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A Geographic Information System (GIS) Approach for Modeling a Soil Erosion Map from Available Data

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Abstract

The Universal Soil Loss Equation (USLE) has been applied to the microcomputer based Geographic Information System (GIS) data planes to model a soil erosion map for a county. The conventional method applied by U S. Soil Conservation Service (SCS) has been tedious and time consuming process on a mainframe computer which yields a multisectioned, hard to interprete, line printer map of the each county's soil loss. The new approach proved to be an economical and efficient tool for the natural resource managers in their decision making in land conservation practice. They can simulate the variety of conservation practices and assess the cost and benefit without physically implementing the conservation measures. The new approach also can produce all the other graphical and statistical reports.

I. Introduction

Geographic Information Systems (GIS) can be used to model and display current or predicted spatial, map-like information on possible alternative land management strategies. Pretesting alternative scenarios provides the basis for improved land management decisions. The user of a GIS system may range anywhere from an individual evaluating an investment to a state managing the utilization of its soil and water resources. The use of a microcomputer based GIS is particularly suitable for site specific and individual or local use of such techniques. Local use means direct input to our characteristically local decision making processes. Possible uses of GIS at the local level include (Figure 1):

- site selection (Short, 1982),
- county soil loss mapping (Fenton, 1982),
- watershed management (Eidenshink and Wehde, 1981),
- cattle management (Haas et al., 1983),
- environmental conservation (Alexander, 1981),
- land use change prediction (Tom et al., 1978),
- irrigation scheduling (Loveland and Johnson, 1981), and
- numerous other applications.

This study will demonstrate the use of a simple GIS system on a microcomputer image processing system to prepare an easily understood image map of the soil loss of Lancaster County, Nebraska, U.S.A. using a model based upon the Universal Soil Loss Equation (USLE).

2. Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) was developed to allow local agricultural managers and soil specialists to predict the average rate of soil erosion from specific sites. The principal applications of the USLE (Wischmeier and Smith, 1978) include:

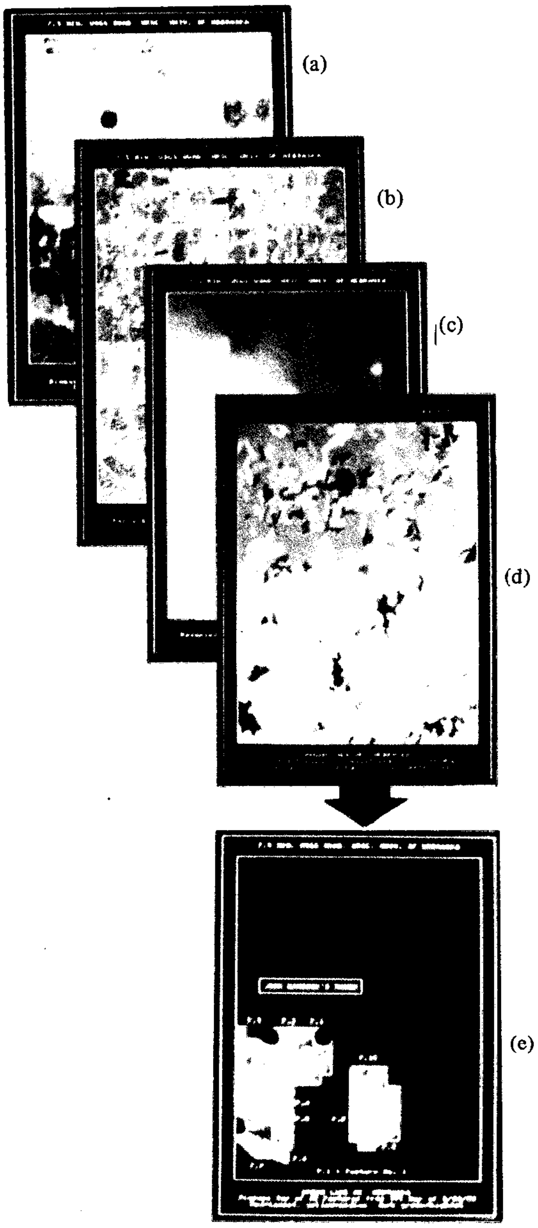
- predicting soil losses from sheet and rill erosion due to precipitation and
- simulating soil erosion for each alternative combination of crop system and management practices associated with soil type, rainfall pattern, and topography.

