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# THE USE OF LANDSAT DIGITAL DATA AND COMPUTER IMPLEMENTED TECHNIQUES FOR AN EROSION HAZARD-REFORESTATION NEEDS ASSESSMENT

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# THE USE OF LANDSAT DIGITAL DATA AND COMPUTER IMPLEMENTED TECHNIQUES FOR AN EROSION HAZARD-REFORESTATION NEEDS ASSESSMENT

By

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## I. Introduction

This report is one of a series of reports that address a project conducted by the NASA Earth Resources Laboratory and the State of Mississippi Office of Science and Technology in cooperation with other State of Mississippi Agencies. The overall project is entitled "Natural Resources Inventory System ASVT" (Applications System Verification and Transfer), and has two facets. One facet involves the transfer of technology associated with the use of Landsat (formerly Earth Resources Technology Satellite) digital data and computer implemented techniques for resource inventory. The other facet encompasses the demonstration of various specific applications for which the system has utility. This particular report addresses the use of Landsat digital data and computer implemented techniques for a demonstration of erosion hazard-reforestation needs assessment. Other reports in this series will address applications such as wildlife habitat assessment, crop production estimation, and campground site selection.

Specifically, this report addresses computer implemented techniques for (1) deriving land cover information from multispectral scanner data acquired by the Landsat satellite, (2) geographically referencing land cover information to soils, topographic, and rainfall information digitized from existing source maps, and (3) the use of the modified Musgrave's equation for soil loss prediction. It is anticipated that the output will be useful for (1) assessing the overall erosion hazard in a given watershed, (2) adding efficiency to field surveys conducted to locate areas in need of reforestation for erosion control, and (3) to provide input to a model which would permit resource managers to predict the possible result of change in land use with respect to future erosion problems.

If the system described in this report were to be implemented by a state or state agency, it is anticipated that it would be implemented to address various applications in addition to erosion hazard-reforestation needs assessment. In so doing, the same information digitized from source maps (e.g., soils, slope) for use in this application could also be used for forest management, wildlife management, site selection, and other applications.

In the case of the erosion hazard-reforestation needs assessment being addressed in this report, the demonstration area was three townships in Yalobusha County, Mississippi.

Yalobusha County is situated in north central Mississippi, and contains two major man-made water bodies - Enid and Grenada Lakes. Of the 322.6 thousand acres in the county, 57% (184.5 thousand acres) is considered commercial forest land with the remainder used mainly for agronomic crops and pasture. With the exception of the Holly Springs National Forest and wetlands areas upstream from the lakes, land use patterns show an intermingling between forestry, agronomic crop, and grazing land uses.

## II. Data Processing Procedures and Results

The intention of this report is to address the use of this Natural Resource Inventory System for the erosion hazard-reforestation application in a step-by-step manner corresponding to how data would actually be processed through the system. In order to facilitate this approach, it will be necessary for the reader to periodically refer to Figure 1 which shows the data flow. Also, in order to allow the reader to keep his train-of-thought as to the procedure, this report will not elaborate on the system details that are covered in other literature cited.

After acquisition of computer compatible tapes (CCT's)[1] that contain the raw data acquired by the multispectral scanner on the Landsat satellite, the first step in data processing involves the use of a module of six computer programs developed at the Earth Resources Laboratory and named PATREC (Pattern Recognition Analysis). The basic function of the PATREC programs is to effect a computer implemented classification of each "pixel" which represents 1.1 acres on the earth's surface, for which data has been acquired by the multispectral scanner on the Landsat satellite. This "classification" results in each 1.1 acre area being categorized as some land cover category, e.g., forest, pasture, cropland, etc.

The computer programs comprising ERL's PATREC module relate to the "supervised" technique, and the classifier algorithm is based

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[1]Computer compatible tapes are available at the EROS Data Center, Sioux Falls, S.D. at a cost of $200 per set of four. Also see Landsat User's Manual.

