Chapter 1

Introduction

Soil Erosion

Recently the Environmental Protection Agency (EPA) and locally, the Department of Pollution Control and Ecology (DPC&E), has sought to reduce the problem of soil erosion from construction sites. Soil erosion causes a loss of the productivity in the land, dumps millions of tons of sediment into waterways, and provides a substrate for toxic chemicals which are carried into the water supply. The EPA estimates that over $13 billion is spent each year mitigating man-made erosion [2]. Those involved in construction work, developments and other disturbances of the land are now faced with large costs to comply with state and federal regulations. The Arkansas Highway and Transportation Department (AHTD) seeks to limit the amount of soil erosion from new construction sites. It is preferable and more effective to prevent soil erosion than to correct the damaging effects of erosion after it has occurred. The AHTD could receive substantial benefit from a software system designed to predict potential soil erosion from future and present construction sites. This project provides such a predictive tool for evaluating potential soil erosion for construction sites by using a mathematical model to predict soil loss in conjunction with a geographic information system (GIS).

Geographic Information Systems

A Geographic Information System (GIS) is an information system that is designed to work with data referenced by spatial or geographic coordinates. A GIS provides an automated manner of collecting, storing, manipulating, and displaying this data. A GIS provides a way in which to facilitate the management of geographic information. Francis Hanigan defined a GIS as the following:

"Any information management system which can:
    Ë Collect, store, and retrieve information based on its spatial location.

1

Ë Identify locations within a targeted environment which meet specific criteria.
Ë Explore relationships among data sets within that environment.
Ë Analyze the related data spatially as an aid to making decisions about that environment.
Ë Facilitate selecting and passing data to application-specific analytical models capable of assessing the impact of alternatives on the chosen environment.
Ë Display the selected environment both graphically and numerically either before or after analysis." [5]

A significant aspect of such systems is that they incorporate both a data base for spatially referenced data, as well as a set of operations for manipulating the data itself. Although the operations involved with a GIS can vary, the concept of layers in the data organization and structure is the basic principle on which a GIS operates. This data base layering concept is illustrated in the Figure 1-1.

DATA BASE LAYERING CONCEPT

Political/Administrative Districts

Zoning

R-1

R-2

Utilities

Parcels

39 38 37 36 35
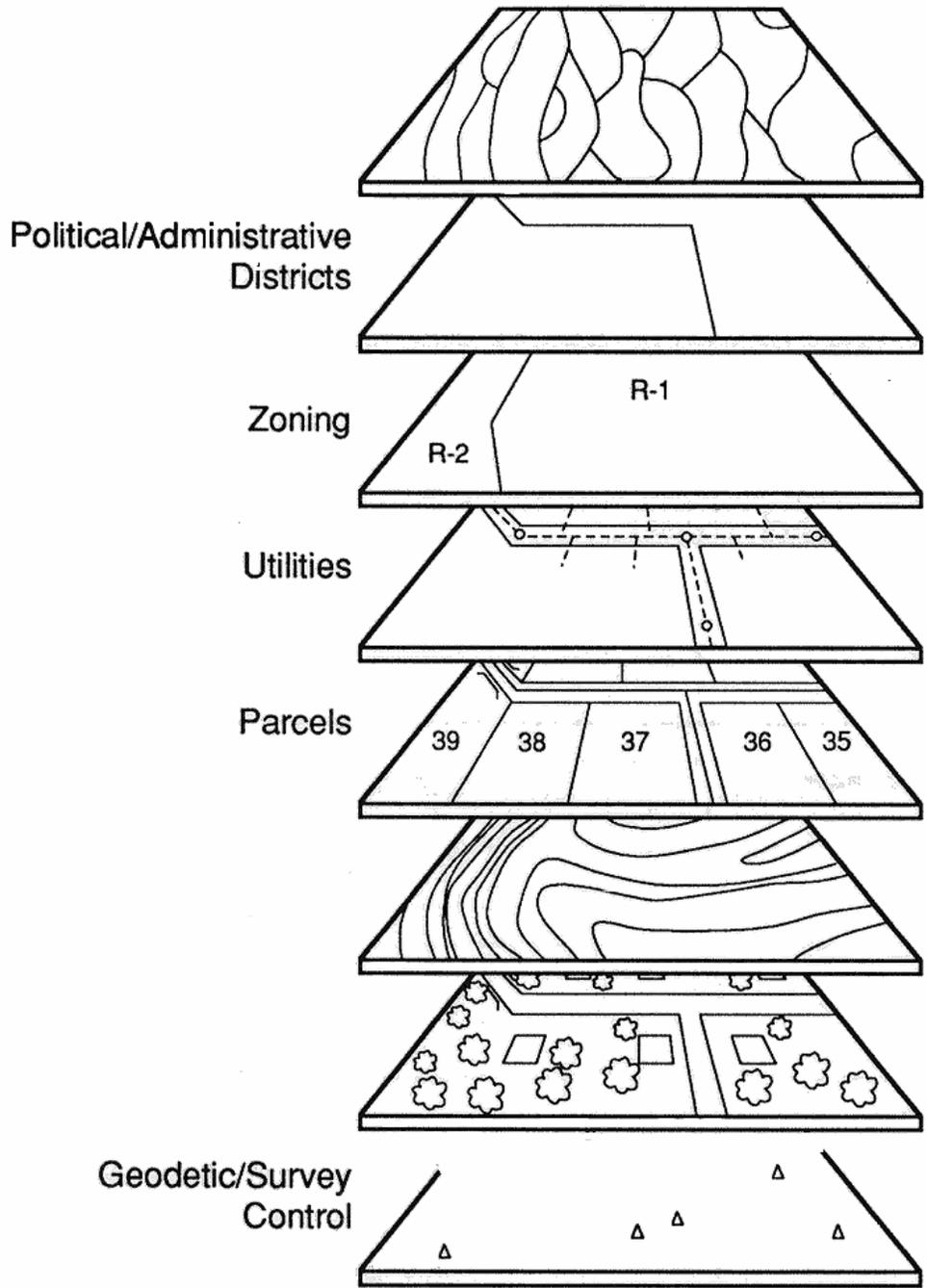
Geodetic/Survey Control

Figure 1-1: GIS layering concept

Figure 1-1 illustrates the data layering concept. Each layer represents a single attribute. For instance, the soils attribute would contain information on the type of soil (clay, loam, silt, etc.), while the topographic layer would contain information about variation in the surface of the land (mountains, hills, etc.). By combining this information about different layers the user can get information regarding different situations through the overlay of pertinent data.

The data layers in a GIS are generally handled in one of two ways, either by a raster or a vector method. Raster data are represented by uniform grid cells of specified resolution, and data are stored as a matrix of cells. Vector data layers are handled as lines between points. Figure 1-2 shows an example of a polygon represented in vector mode and in raster mode [6].

VECTOR/RASTER REPRESENTATION

Vector   *Raster*

$x^1 y^1$

$x^2 y^2$

$x^4 y^4$ $x^3 y^3$

$$x^1 y^1 - x^2 y^2$$
$$x^2 y^2 - x^3 y^3$$
$$x^3 y^3 - x^4 y^4$$
$$x^4 y^4 - x^1 y^1$$
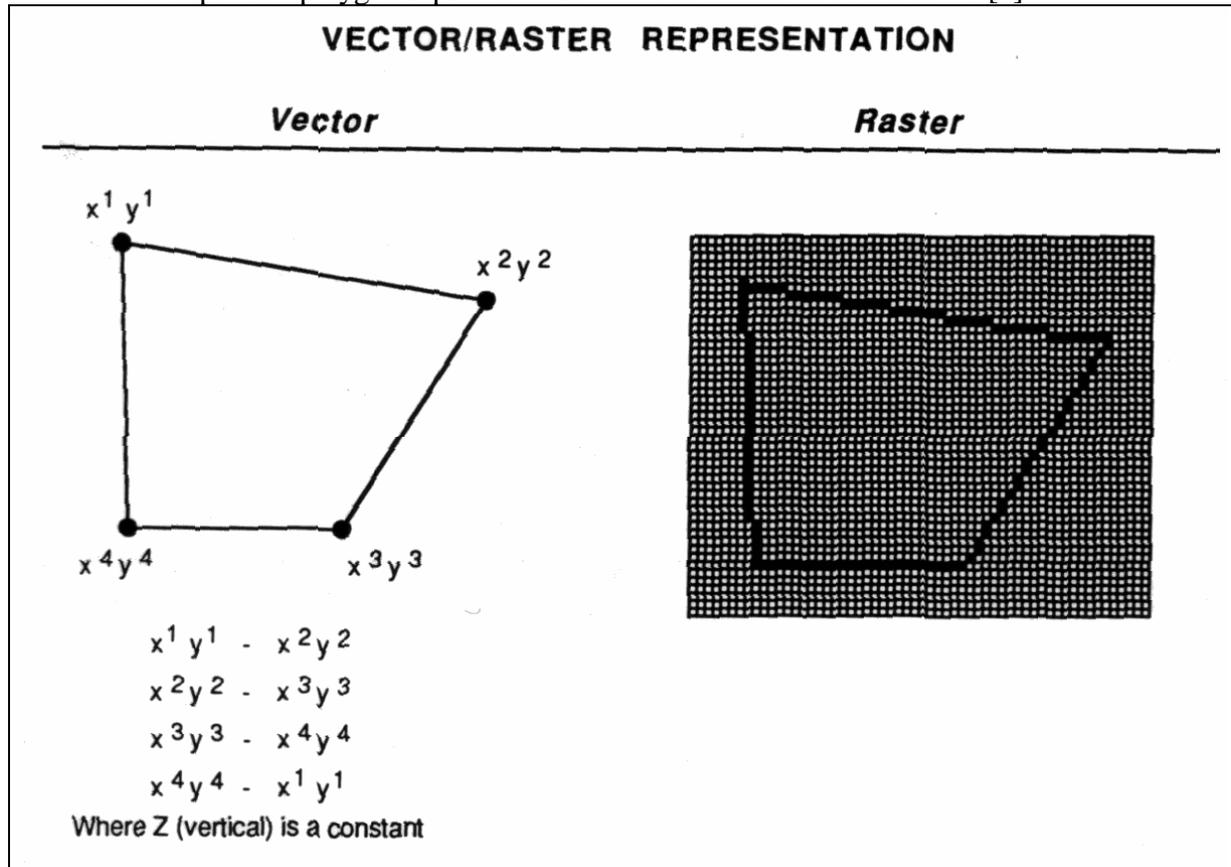
Where Z (vertical) is a constant

Figure 1-2: Vector vs Raster

Generally, operations involving these two types of data are primarily oriented to either raster structures or vector structures, although a GIS usually incorporates algorithms that convert these structures from one to the other form depending on the actual system being used.

Geographic Resources Analysis Support System

The Geographic Resources Analysis Support System (GRASS) is the GIS that is to be used for this research. GRASS is a public domain, general purpose, grid-cell based geographical modeling and analysis software package developed at the U.S. Army Corps of Engineers Research Laboratory (CERL). GRASS data bases consist of three major forms, site or point, vector or line, and raster or grid. While the users of GRASS can model and conduct operations with vector data, it is primarily oriented to raster data.

The GRASS system was chosen for use in this research because it is available on the University of Arkansas Campus through the Center for Advanced Spatial Technologies (CAST). Also there are large data bases with the actual data for parts of the state of Arkansas available through CAST.

Chapter 2

Review of Soil Erosion Models

Introduction

Mathematical models to predict soil erosion are available in a variety of forms. Each of these erosion predicting models seek to predict erosion over a given time event (i.e. day, month, year). Soil erosion models seek to mathematically represent the actual erosion process. Critical to the use of any soil erosion model for this research is that the model must be usable with a GIS such as GRASS. Soil erosion models will be evaluated on the basis of the ease with which they can be understood by practitioners, their applicability for implementation with a GIS, and for the availability of data that their implementation would require.

It is not within the time and scope of this project to cover all the possible models that exist in the current literature, but rather to take an in-depth look at the most commonly used erosion models. This will provide representative examples of soil erosion predictive models, and from these examples, the model will be chosen for implementation with GRASS. To that end, a classification scheme in Table 2-1 is presented that seeks to represent the variety of soil erosion prediction models found in the current literature. The table shows four basic levels, with Level 1 being the most simple of the models to understand and implement and Level 4 being the most complex and difficult.

As stated above there exists a great variety of soil erosion models in the current literature. This research focuses on the most commonly used models because, "most models [soil erosion models] are sufficiently modular that component relationships can be changed to meet the specific needs of the user [11]. Models were chosen to cover in detail the four levels of mathematical difficulty and complexity (see Table 2-1). The models analyzed were the Universal Soil Loss Equation (USLE), the Revised Universal Soil Loss Equation (RUSLE), Meyer and Wischmeier's Simulation of the Process of Soil Erosion By Water, the Nonpoint Source Pollutant Loading Model (NPS), the Watershed Erosion and Sediment Transport Model (WEST), and Storm Water Models

(SWM). Most all of these models incorporate some or all of the factors of the hydrologic cycle with some degree of success [10].

LEVEL OF MATHEMATICAL DIFFICULTY & COMPLEXITY	DEFINITION
1	The prediction equations are developed using regression analysis with average parametric values for input variables. The rational formula for determining runoff is such an equation, and the universal soil loss equation (USLE) for predicting sediment yield, developed by Wischmeier and Smith.
2	These are similar to those in Level 1, but the methods combine potential erosion with a routing procedure (delivery ratios) and are typically developed by using regression analysis with measured data.
3	Incorporates the unit hydrograph theory in hydrology and are appropriately called unit-sediment-graph (USG) methods. Many of the assumptions in the derivation of the unit hydrograph apply to the USG. The advantage of the USG is that it can be used in water-quality modeling where concentration of sediment is a significant indicator of pollution.
4	Uses a combination of equations to solve the dynamic soil erosion process. Many causal factors affect soil erosion. A particle is first detached from the surrounding soil by the impact of the rainfall energy of the erosive properties of the overland flow. Once the soil particle has been detached, it is transported over the construction site by rainfall-runoff. The sediment is finally delivered to the stream system, where it may or may not pose an ecological problem. The methods that constitute Level 4 all attempt to model analytically each of the important steps in the erosion process.

TABLE 2-1: *Classification Scheme for Soil Erosion Prediction Models*

The levels of mathematical difficulty and complexity are shown in Table 2-1 [19]. Models will be examined from each of these four levels so that an accurate examination of soil erosion prediction models can be researched. The mathematical difficulty along with ease of use, compatibility with GRASS, and availability of data, will determine which of the models is best for the prediction of soil erosion for highway construction projects.

Universal Soil Loss Equation: USLE

Background Information

The development of equations for calculating field soil erosion losses began in the 1940's with emphasis being placed on the prediction of soil loss for agricultural lands. Throughout the past years, these equations have been intensely studied and "improved" so as to provide improved prediction accuracy and validity. One of the more commonly used erosion prediction models developed is the Universal Soil Loss Equation (USLE). Developed with over forty years of data, it seeks to provide simplicity and accuracy for erosion modeling [32]. The USLE is a mathematical model that is used to compute the longtime average soil losses from sheet and rill erosion under specified conditions. It can be used for construction sites and other non-agricultural conditions. The USLE does not predict deposition or compute the sediment yields from gullies, streambanks, and streambed erosion [11, 33]. The USLE groups the primary factors of soil erosion into six groups which are described in later sections. As a result of the unpredictable short-time changes in the levels of influential variables, the USLE is less accurate for prediction of specific events than for prediction of longtime averages. However, since the primary purpose of this research is dedicated to construction projects that take a large amount of time to complete, for example six months to a year, specific events are not as great a factor, therefore the USLE is suitable for evaluating soil erosion for the present purpose.

Model and Components

The Universal Soil Loss Equation is as follows [34]:

$$A = R \text{ x } K \text{ x } L \text{ x } S \text{ x } C \text{ x } P$$

where:

A   is the computed soil loss per unit area expressed in the units selected for K   and   for the period selected for R. In practice, these are usually selected so that they compute A in tons per acre per year, but other units can be selected.

R,   the rainfall and runoff factor is the number of rainfall erosion index units, plus a   factor for runoff from snowmelt or applied water where such runoff is significant.

K,   the soil erodibility factor is 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-ft length under identical conditions.

L,   the slope-length factor is the ratio of soil loss from the   field slope length to that from a 72.6-ft length under identical conditions.

S,   the slope-steepness factor is the ration of soil loss from the field slope gradient to that from a 9-percent slope under otherwise identical conditions.

C,   the cover and management factor is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.

P,   the support practice factor is the ration of soil loss with a support practice like contouring, stripcropping, or terracing to that with straight-row farming up and down the slope.

Rainfall and Runoff Factor (R)

The numerical value of R in the USLE quantifies the raindrop impact effect and provides relative information on the amount and rate of runoff likely to be associated with the rain. The rainfall erosion index that is used by the USLE comes from Wischmeier's derivations [31, 35]. For studies in the state of Arkansas, R can be determined from Figure 2-1. A full map of the United Sates R values is included in Appendix B.

For example, to determine the R factor in Fayetteville, AR, the location of the site is examined in relation to the isoerodent lines on the map. In the case of Fayetteville, this site lies in-between the 250 R line and the 275 R line and would therefore be approximately 275. Since the erosive forces of runoff from thaw, snowmelt, and irrigation are considered negligible for the state of Arkansas, these factors will not be included in the factor R.

Soil Erodibility Factor (K)

The soil erodibility factor quantifies soils that potentially erode more readily than other soils
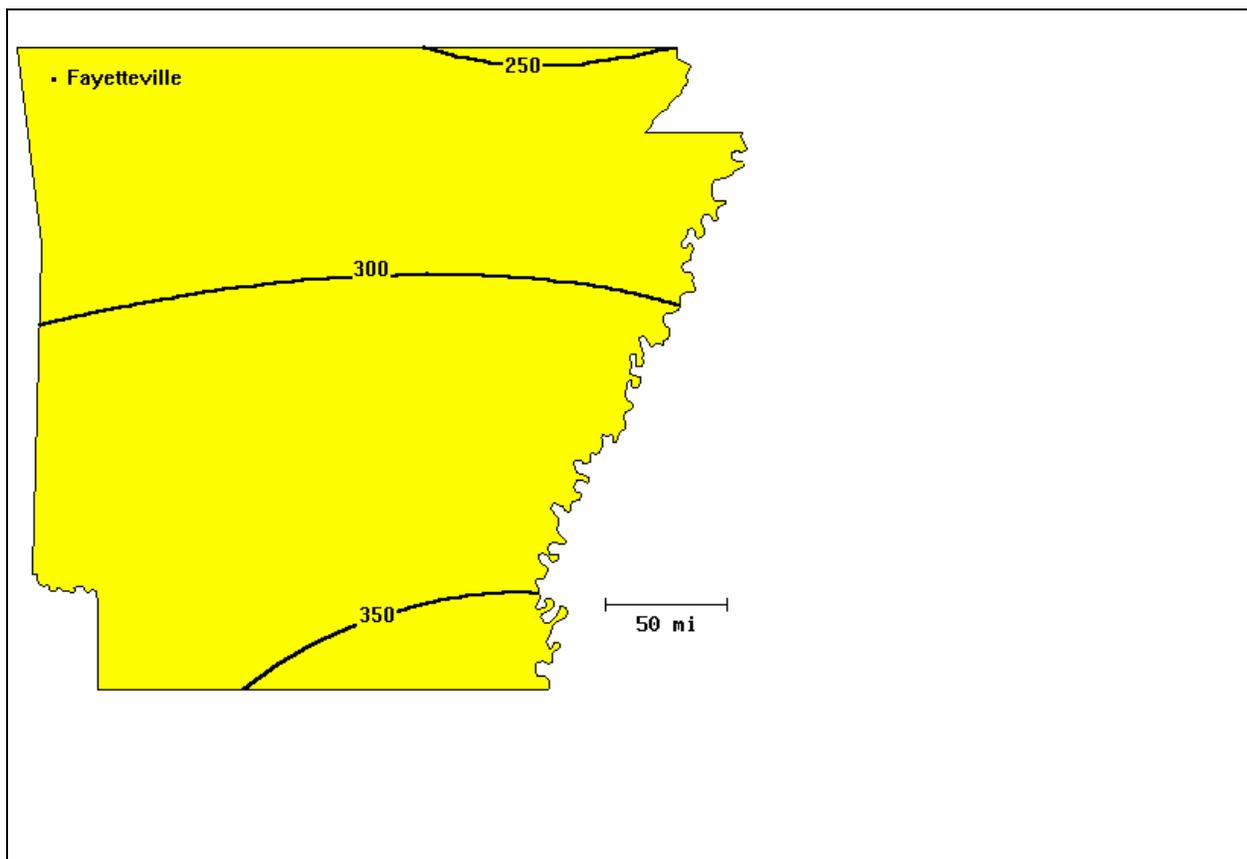
Figure 2-1: Isoerodent Map for Arkansas

even when all other factors are the same. For instance, a loosely packed sandy soil might have a greater potential to erode than tightly packed clay soil. Values used for K were taken from Table 2-2 which can be found in the soil survey for Madison County in the state of Arkansas [28].

Type of Soil	Computed K
Allen	0.28
Arkana	0.24
Moko	0.24
Britwater	0.32
Captina	0.43
Ceda	0.17
Cleora	0.32
Elash	0.28
Enders	0.32
Leesburg	0.15
Johnsburg	0.43
Leadvale	0.43
Leesburg	0.15
Linker	0.28
Mayes	0.43
Mountainburg	0.17
Nella	0.15
Steprock	0.17
Noark	0.28
Peridge	0.37
Secesh	0.32
Summit Variant	0.43
Tonti	0.37
Waben	0.28

Table 2-2: Computed *K values for soils in Madison County, Arkansas*

Topographic Factor (LS)

The topographic factor (LS) comes from the steepness and length of the land from which the entire slope length drains into a particular spot. These two factors have a substantial effect on the rate of soil erosion by water. They are combined into a single factor for convenience and simplicity. The equation used to evaluate LS is:

$$LS = (l / 72.6)^e (65.41 \sin^2 q + 4.56 \sin q + .065)$$

where: l = slope length in feet

e = 0.5 if percent slope is greater than 5

e = 0.4 on slopes of 3.5 to 4.5

e = 0.3 on slopes of 1 to 3 percent

e = 0.3 on slope of less than 1 percent

Cover and Management Factor (C)

The cover and management factor (C) comes from land use and land cover from such things as vegetative canopies and trees. Factor C in the soil loss equation is the ratio of soil loss from land cropped under specified conditions to the corresponding soil loss from clean-tilled, continuous fallow [34]. The factor seeks to measure the combined effect of all the interrelated cover and management variables. Table 2-3 shows the C factors for current land use and land cover [15]. Although the values for C are available for various farm and land use conditions, this study will focus primarily on those values that pertain to construction areas. Since part of this study evaluates the amount of soil erosion that takes place after construction modifications are made to the land area, the factor C for mulches in this study is included in the Table 2-4. This table can be used when

mulches are used and construction work has removed all vegetation and the root zone of the soil which removes the residual effects of prior vegetation. Table 2-4 gives the Cover and Management factors for a variety types of mulches which may be applied to the cleared construction area.

Land Use Land Cover	Cover Factor Value
Residential	0
Commercial	0
Industrial	0
Transportation, Communications, Utilities	0.04
Recreational Areas	0
Mixed or Built-up Land	0.04
Scrub and Brush Land	0.04
Deciduous Forest	0
Evergreen Forest	0
Mixed Forest	0
Strip Mines, Quarries, and Gravel Pits	1
Transitional Areas	1
Row Cropped	0.15
Double Cropped	0.14
Good Pasture	0
EFair Pasture	0
Poor Pasture	0.04
Woodland Pasture	0.09
Overgrazed Pasture	0.1
Confined Animal Operations	0.15

Table 2-3 : C factors for Land Use and Land Cover

Type of Mulch	Mulch Rate	Land Slope	Factor C	Length limit
	Tons per Acre	Percent		Feet
None	0	all	1	N/A
Straw or hay, tied down by anchoring and tacking equipment	1	1-5	0.2	200
"	1	6-10	0.2	100
"	1.5	1-5	0.12	300
"	1.5	6-10	0.12	150
"	2	1-5	0.06	400
"	2	6-10	0.06	200
"	2	11-15	0.07	150
"	2	16-20	0.11	100
"	2	21-25	0.14	75
"	2	26-33	0.17	50
"	2	34-50	0.2	35
Crushed Stone, 1/4 to 1 1/2 in	135	<16	0.05	200
"	135	16-20	0.05	150
"	135	21-33	0.05	100
"	135	34-50	0.05	75
"	240	<21	0.02	300
"	240	21-33	0.02	200
"	240	34-50	0.02	150
Wood Chips	7	<16	0.08	75
"	7	16-20	0.08	50

"	12	<16	0.05	150
"	12	16-20	0.05	100
"	12	21-33	0.05	75
"	25	<16	0.02	200
"	25	16-20	0.02	150
"	25	21-33	0.02	100
"	25	34-50	0.02	75

Table 2-4 : Factor C for Various Mulches

Support Practice Factor (P)

The support practice factor, P, is used primarily in croplands. When the sloping soil is to be cultivated and exposed to erosive rains, the protection offered by sod or close-growing crops in the system needs to be supported by practices that will slow the runoff water and thus reduce the amount of soil loss [22, 34]. Such practices for croplands are contour tillage, stripcropping on the contour, and terrace systems. In general, the value for P will usually equal 1.0 for construction sites because the erosion-reducing effects of shortening slopes or reducing slope gradients are accounted for through the LS factor [36].

Conclusions

The USLE has several advantages over other models. The first and foremost is its simplicity: "The Universal Soil Loss Equation (USLE) is the most widely accepted, user-friendly erosion prediction model currently available [29]." Also, the USLE requires the use of certain data which are available, such as soil types and slope, parameter values which are readily available, adaptable to nonuniform areas where deposition does not occur [10], and is widely used by agencies like the USDA-Soil Conservation Service. The model can be implemented in GRASS with the development of the appropriate software for the calculation of parameters such as the LS factor. The model does have some disadvantages, which are listed below:

(1)   The USLE methodology does not account for the effects of   antecedent soil moisture or the availability of detached soil particles.