The USLE groups the numerous interrelated physical and management parameters that influence the soil erosion rate into five major factors whose site-specific values can be expressed numerically. These factors are:

- rainfall,
- soil erodibility,
- slope-length,
- cropping management, and
- conservation practice.

The major limitations of USLE is that it is:

- only applicable to agricultural lands and construction sites and
- does not account for deposition or sediment yields from gully, streambank, or stream bed erosion.



INPUTS

VEGETATION STATUS:
- (a) Canopy Biomass
  - (e.g. TVI, ND6, Greeness, etc.)
- Water Stress
- Disease
- Others

LAND COVER:
- Crop Type Map
- (b) Rangeland Management Units
- Land Use Change

TOPOGRAPHY:
- (c) Elevation
- Slope
- Aspect
- Shaded Relief
- Solar Insolation

SOIL:
- (d) Soil Type
- Slope Length
- Permeability
- Infiltration Rate

MODELS
- Universal Soil Loss Equation
- Watershed Simulation
- Cattle Management Model
- Site Selection Model

OUTPUTS
- Soil Loss Map
- Hydrography
- (e) Grazing Potential
- Optimal Location of Sites
  - (e.g. industrial, franchises, etc.)

Fig. 1. CONCEPTUAL DIAGRAM OF A GIS MODEL. Spatially registered map and image variables are converted to a common raster from a variety of sources and overlaid in GIS model. These GIS rasters or variables are stored in the multivariable file format which can be used as input to a GIS model(s) to derive specific results. The new computationally derived maps and images are also stored in the same multivariable file format and can be subsequently displayed and processed with any of the existing image processing tools

3. Lancaster county soil and land use data base

A suitable demonstration of the use of a microcomputer GIS is the preparation of an easily understood map of soil loss for a county. As part of a continuing program to identify critical soil erosion areas the Soil Conservation Service (SCS) is preparing soil erosion maps of individual counties in the midwest. This activity prepares digitized map inputs and executes a GIS model on selected critical counties to map out their soil erosion. Unfortunately, this is a tedious and time consuming process on a mainframe computer which yields a multisectioned, hard to interpret, line printer map of the each county's soil loss. HOTLIPS* was used with this existing GIS data base to demonstrate the capability of a microcomputer to more efficiently organize, store, execute, and suitably display a color soil loss map of the county. The appropriate raster data planes were obtained from SCS and input via tape to the HOTLIPS microcomputer for Lancaster County, Nebraska and the USLE GIS model was recomputed. The color image maps which is subsequently produced are easily understood, changed, recomputed, and redisplayed.

The Soil Conservation Service (SCS) digital or raster data planes which were available for Lancaster County, Nebraska on standard computer tape for this demonstration included a:

- soil survey map (69 soil types),
- land use map (10 land use classes),
- cropping management factor map, and
- conservation practice factor map.

These data planes were organized on the original tape such that:

- each digitized map (e.g. soil survey, land use, etc.) was represented by one file,
- each map file was composed of 25 independent, irregularly shaped rasters of a subsection of Lancaster County,
- the soil survey map had a ground cell size of 2 acres and the other three maps had a ground cell size of 8 acres,
- each cell (2 or 8 acres) was in the proportion of 5 high to 4 wide**, and
- each class was represented by a 2 byte EBCDIC code.