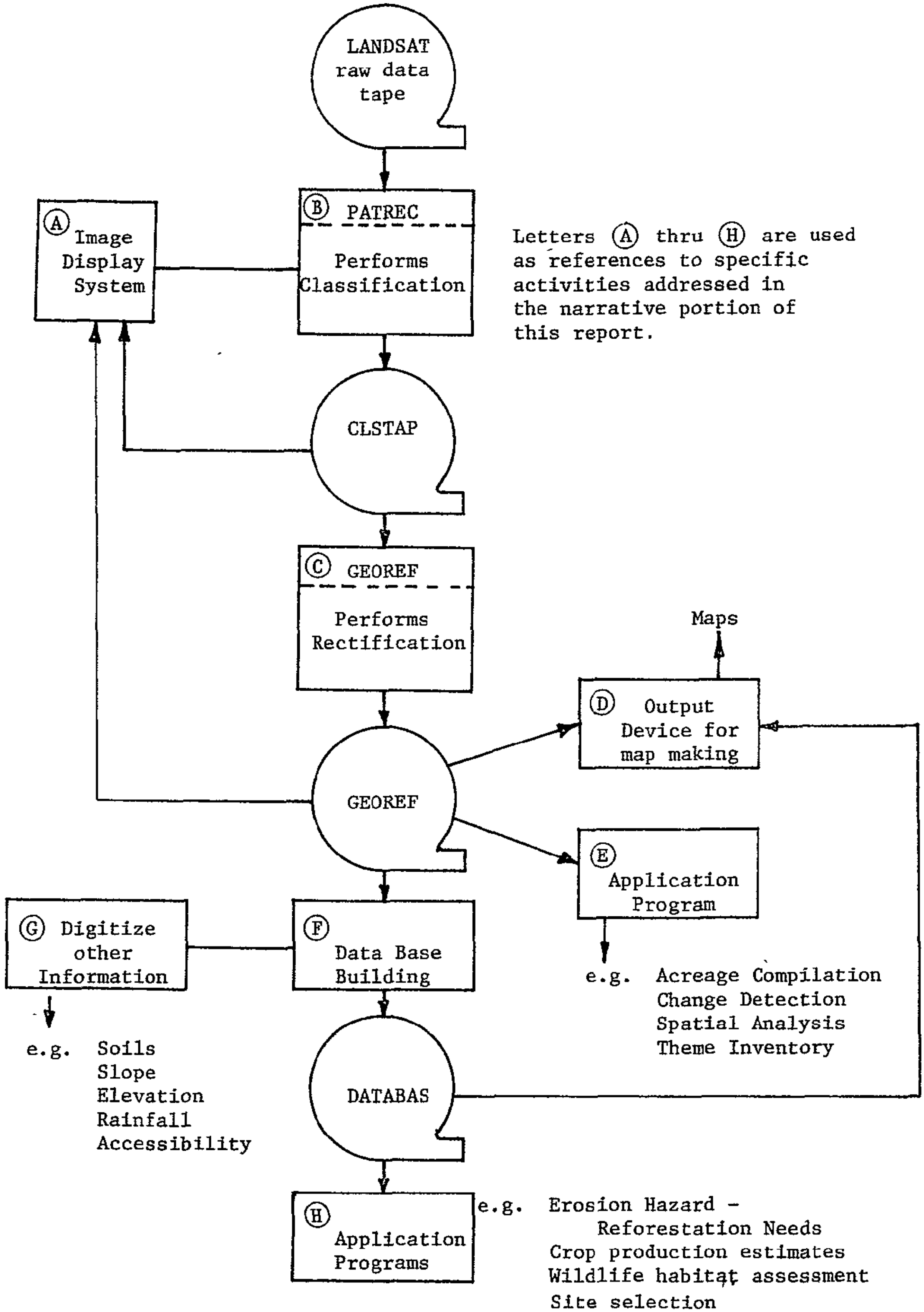


Figure 1. Data Processing Flow Dagram.

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on maximum likelihood ratio calculation and Bayesian decision rules. (See Whitley, S. L., 1975 and Jones, C., 1974 for basic theory and details.) The supervised technique requires that the location of a number of areas within which the land cover material is known (e.g., an oak forest) be established in the data. These areas which are selected to contain a uniform homogeneous land cover (e.g., an oak forest that is uniform in respect to age, density, slope category, etc.) are called "training sample sites" because, in a simplistic sense, they are eventually used to "train" the computer to recognize the same land cover elsewhere.