(2)   The USLE contains no term to specifically account for the effects of overland flow, the major transport mechanism by which soil erosion occurs. Research has shown that runoff is the best single indicator of sediment yield from small

watersheds [1,7]. This is reflected in recent modifications of the USLE to specifically include the effects of runoff [8, 30].

(3)   Although the factors in the USLE are directly relevant to the soil   erosion process (especially K, C, P) , the formulation of the USLE does not   specifically   evaluate the mechanisms of soil detachment and transport;   these   are   the   major determinants of erosion during storm events.

(4)   The USLE was originally developed for estimates ofaverage annual soil loss from croplands east of the Rocky Mountains. It has had limited success in other areas and has been modified numerous times to adapt to local conditions [6].

(5)   Soil losses computed with the USLE are best available estimates, not absolutes. They will generally be most accurate for medium-textured soils, slope lengths of less than 400 ft, gradients of 3 to 18 percent, and consistent cropping and management systems that have been represented in the erosion plot studies. The farther these limits are exceeded, the greater will be the probability of significant extrapolation error [37].

While these disadvantages may be important, the real value of the USLE lies in its ease of use and knowing its limitations.

Revised Universal Soil Loss Equation: RUSLE

Background Information

The Revised Universal Soil Loss Equation is being developed by the USDA's Agricultural Research Service. The model will refine and improve the accuracy of the original Universal Soil Loss equation (USLE) to estimate the effects of various conservation systems on soil erosion [21]. As of this date the revised model is not yet completed [20]; however, it remains an important extension of the work done in this research because the model's basic structure remains the same while the data tables associated with the components have changed. Since the data tables are the only elements to change, the RUSLE could be used with the existing code.

The USLE was initially designed to assist farmers and soil conservationists in farm planning. The data provided for in the USLE was oriented and developed for use on cropland, but by the early 1970's it was being applied to rangeland, disturbed forest land, urban construction areas, highway embankments. Due to the widespread application of the USLE, much of the accuracy and "technical soundness" were causing controversy [23]. The basic RUSLE changes seek to provide improvements in knowledge and technology and put them into the older, USLE model. The results provided in the RUSLE will be an improved soil loss estimate primarily by changing or updating the database and tables that are referenced for the various factors in the model [21].

Model and Components

Even though the model is not yet done, the importance in examining the RUSLE is that the primary factors (**A=R x K x L x S x C x P**) do not change; only the data tables associated with the primary factors change. Thus, once the improved model is finished, it should be relatively easy to use the RUSLE in GRASS and this research. Table 2-5 shows some of the major differences as well as similarities between the RUSLE and the USLE [21] .

Table 2-5: *USLE vs. RUSLE: Similarities and Differences*

Factor	Universal Soil Loss Equation (USLE)	Revised Universal Soil Loss Equation (RUSLE)
R	Based on long-term rainfall conditions for specific geographic areas in the U.S.	Same as USLE except values for Western states (Montana to New Mexico and west) are based on data from more weather stations and thus are more precise for any given location. Only minor changes occurred in other regions. ------------------------------- Some RUSLE R factors are higher and some are lower than USLE R factors
K	Based on soil texture, organic-matter content, permeability, and other factors inherent to soil type	Same as USLE but adjusted to account for seasonal changes such as freezing and thawing or soil consolidation. ------------------------------- Many RUSLE K factors will be slightly lower, but some will be slightly higher, than USLE K factors
LS	Based on length and steepness of slope regardless of land uses.	Refines USLE by assigning different values according to land use (cropland, rangeland, disturbed land, and thawing soils.) ------------------------------- Values vary at most marginally from those used by the USLE.
C	Based on cropping sequence, residue cover, surface roughness, and canopy cover, which are weighted by the percentage of erosive rainfall during six crop stages. Lumps the factors into a table of soil loss rations, by crop and tillage operations. -----------------	Uses the independent subfactors: prior land use, canopy cover, surface cover, surface roughness, soil moisture. Refines USLE by dividing each year in rotation into 15-day intervals, calculating a soil-loss ration for each period. Recalculates a new soil loss ratio every time a tillage operation changes one of the subfactor. ------------------------------- RUSLE provides more accurate estimates of changes as they occur throughout the year. Final C value may be

	Uses a soil loss ratio developed for six crop state periods (1-before planning, 2-seedbed preparation until 10% canopy cover, 3-10-50% canopy cover, 4-50-75% canopy cover, 5-75% canopy cover until harvest, 6-after harvest until plowing or new seeding).	higher or lower than obtained through USLE.
P	Based on installation of practices that slow runoff and thus reduce soil movement. P factor values change according to slope ranges with no distinction for various ridge heights.	P factor values are based on hydrologic groups, slope, row grade, ridge height, and the 10-year single storm index values. -------------------------------- RUSLE estimates of P factor may be higher or lower than estimates obtained through the USLE

Table 2-5 (continued): USLE vs. RUSLE: Similarities and Differences

Conclusions

In terms of complexity the RUSLE would remain a Level 1 model because no delivery mechanism exits for the movement of sediment and water. While both the USLE and the RUSLE do not represent fundamental hydrologic and erosion processes, the RUSLE does provide an excellent simplified representation of the first-order effect of the factors that affect sheet and rill erosion [23]. The final drafts of the documentation on the RUSLE are being reviewed by technical specialists in the USDA and in addition to updates in the tables for the primary factors, the model is designed to run on a personal computer with a DOS or UNIX operating system [20, 23]. The Revised Universal Soil Loss Equation will provide much better prediction capabilities and could be implemented with the software system that will result from when the revisions are available.

SIMULATION OF THE PROCESS OF SOIL EROSION

Background Information

In 1969 L.D. Meyer and W.H. Wischmeier developed a mathematical model for predicting soil erosion. Empirical relations were determined from collected data and then were combined in equations designed to predict long-term soil losses from the particular tracts of land under various combinations of land use and management. "The model presented seeks to detail soil erosion as a dynamic process and is concerned with the feasibility of separating the soil-erosion process into several component processes rather than obtaining quantitative results [18]."

Model and Components

The component parts of the model considered were soil detachment by rainfall, transport by rainfall, detachment by runoff, and transport by runoff as separate but interrelated phases of the process of soil erosion by water [18].

By looking at the model in flow chart form we can see the basic components and processes at work in Figure 2-2. Figure 2-2 illustrates how the model was simulated by Wischmeier with regard to the basic erosion components, as well as how the movement of sediment is accomplished [18].

An examination of each of the terms that are in the simulation by Wischmeier and Meyer provides
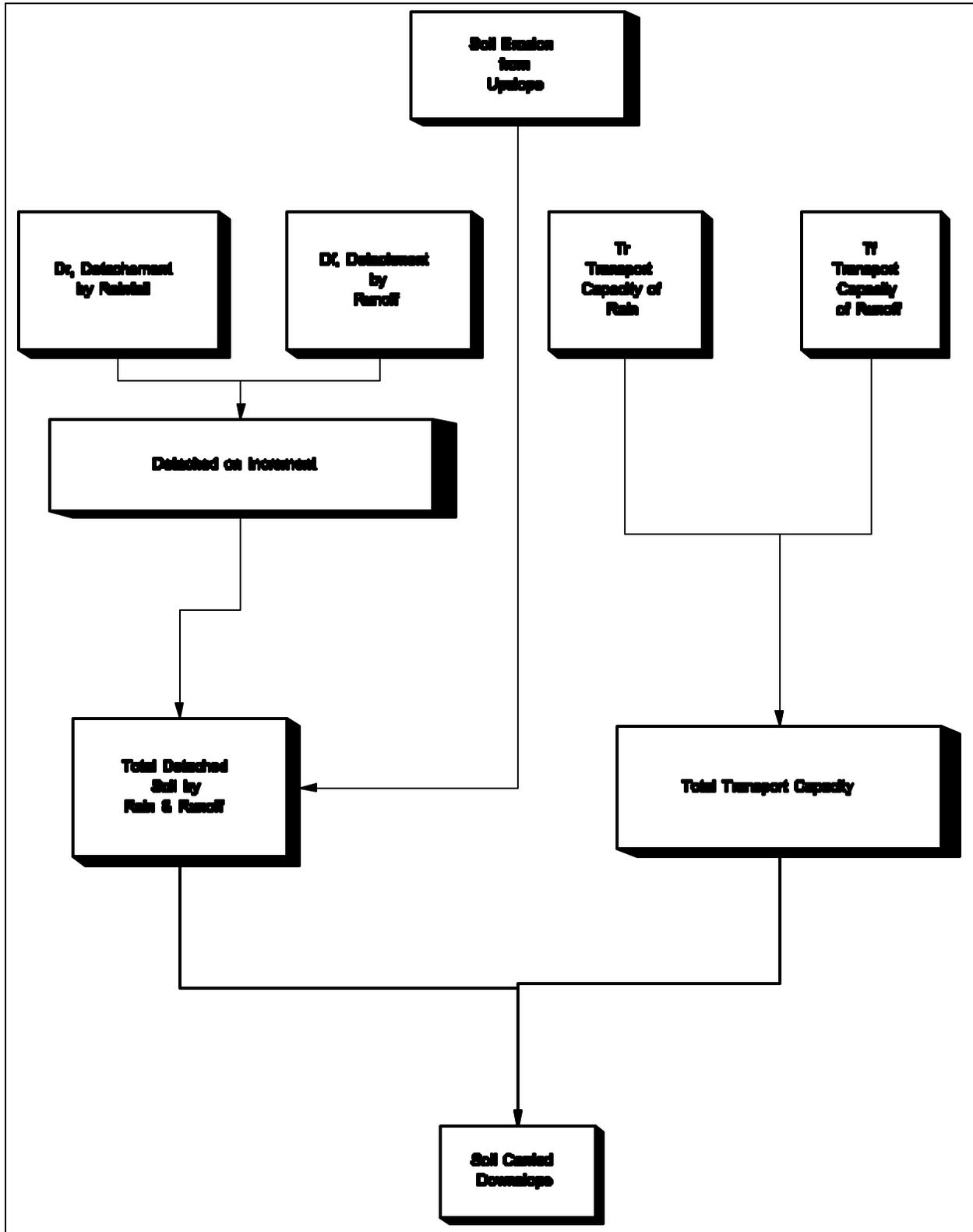
Figure 4-2: The Simulated Soil Erosion Process

26

insight into how the actual erosionprocess was modeled.

Model & Components

$\mathbf{D_R}$= The detachment of soil particles due to rainfall. D_R is calculated by the following equation:

$$\mathbf{D_R = S_{DR} \; x \; A_I \; x \; I^2}$$

where:
S_{DR}= mathematical constant that is a function of the soil type.

A_I= area of increment.

I = Intensity.

$\mathbf{D_f}$ = The detachment of soil particles by runoff calculated by:

$$\mathbf{D_f = S_{DF}A_I 1/2(S_s\,2/3Q_s\,2/3 + S_E\,2/3Q_E\,2/3)}$$

where:

S_{DF}= mathematical constant for soil type/properties

S_S = slope steepness at the start of the increment

S_E= slope steepness at the end of the increment

Q_S= flow rate at the start of the increment

Q_E= flow rate at the end of the increment

$\mathbf{T_R}$= the transportation capacity of rainfall calculated by the equation:

$$\mathbf{T_R = S_{TR}S \; I}$$

S_{TR}= mathematical constant soil effect

$\mathbf{T_F}$= the transportation capacity of runoff calculated by the equation:

$$\mathbf{T_F = S_{TF}S^{5/3}Q^{5/3}}$$

where:

27

S_{TF}= mathematical constant for the effect of particle size and density on the soil's transportability

Calculation of D_R

The detachment of soil particles due to rainfall D_R is calculated by

$$D_R = S_{DR} \text{ x } A_I \text{ x } I^2$$

where:

S_{DR} is a constant that takes into account such things as soil type and density.

Calculation of D_F

The detachment of soil particles by runoff is calculated by:

$$D_f = S_{DF} A_I 1/2 (S_s 2/3 Q_s 2/3 + S_E 2/3 Q_E 2/3)$$

Computational Steps for the Prediction of Soil Loss

Step 1: Calculate D_R, D_F, T_R, and T_F.

Step 2: Calculate the **Total Detached Soil = $D_R + D_F$**

Step 3: Calculate the **Total Transport Capacity = $T_R + T_F$**

Step 4: Compare the Total Detached Soil and the Total Transport Capacity. If the Total Detached Soil is less than the Total Transport Capacity of the soil, then the amount of Soil Carried to the next increment is equal to the amount of available material. If on the other hand, the Total Transport Capacity is less than the soil available for erosion, then the sediment load equals the transport capacity.

Step 5: Calculate the Total Erosion. This is the value acquired from Step 4 minus the previous sediment yield. If the values are negative this indicates a deposition.

Conclusions

The simulated approach to erosion prediction is a Level 2 type of model because the model uses a routing procedure for the movement of sediment. The primary strength that the model has is that the relationships reflect interactions between detachment and transport by rainfall and runoff. The model is also able to reflect interactions due to spatial variability. However, the model has limitations in that it requires calibration and it does not include such things as channeling [1]. The model also does not include the following items:

1. Seepage and other subsurface flow phenomena as they affect soil erosion.
2. Vegetation and crop residues as they affect the erosive potential of rainfall and runoff.
3. Tillage, freezing and thawing and other natural or man-caused actions as they influence soil detachment and transport.
4. Land topography and microtopography as they affect storage, overland flow, and exposure to rainfall.
5. Surface-water depth as it affects detachment and transport.
6. Accumulation of excess detached soil available for removal during subsequent periods of greater transportation capacity.
7. Additional interrelationships among the subprocesses [18].

The model presented by L.D. Meyer and W.H. Wischmeier provides modeling of interactions between detachment and transport by rainfall and runoff. The approach treats soil detachment by rainfall, transport by rainfall, detachment by runoff, and transport by runoff as separate but interrelated parts of the soil erosion process. The model has additional advantages of reflecting interactions between detachment and transport by rainfall and runoff, and is able to reflect interactions due to spatial variability. However, the model requires a great deal of calibration for a given area and would require a database of such elements as particle size and would also require a

continuous simulation type approach. This continuous simulation approach would not be appropriate for implementation with a GIS such as GRASS since a GIS is not designed to handle functions of time in a continuous manner as is required in this model.

Nonpoint Source Pollutant Model: NPS

Background Information

In examining the literature, the Universal Soil Loss Equation is not applicable to the continuous simulation of soil erosion processes although it has been used for this purpose [6]. The NPS Model was developed to provide a consistent method of simulating soil erosion and nonpoint pollution transport from both pervious and impervious areas and is shown on the next page [6]. In July of 1976 a model was developed by Anthony S. Donigian and Norman H. Crawford. The results of their work was called the Nonpoint Source Pollutant Loading (NPS) Model. The NPS uses subprograms to represent the hydrologic response of a watershed and includes such things as snow accumulation and melt, the processes of pollutant accumulation, generation, and washoff from the land surface. The model's primary use lies in its ability to predict pollutants in a watershed, but it can also be used to predict sediment erosion since this is the major mechanism by which it tracks pollutants.

Model and Components

The model continuously simulates the hydrologic processes of snow accumulation and melt, sediment generation, pollutant accumulation, and pollutant transport. NPS is made up of three major components which are shown in Figure 2-3 [6]. The flow chart represents the basic operations of the NPS model. The MAIN section acts as the master or executive routine and does those tasks contained within the dashed line in Figure 2-3. The NPS model integrates the hydrological cycle in the LANDS module which was originally derived from the Stanford Watershed Model [5, 38]. The

31

QUAL subroutine simulates erosion processes, sediment accumulation, and sediment and pollutant washoff from the land surface.
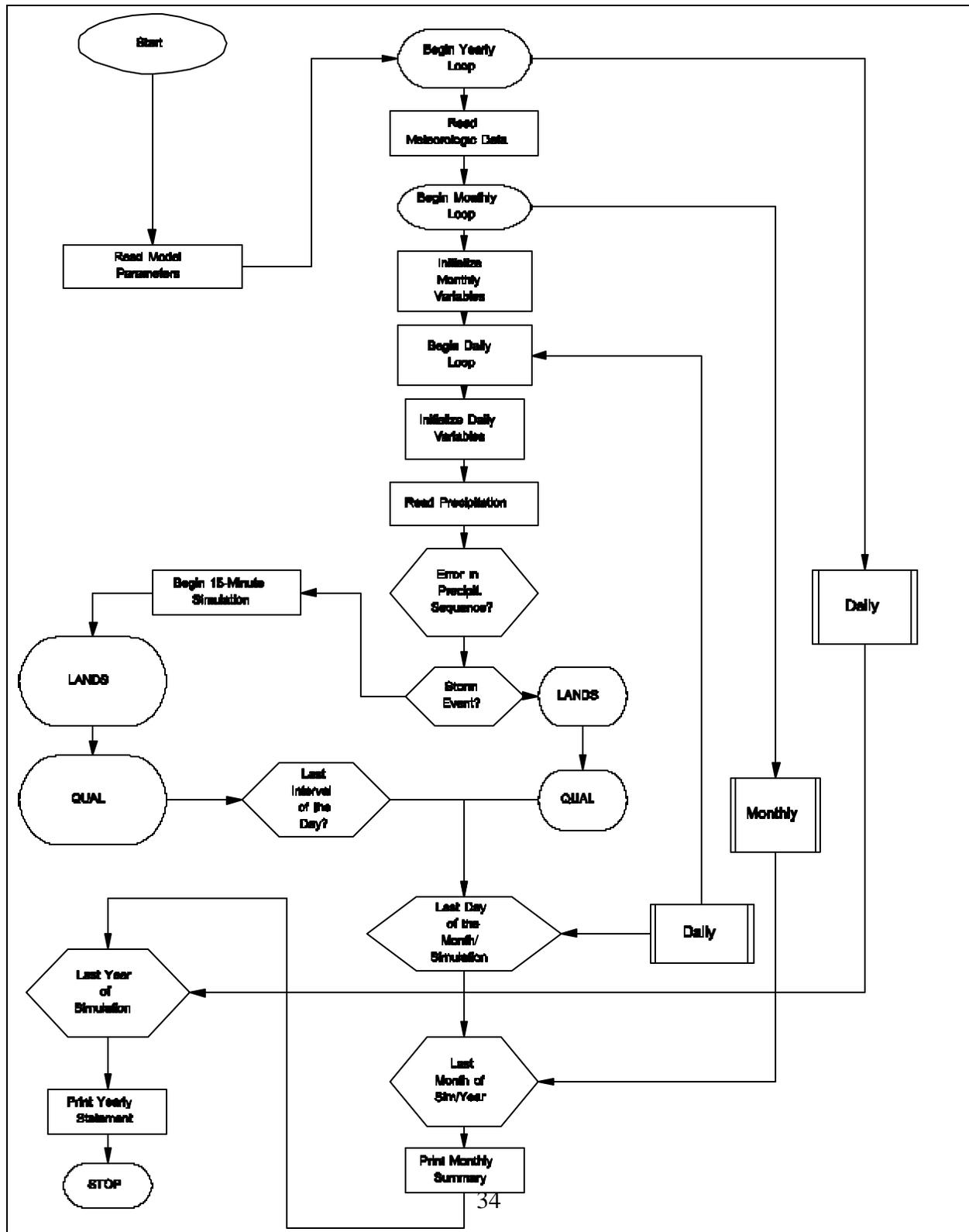
Figure 2-3: NPS Model Structure and Operation

Parameter	Definition
EPXM	The interception storage parameter, related to vegetal cover density
UZSN	The nominal upper zone soil moisture storage parameter.
LZSN	The nominal lower zone soil moisture storage parameter.
K3	Index to actual evaporation (a function of vegetal cover).
K1	The precipitation adjustment factor.
PETMUL	The potential evapotranspiration adjustment factor.
K24L	The fraction of groundwater recharge that percolates to deep groundwater.
INFIL	A function of soil characteristics defining the infiltration characteristics of the watershed.
INTER	Defines the interflow characteristics of the watershed.
AREA	The area of the watershed.
L, LI	Length of overland flow plane (pervious and impervious).
SS, SSI	Average overland flow slope (pervious and impervious).
NN, NNI	Manning's "n" for overland flow (pervious and impervious).
IRC, KK24	The interflow and groundwater recession parameters.

Table 2-6: Parameters of the LANDS Module

The major parameters of the LANDS subroutine are given in Table 2-4 [6]. The flowchart provided in Figure 2-4 shows the subprogram of LANDS. The LANDS subprogram (see Figure 2-4) operates continuously on a 15-minute interval throughout the simulation period. Daily potential evapotranspiration and precipitation for 15-minute or hourly intervals are required inputs. If snowmelt simulation is not performed, precipitation first encounters the interception function. The storage function of interception is dependent on vegetation and land cover. In many areas interception capacity will vary with the season of the year.
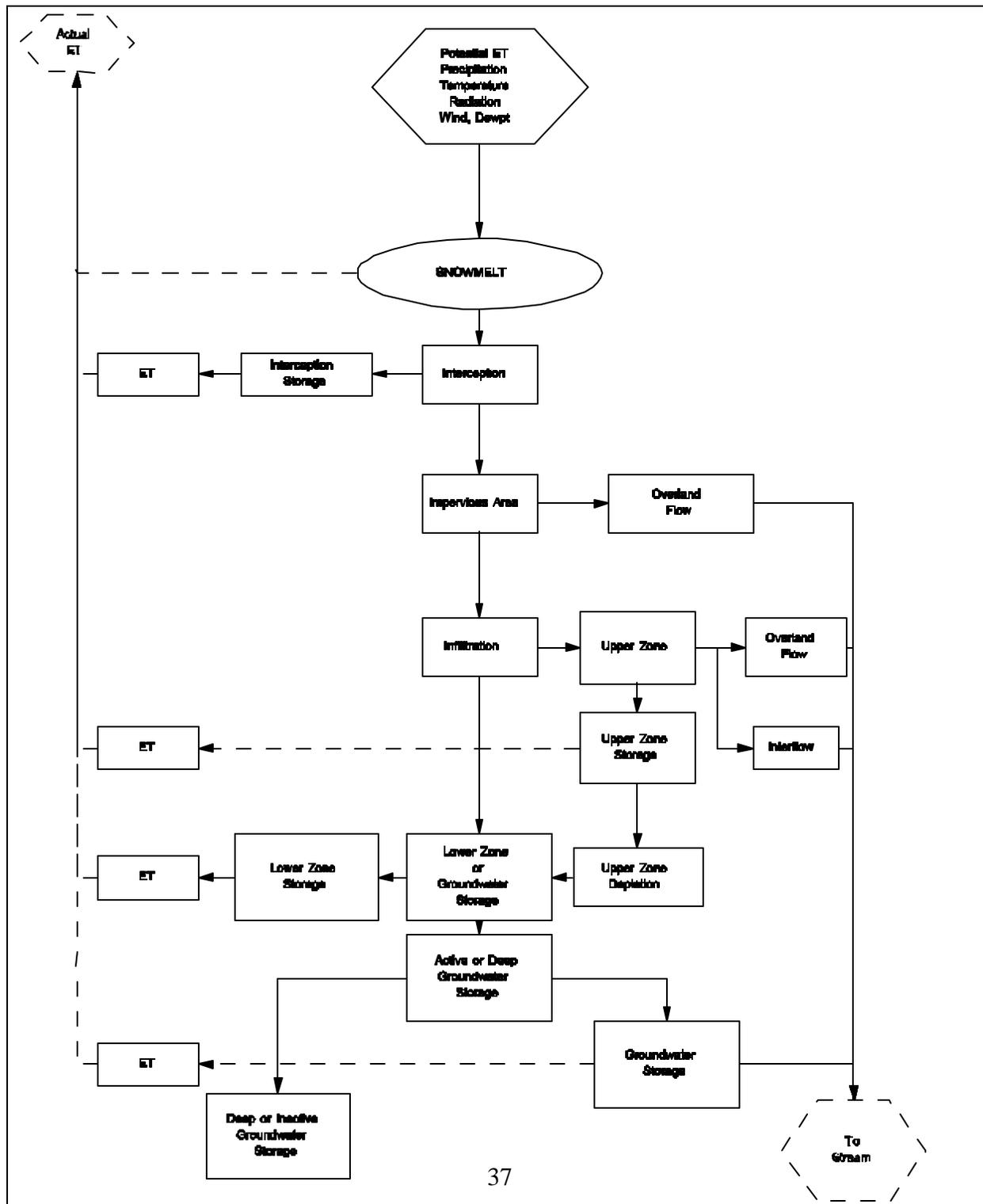
Figure 2-4: LANDS simulation

37

When interception storage is filled, any remaining precipitation is added to the moisture supply of the infiltration function, which performs the basic division of available moisture into surface detention, interflow detention, and infiltration. Surface detention includes overland flow and an increment to upper zone soil moisture storage. Interflow detention is a delay mechanism controlling the release of interflow to the stream. Infiltration and percolation from the upper zone provide the means by which moisture reaches lower zone storage. From lower zone storage, moisture moves to active ground water storage from which the ground water component of streamflow is derived ." [6] The evapotranspiration values occur at different rates form each of the moisture storage.