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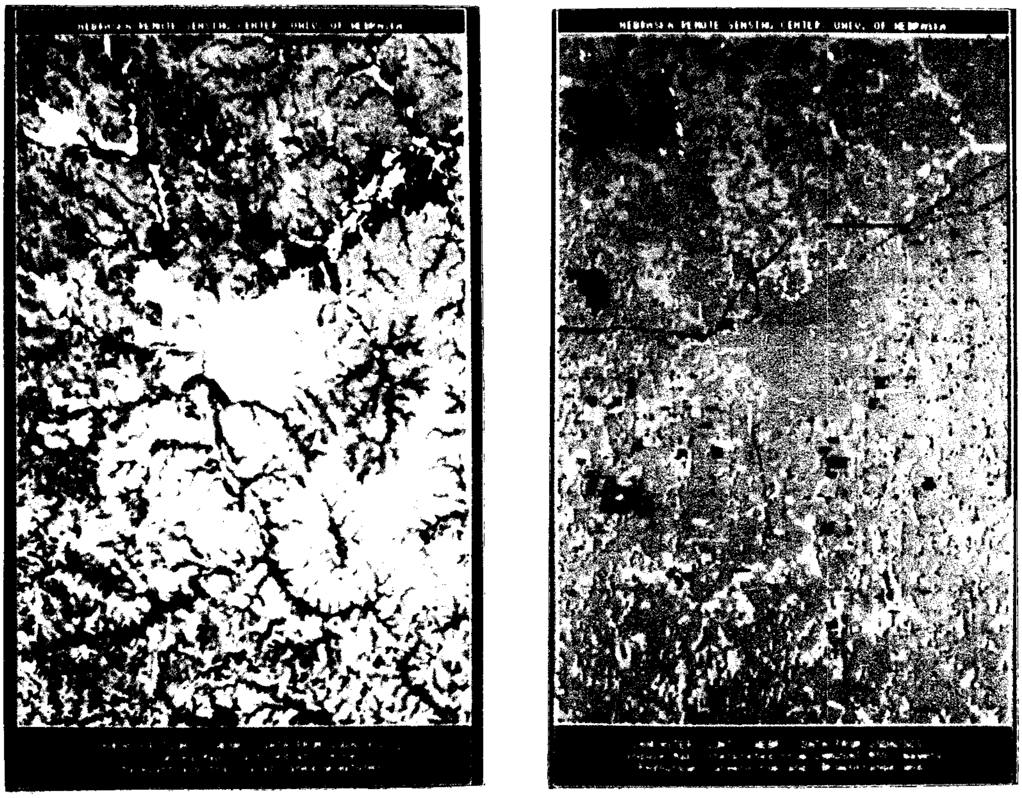
* HOTLIPS (Home and Office Techniques for the Local Image Processing Station) is a microcomputer image processing system developed at Nebraska Remote Sensing Center, University of Nebraska-Lincoln, U.S.A.

** Each 5 by 4 rectangular cell represents a correctly proportioned ground cell when displayed on a line printer with a rectangular character size of 8 lines per inch and 10 characters per inch.

These original four sets of 25 subrasters were cleaned up, concatenated into 4 map rasters each covering the complete county, and reorganized into a single multivariable DPIO* file to simplify their use. The reorganization of the data included:

- merging or digitally mosaicking the 25 individual rasters into one raster map for the whole county,
- converting 2 byte EBCDIC code representing each class into 1 byte numeric code,
- digitally enlarging the rasters of land use, cropping management factor, and conservation



(a) soil type raster map (2 acre cells) (b) land use raster map (8 acre cells)

Fig. 2. SOIL TYPE AND LAND USE RASTER MAPS OF LANCASTER COUNTY, NEBRASKA. The detailed soil type and land use for Lancaster County, Nebraska are depicted in black-and-white and color respectively. The soil type and land use rasters were originally digitized by the Soil Conservation Service (SCS) as rectangular cells of 2 acres and 8 acres respectively and in the proportions of 5 high to 4 wide. They are redisplayed here as rectangular cells creating a correct height and width relationship in these raster maps. The land use raster has been digitally enlarged by factor of two to be combined with the soil type raster. All of Lancaster County is represented with 474 by 576 cells of 2 acres in size in both displays. There are 69 soil classes in the black-and-white Lancaster County soil type raster map (a) and 10 land use classes in the color raster map (b)

* HOTLIPS raster data file format.

practice factor by factor of two to represent 2 acres each, and

- combining the four of 2 acre rasters representing each of the four variables into a single multivariable DPIO file.