The potential "training sample sites" are established independently from the data processing operation. They may be pre-selected through photo interpretation, if some relatively recent (up to 5 years old) photography is available, and subsequently visited on the ground, or they may be located through direct field observations. In the case of this work, both methods were used in that the forest training sample areas were preselected using two-year-old Color IR photography at a 1:120,000 scale and then visited on the ground, whereas pasture and crop training samples were located through direct ground observations. The activity associated with ground observations is usually referred to as a "ground truth" operation, and involves verifying the fact that the potential training sample site is uniform and homogeneous with respect to the land cover category that it was picked to represent, and involves recording certain observations about the training sample area on a ground truth data form (See Appendix A for some examples of ground truth data forms). Usually, the size of each potential training sample site is about 40 acres. The number of training samples needed varies with the number of land cover categories to be classified and the variation within each category. However, as an example, if twelve land cover categories were to be classified within a 115 statute mile by 115 statute mile area that relates to a set of 4 CCT's from a particular Landsat scene, one may, as a rule-of-thumb, expect to encounter variation in each land cover category that may result in a total of from 100 to 140 potential training sample areas being selected.[2]

Usually the boundary of each potential training sample site is outlined on a recent black and white air photo print or a suitable map (e.g., 7½ min. series topo map).

The exact procedures and details of the ground truth activities for training sample site establishment for this project are treated in a separate document (Joyce, A. T., 1977). However, in summary, the training sample sites for this application demonstration were established as part of a state-wide ground truthing activity that was organized to furnish ground truth for all applications being demonstrated during the project as well as for a quasi-operational test of the system on a State-

[2]Using this example, one can calculate that 40 acres times 140 training samples would amount to less than one one-thousandth's of the 8½ million acres encompassed by one Landsat scene (4 CCT's) being within training sample areas relating to the twelve categories.

of-Mississippi computer.

The total statewide effort was conducted by county agricultural extension agents, county foresters, wildlife biologists, botanists, park managers, and geologists of the various cooperating Mississippi agencies. There were a total of 189 state agency personnel involved in the statewide ground truthing effort. The bulk of the field observations were made during the course of field personnel's routine work as opposed to a separate effort.

The potential "training sample sites" were related to the satellite acquired data contained on CCT's through the use of an image display system shown as Activity A in Figure 1. Various types and makes of image display systems are available for this operation, but most display the image on a CRT (Cathode Ray Tube) similar to a home television set. (See Whitley, S. L., 1976 for several devices that have been used at the NASA Earth Resources Laboratory). The particular image display system used for this application demonstration was a computer interactive system. As individual tapes were mounted and the image was displayed on the CRT, the operator matched the image on the CRT with the air photo or map on which the training sample sites were outlined. In order to identify the location of a particular training sample site in the data, the operator positioned a movable cursor in the shape of a plus-sign on the CRT on each corner of the training sample site, after which the coordinates (scan line count and element count) were automatically recorded in a computer memory for use in the implementation of subsequent computer programs in the PATREC module. Activity B on Figure 1 includes the implementation of six computer programs that perform different functions in the PATREC module, and includes both human and machine analysis to produce tapes labeled CLSTAP in Figure 1. In the case of this application demonstration, the actual classification of the data for scene 2030-15552 was accomplished through a technique known as geographic signature extension. The possibility for employing geographic signature extension arises in a situation where two or three cloud-free scenes of data are acquired on a particular pass under uniform atmospheric conditions over the area of concern. This situation is most often encountered when the passage of a strong cold weather front precedes a Landsat pass by one or two days. Such a situation was encountered on February 21, 1977 at the time that data was needed for this demonstration. Consequently, it was decided to use this opportunity to demonstrate the results of geographic signature extension in the context of this application demonstration. In this particular case,. signatures were developed for each vegetation/ land cover class using tapes corresponding to Landsat scene E2030-15561; then, these signatures were used to derive a land cover classification for the demonstration area which was located within Landsat scene E2030-15552 about 110 miles uptrack from the set of tapes used for signature development.

The reader should, therefore, be conscious of the fact that whenever results are mentioned, they are based on land cover classes derived through the geographic signature extension technique.

Tapes produced at this point contain information as to the computer implemented classification (land cover category) of each pixel (1.1 acre area on the ground) that fell within the geographic area to which the tape pertains. Each tape encompasses about 2.1 million acres and relates to the same 115 mile by 28 mile geographic area contained on the original CCT's. However, the data contained on tapes produced at this point are not geometrically corrected to fit a given map projection.