The QUAL portion of the model, as stated earlier, is used for simulating nonpoint pollutant accumulation and transport. A flow chart is provided for the QUAL subroutine in Figure 2-5. Operation of the QUAL subroutine in Figure 2-5 is directly controlled by the MAIN part of the NPS model. The subroutine consists of two alternate loops, each one iterated with different frequency, depending on the rainfall and runoff conditions as they are transferred from the LANDS subprogram. "The major portion of the QUAL algorithm pertains to the 'storm day' path. The key portions of this loop are the analytical representations from pervious and impervious areas. Simulation of these processes is carried out for each land use within the watershed. The aggregate quantities of the washed-off sediments and pollutants are summed to yield the total mass and the equivalent concentration of pollutants in the overland flow." [6]
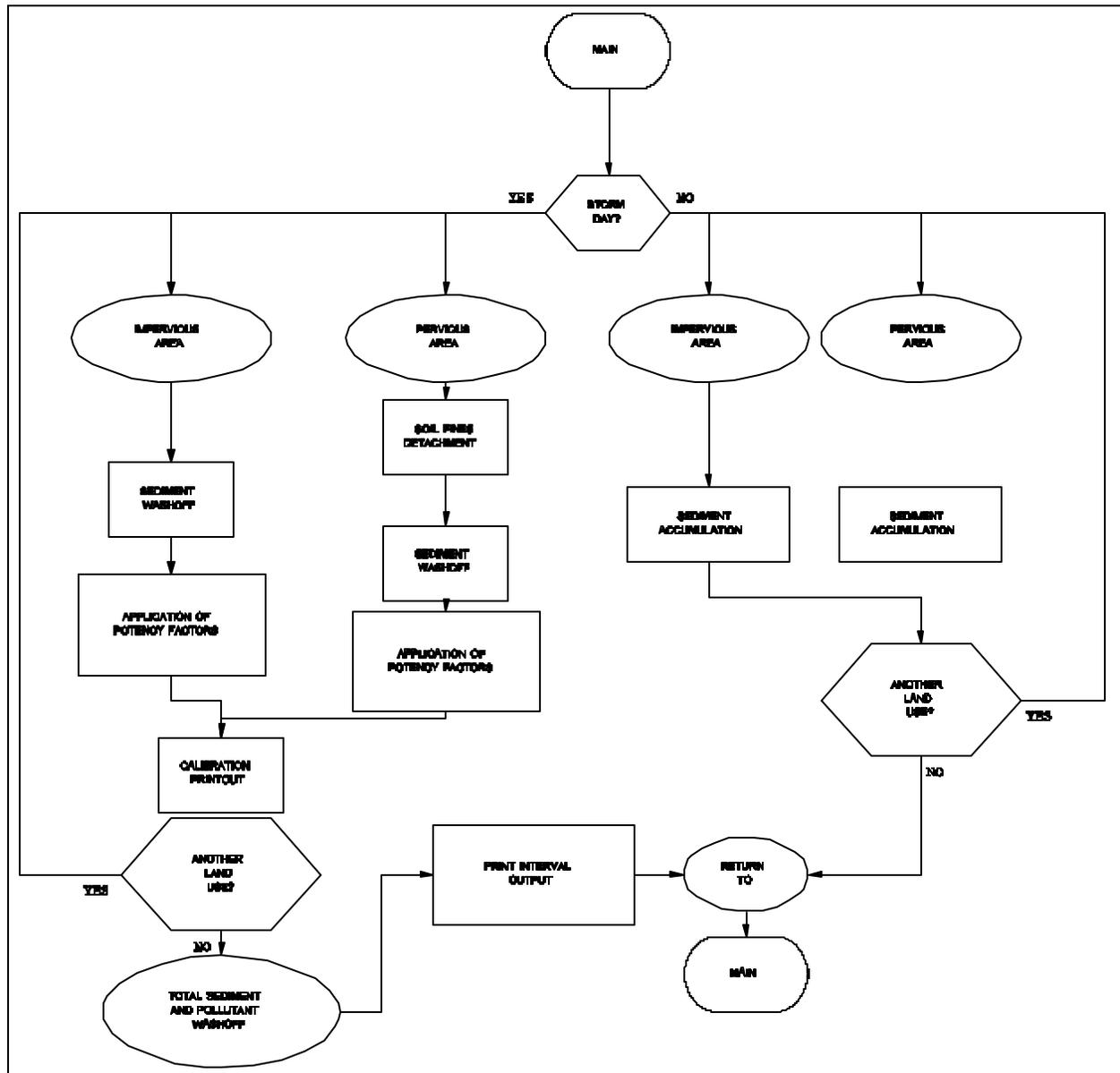
Figure 2-5: Functional flowchart of the QUAL subroutine

Conclusions

The NPS has potential for simulation in a continuous environment. For purposes of this research, the model would be classified as a Level III model because it incorporates hydrograph theory as well as water-quality modeling where concentration of sediment is a significant indicator of pollution. To validate the model, simulations were conducted and actual data was compared against that found in the simulated runs and the results compared favorably in terms of accuracy and precision. NPS provides a means for simulating sediment runoff; however, the complexity and amount of data required to calibrate the model, as well as its continuous simulation nature, preclude its use with a GIS.

Watershed Erosion and Sediment Transport Model: WEST/ARM

Background Information

The Watershed Erosion and Sediment Transport (WEST) model was engineered to simulate and predict both water and sediment movement from the land surface and through the stream system of a watershed [13]. The development of the WEST model in 1979 incorporated the ARM model developed in 1976 and the CHANL model. The WEST model is a combination of both the ARM and the CHANL model, which are linked by a simple data management system. The ARM model [13] simulates the land paths processes and the CHANL Model simulates the in-stream or channel process.
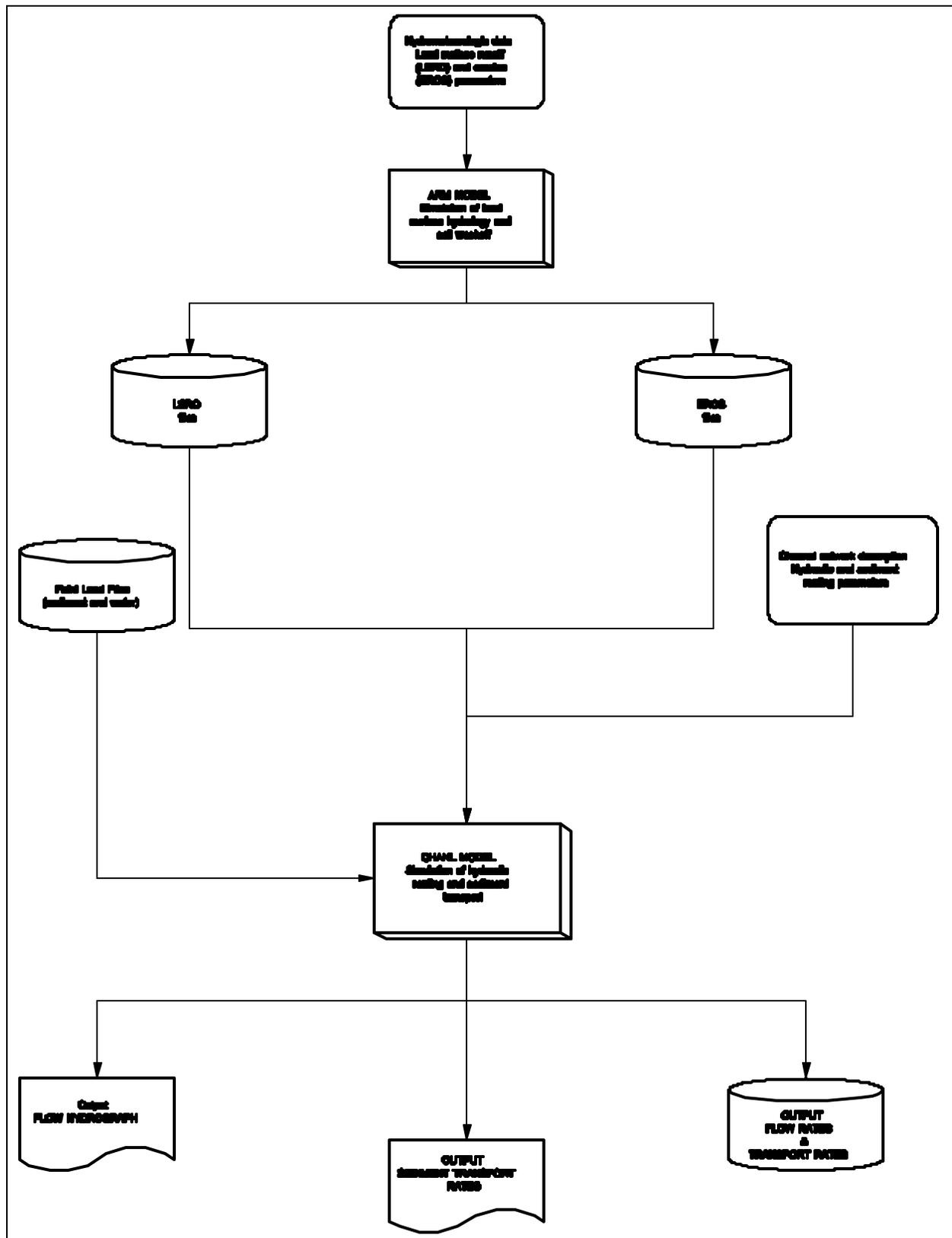
Figure 2-6: WEST Model Organization

Model and Components

The fundamental principle underlying the WEST Model is that simulation of the processes in a watershed can be performed in two distinct phases: a land phase and a channel phase shown in Figure 2-6 [13]. Figure 2-6 shows the flow of information involved in the land paths of the WEST simulation [13]. Inputs of hydrometeorologic data are transformed by the ARM model to time series outputs of land surface runoff (LSRO) and land surface erosion (EROS). LSRO is the depth of runoff, both surface and subsurface, flowing into the stream system in each modeling interval for a particular segment. EROS is the mass sediment washoff per unit area reaching the stream system in each modeling interval. Both LSRO and EROS, representing the response from a unit, are written to disk in specially formatted data files for use as input to the CHANL model. For sake of clarity, the previous figure only shows one LSRO and one EROS file. In practice, for a watershed divided into a number of segments, one LSRO file and one EROS file would be produced for each segment [19].

The ARM portion of the WEST model simulates the processes of surface and subsurface hydrology, sediment production and removal from the land surface, absorption / desorption and degradation processes for pesticides, and then outputs both runoff and sediment contributions to the stream channels which are used as input to the channel phase simulation . The CHANL portion of the WEST model operates on the inputs to give flow discharge and sediment transport rates at the required points in the system. The outflow from each segment or reach is computed every time interval and becomes the inflow to the channel immediately downstream [13]. This portion of the model is very complex and uses algorithms which have the principle variables of flow discharge, depth of flow, cross-sectional area, energy slope, sediment transport concentrations, and channel be composition [19]. Hydraulic routing is performed by using a kinematic wave approximation of water flows. Sediment routing is performed by explicitly modeling the component processes such as

42

scour, deposition, and armoring. This is done to keep the range of application of the model as wide as possible and to facilitate its extension to cover other processes dependent on sediment movement, such as those affecting nutrients and pesticides [13].

Conclusion

The WEST model was developed to simulate the movement of water and sediment through the land channel phases of the hydrologic cycle. The WEST model is a very complex series of simulations and is classified as a Level 4 model with regard to mathematical complexity. In terms of both precision and accuracy, its estimates for erosion and sediment yield are promising, and in fact the CHANL gave favorable results when tested on laboratory data from the Georgia Institute of Technology and file data collected by the U.S. Geological Survey on the East Fork River, Wyoming [13]. The strengths of the ARM portion of the model are that it considers the erosion-sediment yield subprocesses and uses hydrologic inputs for both rainfall and runoff to get interaction effects. However, it has certain limitations in that it lumps parameter values over the watershed, requires historical data to calibrate, and there may not be transferable to ungaged areas and to land uses significant different those used during the mode calibration [10]. Of importance to this study, this continuous model cannot be implemented with a GIS.

Storm Water Models

Background Information

       Storm Water Models known as SWM's are significant in the current research in that they describe both stormwater quantity and quality. Currently, the most commonly used or reference SWM models are Stormwater Management Model (SWMM) [12, 17, 26, 39], Storage, Treatment, Overflow, Runoff Model (STORM) [23, 31], and Hydrologic Simulation Program, Fortran (HSPF) [9, 38]. Often times these models provide mechanisms for estimating erosion or stormwater runoff.

       "SWM models can be categorized into the following:
1. Models for predicting stormwater runoff pollution loadings.

       2. Models for describing the transformation and transport of stormwater generated pollutants.

       3. Models for describing pollutant-removal mechanisms.

       4. Models for SWM strategies, for example, models for strategically locating detention ponds." [39]

Model and Components

These models typically have three major components consisting of:
      1. Overland flow component: quantity and quality, including pollutant accumulation   and washoff and transport over land surface.

      2. Drainage system component: quantity and quality, including channel or pipe flow transport, storage routing (such as detention ponds), etc.

      3. Receiving water component: quantity and quality, including fate and transport of pollutants and receiving water response (most SWM models do not include this component).

Figure 2-7 shows how these three modules are combined to provide a prediction of stormwater quality and quantity [39].
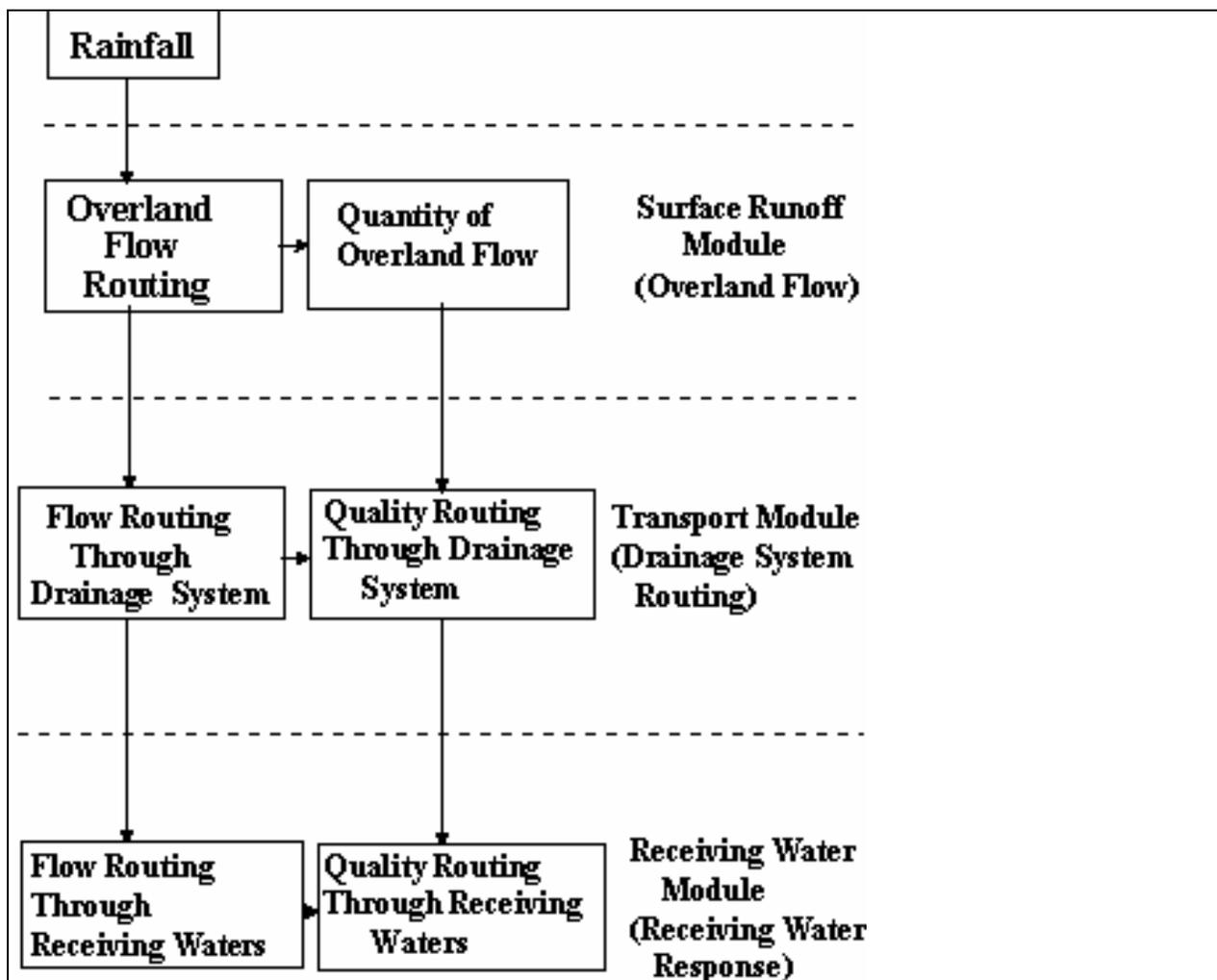
Figure 2-7: Operations of Stormwater Models

Stormwater Models

Table 2-7, taken from the Virginia Department of Transportation Manual sums up the basic

capabilities of the SWM models in the current literature [39].

Table 2-7: *A Comparison of Stormwater Models*

Capability	HSPF	STORM	SWMM
Event (E) or (C) continuous (Event refers to a single rainfall event, while continuos refers to predictions based on a period of time such as a year or month.)	E,C	C	E,C
Infiltration loss techniques	Stanford Watershed model, infiltration as function of soil moisture and permeability	Runoff coefficient	(1) Horton model (2) Modified Green-Ampt model
Runoff modeling techniques	Manning's equation and storage routing	Modified rational formula	Storage routine using Manning's equation and continuity equation
Sewer routing	Yes	No	Yes
Non-point source pollutant accumulation and washoff modeling techniques	Sediment detachment transport; pollutant is related to sediment.	Based on pollutant accumulation and washoff	Based on pollutant accumulation and washoff
Number of pollutants	10	6	10

Storage/treatment Analysis	Yes	Yes	Yes
Executable on a microcomputer	Yes	Yes	Yes
Program output can be graphically presented	Line printer	Line printer	Line printer
Level of documentation	High	Moderate	High
Ease of Program implementation	Difficult	Easy	Difficult
Data Requirement	Very High	Moderate	High
Source	Environmental Protection Agency	Corps of Engineers	Environmental Protection Agency

Conclusions

The SWM's presented in this review are more oriented to an urban environment and are particularly useful in estimating stormwater planning and are not necessarily useful for estimating erosion prediction. While they can be used to estimate sediment yield, the use of other models seems more appropriate considering the time and money that would be involved in using these models with GRASS or any GIS. Another complicating factor is that SWM's often require a continuous type simulation while GRASS is oriented towards predicting erosion at a point in time. In addition, these models often require a substantial amount of data taken at short time intervals and under various "environmental" conditions, to enable one to differentiate the previously mentioned factors and obtain definitive estimates of stormwater runoff pollution loads [39].

Chapter 3

Primary Goal & Model Selection

Primary Goal

The primary goal of the current research is to design a software system for predicting erosion potential at construction sites. This system will incorporate the GRASS GIS and the data bases for GRASS that have been built and maintained by CAST. The results of the evaluation for various erosion prediction models reported in Chapter 2 and the availability of data for GRASS has resulted in the use of this GIS for this project. The software system will allow the user to simulate the application of preventative erosion practices as well as construction methods such as clearing and grubbing. For example, the designer of a proposed construction site could use this system to simulate the application of various mulches or other erosion reducing products to land that is to be altered and then calculate the effect on the potential soil erosion as compared to no use of such products. The software system will focus on allowing the user to be able to do the following:

1.   Calculate and display the erosion potential for a   geographic   region based on an erosion prediction model.

2.   Zoom in on a region for closer examination.
3.   Define an area proposed for construction where   modification will take place.

4.   Display and report the predicted amount of erosion that   will   result from disturbing the land, given certain   construction methods.

5.   Simulate the application of mulches to an area to reduce   erosion   and then recalculate the amount of erosion that   will occur.

6.   Simulate future erosion prevention techniques in the   software system.

Model Selection

To accomplish the primary goal a soil erosion model was chosen that could be implemented using a GIS. The Universal Soil Loss Equation (USLE) was selected on the basis of criteria including its prevailing widespread use, its compatibility with GRASS, and the availability of data for the GRASS system. The USLE provides an efficient means of analyzing potential soil erosion as well as a mechanism for simulating different types of mulching factors to modify erosion taking place at construction sites.

The USLE can be used to accomplish this because values for all of its parameters for erosion can either be obtained directly from primary data layers in existing data bases or can be derived from the primary data layers into secondary data layers that can then be used to predict erosion potential. For example, the USLE requires the use of slope and slope length for a given area to determine a LS factor that is used in the basic equation for predicting erosion. Slope and slope length can be derived from the primary data layer of elevation and would be considered secondary data layers since they derive from a primary data layer. The derivations of secondary data layers are efficient since they do not require the collection of new data for an area. The other models examined would require field collection of data for pertinent parameter values. Because of the factors cited above, the USLE was determined to be the most appropriate choice and will be used throughout the remainder of this research to predict potential soil erosion.

Chapter 4

System Design & Software Overview

System Design

The software system is designed to run on a SUN work station under the X Windows System which is a network-based graphics window system. The software developed to predict erosion took into account construction practices and erosion prevention measures. The software system is divided into four main modules that work together to provide an estimate of erosion potential for a variety of construction situations. These four modules are: setup, definition of a construction area, simulation of clearing and grubbing, and the simulation of the application of mulches. Figure 4-1 shows how the four main modules work in the software system and the functions that take place under each module. The system uses the existing GRASS data bases as a source of the primary data layers. Secondary data layers are derived from the primary data layers, such as slope length from elevation. The setup module then uses both the primary and secondary data layers to conduct an initial erosion estimate. The other modules use the information from the setup module to allow the user to simulate altering the land to design considerations and obtain an erosion potential estimate. The software system reports the erosion potential estimate and a visual representation of the erosion that would occur from altering the geographic region.

```
┌─────────────────────┐                    ┌─────────────────────────┐
│    GRASS SESSION    │                    │ -ABILITY TO ZOOM IN ON AREA │
│        WITH         │───────────────────▶│ -DEFINE AN AREA            │
│  GRAPHICS MONITOR   │                    │  OF CONSTRUCTION           │
│      RUNNING        │                    │ -CURRENT EROSION IS        │
└─────────────────────┘                    │  DISPALYED                 │
          │                                └─────────────────────────┘
          ▼
┌──────────────────────────────┐
│          EROSION1            │
│ DEFINITION OF CONSTRUCTION   │
│            AREA              │
└──────────────────────────────┘
```
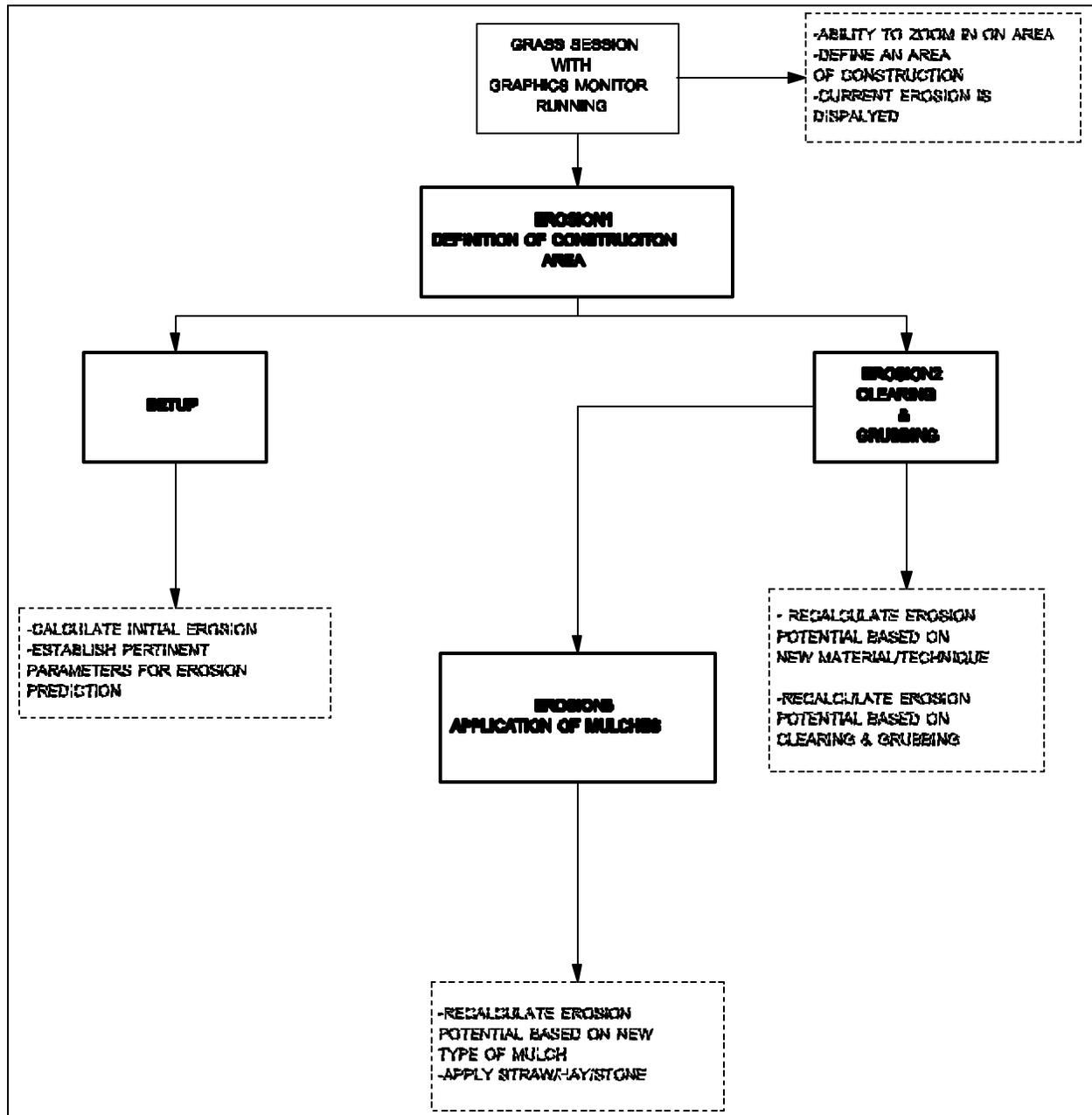
Figure 4-1: The System Design

Setup

The setup portion of the software system is called **setup_erosion**. The purpose of this part of the program is to establish the file names of the required primary data layers. Once the names are known, then the software calculates an erosion estimate for the geographic region under consideration. The setup module prompts the user for the names of primary data layers because the system has to know what the user has defined for these data layers. For example, the user may have digitized a map of elevation values required as one of the primary data layers, and this data layer may have been named "**elevation.values**" as the file name. When the setup module prompts the user for the name of the elevation data layer, the user would enter "**elevation.values**". From that point on the software system would know what the elevation data layer is named so the values from this file may be used in calculating erosion potential. This process is repeated in the setup module for required data layers used by the system. Once the user provides the names of the required primary data layers, the system derives the necessary secondary data layers and then calculates a data layer containing estimates for erosion potential based upon the geographic region defined by the user. Once this has been done for the geographic region of interest, this process need not be done again. However, if a new region is to be assessed for erosion potential, then the setup process must be rerun for the new area. After the **setup_erosion** portion of the software is done, the user would normally go to the portion of the program for defining of a construction area.