The combined, four variable DPIO file of Lancaster County contains 474 by 576 matching cells of 2 acres and easily fits on a single 8″ floppy disk. This simple DPIO file can be used as input to subsequent GIS models or can be displayed in black-and-white or color in an image map format (Figure 2).

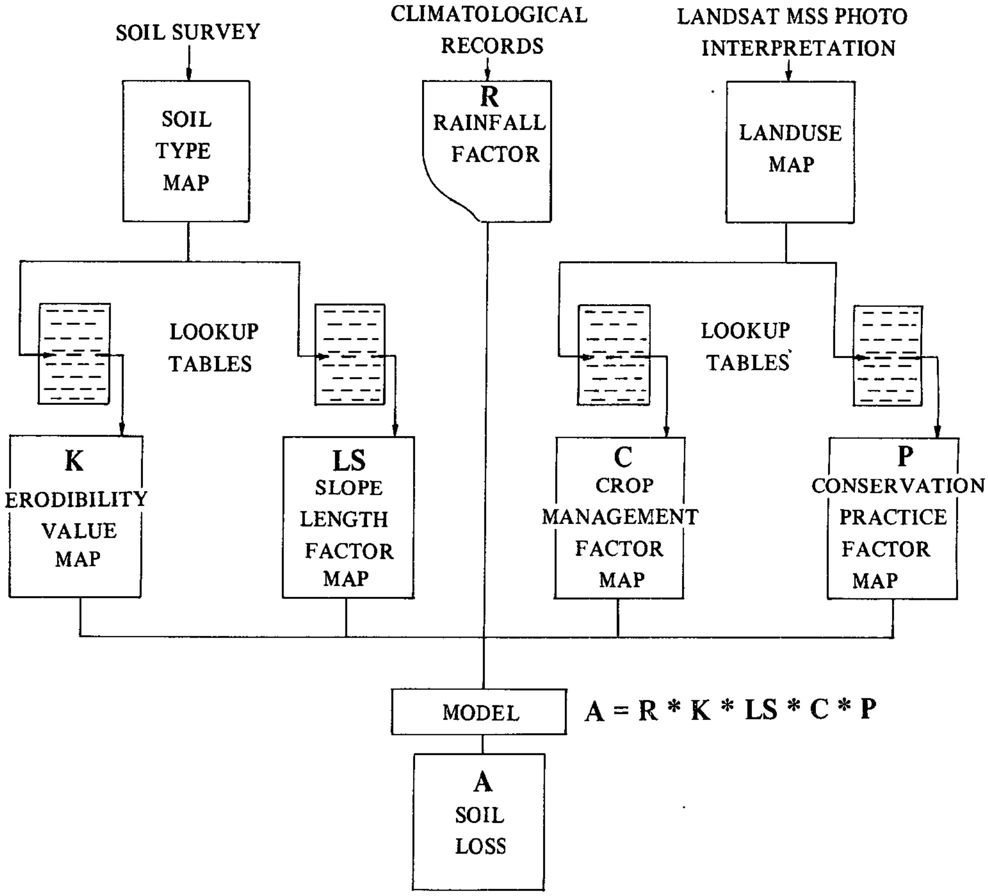


Fig. 3. FLOW CHART FOR COMPUTING SOIL LOSS FROM A GIS SYSTEM USING SOIL TYPE AND LAND USE RASTER MAPS. The Universal Soil Loss equation (USLE) requires five input variables which include R value (rainfall factor), C factor (cropping management factor), P factor (conservation practice factor), K value (erodibility factor), and LS factor (slope-length factor). R is determined from the climatological records of the area being modeled and is available in tabular and graphical form (Wischmeier and Smith, 1978). The K map and the LS map are fixed for each soil class and can be derived from soil type map (Figure 2a) with reference to a lookup table. The C map and the P map are fixed for each land use class and can be derived from land use map (Figure 2b) using the appropriate lookup tables. The soil loss or A map can thus be computed for each 2 acre cell by the Universal Soil Loss Equation: $A = R * K * LS * C * P$

4. Generating soil loss map

The soil loss for each 2 acre cell in Lancaster County, Nebraska was calculated using the DPIO file described above and the widely used Universal Soil Loss Equation (Figure 3) of

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

where, A = soil loss in tons/acre/year,

R = rainfall factor,

K = soil erodibility factor for each soil type,

LS = slope-length factor,

C = cropping management factor, and

P = conservation practice factor.