Activity C in Figure 1 uses Tape CLSTAP as input and involves the use of two computer programs in the GEOREF (geographic referencing) module developed at NASA-ERL. The function of these two computer programs is to perform a rectification of the data. The rectification takes place by registering each pixel to the UTM (Universal Transverse Mercator) projection. The actual procedure involves the determination of both UTM Northing and Easting coordinates and Landsat data scan line and element coordinates for three to ten points distributed over the four tapes in each Landsat scene. The operation was performed by visually matching the image displayed on the CRT of the image display device mentioned earlier with a map constructed with a UTM projection and determining the coordinates for three to ten surface features (e.g., intersection of roads, bridges over water bodies) that are apparent on both the image and the map. The method involves the use of the control point coordinates input on cards and a formula involving a least squares solution to perform the registration. In the course of registering each and every pixel to the UTM projection, the informational content that corresponds to each 1.1 acre pixel is resampled and interpolated to fit a 50 meter by 50 meter cell (¼ hectare or 0.62 acres) through the "nearest neighbor" approach. The rectification can be performed for a 1 degree latitude by 1 degree longitude area (about 4000 square miles) during one computer run. In the course of rectifying data for a $1^{o}$ by $1^{o}$ area, which usually relates to portions of three or more CLSTAP tapes, all data are brought to one tape. The end result is a tape indicated as GEOREF on Figure 1 that relates to a 4000 square mile area and contains the land cover computer implemented classification in 50 meter by 50 meter cells with sides oriented to the cardinal directions in a grid referenced to a UTM projection. (See Pendleton, T. W., 1976). The tapes produced in this manner are used for mapmaking (Activity D in Figure 1), and as a data source for data base building (Activity E in Figure 1). The data on the tapes can also be displayed as a classified image on the CRT of the image display device mentioned earlier for visual analysis.

The geographically rectified land cover information on the GEOREF tape was then used to produce a map at a scale of approximately 1:125,000 through the use of the density plot/ Cromalin technique. (See Whitley, S. L., 1976 for details on this process as well as an explanation of other means of producing color coded maps from digital data.) This map product was then mounted on a layout board and, after lettering and legend color chips are affixed, the layout board was photographed and printed at the 1:125,000 scale for project participants and in 8½" X 11" format for this report (See Figure 2).

In viewing Figure 2, the reader should understand that the color assignment is completely arbitrary. For example, although blue was assigned to cells classified as water, any color could have been assigned to water. In addition, since the human eye cannot comfortably deal with more than twelve colors, it is common practice to aggregate the specific land cover types that were classified and for which information exists on the GEOREF tape into broader categories during the map-making operation. It is also possible to use the same GEOREF tape used to produce the map product for Figure 2 and create different land cover groupings by simply providing different instructions at the time that the digital data contained on the GEOREF tape is converted to a map product.

In addition to the flexibility for making various types of color-coded maps with digital data on the GEOREF tapes, there is also the option of making maps at various scales. As one example of this option, the same GEOREF tape used to make the 1:125,000 map (a reduced version of which is shown in Figure 2) was used to make maps of the three demonstration townships