Defining of a construction area

This portion of the software system is the main area from which the user accesses the erosion prediction ability of the system. This module of the software is called **erosion1**. The user can view the current erosion map on the monitor screen, zoom in on an area for a closer look, and also define an area (s) for construction. The main purpose of this portion of the software is to define

the area on which modifications will be required by the construction design. The user uses a pointing device such as a mouse to establish the boundaries of a proposed construction area. Once the construction area is established the software allows the user to simulate the application of measures such as clearing and grubbing, mulches, and other erosion prevention techniques. The software also reports the amount of erosion potential on a before and after basis with regard to erosion potential of the defined construction area.

Clearing and Grubbing

The name of the program that simulates clearing and grubbing is called **erosion2**. This portion of the software consists of two major parts. First, once the construction area is established by the user, the user has the option of simulating clearing and grubbing of the area. After this option is selected, a report is generated which gives the predicted amount of erosion potential before clearing and grubbing, and after clearing and grubbing. The second function of **erosion2** allows the user to define a new technique or new material for preventing erosion. For example, suppose that a new type of geotextile blanket is developed that is considerably more effective at reducing erosion than the application of mulches which are currently provided for in the software. The user can enter this new material along with the C factor associated with this particular type of erosion prevention measure. This allows for future improvements to erosion prevention to be used with the software. Once the new type of erosion prevention measure is given, a before and after analysis of the erosion potential will be completed and reported back to the user.

Application of Mulches

The final portion of the software deals with applying various types of mulches [40] to the defined construction area and is called **erosion3**. **Erosion3** uses simulates the application of mulches to an area that is already supposed to be cleared and grubbed. Once a mulch such as straw or gravel is supposed to be applied, the software considers such things as slope and type of mulch to

determine a new estimate of erosion potential based upon the application of this mulch. Once the application of the mulch is simulated, a before and after analysis allows the user to compare the amount of erosion potential reduction that would be afforded by the proposed mulch.

Menu Structure

The menu structure is provided in Figure 4-2 to show how the menus interconnected to allow the user to efficiently use the software system. The menu commands are displayed on the graphics monitor running under the GRASS platform. The user selects these menu commands by clicking with the left button of the mouse. Once the user selects a menu option this either executes a series of instructions or accesses another menu.

Software Overview

The focus of the software system is to allow the simulation of a change of the cover and management factors (C factors) as a parameter in the USLE. The GRASS command *r.digit* is an interactive tool used to draw and save vector and raster features on a graphics monitor using a pointing device such as a mouse. The software system allows the user to select geographically
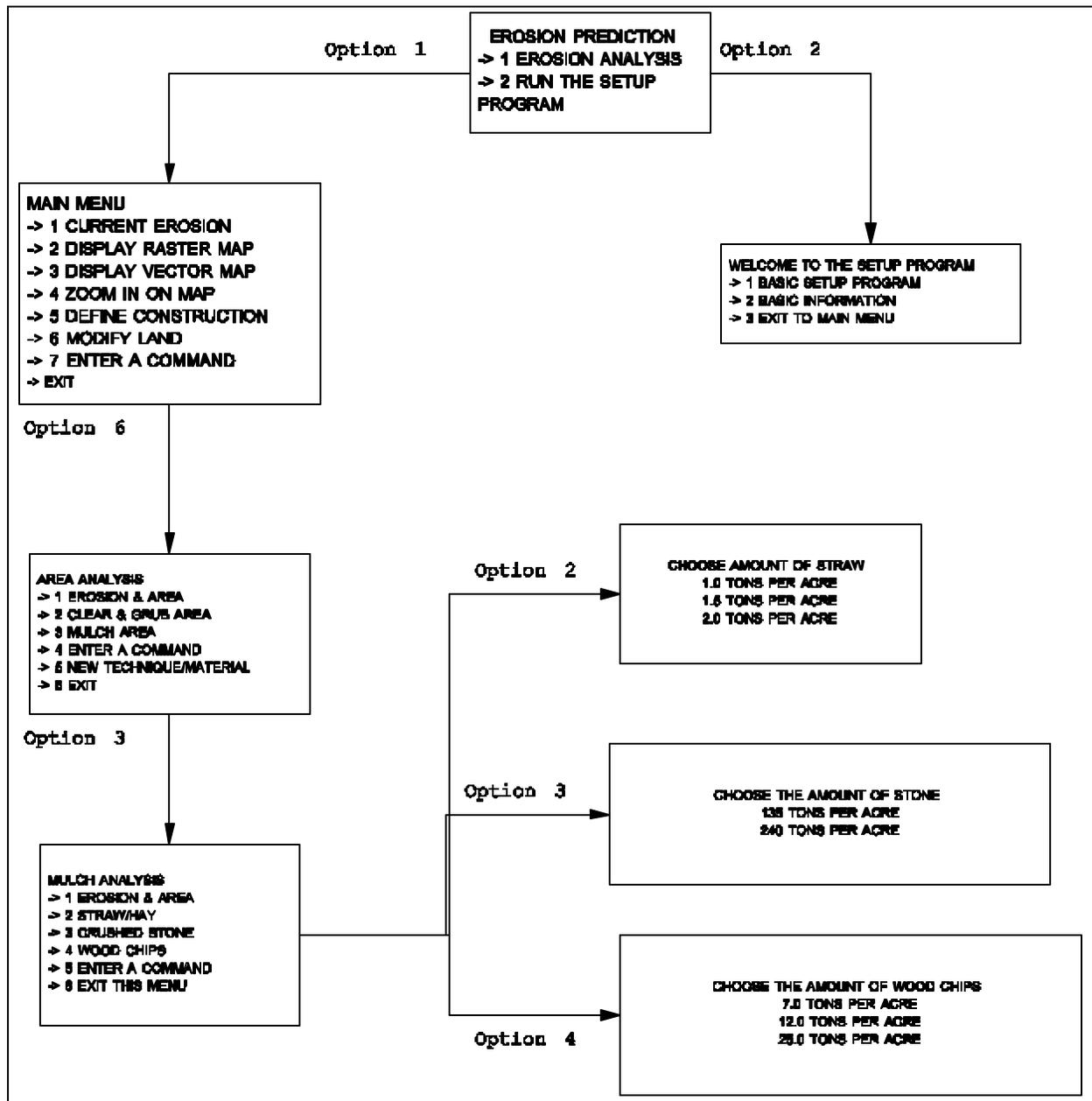
Figure 4-2: Menu Structure

specific areas with a computer mouse. Following the selection of an area, such construction techniques as clearing and grubbing or application of mulches, are simulated to predict the before and after erosion potential. Once a construction area is selected, new C factors are pertinent to that area for simulating different practices. The program recalculates erosion potential taking into account the proposed modifications to the land. Using the C factor data layer, an example is shown below in Figure 4-3 of the basic principles on which the software works. In this example, a sample area will be supposed to be cleared of all vegetation and root structure (i.e. cleared and grubbed). The area shaded in gray represents an area selected by the user via a pointing device such as a mouse and the raster values for this area are given. Once this area has been defined the user is asked what modifications are to be simulated in the selected area (gray). In this example the land is proposed to be cleared and grubbed. The original C factors are modified to reflect the clearing and grubbing by changing these factors to higher C factors. After the new C factors are changed to reflect modifications to the land, new values for the potential erosion are calculated for the areas in gray.
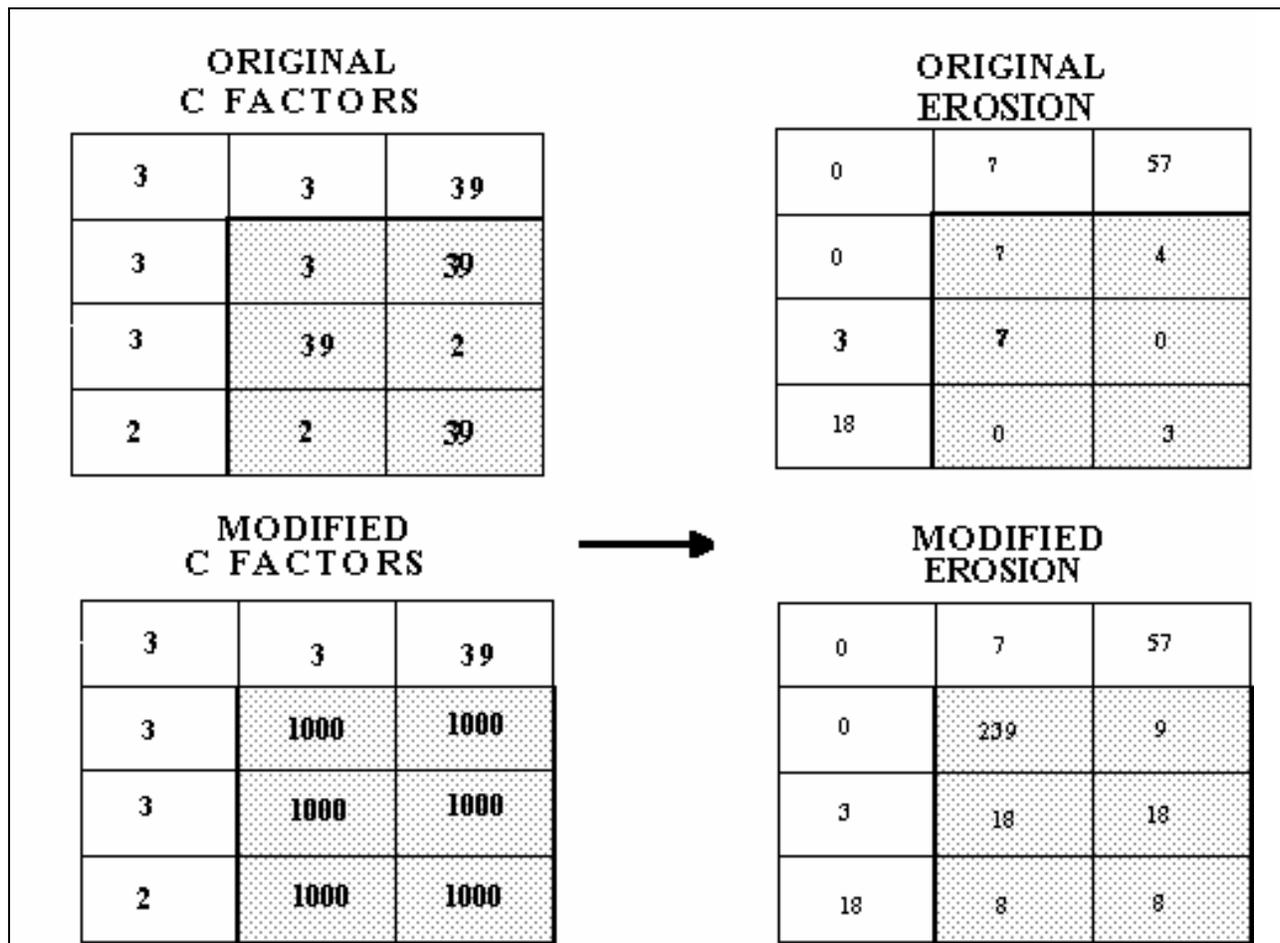
Figure 4-3: Example modification of C factors

Conclusions

The major portions of the software, **setup_erosion**, **erosion1**, **erosion2**, and **erosion3**, work together to provide the user with an estimate of erosion potential for a variety of construction practices. The system allows the user to obtain a prediction for erosion potential based on a before and after scenario, which allows the user to determine the most effective erosion prevention program for a specific area. Also, the software system allows for the computation of the relative differences between different types of erosion prevention techniques.

Chapter 5

USLE Factors and Software Development

Introduction

Development of software using the USLE as a model to predict soil erosion potential began with examining the primary data layers and factors required by the USLE to calculate erosion potential. These data layers are usually input by hand or from such devices as map digitizers or from digitized satellite imagery. Secondary data layers are those that are derived from the primary data layers. For example, the data layer for elevation values for a given area can be used to determine the slope data layer for the same area. The elevation data layer is considered a primary data layer. The derived data layer of slope is considered to be a secondary data layer since it is calculated from the primary data layer of elevation. For this research the primary data layers are, elevation (in meters), soil classification, cover and management (C factor), and a data layer that identifies current existing water areas such as lakes and streams.

Each factor for the USLE (R, K, LS, C, P) is represented in a data layer that is accessed by GRASS to predict the potential erosion at a given location. The data for the USLE factors is manipulated by different raster operations accomplished be GRASS commands, such as the command *r.mapcalc*. This GRASS command is used for manipulating and performing operations on maps represented as raster based data layers. New raster map layers can be created which are arithmetic expressions involving existing raster map layers, integer or floating point constants, and functions [25].

The maps that GRASS uses for calculations and for displaying images on the screen are data base files stored in raster format, ie., two-dimensional matrices of integer values. With *r.mapcalc,* cell position in a map may be followed by a neighborhood modifier that specifies a relative offset from the current cell being evaluated. The format is **map_name [row, column]**. As an example,

map [1,1] refers to the cell one row below and one column to the right of the current cell. Figure 5-1 shows a representation of how *r.mapcalc* identifies a particular cell in a data layer name **map**.

MAP [-1,-1]	MAP [-1,0]	MAP [-1,1]
MAP [0,-1]	CURRENT **CELL** MAP [0,0]	MAP [0,1]
MAP [1,-1]	MAP [1,0]	MAP [1,1]

Figure 5-1: Neighborhood identifiers used by *r.mapcalc*

Neighborhood identifiers are used in the developed software system to calculate the slope length needed for the USLE. In addition, the area that is used to demonstrate the developed system is Huntsville quadrangle which is in northwest Arkansas.

60

Rainfall and Runoff Factor (R)

The rainfall and runoff factor is used to approximate the amount and intensity of rainfall for a given area over a period of a single year. The rainfall and runoff factor is the number of rainfall erosion index units, plus a   factor for runoff from snowmelt or applied water where such runoff is significant [34]. For northwest Arkansas, this factor is 275 [35] for the Huntsville area (for a more detailed map of R factors see Appendix C for a map of the entire United States). The factor R was input into the potential erosion calculations by using the *r.mapcalc* statement in GRASS.   In calculating the potential erosion the following GRASS command was used in Equation [1]:

r.mapcalc erosion = 'round((275*(kfactor * 0.01)*(lsfactor *   0.01)*

Equation [1]

This command uses 275 as a constant for this area so it was not necessary to create data layer for the R factor.

Soil Erodibility Factor (K)

The soil erodibility factor is 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-ft length under identical conditions [34]. This factor is specific to the type of soil under consideration for a given area and is between 0 and 1. The soil erodibility factor is a primary data layer and is found in the soil survey document of the area. Since GRASS can only store integer numbers in the data layers, these factors were multiplied by a factor of 100 for relative accuracy. The values used for K in this analysis were taken from Table 2-1 which can be found in the Soil Survey For Madison County in the state of Arkansas [28]. As an example, in the soil survey for Huntsville, AR, the K factor for the soil called Allen is 0.28, this value is stored as the integer 28 representing the soil Allen. A portion of the actual data layer is illustrated in Table 5-1.

28	28	17
28	28	17
32	32	32
15	15	15

Table 5-1: Example of K factors in GRASS

Cover and Management Factor (C)

Cover and management factors come from land use and land cover from such things as vegetative canopies and trees. The C factor in the soil loss equation is the ratio of soil loss from land cropped under specified conditions to the corresponding soil loss from clean-tilled, continuous fallow land [34]. The factor measures the combined effect of all the interrelated cover and management variables. The C factor is a required primary data layer and the value is between 0 and 1. These values can be found in Table 2-3 and Table 2-4 for the different types of cover and mulches that can be applied. The values for the C factor can be quite small and as a result a factor of 1000 was applied to the various C factors for relative accuracy. A sample of data for the C factor data layer is shown in Table 5-2 with the applied factor of 1000 illustrated. As an example, the C factor for a residential area is 0.003 and this number multiplied by 1000 would be stored in a GRASS data layer as the integer 3.

3	3	39

3	3	39
3	39	2
39	2	2

Table 5-2: Example of C factors in GRASS

Support Practice Factor (P)

The support practice factor, P, is used primarily in croplands. Such practices for croplands are contour tillage, stripcropping on the contour, and terrace systems. As stated in Chapter 2, the value for P is equal to 1.0 for construction sites [34, 36]. Since the value of the P factor is 1 and the data layers are multiplied with each other, it is not necessary to create a specific data layer.

Slope-Length Factor (LS)

The topographic factor (LS) comes from the steepness and length of the land from which the entire slope length drains into a particular spot [34]. These two factors have a substantial effect on the rate of soil erosion by water. They are combined into a single factor by the USLE model. The equation used to evaluate LS (e is a correction factor) is:

$$\mathbf{LS = (l\,/\,72.6)^{e}\,(\ 65.41 sin^{2}\,q + 4.56 sin\ q + .065\ )}$$

Equation [2]

where: l = slope length in feet

q = slope in degrees from horizontal

e = 0.5 if percent slope is greater than 5

e = 0.4 on slopes of 3.5 to 4.5

e = 0.3 on slopes of 1 to 3 percent

e = 0.3 on slope of less than 1 percent

Slope length is the distance from where runoff begins to where deposition begins at a decrease in slope or where runoff enters a well defined channel [14]. The slope is calculated using the GRASS command *r.slope.aspect* which used the elevation primary data layer to determine slope in degrees (q), as well as percent, from the horizontal. Aspect for the area is calculated which shows the cardinal direction the slope faces. The aspect data layer is generated by the GRASS command *r.slope.aspect*. The data layer in the software system representing aspect is a reclassification of the original aspect data layer generated by GRASS. Each of the 8 categories represents a 45 degree arc with category 1 facing north and category 5 facing south. Slope length, l, is generated on a cell by cell basis by evaluating all eight surrounding cells. A series of scripts written by Martin McKimmey [14] is used to describe conditions that identify part of a multi-cell slope length using the USDA slope length definition. Conditions for each cell are shown schematically in the Figure 5-2. The conditions in Figure 5-2 show that as long as the neighboring cells are greater in elevation, less than or equal to the slope (degrees), they drain into the current cell, and if they are not water, then they are part of a multi-cell slope length. One portion of a script that does this is given in the following example (the remaining scripts are in Appendix A).

count2 = **if ((** **elevation <= elevation [-1,-1] &&**
        slope >= slope [-1,-1] &&
        aspect [-1,-1] == 4 &&
        water == 0), 2 , 0)
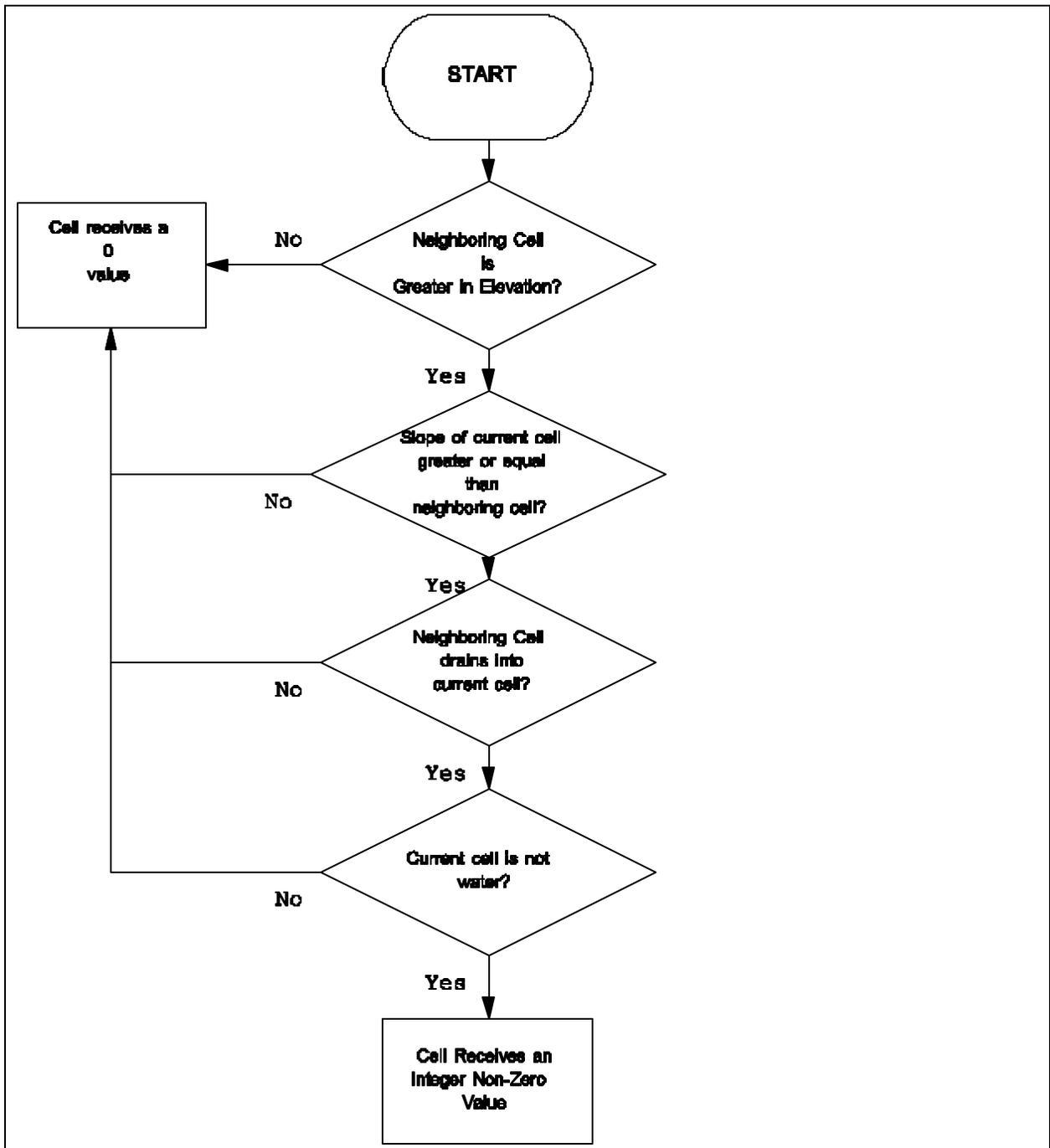
Figure 5-2: Criteria for multi-cell slope length

The script called **count2** is only part of the actual equation used (see Appendix A). This script addresses the upper left neighboring cell only, which is indicated by the [-1,-1] map location identifier. GRASS addresses the actual values for each current cell in the following manner: "The actual script would duplicate the first three lines seven times with only the addresses of the neighboring cells changing. The script reads: Create a map called count2 with the following conditions; if the elevation at the current cell location is less than or equal to the upper left cell, and the slope at the current cell location is greater than or equal to the upper left cell, and upper left cell drains (aspect map value of 4) into the current cell, and the current cell is not water, then assign a value of 2 to the current cell, else return a value of 0. If one of these criteria was not met, the cell received a zero value indicating that the cell was either water or was not part of a multi-cell slope length [16]." The result of the script called **count2** is a new data layer called **count2** (not to be confused with the script called **count2**). The data layer **count2** showed areas where slope length is two cells or more. All slopes despite actual length are assigned a value of 2 representing slope length. Since the resolution of the map is 30 meters per cell, this would mean that the slope length is 2 X 30 meters or 60 meters. Actual slope lengths are calculated with a series of 20 scripts (**count2**-**count21**). Each software script has the potential of extending the slope lengths by one cell to a maximum of 20 cells (>= 2000 ft. at a resolution of 30 meters). The result is a data layer called **count21** that has the total number of cells that are part of the a slope length for each individual cell. Once the total number of cells that are part of a slope length are calculated, the cell values are converted into a data layer that takes into account whether bodies of water such as streams and lakes are present. If water is present the cell is considered to have a slope length of zero, indicating no erosion for that cell. After the water checking script is completed, the cell values are converted into feet and a correction factor called e is applied to the data layer on the basis of percent slope. Finally, LS factors are calculated using the Equation [2].

This results in a data layer called LS factor, which is multiplied by a factor of 100 for relative accuracy in storing numbers in GRASS. A sample data for LS factors (Table 5-3) is shown with the applied factor of 100 for LS factors in the Huntsville, AR, area.

14	3,100	3,100
14	3,100	200
1,125	200	200
1,125	200	200

Table 5-3: Example of LS factors in GRASS

To summarize the calculation of the LS factors, the following list (Table 5-4) in sequential order shows how these scripts are used, what data layers are created, and the purpose or meaning of each data layer.

Script Name and Sequential Order	Data Layer Generated by GRASS	Purpose and Meaning of Data Layer
1. count2	count2	Calculates if slope length 1 cells or more
2. count3	count3	Calculates if slope length 2 cells or more
3. count4	count4	Calculates if slope length 3 cells or more

4. count5	count5	Calculates if slope length 4 cells or more
5. count6	count6	Calculates if slope length 5 cells or more
6. count7	count7	Calculates if slope length 6 cells or more
7. count8	count8	Calculates if slope length 7 cells or more
8. count9	count9	Calculates if slope length 8 cells or more
9. count10	count10	Calculates if slope length 9 cells or more
10. count11	count11	Calculates if slope length 10 cells or more
11. count12	count12	Calculates if slope length 11 cells or more
12. count13	count13	Calculates if slope length 12 cells or more
13. count14	count14	Calculates if slope length 13 cells or more
14. count15	count15	Calculates if slope length 14 cells or more
15. count16	count16	Calculates if slope length 15 cells or more
16. count17	count17	Calculates if slope length 16 cells or more
17. count18	count18	Calculates if slope length 17 cells or more
18. count19	count19	Calculates if slope length 18 cells or more
19. count20	count20	Calculates if slope length 19 cells or more

20. count21	count21	Calculates if slope length 20 cells or more
21. slope.length.c	s.l.c	Checks to see if water present (lakes, etc.)
22. cell2ft	s.l.ft	Converts slope lengths to feet
23. e	e	Correction factor for slope
24. ls	lsfactor	Calculates the LS factors

Table 5-4: Scripts for calculating LS factors

Calculating Erosion Potential

After all factors in the USLE are in an appropriate form, Equation [1] calculates the erosion potential for each cell in the data layer called erosion. The equation when executed does the following, multiplies each cell in the **kfactor** data layer by 0.01, then multiplies each cell in **lsfactor** by 0.01, then multiplies each cell in **cfactor** by 0.001. Following this it multiplies the data layers of kfactor, lsfactor, cfactor, and the constant 275. The final number is rounded up or down and then an integer value is placed in the current cell for the data layer called **erosion**. This process is repeated for each individual cell in the data layer **erosion** with the result being a specific value of erosion potential for each 30 meter cell in the data layer. Figure 5-3 shows an example erosion potential computation for a single cell in data layer. The cells that are shaded gray show the calculations that are taking place for a current cell.

