Equation factors).

• Generate a runoff *(R)* factor map representing partial value of the *R* factor per cell. This will permit calculating sediment yield for each cell making use of the cell-by-cell calculation of the terrain *(LS)* factor.

• Multiply the cell runoff *(R)* factor map by the other factor maps to produce the sediment yield *(S)* map for the area of study using the simplifying assumption that runoff is distributed evenly for each watershed.

• Add the tonnage values contained in each acre cell for each subwatershed in the sediment yield map to produce estimates of sediment yield per storm from each subwatershed. Add the values for all the subwatersheds to produce sediment yield per storm for the entire watershed under study.

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