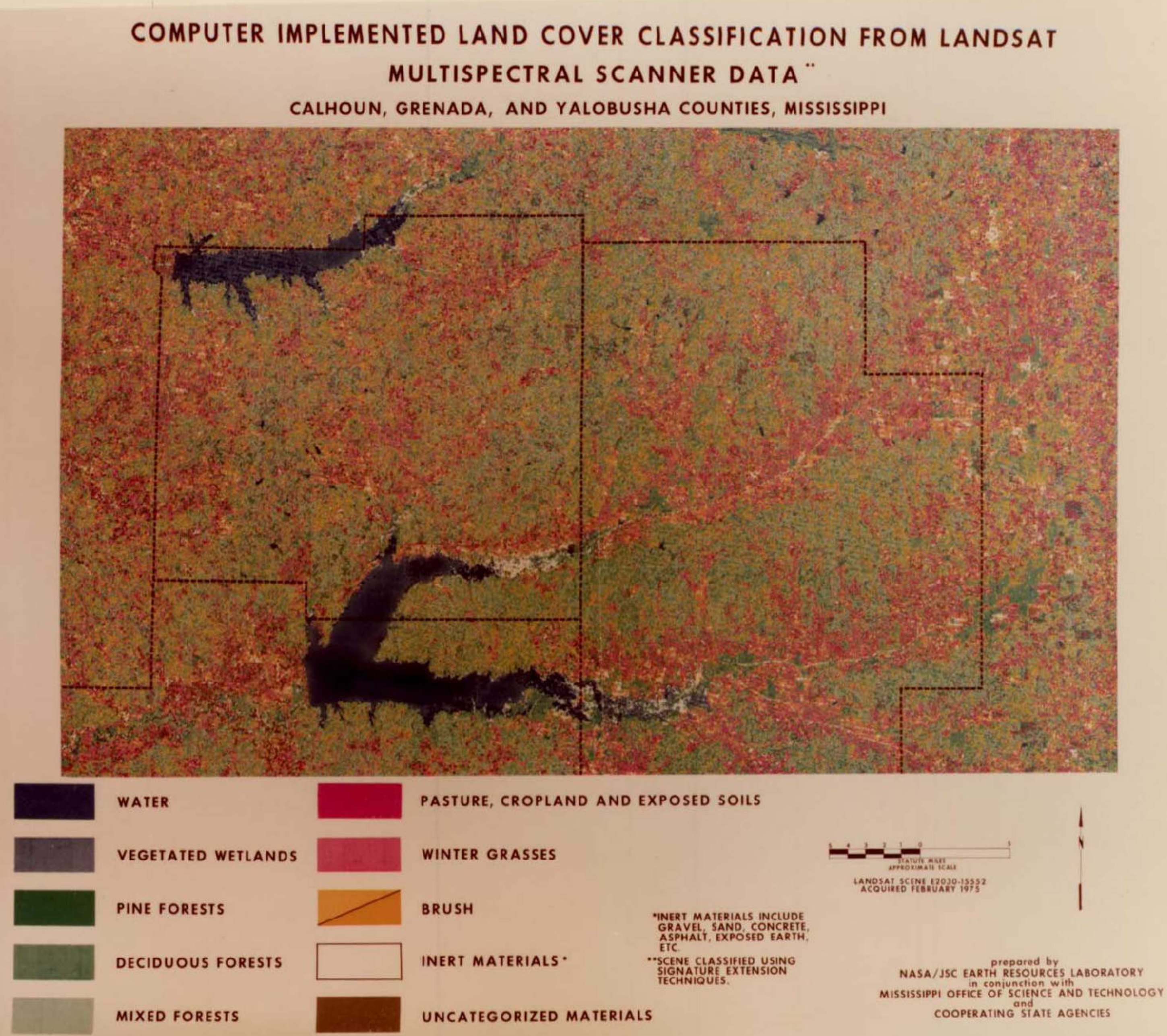
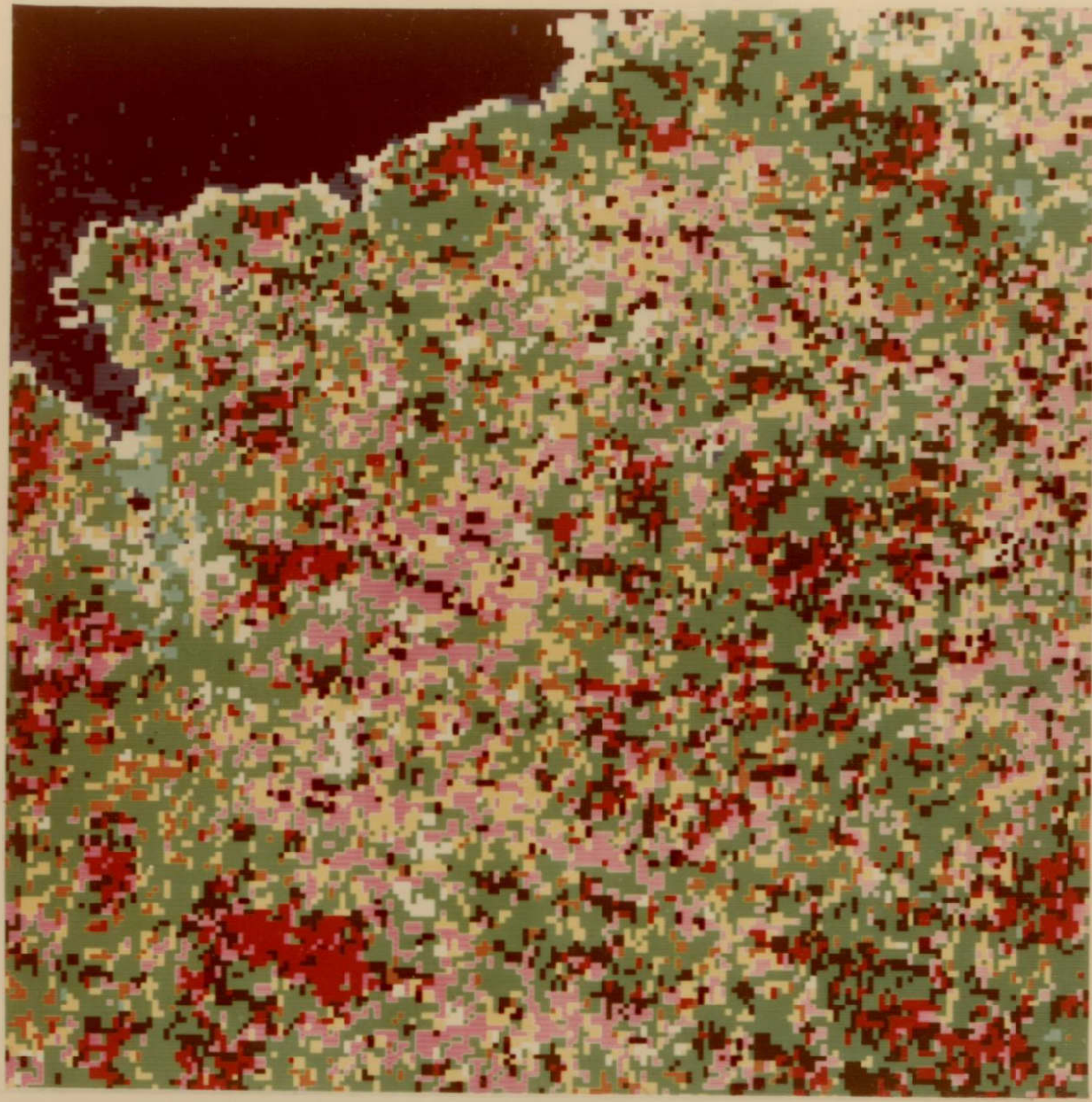