K FACTORS

28	28	17
28	28	17
32	32	32
15	15	15

-> 15 x 0.01 = 0.15

X

C FACTORS

3	3	39
3	3	39
3	39	2
2	2	39

-> 39 x 0.01 = 0.39

X

LS FACTORS

14	3,100	3,100
14	3,100	200
1,125	200	200
1,125	200	200

-> 200 x 0.001 = 0.20

x 275 **R factor**

=

EROSION (tons/acre/year)

0	7	57
0	7	4
3	7	0
18	0	3

-> 0.15 x 0.39 X 0.20
x 275 = 3.2175
Round (3.2175) = 3
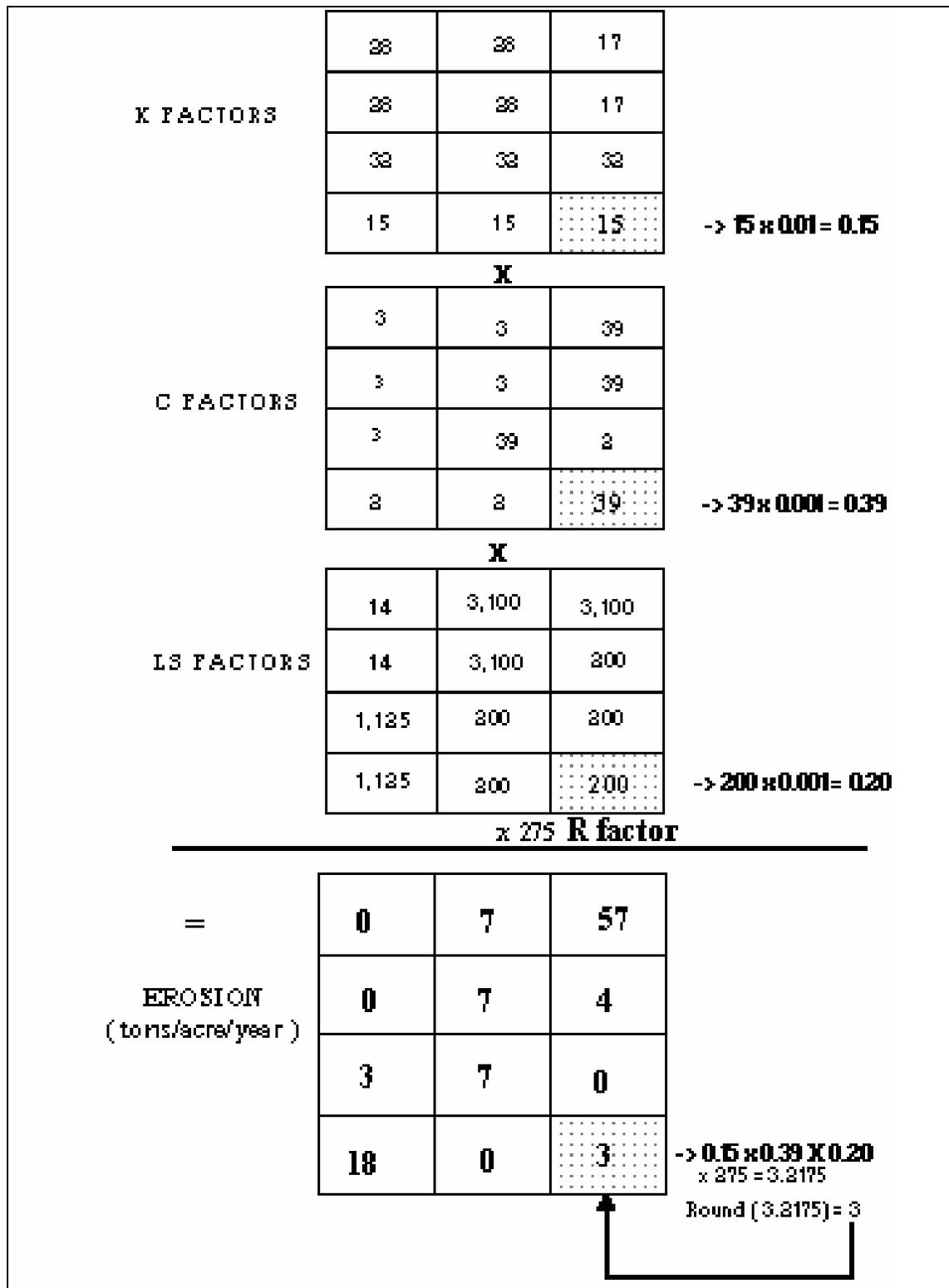
Figure 5-3: Sample calculation of
Erosion Potential

Chapter 6

Instruction Manual

Introduction

The instruction manual provided in this chapter gives the user a knowledge of basic commands and options available in the erosion potential software system. All commands are either input from the keyboard or with a pointing device such as a computer mouse. Commands are in quotation marks and followed by the return key. The software runs under GRASS from a SUN workstation. A recommended setup for displaying both information about maps and the maps themselves requires a graphics monitor (i.e. *d.mon start=x0*) and command tool be running. Once the graphics monitor is initiated, the command to start the software can be given. The user has the option of making the graphics window any size. However, the following arrangement of windows in Figure 6-1 is recommended for optimal displaying of maps and information.
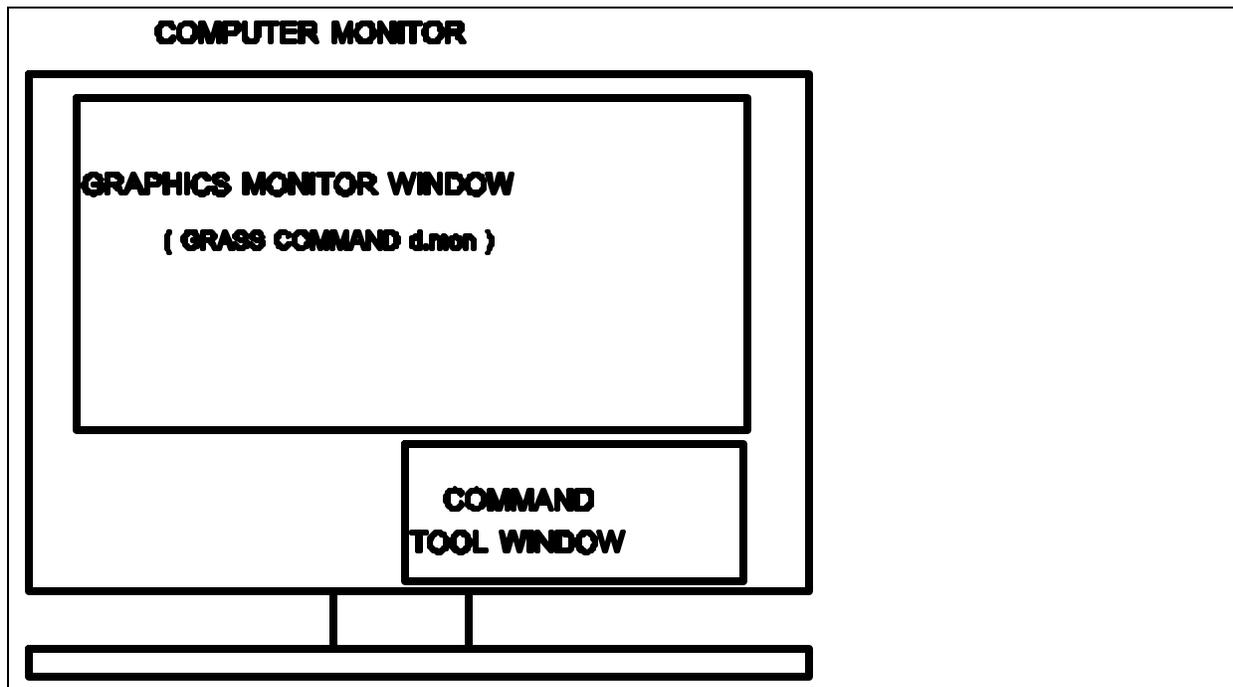
Figure 6-1: Recommended layout of windows

Starting the Software System

The software system is started by typing the command "**erosion1**". At this point the following screen (Figure 6-2) will be displayed on the graphics monitor.

Figure 6-2: Opening screen for the software

The screen is divided into three basic areas. Figure 6-3 illustrates the areas with the corresponding numbers. Area 1 is the location for the display of maps. Area 2 gives the map legend for the map currently displayed in Area 1. Area 3 shows commands or options that the are
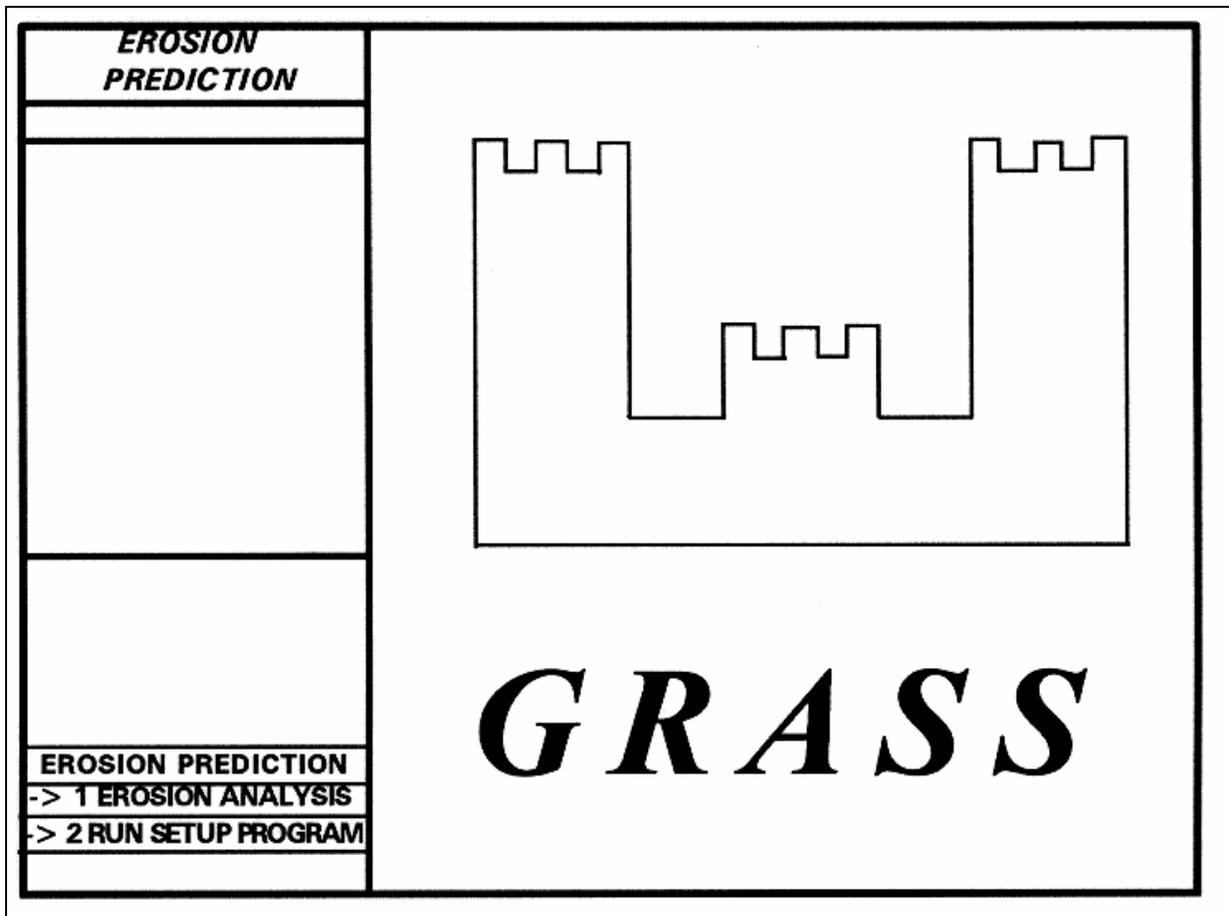
selected with a pointing device. The user need only click with the left mouse button on an option in Area 3 and the selected option will be executed.

Once the opening screen (Figure 6-2) is illustrated on the graphics monitor, the user has two options. The first option is **-> 1 EROSION ANALYSIS**. The user selects this option by using the pointing device to click on option 1. This option starts a session for predicting erosion
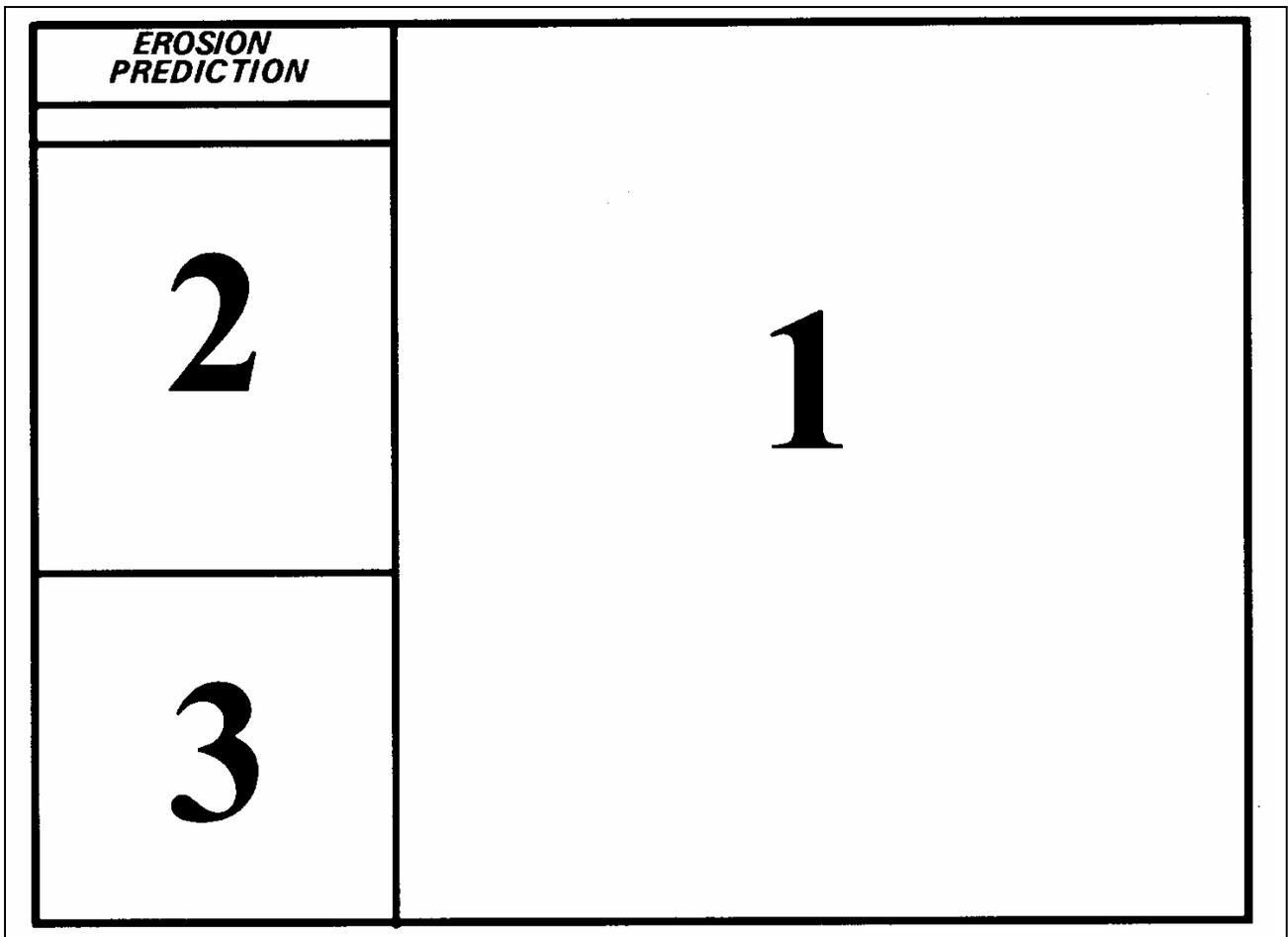
Figure 6-3: Layout of Graphics monitor window

potential. Option 1 should only be selected after the user has completed the setup program once

for a particular region. If the user selects Option 1, a new set of menu options appear on the screen (Figure 6-5). These options allow the user to conduct an erosion potential analysis.

Opening Screen - > 2 RUN SETUP PROGRAM

The first time a new geographic region is identified, the user must choose this option. This portion of the software system establishes the names of the required primary data layers as well as calculates the erosion potential for the identified region. Once the **Setup program** is completed, the user need not choose this option for future sessions regarding the same area of analysis. The only time the user needs to run the setup program again would be if a different geographic region is to be analyzed for erosion potential. For example, the data used in this research was from the Huntsville quadrangle. If data from another quadrangle is desired, the Setup Program would have to be run again for the different. The selection of Option 2 runs the Setup Program and new menu options are displayed (Figure 6-4).

EROSION
PREDICTION

WELCOME TO THE SETUP PROGRAM

-> BEGIN SETUP

-> BASIC INFORMATION & HELP

-> EXIT

GRASS
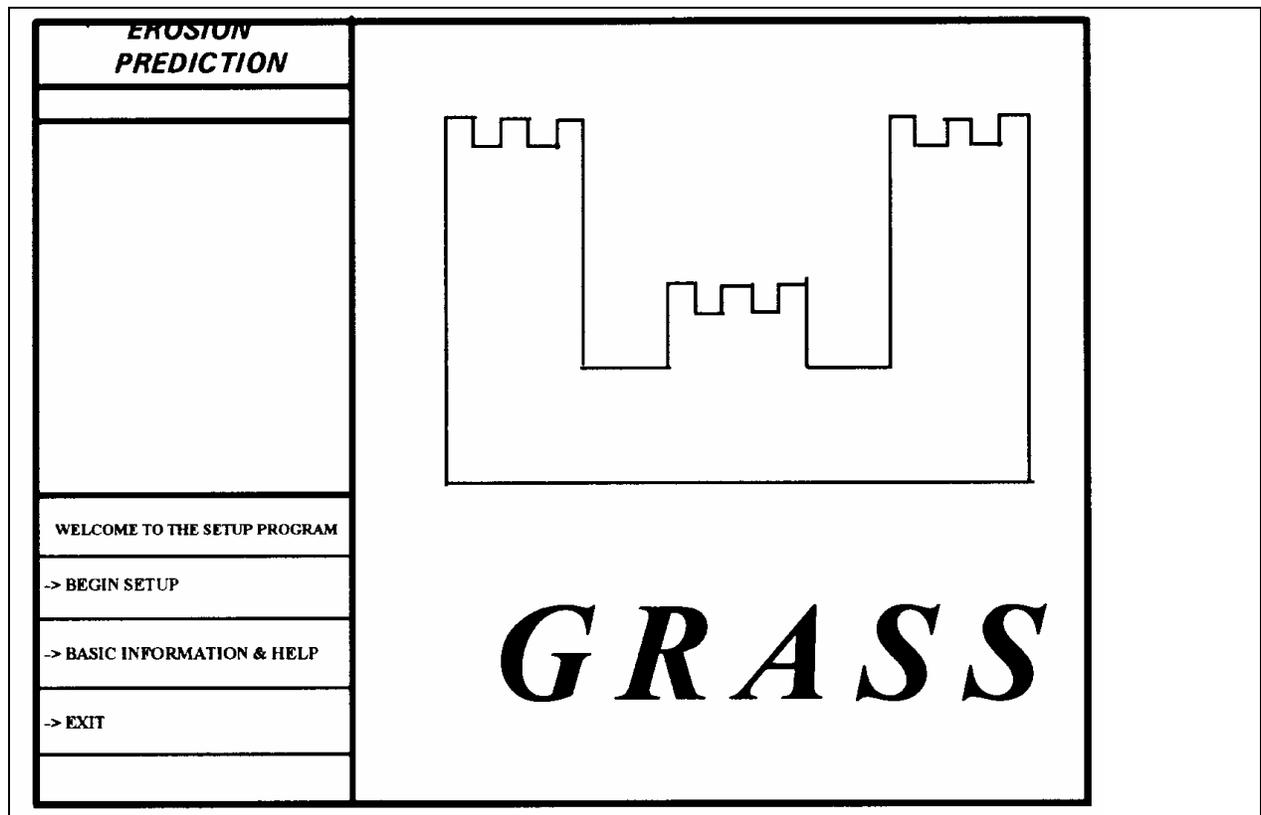
Figure 6-4: Setup Program

Clicking on the **BEGIN SETUP** option starts the process of defining the required primary data layers. Choosing the **BASIC INFORMATION & HELP** option gives the user information concerning the **Setup program**. Lastly, the **EXIT** option ends the setup program and puts the user back to the screen for analyzing erosion (Figure 6-5).

Main Menu Screen

After the user chooses Option 1 **(-> 1 EROSION ANALYSIS)** from the Opening Screen, the Main Menu Screen is displayed. Figure 6-5 illustrates the Main Menu Screen with

the respective commands available to the user via a pointing device. Each of these menu options

EROSION PREDICTION

EROSION ANALYSIS
-> 1 CURRENT EROSION
-> 2 DISPLAY RASTER MAP
-> 3 DISPLAY VECTOR MAP
-> 4 ZOOM IN ON A MAP
-> 5 DEFINE CONSTRUCTION
-> 6 MODIFY LAND
-> 7 ENTER A COMMAND
-> 8 EXIT
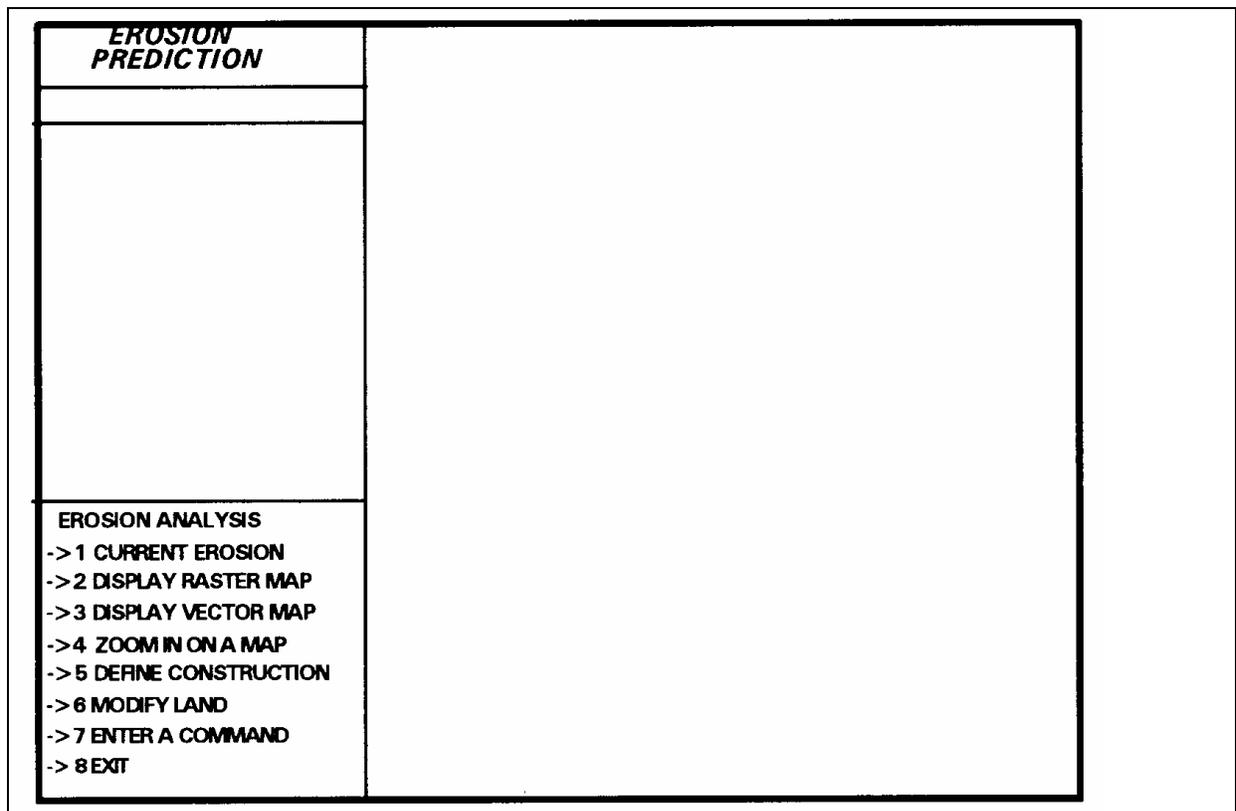
Figure 6-5: Main Menu Screen

will be discussed below.

Option 1 (-> 1 CURRENT EROSION)

Option 1 displays a map which indicates the current erosion potential for the area of interest along with a legend for interpreting the map. Different colors on the map represent differing levels of erosion potential and these levels are identified in the legend. Figure 6-6 illustrates this display. The user may choose this option from any menu screen in the program.

The current erosion option allows the return to a map which illustrates the area of interest with no modifications to essentially restart an analysis of the area.