The R value (rainfall factor) was determined from climatological records of the area being modeled and is available in tabular and graphical form (Wischmeier and Smith, 1978). The K map (soil erodibility factor) and LS map (slope-length factor) are fixed for each soil class and were derived from the soil type map (Figure 2) with reference to a lookup table provided by SCS. The C map (cropping management factor) and P map (conservation practice factor) are fixed for each land use class and were derived from the land use map with reference to lookup tables by SCS (Figure 3). The computed soil loss map (A) was combined into the existing four variable DPIO as a fifth variable and subsequently displayed by assigning colors to specific soil loss ranges (Figure 4 and 5). This color coded soil map is considerably more useful than conventional, multipart line printer maps since:

- it is far easier to recognize each of the different levels of soil loss on a color display, and
- it shows the amount and spatial distribution of the soil losses of the whole county in a single, small map.

5. Interpretation of the predicted soil loss map of Lancaster county

The total predicted soil loss for the 542,976 acres of Lancaster County is predicted by the model to be ~2.3 million tons per year or an average loss of 4.4 tons/acre/year. Small areas of hilly rangeland and cropland in the headwaters of small drainage systems have the highest soil loss of more than 25 tons/acre/year. A recent visit to one of the general areas of highest erosion in the southwest quadrant of the county confirmed that the heaviest erosion was occurring on