EROSION PREDICTION

MAP LEGEND

☐ ─────────

☐ ─────────

☐ ─────────

☐ ─────────

☐ ─────────

EROSION ANALYSIS
-> 1 CURRENT EROSION
-> 2 DISPLAY RASTER MAP
-> 3 DISPLAY VECTOR MAP
-> 4 ZOOM IN ON A MAP
-> 5 DEFINE CONSTRUCTION
-> 6 MODIFY LAND
-> 7 ENTER A COMMAND
-> 8 EXIT
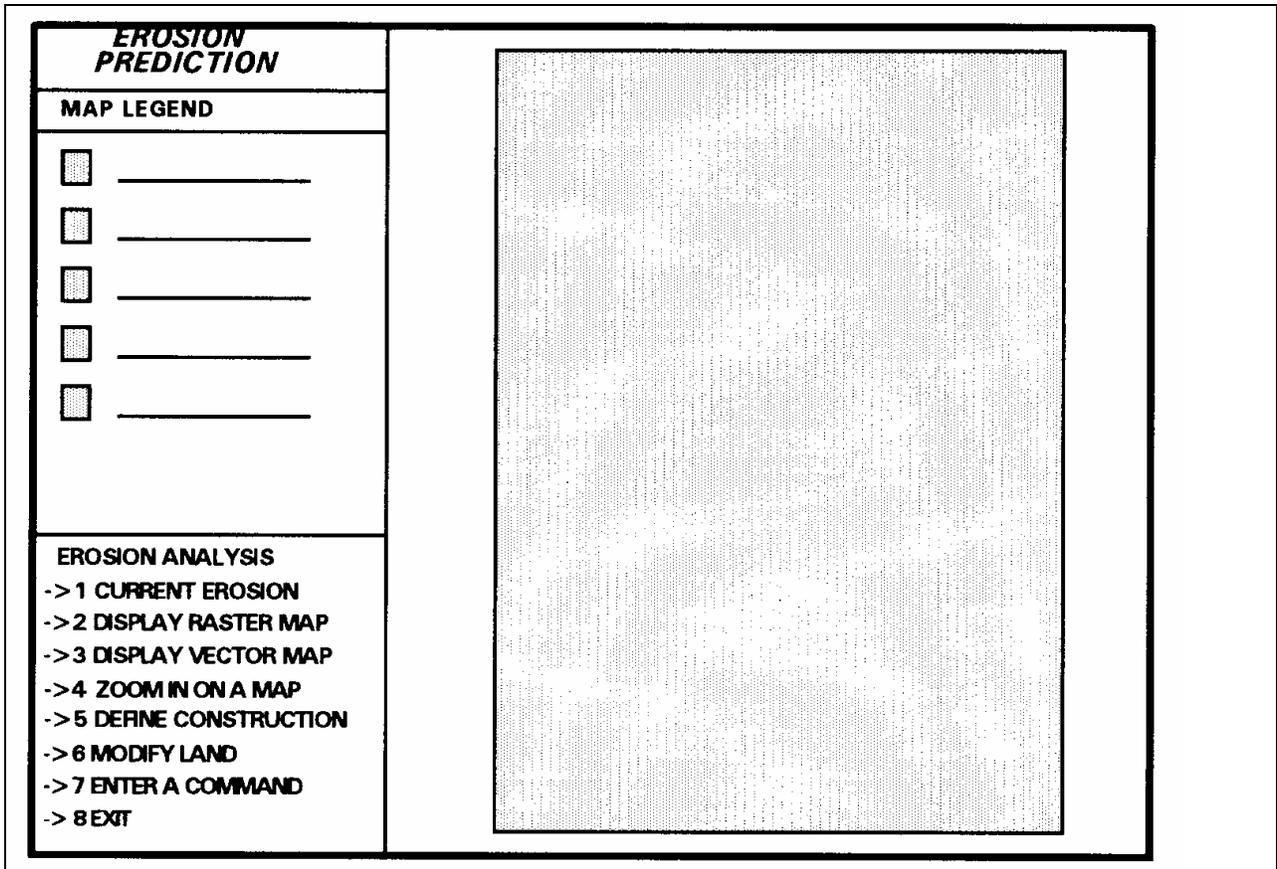
Figure 6-6: Option 1, Current Erosion

Option 2 (-> 2 DISPLAY RASTER MAP)

The selection of Option 2 results in the display of the names of all of the raster maps (i.e. data layers) that are in the user's *mapset*. A file menu shown in Figure 6-8 is displayed on the graphics monitor. Paging up or down is accomplished by clicking on the arrows location on the upper right of lower right corners of the file menu. The user ma either select a data layer to display or

78

return to the previous menu. The latter is accomplished by double clicking on the top portion of

the menu.

Double Click on the Data Layer for _____
Double Click Here to **CANCEL**

MAPSET _____	
Data Layer	Data Layer
Data Layer	Data Layer
Data Layer	Data Layer
Data Layer	Data Layer
Data Layer	Data Layer
Data Layer	Data Layer
Data Layer	Data Layer
Data Layer	Data Layer
Data Layer	Data Layer

Figure 6-7: File Menu

A double click on the desired data layer results in the display of the selected map. After a raster

map is chosen, the user will be prompted to indicate whether the requested map is to be overlaid

on top of any current display or whether the system is to erase any current display before

displaying the requested raster map.

Option 3 (->3 DISPLAY A VECTOR MAP)

79

The result of the choice of Option 3 is similar to that of Option 2; however, with this option vector maps may be displayed. After the selection of Option 3, the user is asked to select the color for the display of the vector map.

Option 4 (-> 4 ZOOM IN ON A MAP)

The option to zoom in on a raster map allows the user to see in closer detail a portion of the region currently on the screen. Zooming will be appropriate for a better examination of a proposed construction area than would be accorded by the display of a larger area. The pointing device is used to locate two corners of a smaller region which included the area proposed for modification. The region so identified is displayed on the screen.

Option 5 (-> 5 DEFINE CONSTRUCTION)

Option 5 permits the user to define a specific area of construction. Locating an area of construction is necessary Options 6 or 7 may be selected. The user locates the proposed construction by using the pointing device to define one or more polygons, circles, or lines. The selection of Option 5 results in the presentation of the following choices displayed in the command tool:

Please choose one of the following

A define an area
C define a circle
L define a line
Q quit (and create map)

>

Entering letter **A** allows the user to define polygon shapes. Entering the letter **C** allows a circle to

located, and entering the letter **L** allows the user to locate a line. Any combination of these

shapes may be used to define a construction area. After the location of the construction area is

completed, a click on the right mouse button presents the following questions in the command

tool:

Enter the category number for this area: 1
Enter a label for category 1 [] new area
1 [new area]
Look ok? (y/n) y

Please choose one of the following
A define an area
C define a circle
L define a line
Q quit (and create map)
> Q

Enter name of map to be created
Enter 'list' for a list of existing raster files
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> *new_area*

<new_area>

Creating raster map new_area

writing raster map ... 100%

Creating support files for raster map <new_area>

Done

The user enters the number **1** for the category value and gives a name to the map being created. The user will again be asked what the name of their map is called. The following message will be displayed in the Command Tool:


```
--------------------------------------------------
|    You now  need to enter the name of the area |
|     you just drew using your mouse.            |
|                -OR-              |          |
|                              |
|    You can enter a previously saved area.      |
--------------------------------------------------
```


Enter the name for your area--> *new_area*

Following the entry of a name for your area of construction the program will display the commands shown in Figure 6-6.

Option 6 (-> 6 MODIFY LAND)

Option 6 displays the menu options in Figure 6-8. Choosing this option allows for clearing and grubbing of the construction area.

Option 7 (-> 7 ENTER A COMMAND)

Selecting Option 7 permits GRASS commands via the command tool to be executed. Option 7 allows added flexibility to modify what is going on in the Graphics Monitor. For

instance, the user might want to temporarily see a three dimensional view of erosion for their region. The user could then use Option 7 to display a three dimensional view.

Option 8 (-> 8 EXIT)

Option 8 quits the current menu and sends the returns control back to the Startup Menu screen (Figure 6-2).

Menu1

Selecting Menu1 options simulated clearing and grubbing of a construction area and application of new erosion prevention techniques and materials. Menu1 is displayed when Option 6 from the Main Menu (Figure 6-5) is selected. The commands for Menu1 are displayed in Figure 6-8.

Option 1 (-> 1 EROSION & AREA)
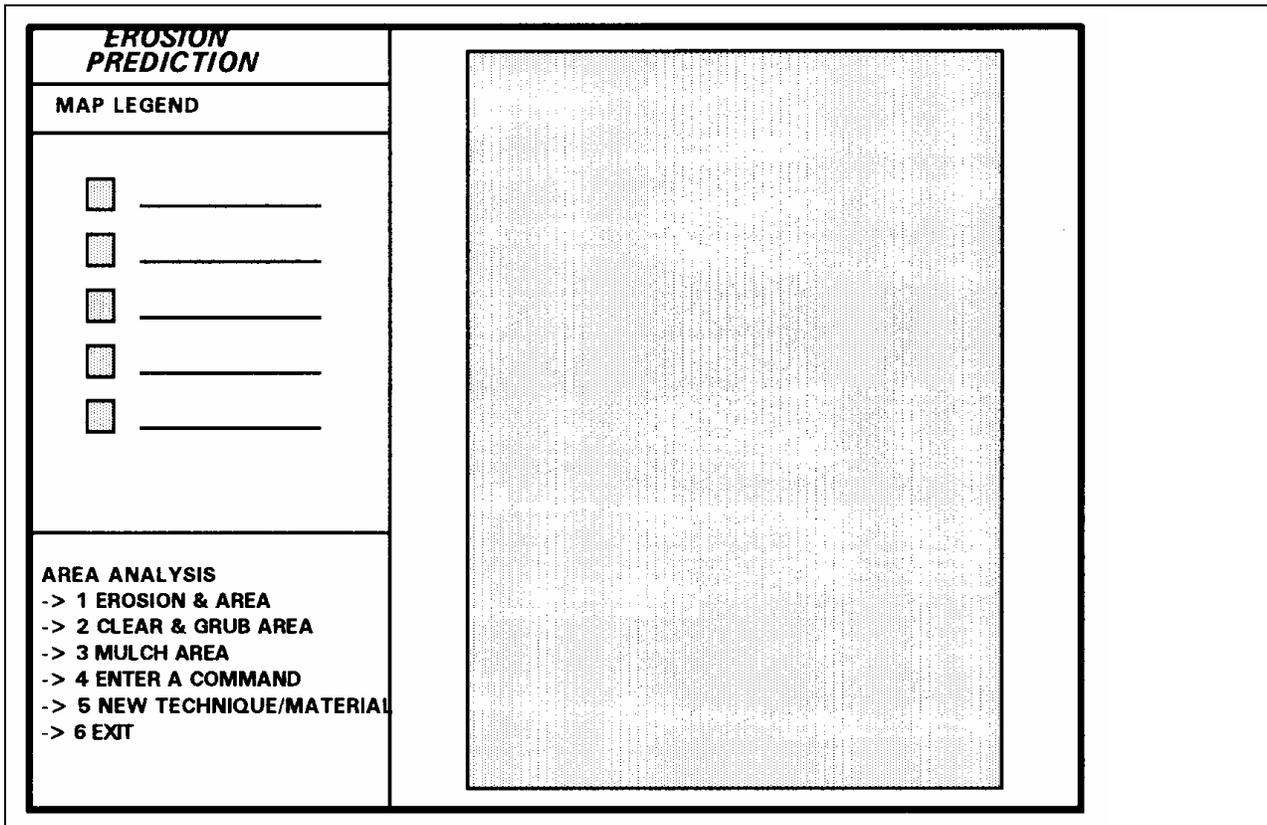
Figure 6-8: Menu1

Option 1 displays a map which indicates the current erosion
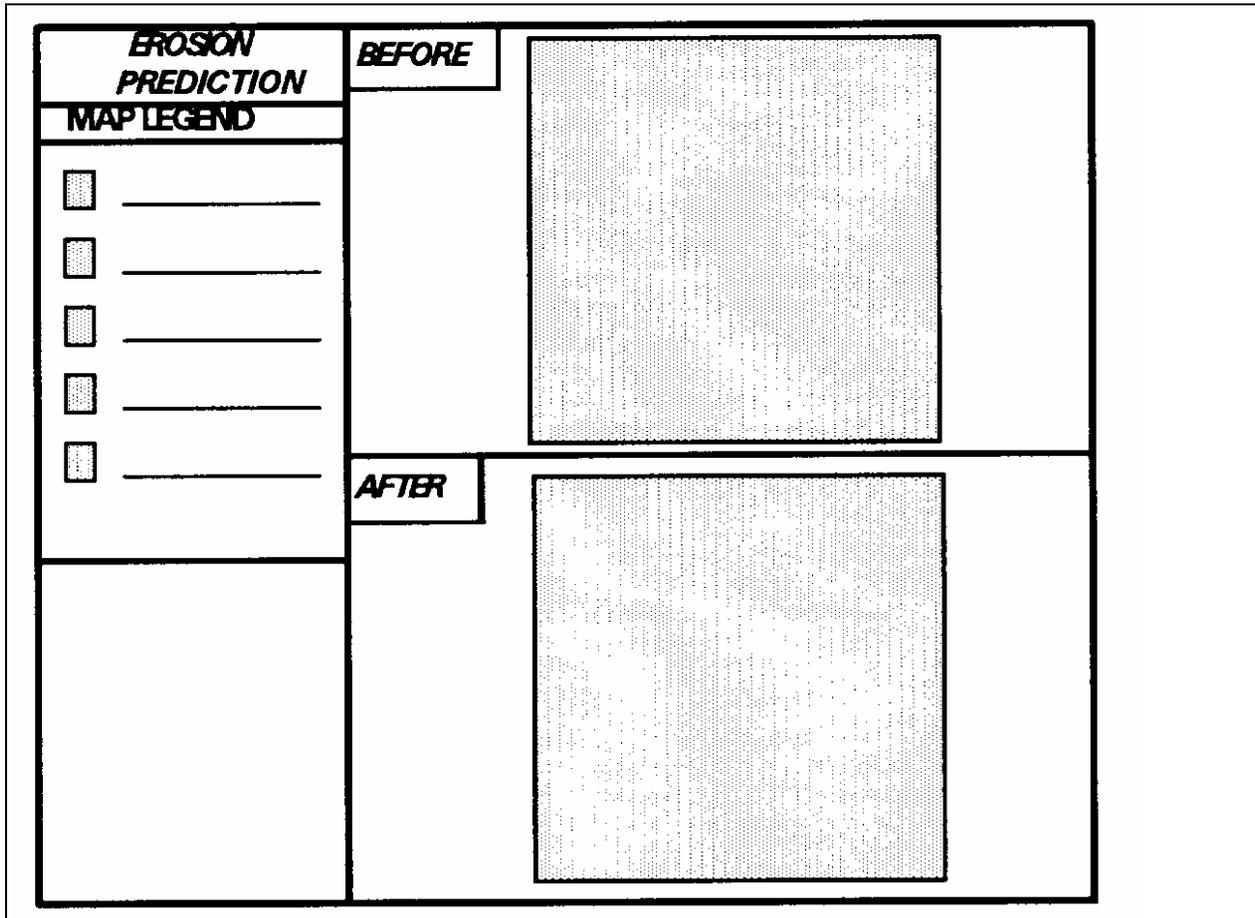
**Figure 6-9: Before and After Display
in Graphics Window**

potential for the area of interest along with a legend for interpreting the map. Different colors on

the map represent differing levels of erosion potential and these levels are identified in the

legend. Figure 6-6 illustrates this display. The current erosion option allows the return to a map

which illustrates the area of interest with no modifications to essentially restart an analysis of the

area. Option 1 is identical to Option 1 found in the Main Menu.

Option 2 (-> 2 CLEAR & GRUB)

Selection of Option 2 simulates the removal of plant matter and root structure from a construction area by clearing and grubbing the area. Option 2 gives a choice of a before and after erosion analysis report . If the option YES is selected, the Graphics Monitor Window is changed to illustrate the erosion potential before the construction area is cleared and grubbed, and after the area is cleared and grubbed. Besides a visual to display like that of Figure 6-9, the total amount of erosion for the area is determined and displayed in the command tool window. Choosing the option of NO returns control back to the original menu options.

Figure 6-9: Before and After display in Graphics Monitor Window
The user has the option to go back to the current display with only one map being displayed if Option 1 is chosen. However, the same set of commands in Menu1 will be displayed (Figure: 6-8).

Option 3 (-> 3 MULCH AREA)

Option 3 passes control to the Mulch Analysis Menu options and allows for the use of a variety of mulches (straw, stone, wood) to an established area. The area selected is cleared and grubbed prior to selecting this option.

Option 4 (-> 4 ENTER A COMMAND)

Option 4 uses GRASS commands via the command tool. Option 4 is identical to Option 7 in the Main Menu.

Option 5 (-> 5 NEW TECHNIQUE/MATERIAL)

Option 5 simulates the application of a new technique or material to the established construction area to prevent erosion. The user is prompted by the software system for the new technique or material being used to prevent erosion. The user is prompted to enter a C factor (between 0 and 1) associated with the new material or technique. The C factor comes from the USLE and is determined before initiating this option. Erosion is then calculated and displayed in both a before and after analysis identical to that of clearing and grubbing and the application of mulches.

Option 6 (-> 6 EXIT)

This option displays the Main Menu options.

Mulch Analysis

The menu called Mulch Analysis is displayed when the user selects Option 3 from Menu1 (Figure 6-8). The user can simulate the application of mulches such as straw, stone, and wood. Once a mulch is applied to the cleared and grubbed construction area, a before and after report of erosion potential is displayed. The report is identical to that given when the land is cleared and grubbed, except that erosion prior to the application of mulches represents land that has previously been cleared and grubbed. The commands and display are shown in Figure 6-10 below.

Option 1 (-> 1 EROSION AREA)

Option 1 displays a map which indicates the current erosion potential for the area of interest along with a legend for interpreting the map. Different colors on the map represent differing levels of erosion potential and these levels are identified in the legend. Figure 6-6 illustrates this display. The current erosion option allows the return to a map which illustrates
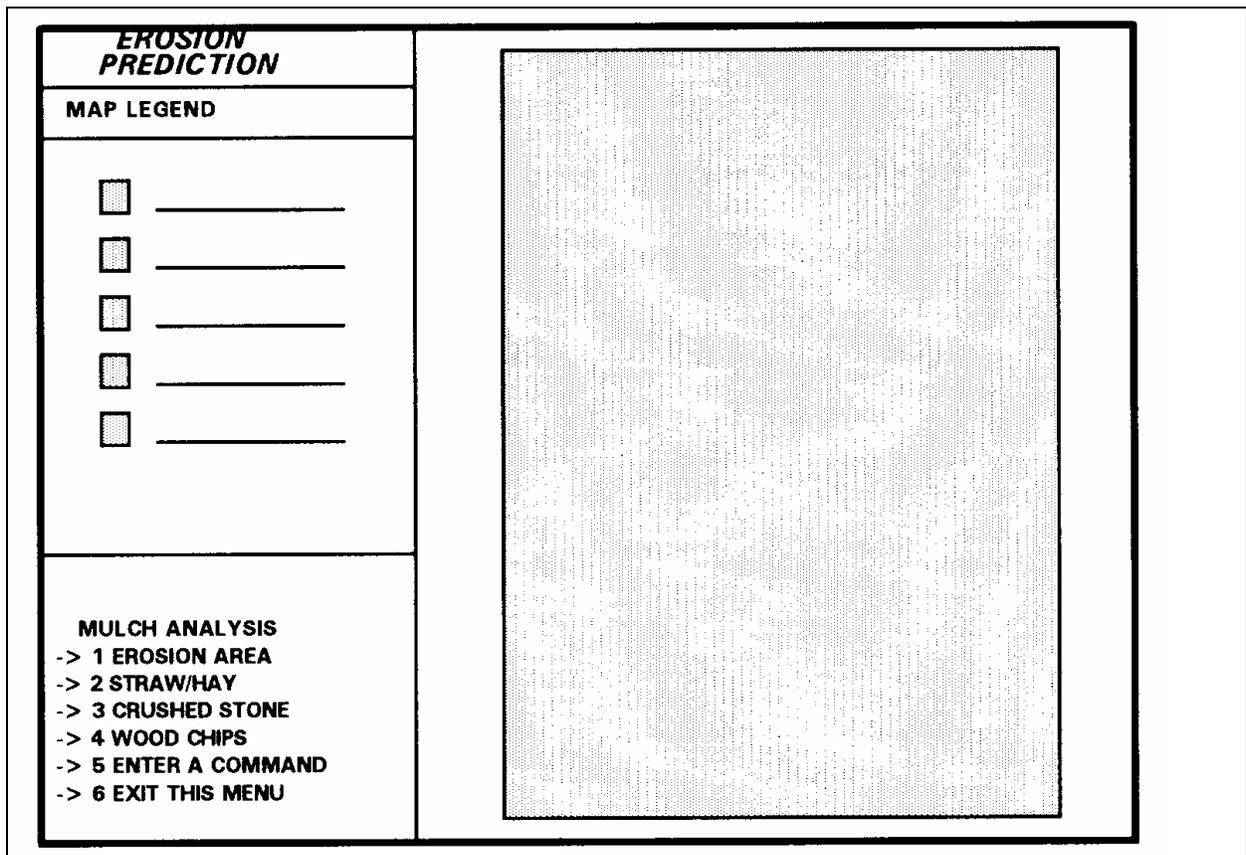
Figure 6-10: Mulch Analysis Menu

the area of interest with no modifications to essentially restart an analysis of the area. Option 1 is identical to Option 1 found in the Main Menu.

Option 2 (-> 2 STRAW/HAY)

Option 2 simulates application of straw/hay once the amount is selected. The choices are as follows:

1.0 tons per acre
1.5 tons per acre

2.0 tons per acre

The amount is selected and applied to the construction area and a new erosion potential is calculated. Once the new erosion potential is calculated, the user has the option of generating a before and after erosion potential report (Figure 6-9).

Option 3 (-> 3 CRUSHED STONE)

Option 3 simulates application of stone once the user decides how much stone to place in the construction area. The choices are as follows:

135 tons per acre

240 tons per acre

The amount is selected and applied to the construction area and a new erosion potential is calculated. Once the new erosion potential is calculated, the user has the option of generating a before and after erosion potential report (Figure 6-9).

Option 4 (-> 4 WOOD CHIPS)

Option 4 simulates the application of wood chips once the user decides how much wood chips they want to put down. The choices are as follows:

7.0 tons per acre
12.0 tons per acre

25.0 tons per acre

The amount is selected and applied to the construction area and a new erosion potential is calculated. Once the new erosion potential is calculated, the user has the option of generating a before and after erosion potential report (Figure 6-9).

Option 5 (-> 5 ENTER A COMMAND)

Option 5 uses GRASS commands via the command tool. Option 5 is identical to that of Option 7 in the Main Menu.

Option 6 (-> 6 EXIT)

Choosing this option displays options in Menu1.

Software Installation

The installation of the erosion prediction software requires the following list of files. The

user can run the software in a GRASS session by copying the files to their working directory and

giving executable file priveledges.These files are:
erosion1
erosion2
erosion3
seutp_erosion
logo
menu1.data
menu2.data
menu3.data
menu4.data
menu5.data
menu6.data
menu7.data
menu8.data
menu9.data
setup_erosion.data
count2
count3
count4
count5
count6
count7
count8
count9
count10
count11
count12
count13
count14
count15
count16
count17
count18
count19
count20
count21

slope.length.c
cell2ft
e

ls

Chapter 7

Example of Erosion Prediction Software System

Introduction

The example provided is meant to provide output as well as to show the user how the software works. Commands entered by the user are highlighted in bold italics. Output from the software and GRASS is in regular non-bold form. Notes about the software are denoted by brackets in the following format **[NOTE: XXXXX]**.
tns@uafsun4:/home/tns 106 % ***grass4.1***


```
                          GRASS 4.1
LOCATION: This is the name of an available geographic location.
        -spearfish- is the sample data base for which all
     tutorials are written.

MAPSET:   Every GRASS session runs under the name of a MAPSET.
     Associated  with each MAPSET is a rectangular COORDINATE
     REGION and a list of any new maps created.

DATABASE: This is the unix directory containing the geographic
     databases

        The REGION defaults to the entire area of the chosen
     LOCATION.  You may change it later with the command:
     g.region
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


LOCATION:    huntsville____    (enter list for a list of locations)
MAPSET:      copy_____    (or mapsets within a location)

DATABASE:    /app/grass/data/_____


         AFTER COMPLETING ALL ANSWERS, HIT <ESC> TO CONTINUE
```

(OR <Ctrl-C> TO CANCEL)

[NOTE: The <ESC> key was entered]

GRASS 4.1 > *d.mon start=x0*

Graphics driver [x0] started

[NOTE: Once GRASS and the graphics monitor has been started, the user can start the software]

Mapset <copy> in Location <huntsville>

GRASS 4.1 > *erosion1*

[NOTE: Figure   7-1   shows   the   actual   opening   screen   for   the software]

26

Figure 7-1: Opening Screen for Software System

[NOTE: click on BEGIN SETUP]

Entering the SETUP program....
[NOTE: Figure 7-2 shows the screen for the setup portion of the software system]

27

Figure 7-2: Screen for the Setup portion of the software system

[NOTE: Use the mouse to click on HELP and basic information about the setup program will be displayed]

```
------------------------------------------------------------------
|              BASIC INFORMATION ON THE SETUP PROGRAM          |
|---------------------------------------------------------------|
|                                                               |
| This program is used to 'setup' the erosion analysis program.|
|It  has the main purpose of finding out the names of primary  |
| data layers. Once these data layers are chosen by the user the
| program calculates the slope-length factors (LS factors).    |
|                                                               |
| THIS PROGRAM ONLY NEEDS TO BE RUN ONE TIME.....              |
| The setup program will provide the necessary alterations to  |
| the area of interest. The program is time consuming, but once|
|it is run, the only reason you would need to run it again is
if| |you ran it incorrectly, are using a new mapset, or
accidentally| | deleted one of the data layers the program
generates.           | ------------------------------------------
---------------------
```

Hit [RETURN] to continue.....
[NOTE: return entered and the mouse was used to click on BEGIN SETUP]

You will now be asked to click on the raster map that contains

the primary data for each of these data layers

```
Theses data layers are as follows:




  ----------------------------------------------------------------
-
   ACTUAL NAME OF MAP              WHAT THE MAP STANDS FOR IN USLE
  ----------------------------------------------------------
```
     kfactor   Soil Erodibility Factor
     rfactor   Rainfall and runoff factor
     lsfactor   Slope-Length factor
     cfactor   Cover and Management factor
     pfactor   Support practice factor
     elevation   Elevation of the land (meters)
     we.water.tva   Water areas (streams, creeks, etc.)
```
  ------------------------------------------------------------
```

Hit the [RETURN] key to continue....