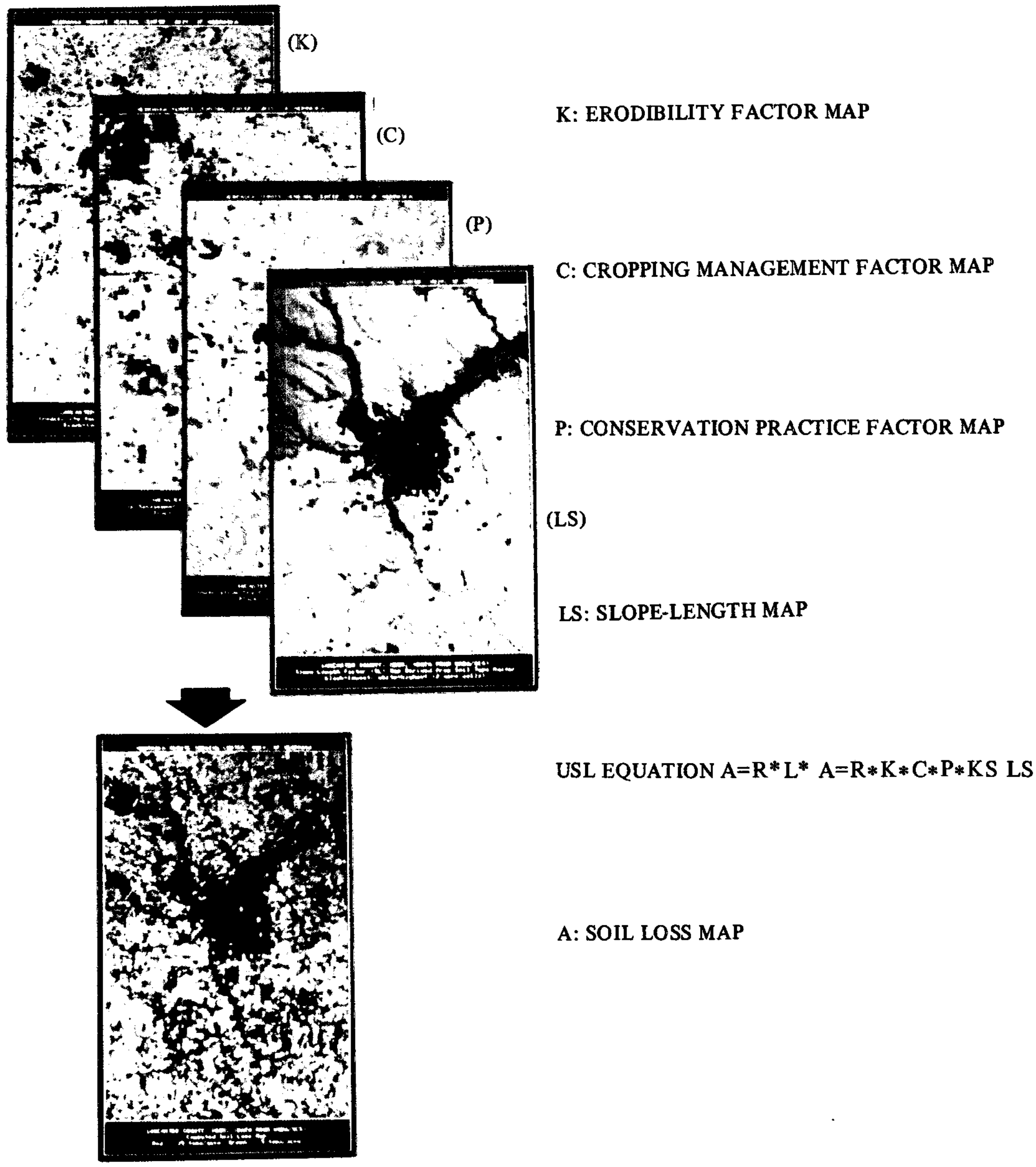
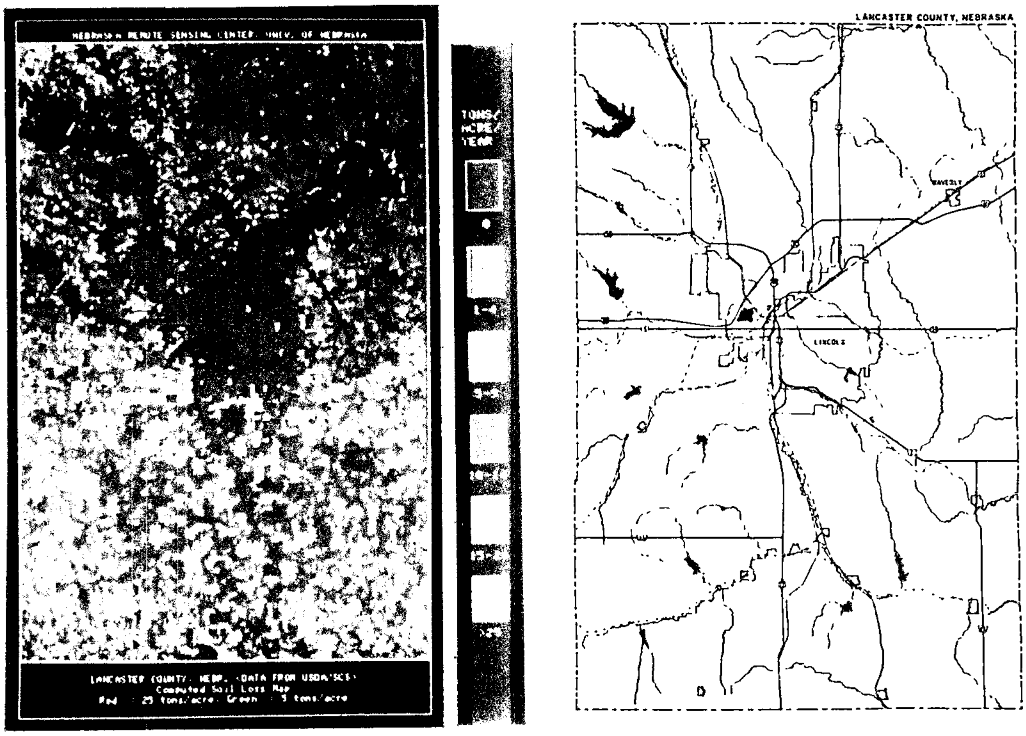