[NOTE: the return key was entered]

**[NOTE: A file window will appear and ask you to click on the map
 that corresponds with its respective data layer see Figure 7-3]**

28

   Figure 7-3: Example of the File Manger for the SETUP program

Use the mouse to select the data layer for kfactors

**[NOTE: Double click on the map layer called kfactors
after scrolling to next page from file manager. Figure 7-4 shows a close-up view of the file
manger.]**

The map that represents your kfactor values was : kfactor

Is this correct? (y/n) *y*

Figure 7-4: Close-up view of the file manager

[NOTE: The letter "y" was entered indicating the map was correct]

EXECUTING kfactor = ... 100%

CREATING SUPPORT FILES FOR kfactor

minimum value 0, maximum value 43

             **** SELECTION OF LSFACTORS ****

This part differs from other primary data layers in that the slope-length factors can be calculated or the user
may choose the map that contains this information.

Most likely, the user will need to calculate the lsfactors since they will probably not have been calculated already. In addition, this step will require a lengthy period of calculations. On a 486 DX2 the process took about 1-2 hours. Once these factors are completed for an area, this process should not be needed again.

Hit the [RETURN] key to continue........

[NOTE: Return key entered]

You now need to pick your map that contains the elevation values in meters
Use the mouse to select the data layer for elevation

[NOTE: File manager shows up...double click on map called elevation]

 The map that represents your elevation values was : elevation
Is this correct? (y/n) *y*

EXECUTING we.dem = ... 100%
CREATING SUPPORT FILES FOR we.dem
minimum value 0, maximum value 604

EXECUTING elevation = ... 100%
CREATING SUPPORT FILES FOR elevation
minimum value 0, maximum value 604

You now need to pick your map that contains information about water areas
This map tells if a water areas such as streams, lakes, creeks, etc. are
present.

THIS MAP MUST BE IN THE FORM WHERE 1=WATER 0=NO WATER/NO DATA

[NOTE: Use the mouse to select the data layer for water areas by selecting the map from the file manager]

The map that represents your water areas values was : we.water.tva
 Is this correct? (y/n) *y*

Do you already have the slope-length (ls factors) done(y/n)? *n*


```
 -------------------------------------------------------------
|          The following maps will now be created:            |
|----------------------------------------------------------   |
| MAP                  DESCRIPTION OF THE MAP                  |
|--------------------------------------------------------     |
| we.slope        slope in degrees (1-360)               |
| slope.percent          percent slope (% rise f/ horizontal)    |
| aspect          aspect in degrees (1-360)              |
| asp             aspect reclassed into 9 categories     |
| lsfactor        USLE slope-length factors              |
 -------------------------------------------------------------
```


Hit [RETURN] to continue.....

[NOTE: Return is entered and now the user must wait for calculations to finish]

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 0, maximum value 0
percent complete: 100%

CREATING SUPPORT FILES
ELEVATION PRODUCTS for mapset [copy] in [huntsville]
360 categories of aspect
Color table for [aspect] set to aspect
ASPECT [aspect] COMPLETE
61 categories of slope
SLOPE [we.slope] COMPLETE
percent complete: 100%
CREATING SUPPORT FILES
ELEVATION PRODUCTS for mapset [copy] in [huntsville]
175 categories of slope
SLOPE [slope.percent] COMPLETE

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 0, maximum value 1

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 0, maximum value 2

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 0, maximum value 3

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 0, maximum value 3

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 0, maximum value 4

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 0, maximum value 5

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 0, maximum value 6

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 0, maximum value 7

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 0, maximum value 8

EXECUTING asp = ... 100%
CREATING SUPPORT FILES FOR asp
minimum value 1, maximum value 9

EXECUTING count2 = ... 100%
CREATING SUPPORT FILES FOR count2
minimum value 0, maximum value 2

EXECUTING count3 = ... 100%
CREATING SUPPORT FILES FOR count3
minimum value 0, maximum value 3

EXECUTING count4 = ... 100%
CREATING SUPPORT FILES FOR count4
minimum value 0, maximum value 4

EXECUTING count5 = ... 100%
CREATING SUPPORT FILES FOR count5
minimum value 0, maximum value 5

EXECUTING count6 = ... 100%
CREATING SUPPORT FILES FOR count6
minimum value 0, maximum value 6

EXECUTING count7 = ... 100%
CREATING SUPPORT FILES FOR count7
minimum value 0, maximum value 7

EXECUTING count8 = ... 100%
CREATING SUPPORT FILES FOR count8
minimum value 0, maximum value 8

EXECUTING count9 = ... 100%
CREATING SUPPORT FILES FOR count9
minimum value 0, maximum value 9

EXECUTING count10 = ... 100%
CREATING SUPPORT FILES FOR count10
minimum value 0, maximum value 10

EXECUTING count11 = ... 100%
CREATING SUPPORT FILES FOR count11
minimum value 0, maximum value 11

EXECUTING count12 = ... 100%
CREATING SUPPORT FILES FOR count12
minimum value 0, maximum value 12

EXECUTING count13 = ... 100%
CREATING SUPPORT FILES FOR count13
minimum value 0, maximum value 13

EXECUTING count14 = ... 100%
CREATING SUPPORT FILES FOR count14
minimum value 0, maximum value 14

EXECUTING count15 = ... 100%
CREATING SUPPORT FILES FOR count15
minimum value 0, maximum value 15

EXECUTING count16 = ... 100%
CREATING SUPPORT FILES FOR count16
minimum value 0, maximum value 16

EXECUTING count17 = ... 100%
CREATING SUPPORT FILES FOR count17
minimum value 0, maximum value 17

EXECUTING count18 = ... 100%
CREATING SUPPORT FILES FOR count18
minimum value 0, maximum value 18

EXECUTING count19 = ... 100%
CREATING SUPPORT FILES FOR count19
minimum value 0, maximum value 19

EXECUTING count20 = ... 100%
CREATING SUPPORT FILES FOR count20
minimum value 0, maximum value 20

EXECUTING count21 = ... 100%
CREATING SUPPORT FILES FOR count21
minimum value 0, maximum value 21

EXECUTING s.l.c = ... 100%
CREATING SUPPORT FILES FOR s.l.c
minimum value 0, maximum value 21

EXECUTING s.l.ft = ... 100%
CREATING SUPPORT FILES FOR s.l.ft
minimum value 0, maximum value 2066

EXECUTING e = ... 100%
CREATING SUPPORT FILES FOR e
minimum value 0, maximum value 5

EXECUTING lsfactor = ... 100%
CREATING SUPPORT FILES FOR lsfactor
minimum value 0, maximum value 7508

Use the mouse to select the data layer for c factors

[NOTE: File manager shows up...double click on the data layer containing the C factors.]

 The map that represents your cfactor values was : cfactor

 Is this correct? (y/n) *y*

EXECUTING cfactor = ... 100%
CREATING SUPPORT FILES FOR cfactor
minimum value 0, maximum value 1000
EXECUTING erosion = ... 100%
CREATING SUPPORT FILES FOR erosion
minimum value 0, maximum value 1074
Color table for [erosion.reclass] set to rules

[NOTE: Finished and the user goes into Main Menu shown in Figure 7-5.]

30

Figure 7-5: Main Menu

[NOTE: Click on Option 1 and the erosion for the region is displayed (see Figure 7-6).]

31

Figure 7-6: Option 1 from Main Menu

Displaying Erosion Potential...

[NOTE: Figure 7-4 shows the Main Menu screen and the erosion potential for the geographic region]

done

[NOTE: Zoom in on new area by selecting Option 4 from the Main Menu which is shown in Figure 7-7]

32

Figure 7-7: Option 4 (Zoom) from Main Menu

north: 3991460 south: 3990380 east: 435420 west: 434550

 Establish a corner
Middle: Check coordinates
R

[NOTE: Click on YES to accept new region, the area is redisplayed new zoomed in level.]

[Note: Use mouse to choose Option 5 Define Construction. The user then defines the construction area using the mouse to outline the area (see Figure 7-8)]

Please choose one of the following
   A define an area
   C define a circle
   L define a line
   Q quit (and create map)
> *A*
 Buttons:
  Left: where am i
  Middle: mark point
  Right: done
EAST: 434692.66917293   NORTH: 3991234.2556391
EAST: 435270.83458647   NORTH: 3991232.63157895
EAST: 435269.21052632   NORTH: 3990941.92481203
EAST: 434692.66917293   NORTH: 3990943.54887218
EAST: 434689.42105263   NORTH: 3991235.87969925

33

Figure 7-8: Zoomed in construction area

Enter the category number for this area: *1*
Enter a label for category 1 [] large rectangle
1 [large rectangle]
Look ok? (y/n) *y*

Please choose one of the following
   A define an area
   C define a circle
   L define a line
   Q quit (and create map)
> *Q*

Please choose one of the following
   A define an area
   C define a circle
   L define a line
   Q quit (and create map)
> *Q*

 The name of your area is : area#1
 Is this correct? (y/n) *y*

Opening files
Performing extraction
Consolidating area information
Closing files

[NOTE: The construction area defined by the user is converted to a vector map called area.vector]

Now Displaying the current erosion potential and your area
Vector file [area.vector]

Selected information from dig header
 Organization: organization
 Map Name: mapname
 Source Date:
 Orig. Scale: 24000

 North: 3991460
 South: 3990380
 East: 435420
 West: 434550

Plotting ... Done

done

[NOTE: Choose option to modify land and clear and grub the construction area]

EXECUTING after_grub = ... 100%
CREATING SUPPORT FILES FOR after_grub
minimum value 0, maximum value 0

EXECUTING before_grub = ... 100%
CREATING SUPPORT FILES FOR before_grub
minimum value 0, maximum value 0

EXECUTING new_cfactor = ... 100%
CREATING SUPPORT FILES FOR new_cfactor
minimum value 3, maximum value 43

EXECUTING new_cfactor = ... 100%
CREATING SUPPORT FILES FOR new_cfactor
minimum value 3, maximum value 1000

EXECUTING new_cfactor_grub = ... 100%
CREATING SUPPORT FILES FOR new_cfactor_grub
minimum value 3, maximum value 1000

EXECUTING erosion_grub = ... 100%
CREATING SUPPORT FILES FOR erosion_grub
minimum value 0, maximum value 46

EXECUTING before_grub = ... 100%
CREATING SUPPORT FILES FOR before_grub
minimum value 0, maximum value 0

EXECUTING after_grub = ... 100%
CREATING SUPPORT FILES FOR after_grub
minimum value 0, maximum value 0
Color table for [after_grub.reclass] set to rules

Now redisplaying your erosion from clearing and grubbing...

Vector file [area.vector]

Selected information from dig header
Organization: organization
 Map Name: mapname
 Source Date:
 Orig. Scale: 24000

 North: 3991460
 South: 3990380
 East: 435420
 West: 434550
Plotting ... Done

Now redisplaying your erosion from clearing and grubbing...

[NOTE: Use the mouse to click on YES to Before/After Report and the amount of erosion potential is reported and displayed (see Figure 7-9).]

Figure 7-9: Before and After display simulating Clearing and Grubbing

r.stats: 100%

r.stats: 100%

r.stats: 100%

Vector file [area.vector]

Selected information from dig header
 Organization: organization
 Map Name: mapname
 Source Date:
 Orig. Scale: 24000

 North: 3991460
 South: 3990380
 East: 435420
 West: 434550

Plotting ... Done
Vector file [area.vector]

Selected information from dig header
 Organization: organization
 Map Name: mapname
 Source Date:
 Orig. Scale: 24000

 North: 3991460
 South: 3990380
 East: 435420
 West: 434550

Plotting ... Done

Total Erosion BEFORE clearing & grubbing is : 0 tons/acre/year
Total Erosion AFTER clearing & grubbing is : 59 tons/acre/year

**[NOTE: A before and after display is shown on the screen.
Now enter mulch menu and choose the amount of stone to use]**

Initializing Mulches for Areas of Interest...
USING CRUSHED STONE...

EXECUTING new_cfactor = ... 100%
CREATING SUPPORT FILES FOR new_cfactor
minimum value 0, maximum value 1000

EXECUTING stone_cfactor = ... 100%
CREATING SUPPORT FILES FOR stone_cfactor
minimum value 0, maximum value 1000

EXECUTING stone_grub = ... 100%
CREATING SUPPORT FILES FOR stone_grub
minimum value 0, maximum value 1

EXECUTING stone_cfactor = ... 100%
CREATING SUPPORT FILES FOR stone_cfactor
minimum value 0, maximum value 420

[NOTE: Use the mouse to click on YES to Before/After report (see Figure 7-10).]
`      35Figure 7-10: Before and After display simulating the`
`                 application of mulch`

Initializing Mulches for Areas of Interest...

USING CRUSHED STONE...

EXECUTING new_cfactor = ... 100%
CREATING SUPPORT FILES FOR new_cfactor
minimum value 0, maximum value 1000

EXECUTING stone_cfactor = ... 100%
CREATING SUPPORT FILES FOR stone_cfactor
minimum value 0, maximum value 1000

EXECUTING stone_grub = ... 100%
CREATING SUPPORT FILES FOR stone_grub
minimum value 0, maximum value 1

EXECUTING stone_cfactor = ... 100%
CREATING SUPPORT FILES FOR stone_cfactor
minimum value 0, maximum value 420

Vector file [area.vector]

Selected information from dig header
 Organization: organization
 Map Name: mapname
 Source Date:
 Orig. Scale: 24000

 North: 3989690
 South: 3988400
 East: 436950
 West: 435900

Plotting ... Done
Vector file [area.vector]

Selected information from dig header
 Organization: organization
 Map Name: mapname
 Source Date:
 Orig. Scale: 24000

 North: 3989690
 South: 3988400
 East: 436950

Plotting ... Done

Total Erosion BEFORE putting gravel/stone down : 59 tons/acre/year
Total Erosion AFTER putting gravel/stone down : 1 tons/acre/year

Chapter 8

Conclusions and Recommendations

The primary goal of this research is to use the Geographic Information System of GRASS for predicting erosion potential at construction sites. This research project accomplishes the primary goal by using a mathematical model to predict potential soil losses together with a geographic information system. The software program provides three primary contributions. First, the software system calculates erosion potential for a geographic area using the GIS of GRASS. The prediction of initial erosion potential helps designers look at current erosion potential conditions for areas of interest. Secondly, the software system provides a means of simulating before and after analyses of erosion conditions without actually modifying the land. Lastly, the software system allows for the simulation of the application of erosion reduction methods as well as construction methods such as mulches and future developments in erosion prevention.

Future work should incorporate the Revised Universal Soil Loss Equation (RUSLE). The application of the work presented to the RUSLE should not be complex because the basic factors (R, K, LS, C, P) are not going to change. The major change that will occur is in the data tables associated with the basic factors. In addition, further research that addresses deposition and sediment yields from gully, streambed, and streambank erosion would be of benefit to the research that has already been completed. This would greatly improve the accuracy of the erosion potential estimate.

A GEOGRAPHIC INFORMATION SYSTEM TO PREDICT SOIL EROSION POTENTIAL IN RURAL TRANSPORTATION CONSTRUCTION PROJECTS

SANDRA C. PARKER, DAVID G. PARKER AND
THOMAS N. STADER

1.   American Society of Civil Engineers, Sediment Sources and Sediment Yields In: Sedimentation Engineering, New York, NY, ASCE, pp. 437-493, 1975.

2.   American Society of Civil Engineers, Soil Erosion & Sediment Control, Video New York, NY, 1994.

3.   Antenucci, John C., Kay Brown, Peter L. Croswell, and Michael J. Kevany, Geographic Information Systems A GUIDE TO THE TECHNOLOGY, Van Nostrand Reinhold, NY, p. 7, 1991.

4.   Antenucci, John C., Kay Brown, Peter L. Croswell, and Michael J. Kevany, Geographic Information Systems A GUIDE TO THE TECHNOLOGY, Van Nostrand Reinhold, NY, p. 89, 1991.

5.   Crawford, N.H. , and R.K. Linsley, Digital Simulation in Hydrology: Stanford Watershed Model IV, Department of Civil Engineering, Stanford University, Stanford, Califronia, Technical Report No. 39, p 210, July 1966.

6.   Donigian, Anthony S., and Norman H. Crawford, MODELING NONPOINT POLLUTION FROM THE LAND SURFACE, U.S. Environmental Protection Agency, EPA -600/3-76-083, July 1976.

7.   Dragoun, F.J. , and C.R. Miller, Sediment Characteristics of Two Small Agricultural Watersheds in Central Nebraska, Paper presented at 1964 Summer Meeting of the American Society of Agricultural Engineers, Fort Collins, Colorado, Jun 21-24, p. 19, 1964.

8.   Foster, G.R., and L.D. Meyer, and C.A. Onstad, Erosion Equations Derived from Modeling Principles, American Society Agricultural Engineering, St. Joseph, Michigan, Paper No. 73-2550, 1973.

9.   Fulkerson, W., W.D. Shultz, and R.I. Vanhook, Ecology and the Analysis of Trace Contaminants, Progress Report: January 1973-September 1973, Oak Ridge National Laboratory, Atomic Energy Commission, Oak Ridge, TN, ORNL-NSF-EATC-6, p. 186, January 1974.

10.   Haan, C.T. , H.P. Johnson, and D.L. Brakensiek, HYDROLOGIC MODELING OF SMALL WATERSHEDS, American Society of Agricultural Engineers, Michigan, p. 4, 1982.

11.   Haan, C.T. , H.P. Johnson, and D.L. Brakensiek, HYDROLOGIC MODELING OF SMALL   WATERSHEDS, American Society of Agricultural Engineers, Michigan, p. 10, 1982.

12.   Heaney, J.P., et al., <u>Urban Stormwater Management Modeling and Decision Making Office of Research and Developement</u>, EPA, Cincinnati, OH, EPA-670/2-75-002, p 186, May 1975.

13.   Leytham, K. A., and R. C. Johanson, <u>WATERSHED EROSION AND SEDIMENT TRANSPORT MODEL</u>, U.S. Environmental Protection Agency, EPA-600/3-79-028, March 1979.

14.   McKimmey, James M., <u>PREDICTION AND MANAGEMENT OF SEDIMENT LOAD AND PHOSPHOROUS IN THE BEAVER RESEVOIR WATERSHED USING A GEOGRAPHIC INFORMATION SYSTEM</u>, Masters Thesis, University of Arkansas, 1994.

15.   McKimmey, James M., <u>PREDICTION AND MANAGEMENT OF SEDIMENT LOAD AND PHOSPHOROUS IN THE BEAVER RESEVOIR WATERSHED USING A GEOGRAPHIC INFORMATION SYSTEM</u>, Masters Thesis, University of Arkansas, p. 65, 1994.

16.   McKimmey, James M., <u>PREDICTION AND MANAGEMENT OF SEDIMENT LOAD AND PHOSPHOROUS IN THE BEAVER RESEVOIR WATERSHED USING A GEOGRAPHIC INFORMATION SYSTEM</u>, Masters Thesis, University of Arkansas, p. 67, 1994.

17.   Metcalf & Eddy, Inc., <u>University of Florida and Water Resources Engineers, Inc., Storm Water Management Model</u>, Water Quality Office, EPA, Washington D.C. , 11024 DOC. 4 Volumes, 1971.

18.   Meyer, L. D. , and W. H. Wischmeier, "*Mathematical Simulation of the Process of Soil Erosion by Water*", <u>Transactions of the ASAE</u>, pp 754-758, 1969.

19.   Miller, Arthur C., William J. Veon, and Ronald A. Chaddrerton, "*Comparison of Prediction Methods for Soil Erosion from Highway Construction Sites*", <u>Transportation Research Record</u>, NO. 896, pp 33-39, 1982.

20.   Mitchell, Jim, Phone Conservation, Conservation Technology Information Center, September 22, 1993.

21.   Mitchell, Jim, <u>RUSLE Q & A</u>, Conservation Impact, January 1993.

22.   Onstad, C. C., and Foster, G. R. <u>Erosion Modeling on a Watershed</u>. American Society of Agricultural Engineers Transactions 18:288-292, 1975.

23.   Renard, Kenneth G., George R. Foster, Glenn A. Weesies, and Jeffrey P. Porter, "*RUSLE, Revised universal soil loss equation*", <u>Journal of Soil and Water Conservation</u>, VOL 46, pp 30-33, January-February 1991.

24.   Roesner, L. A., R. P. Shubinski, and J. A. Aldrich, <u>Storm water management model user's manual: Version III</u>. EPA-600/2-84-109b, U.S. Environmental Protection Agency, Athens, GA, 1981.

25.   U.S. Corps of Engineers, GRASS Users's manual from software, 1994.

26.   U.S. Corps of Engineers, <u>Urban storm water runoff, STORM</u>. Computer Program 723-S8-L2520. Davis, CA, 1974.

27.   U.S. Weather Bureau, <u>Rainfall intensity-frequency regime</u>. Technical Paper No. 29, 5 parts, 1958.

28.   USDA, and Soil Conservation Service, <u>Soil Survey of Madison County, Arkansas</u>. pp. 138-140, 1982.

29.   Warren, Steven, V. Diersing, and Pamela Thompson," EROSION-BASED LAND CAPABILITY SYSTEM FOR HOOD", <u>GRASS CLIPPINGS</u>, VOL 2, No. 1, Winter 1988.

30.   Williams, J.R. , <u>Sediment-Yield Predictions with Universal Equation Using Runoff Energy Factor. In: Present and Prospective Technology for Predicting Sediment Yeilds and Sources</u>. Agricultural Research Service. Department of Agriculture, ARS-S-40, pp. 244-252, June 1975.

31.   Wischmeier, W. H. , <u>A rainfall erosion index for a universal soil-loss equation</u>. Soil Science Society of America Proceedings, 23:246-249, 1959.

32.   Wischmeier, W.H., and D.D. Smith, Predicting Rainfall Erosion Losses, U.S. Department of Agriculture, Agriculture Handbook 537, p.3, 1978.

3.   Wischmeier, W.H., and D.D. Smith, <u>Predicting Rainfall Erosion Losses</u>, U.S. Department of Agriculture, Agriculture Handbook 537, abstract, 1978.

34.   Wischmeier, W.H., and D.D. Smith, <u>Predicting Rainfall Erosion Losses</u>, U.S. Department of Agriculture, Agriculture Handbook 537, p. 4, 1978.

35.   Wischmeier, W.H., and D.D. Smith, <u>Predicting Rainfall Erosion Losses</u>, U.S. Department of Agriculture, Agriculture Handbook 537, Figure 1, 1978.

36.   Wischmeier, W.H., and D.D. Smith, <u>Predicting Rainfall Erosion Losses</u>, U.S. Department of Agriculture, Agriculture Handbook 537, p. 45, 1978.

37.   Wischmeier, W.H., and D.D. Smith, <u>Predicting Rainfall Erosion Losses</u>, U.S. Department of Agriculture, Agriculture Handbook 537, p. 47, 1978.

38.   Wright, A.C., and R. Webster, "*A STOCHASTIC DISTRIBUTED MODE OF SOIL EROSION BY OVERLAND FLOW*", Earth Surface Processes and Landforms, VOL.16, pp 207-226, 1991.

39.   Yu, Shaw L. and Robert J. Kaighn, Jr., VDOT Manual Of Practice For Planning Stormwater Management, Virginia Transportation Research Council, 1987.

40.   Wischmeier, W.H., and D.D. Smith, Predicting Rainfall Erosion Losses, U.S. Department of Agriculture, Agriculture Handbook 537, p. 31, 1978.

Anderson, Bradley A., "*SOIL EROSION AND SEDIMENTATION ANALYSIS OF FOREST ROADS IN NORTHERN CALIFORNIA*", Colorado State University, 1992.

Anderson, Bradley A. and Daryl B. Simons, "*Soil Erosion Study of Exposed Highway Construction Slopes and Roadways*", <u>Transportation Research Record</u>, NO. 948, 1983.

Burrough, P. A., Principles of Geographical Information SYstems for Land Resources Assessment, Oxford Science Publications, New York, 1986.

Chaves, H.M. and M.A. Nearing, "*UNCERTAINTY ANALYSIS OF THE WEPP SOIL EROSION MODEL*", <u>Journal of Range Management</u>, VOL 34(6), 1991.

Dissmeyer, George E. and Richard F. Stump, <u>PREDICTED EROSION RATES for Forest Management Activities in the Southeast</u>, U.S. Department of Agriculture, April 1978.

Duttweiler, David W., <u>WATERSHED EROSION AND SEDIMENT TRANSPORT MODEL</u>, U.S. Environmental Protection Agency, EPA-600/3-79-028, March 1979.

Environmental Protection Agency, <u>Hydrocomp simulation package-FORTRAN: User's manual</u>, Athens, GA, 1980.

Huber, W. C., J. P. Heaney, S. J. Nix, R.E. Dickinson, and D. J. Polmann, <u>Storm water management model user's manual: Version III</u>. U.S. Environmental Protection Agency, EPA-600/2-84-109a, Athens, GA,, 1981.

Hydraulics Section, Arkansas Highway and Transportation Department, <u>DRAINAGE MANUAL</u>, 1982.

Johnson, A.I., C.B. Petterson, and J.L. Fulton, <u>Geographic Information Systems (GIS) and Mapping-Practices and Standards</u>, American society for Testing and Materials, 1992.

Kochand, Stephen G. and Patrick H. Wood, <u>UNIX SHELL PROGRAMMING</u>. Pipeline Associates, Inc., Carmel, IN, 1993.

Maguire, David, Michael F. Goodchild, and David W. Rhind, <u>GEOGRAPHICAL INFORMATION SYSTEMS</u>, Vol 1 - PRINCIPLES, Longman Scientific & Technical, England, 1991.

Maguire, David, Michael F. Goodchild, and David W. Rhind, <u>GEOGRAPHICAL INFORMATION SYSTEMS</u>, Vol 2 - APPLICATIONS, Longman Scientific & Technical, England, 1991.

Quercia, Valerie, and Tim O'Reilly, <u>X Window System User's Guide</u>. Volume 3, O'Reilly & Associates, Inc., 1991.

Wilcox, Bradford P., Mina Sbaa, Wilberth H. Blackburn and James H. Milligan, "*Runoff prediction from sagebrush rangelands using water erosion prediction project (WEPP)technology*", <u>Journal of Range Management</u>, VOL 45, 1992.

Zachar, D. , <u>SOIL EROSION</u>, Elesevier Scientific Publishing Company, NY, 1982.

Appendix B

Isoerodent map of the United States

0

Figure B-1: Isoerodent Map of the US used for the R factor in the USLE

Appendix C

Logic Flow Chart

```
                    ┌─────────────┐
                    │    START    │
                    └─────────────┘
                           │
                           ▼
                 ┌───────────────────┐
                 │  CREATE WINDOWS   │
                 │        &          │
                 │  SYSTEM DISPLAY   │
                 └───────────────────┘
                           │
                           ▼
                 ┌───────────────────┐
                 │  DISPLAY GRASS    │
                 │      LOGO         │
                 └───────────────────┘
                           │
                           ▼
                  ◇ HAS SETUP ◇   NO    ┌──────────────┐           ⊙
                  ◇ BEEN RUN? ◇ ──────► │  RUN SETUP   │ ───────►  A
                                        │   PROGRAM    │
                      │ YES             └──────────────┘
                      ▼
                  ◇ EROSION  ◇   NO     ┌──────────────┐
                  ◇ ANALYSIS?◇ ──────►  │    EXIT      │
                                        │ THE SOFTWARE │
                      │ YES             │   SYSTEM     │
                      ▼                 └──────────────┘
                 ┌───────────────────┐
                 │     DISPLAY       │ ◄────────────────────┐
                 │   MAIN MENU       │                      │
                 └───────────────────┘                      │
                           │                                │
                           ▼                                │
                 ┌───────────────────┐                      │
                 │    USE MOUSE      │                      │
                 │    TO CLICK       │                      │
                 │    ON MENU        │                      │
                 └───────────────────┘                      │
                           │                                │
                           ▼                                │
                  ◇ IF MENU ◇  YES     ┌──────────────────┐ │
                  ◇ CHOICE 1◇ ──────►  │     DISPLAY      │ │
                                       │ EROSION.RECLASS  │─┘
                      │                │        &         │
                    NO│                │ LEGEND FOR MAP   │
                      ▼                └──────────────────┘
                    ⊙ 1                        121
```

122

```
          ┌─────┐
          │  2  │
          └──┬──┘
             │
             ▼
    ╱◆╲              ┌──────────────┐        ┌──────────────┐            ┌──────────────┐
   ╱IF MENU╲  YES    │    MOUSE     │        │ RESET REGION │            │   DISPLAY    │
  ◆ CHOICE 4 ◆──────▶│USED TO ZOOM IN│──────▶│ ON MONITOR   │            │  MAIN MENU   │
   ╲       ╱         │  ON AN AREA  │        │ TO ZOOMED    │            │              │
    ╲◆╱             │   (d.zoom)   │        │   IN AREA    │            └──────────────┘
     │NO             └──────────────┘        └──────┬───────┘                   ▲
     │                                               │                           │
     │            ┌──────────────┐      ╱◆╲          ▼                           │
     │            │DISPLAY ZOOMED│ NO  ╱CONSTRUCT╲                                │
     │            │    AREA      │◀───◆ DEFINED?  ◆                               │
     │            │              │     ╲        ╱                                │
     │            └──────────────┘      ╲◆╱                                      │
     │                                   │YES                                    │
     │                                   ▼                                       │
     │                            ┌──────────────┐                              │
     │                            │ DISPLAY AREA │                              │
     │                            │ CONSTRUCTION │                              │
     │                            │ OVER ZOOMED  │──────────────────────────────┤
     │                            │   IN AREA    │                              │
     │                            └──────────────┘                              │
     ▼                                                                          │
    ╱◆╲              ┌──────────────┐        ┌──────────────┐                  │
   ╱IF MENU╲  YES    │DEFINE AREA OF│        │  ENTER THE   │                  │
  ◆ CHOICE 5 ◆──────▶│ CONSTRUCTION │───────▶│ NAME FOR THE │                  │
   ╲       ╱         │ WITH MOUSE   │        │ CONSTRUCTION │                  │
    ╲◆╱             │   (r.digit)  │        │    AREA      │                  │
     │NO             └──────────────┘        └──────┬───────┘                  │
     │                                               │                          │
     │                                               ▼                          │
     │            ┌──────────────┐              ╱◆╲                            │
     │            │  START THE   │              ╱   ╲                          │
     ▼            │  EROSION2    │        NO    ╱NAME ╲                         │
    ╱◆╲   YES    │   MODULE     │◀────────────◆CORRECT?◆                        │
   ╱IF MENU╲─────▶│              │              ╲     ╱                         │
  ◆ CHOICE 6 ◆    └──────┬───────┘               ╲◆╱                           │
   ╲       ╱             │                         │YES                         │
    ╲◆╱                 ▼                         ▼                            │
     │NO            ┌─────┐              ┌──────────────┐                      │
     │              │  B  │              │ CONSTRUCTION │                      │
     │              └─────┘              │AREA CONVERTED│                      │
     │                                   │  TO VECTOR   │──────────────────────┘
     ▼                                   │CALLED: area.vector│
    ╱◆╲                                  └──────────────┘
   ╱IF MENU╲
  ◆ CHOICE 7 ◆──┐   ┌──────────────┐
   ╲       ╱    │   │ENTER COMMAND │
    ╲◆╱        └──▶│  FROM THE    │
     │NO            │  KEYBOARD    │
     │              └──────────────┘
     ▼
    ╱◆╲                                   ┌──────────────┐
   ╱IF MENU╲                              │  EXIT & QUIT │
  ◆ CHOICE 8 ◆────────124───────────────▶│ THE SOFTWARE │
   ╲       ╱                              │    SYSTEM    │
    ╲◆╱                                   └──────────────┘
```

```
                          ( B )

                    ┌─────────────────┐
                    │ RESET VARIABLES │
                    │    TO 0 FOR     │
                    │  after_grub AND │
                    │   before_grub   │
                    └─────────────────┘
                             │
                    ┌─────────────────┐              ┌──────────────┐
                    │    DISPLAY      │              │  RETURN TO   │
           ┌───────▶│    MENU1        │              │  MAIN MENU   │
           │        └─────────────────┘              └──────────────┘
           │                 │                              ▲
           │                 ▼                              │
           │            ◇ IF MENU ◇   YES  ┌──────────┐   ◇ CONSTRUCTION ◇   NO
           │            ◇ CHOICE 1 ◇─────▶│ EROSION  │──▶◇    AREA      ◇────┘
           │            ◇         ◇       │  AND     │   ◇  DEFINED?    ◇
           │                 │            │ LEGEND   │
           │                NO            │DISPLAYED │        │
           │                 │            └──────────┘       YES
           │                 │                                │
           │                 │                                ▼
           │                 │                         ┌──────────────┐
           │                 │                         │   EROSION    │
           └─────────────────┼─────────────────────────│      &       │
                             │                         │ CONSTRUCTION │
                             │                         │AREA DISPLAYED│
                             │                         └──────────────┘
                             ▼
                        ◇ IF MENU ◇   YES  ┌────────────┐   ┌────────────┐   ┌──────────────┐
                        ◇ CHOICE 2 ◇─────▶│NEW C FACTORS│──▶│  EROSION   │──▶│RECLASS OF NEW│
                        ◇         ◇       │ APPLIED FOR │   │ CALCULATED │   │ EROSION MAP  │
                             │            │  AREA OF    │   │ USING NEW  │   │FOR CONSTRUCTION│
                            NO            │CONSTRUCTION │   │ C FACTORS  │   │    AREA       │
                             │            └────────────┘   └────────────┘   └──────────────┘
                             ▼                                                      │
                           ( 1 )                                                    ▼
                                                                           ┌──────────────┐
                                                                           │ COLOR SCHEME │
                                                                           │ APPLIED TO NEW│
                                                                           │ EROSION MAP  │
                                                                           └──────────────┘
                                                                                   │
                                                                                   ▼
                                                                                 ( 2 )
```

```
                    ┌─────┐
                    │  3  │
                    └──┬──┘
                       │
                       ▼
          ◇ IF MENU        YES      ┌──────────────┐
          ◇ CHOICE 5  ────────────▶ │ ENTER NEW    │
          ◇                         │ MATERIAL/TECH.│
             │                      └──────┬───────┘
             │ NO                          │
             │                             ▼
             │         NO          ◇ CORRECT
             │      ◀──────────────◇  NAME?
             │                             │
             │                             │ YES
             │                             ▼
             │                   ┌──────────────┐
             │          ┌───────▶│ ENTER C FACTOR│
             │          │        │ FOR NEW       │
             │          │        │ MATERIAL/TECH │
             │          │        └──────┬───────┘
             │          │               │
             │          │               ▼
             │        NO ◇ CORRECT              BEFORE/          NO   ┌──────────┐
             │      ◀────◇ C FACTOR? ──────────◇ AFTER  ─────────────▶│ DISPLAY  │
             │                                  DISPLAY?               │ MENU1    │
             │                │                     │                 └──────────┘
             │                │ YES                 │ YES                   ▲
             │                ▼                     ▼                       │
             │       ┌──────────────┐      ┌──────────────┐                │
             │       │ NEW C FACTOR │      │ CALCULATE    │                │
             │       │ FOR NEW      │      │ AMOUNT OF    │                │
             │       │ MATERIAL/TECH│      │ EROSION      │                │
             │       │ APPLIED TO   │      │ BEFORE/AFTER │                │
             │       │ AREA         │      └──────┬───────┘                │
             │       └──────────────┘            │                        │
             │                                   ▼                        │
             │                           ┌──────────────┐                 │
             │                           │ DISPLAY      │                 │
             │                           │ BEFORE/AFTER │─────────────────┘
             │                           │ EROSION      │
             │                           └──────────────┘
             ▼
          ◇ IF MENU        YES      ┌──────────────┐
          ◇ CHOICE 6  ────────────▶ │ GO TO        │
          ◇                         │ MAIN MENU    │
                                    └──────────────┘
```

```
                        ┌───────┐
                        │   C   │
                        └───┬───┘
                            │
                            ▼
                  ┌───────────────────┐
                  │     DISPLAY       │◄──────────────────────────────┐
                  │  APPLICATION OF   │                               │
                  │   MULCHES MENU    │                               │
                  └─────────┬─────────┘                               │
                            │                                         │
                            ▼                                         │
                        ╱╲                 ┌──────────────┐           │
                      ╱      ╲    YES       │   EROSION    │           │
                    ╱ IF MENU  ╲──────────► │     AND      │───────────┘
                    ╲ CHOICE 1 ╱            │    LEGEND    │
                      ╲      ╱              │  DISPLAYED   │
                        ╲╱                  └──────────────┘
                         │ NO
                         │
                         ▼
                        ╱╲                 ┌──────────────┐      ┌──────────────┐
                      ╱      ╲    YES       │  USE MOUSE   │      │  APPLY NEW   │
                    ╱ IF MENU  ╲──────────► │ TO CHOOSE THE│─────►│  C FACTORS   │
                    ╲ CHOICE 2 ╱            │  AMOUNT OF   │      │   BASED ON   │
                    ╲STRAW/HAY╱             │  MULCH USED  │      │AMOUNT OF MULCH│
                      ╲      ╱              └──────────────┘      │  AND SLOPE   │
                        ╲╱                                        └──────┬───────┘
                         │ NO                                            │
                         │                                               ▼
                         │                                            ╱╲
                         │                                          ╱      ╲    NO
                         │                                        ╱ BEFORE/  ╲──────────┐
                         │                                        ╲  AFTER?  ╱          │
                         │                                          ╲      ╱            │
                         │                                            ╲╱                │
                         │                                             │ YES            │
                         │                                             ▼                │
                         │                                  ┌──────────────┐            │
                         │                                  │  CALCULATE   │            │
                         │                                  │ EROSION FOR  │            │
                         │                                  │APPLIED MULCH │            │
                         │                                  └──────┬───────┘            │
                         ▼                                         │                    │
                    ┌───────┐                                      ▼                    │
                    │   1   │                          ┌──────────────┐                 │
                    └───────┘                          │  DISPLAY ON  │                 │
                                                       │MONITOR EROSION│◄───────────────┘
                                                       │ BEFORE & AFTER│
                                                       │MULCH IS APPLIED│
                                                       └──────────────┘
```

130

```
                    ┌───────┐
                    │   1   │
                    └───┬───┘
                        ▼
      ◇ IF MENU          ┌──────────────┐      ┌──────────────┐
        CHOICE 2  ──YES─▶│ USE MOUSE    │─────▶│ APPLY NEW    │
        STONE            │ TO CHOOSE THE│      │ C FACTORS    │
                         │ AMOUNT OF    │      │ BASED ON     │
                         │ MULCH USED   │      │ AMOUNT OF    │
                         └──────────────┘      │ MULCH AND    │
                                               │ SLOPE        │
                                               └──────┬───────┘
                                                      ▼
                                               ◇ BEFORE/
                                                 AFTER?
                                                      │ YES
                                                      ▼
  ┌──────────────┐   ┌──────────────────┐   ┌──────────────┐
  │ DISPLAY MULCH│◀──│ DISPLAY ON       │◀──│ CALCULATE    │
  │ ANALYSIS     │   │ MONITOR EROSION  │   │ EROSION FOR  │
  │ MENU         │   │ BEFORE & AFTER   │   │ APPLIED MULCH│
  └──────────────┘   │ MULCH IS APPLIED │   └──────────────┘
                     └──────────────────┘
```

IF MENU CHOICE 2 STONE — YES — USE MOUSE TO CHOOSE THE AMOUNT OF MULCH USED — APPLY NEW C FACTORS BASED ON AMOUNT OF MULCH AND SLOPE — BEFORE/AFTER? — YES — CALCULATE EROSION FOR APPLIED MULCH — DISPLAY ON MONITOR EROSION BEFORE & AFTER MULCH IS APPLIED — DISPLAY MULCH ANALYSIS MENU

IF MENU CHOICE 2 WOOD — YES — USE MOUSE TO CHOOSE THE AMOUNT OF MULCH USED — APPLY NEW C FACTORS BASED ON AMOUNT OF MULCH AND SLOPE — BEFORE/AFTER? — NO — DISPLAY MULCH ANALYSIS MENU

BEFORE/AFTER? — YES — CALCULATE EROSION FOR APPLIED MULCH — DISPLAY ON MONITOR EROSION BEFORE & AFTER MULCH IS APPLIED — DISPLAY MULCH ANALYSIS MENU

IF MENU CHOICE 2 WOOD — NO — IF MENU CHOICE 5 — YES — ENTER COMMAND FROM KEYBOARD — DISPLAY MULCH ANALYSIS MENU

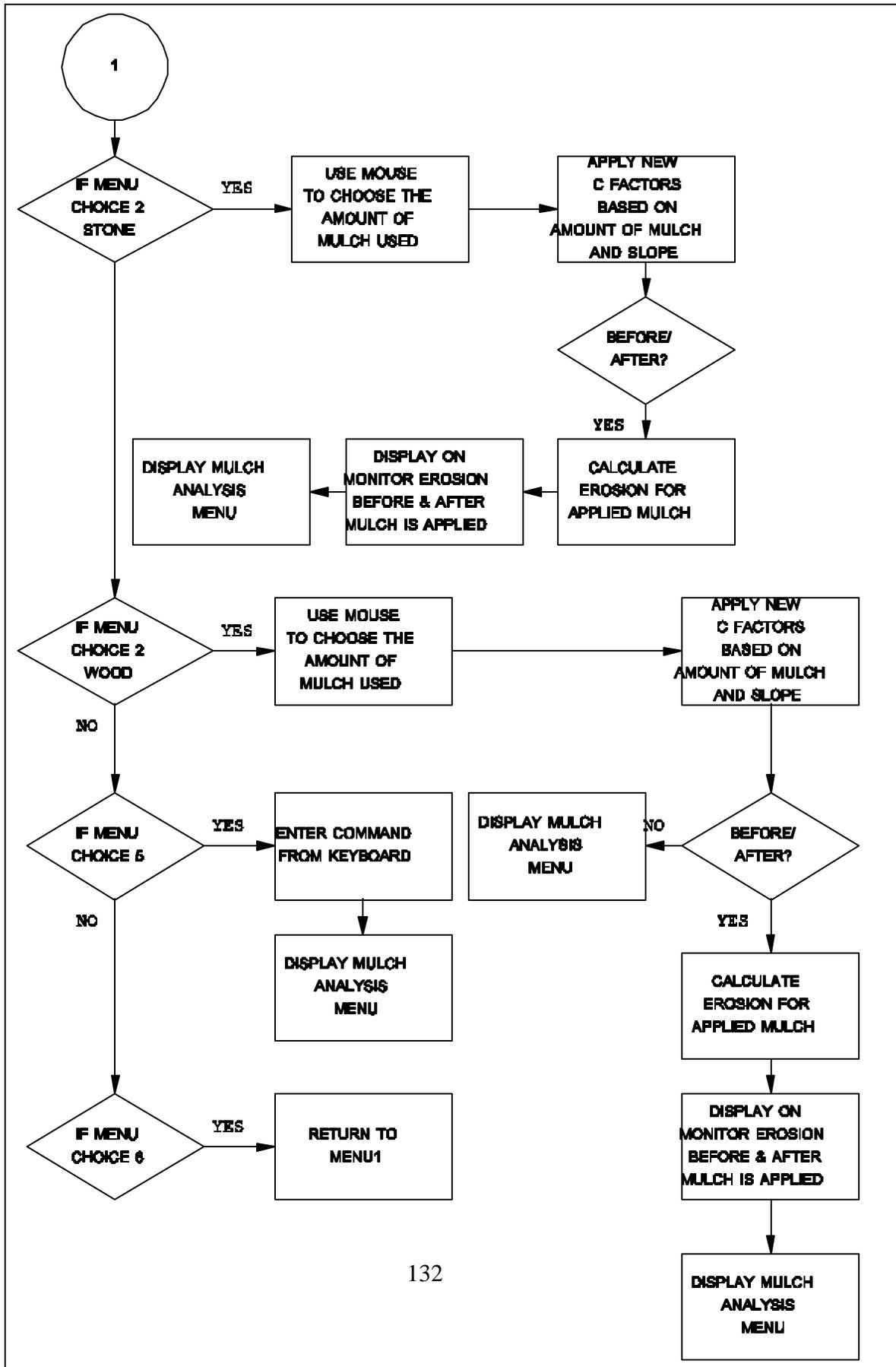IF MENU CHOICE 5 — NO — IF MENU CHOICE 6 — YES — RETURN TO MENU1

132

A GEOGRAPHIC INFORMATION SYSTEM TO PREDICT SOIL EROSION POTENTIAL IN RURAL TRANSPORTATION CONSTRUCTION PROJECTS

Sandra C. Parker, Professor
Industrial Engineering
University of Arkansas

David G. Parker, Professor
Civil Engineering
University of Arkansas

Thomas N. Stader, Graduate Assistant
University of Arkansas

Report submitted to

MACK-BLACKWELL NATIONAL RURAL TRANSPORTATION STUDY CENTER

and

ARKANSAS HIGHWAY AND TRANSPORTATION DEPARTMENT

June 30, 1995

ABSTRACT AND SUMMARY

Abstract

A graphic software system is designed and implemented to allow for the analysis of erosion potential on proposed highway construction sites. The system is based on Geographic Information System technology and allows for the consideration of erosion prevention products such as straw and other mulches as well as other types of cover products designed to prevent or minimize erosion from construction practices. The use of this system will allow for effective decisions concerning erosion control before construction has begun and erosion damage has already occurred.

Introduction

Topographic surface modeling using a Geographic Information System (GIS) can be useful for the prediction of soil erosion resulting from highway construction projects. The assumption is that terrain, along with other parameters, will influence the potential for soil erosion in a given area. Disturbance of the surface in highway construction will result in soil erosion and deposition, a source of pollution for streams and lakes. Modeling these various parameters with a GIS can provide an analysis tool for determining the potential for erosion

while construction is in the planning stage, thereby minimizing the deleterious effects of construction on water quality. The authors have designed and implemented a GIS based system which allows for predictive modeling of erosion potential and effectiveness of erosion control products for proposed highway construction projects.

Geographic Information Systems

A Geographic Information System is an information system that is designed to work with data referenced by spatial coordinates (Antenucci et al. 1991). A GIS provides an automated manner of collecting, storing, manipulating, combining, and displaying this data. A significant aspect of such systems is that they incorporate both a database for 'layers' of spatially referenced data, each representative of a spatial parameter of interest for analysis, as well as a set of operations for manipulating the data layers. Soil type, topography, and streams, for example, are spatial attributes that would be essential in a GIS database to be used for environmental analysis.

The data layers in a GIS are generally handled in one of two ways, either by a raster or a vector method. Raster data are represented by uniform grid cells of specified resolution, and data are stored as a matrix of cells. Vector data layers are handled as lines between points. Generally, operations involving these two types of data are primarily oriented to either raster structures or vectors, although a GIS usually incorporates algorithms that convert these structures from one to the other form depending on the actual system being used.

Geographic Resources Analysis Support System

The Geographic Resources Analysis Support System (GRASS) is the GIS that has been used in designing this system. GRASS is a public domain, general purpose, grid-cell based geographical modeling and analysis software package developed at the U.S. Army Corps of Engineers Research Laboratory. GRASS databases consist of three major forms, site or point, vector or line, and raster or grid. While the users of GRASS can model and conduct operations with vector data, it is primarily oriented to raster data.

Soil Erosion Models and the Universal Soil Loss Equation (USLE)

A variety of mathematical models to predict soil erosion have been proposed, and each is an attempt to represent the actual erosion process over a given time horizon. The USLE is one such model. It was originally developed for calculating field soil erosion losses for agricultural lands. The USLE is widely known and understood and is compatible with a raster-based GIS. Additionally, large databases for the application of this model, including such parameters as soil type and slope, were available for this research, therefore, the predictive system is based on the USLE.

The USLE is a mathematical model that is used to compute the longtime average soil losses from sheet and rill erosion under specified conditions and can be used for construction sites and other non-agricultural conditions. As a result of the unpredictable short-time changes in the levels of influential variables, the USLE is less accurate for prediction of specific events than for prediction of longtime averages. However, since the primary purpose of this research is dedicated to construction projects that take a large amount of time to complete, for example six months to a few years, specific events are not as great a factor, therefore the USLE is suitable for evaluating soil erosion for the present purpose.

Model and Components

The Universal Soil Loss Equation is given as follows (Wischmeier and Smith 1978):

$$A = R \times K \times L \times S \times C \times P$$

where:

A is the computed soil loss per unit area usually expressed in tons per acre per year,

R is the rainfall and runoff factor which quantifies the raindrop impact effect and provides relative information on the amount and rate of runoff likely to be associated with the rain. The map layer for this factor is a secondary map produced from an isoerodent map for the state (Wischmeier 1959),

K is the soil erodibility factor which is a secondary map derived from the primary data layer of soil type,

L and S are combined into a secondary map layer called slope length. This factor reflects the steepness and length of the land from which the entire slope length drains into a particular spot and is derived from another secondary map, slope, which is derived from a topographic map of the study area,

C is the cover and management factor which comes from land use and land cover from such things as vegetative canopies and trees,

and P is the support practice factor used primarily in croplands. In general, the value for P will usually equal 1.0 for construction sites because the erosion-reducing effects of shortening slopes or reducing slope gradients are accounted for through the LS factor (Wischmeier and Smith 1978).

System Design for Erosion Prediction

The erosion prediction software system is based on GRASS as the underlying GIS and uses the USLE to calculate erosion potential. It runs on a SUN work station under the X

Windows System which is a network-based graphics window system. The software developed to predict erosion takes into account construction practices and erosion prevention measures and uses the existing GRASS databases as the source of the primary data layers and some secondary data layers, such as slope. Other secondary data layers are derived from primary data layers, such as slope length from elevation (McKimmey 1994).

The system uses both primary data layers and secondary data layers to conduct an erosion estimate for a proposed construction path or area as defined by the user for a session with the software. The initial erosion estimate is based on the present conditions of the proposed path. The system provides numerical data in the form of tons per acre per year as well as providing graphic representation of this data on the screen. The graphic output is a color coded raster map of the area of interest, along with a color legend which allows the user to identify portions of the area that have the same potential for erosion. Each color is assigned to a class of erosion potential, arranged from the lowest to the highest. Highway construction procedures, such as clearing and grubbing, may be defined for the proposed area, and the system will respond with a new calculation of erosion potential considering the procedure and a new color raster map indicating the erosion potential for each raster in the area, as well as numeric data which indicates the new predicted erosion potential.

After a proposed area is defined for construction procedures, i.e. clearing and grubbing, the user of the system can conduct analyses concerning possible use of several different erosion control products. Those products that may be used for ground cover and are presently built into the system are mulches of straw, crushed stone or wood chips. The user may choose one of three different straw mulches (1, 1.5, or 2 tons per acre), or two different crushed stone mulches (135 or 240 tons per acre), or one of three different wood chip mulches (7, 12, or 25 tons per acre). After the selection of a particular mulch type and amount, the system recomputes the USLE by incorporating the cover factor (C, as defined above) for the mulch instead of the cover factor for the actual ground cover at present. The cover factors for these mulches have been computed and are given in (Wischmeier and Smith 1978). By doing such analyses, the user can decide on an effective ground cover for reducing or preventing erosion in the proposed construction area.

Conclusions

The use of such a system based on GIS can be a valuable tool in evaluating erosion potential and recommending appropriate ground covers. As cover factors for new erosion prevention products become available, they can be used with the present system by virtue of its being designed for the input of user-defined erosion control products, such as soil conditioners, stabilizing emulsions, erosion control blankets, and other such products, provided that there is access to effectiveness data for these various products. Such analyses allow for effective decisions regarding construction paths before work has begun and damage from erosion has already occurred.

Appendix I. References

Antenucci, J. C., Brown, K., Croswell, P. L., and Kevany, M. J. (1991). *Geographic Information Systems: A Guide To The Technology*, Van Nostrand Reinhold, NY.

McKimmey, J. M. (1994). *Prediction and Management of Sediment Load and Phosphorous in the Beaver Reservoir Watershed Using A Geographic Information System*, Masters Thesis, University of Arkansas, Fayetteville, AR.

Wischmeier, W. H. (1959). "A Rainfall Erosion Index for a Universal Soil Loss Equation". *Soil Science Society of America Proceedings* 23.

Wischmeier, W. H. (1978). *Predicting Rainfall Erosion Losses*, U.S. Department of Agriculture, Agriculture Handbook 537.