Fig. 4. CONCEPTUAL DISPLAY OF THE MULTIVARIABLE UNIVERSAL SOIL LOSS MODEL IN A GIS FORMAT. The four maps which are needed to compute the soil loss map as described in Figure 3 are shown in overlay fashion. These maps or rasters of the C factor, P factor, K factor, and LS factor are stored in the HOTLIPS multivariable Data Plane Input/Output (DPIO) disk format. They can be used as multiplane inputs to the GIS Model which solves the Univeral Soil Loss Equation (USLE) and outputs a soil loss map which is added as another variable to the original DPIO disk file. The resulting A map or soil loss plane is thus joined with the existing four variable multiplane GIS file for further use and display in HOTLIPS



(a) soil loss map

(b) Lancaster County map

Fig. 5. COMPUTED OR MODELED SOIL LOSS MAP AND COUNTY REFERENCE MAP FOR LANCASTER COUNTY, NEBRASKA. Computed soil loss map is depicted in a pseudo or color coded format (a) along with a map of Lancaster County (b). The center of the Lancaster County map is dominated by the urban built-up area of the city of Lincoln (depicted in blue). Small areas of rangeland and hilly cropland have the highest soil loss of more than 25 tons/acre/year (red) while most of the croplands have 5 tons/acre/year or less of soil loss (green). The average soil loss for this county is 4.4 tons/acre/year and a class by class summary of the losses occur in table 1

these hilly rangelands. Most of the productive croplands have 5 ton/acre/year or less of soil loss and occupy 60% of the area of county (Table 1). The intermediate category of 10-15 tons/acre/year occuring on marginal agricultural lands comprises only 14% of area but is the most critical as it contributes 41.5% of total soil loss.

Microcomputer based soil loss modeling can be used as an effective tool for supporting decision making in conservation planning by local agricultural and natural resource managers. For example, a soil scientist can use such procedures to test the effectiveness of conservation practices on a county or a drainage basin by comparing various alternative projects costs and their modeled reductions in soil loss. Evaluating or tracking the effectiveness of already implemented projects

Table 1. SUMMARY OF ANNUAL SOIL EROSION LOSSES FOR LANCASTER COUNTY. Potential soil loss was computed using the Universal Soli Loss Equation (USLE) and summarized by category for each 2 acre cell of the 474 by 576 raster covering Lancaster County. Total computed soil loss for the 542,976 acres in the county is 2.4 million tons per year which indicates an average soil loss of 4.4 tons/acre/year. The most common category of erosion is that of less than 5 tons/acre/year which accounts for 60% of area of this county. The most significant erosion category which occurs is 10-15 tons/acre/year which comprises 14% of area and contributes 42% of total computed soil loss for the county

Computed Soil Erosion Category	Area		Soil Loss	
	acres	%	tons	%
not defined	73768	13.6	0	0
<5 tons/acre/year	325824	50.0	685000	28.7
5-10 tons/acre/year	54608	10.1	429000	17.9
10-15 tons/acre/year	77952	14.4	994000	41.5
15-25 tons/acre/year	6696	1.2	118000	4.9
25-50 tons/acre/year	3616	.7	124000	5.2
50-75 tons/acre/year	112	.02	6000	.3
75-100 tons/acre/year	264	.05	22000	.9
>100 tons/acre/year	136	.03	14000	.6
Total	542976	100.00	2394000	100.00

(e.g. dam site, terraces, etc.) can also be made by computer comparison of pre- and post-project models of soil loss maps* and associated summaries. Thus, modeling soil loss maps by microcomputer:

- is an economic approach since the possible soil conservation practices don't have to be physically implemented to quantitatively evaluate their effectiveness,
- is an efficient approach since a "potential" soil loss map can be quickly generated for any combination of proposed soil conservation practices for any irregularly shaped subunit of the area modeled, and
- can produce, not only direct visual displays or color coded maps, but can also generate other graphical representations of the soil loss (e.g. bar chart, pie chart, etc.) for all or any subunit (e.g. watershed) of the area modeled.

* Landsat MSS imagery or air photos can be used as the basis for the preparation of the required land use maps. Earlier MSS imagery dating back to 1972 or historical air photos provide the basis for computing a preproject, baseline soil loss map.

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