COMPUTER IMPLEMENTED LAND COVER CLASSIFICATION FROM LANDSAT
MULTISPECTRAL SCANNER DATA**
CALHOUN, GRENADA, AND YALOBUSHA COUNTIES, MISSISSIPPI
WATER
VEGETATED WETLANDS
PINE FORESTS
DECIDUOUS FORESTS
MIXED FORESTS
PASTURE, CROPLAND AND EXPOSED SOILS
WINTER GRASSES
BRUSH
INERT MATERIALS*
UNCATEGORIZED MATERIALS
*INERT MATERIALS INCLUDE GRAVEL, SAND, CONCRETE, ASPHALT, EXPOSED EARTH, ETC.
**SCENE CLASSIFIED USING SIGNATURE EXTENSION TECHNIQUES.
STATUTE MILES
APPROXIMATE SCALE
LANDSAT SCENE E2030-15552
ACQUIRED FEBRUARY 1975
N
prepared by
NASA/JSC EARTH RESOURCES LABORATORY
in conjunction with
MISSISSIPPI OFFICE OF SCIENCE AND TECHNOLOGY
and
COOPERATING STATE AGENCIES

Figure 2.

in Yalobusha County, at a scale of 1:63,360 (See Figures 3, 4, and 5). This was accomplished by following the same procedure as was followed for the 1:125,000 map but by using a larger expansion factor during density plot preparation. In density plots of digital data, expansion involves the expanding of the data electronically (e.g., a 2 X expansion outputs the intitial data four times), and does not involve any degradation of an image as takes place in photographic enlargement. However, the positional accuracy of the data does not change with different scales selected for map products.

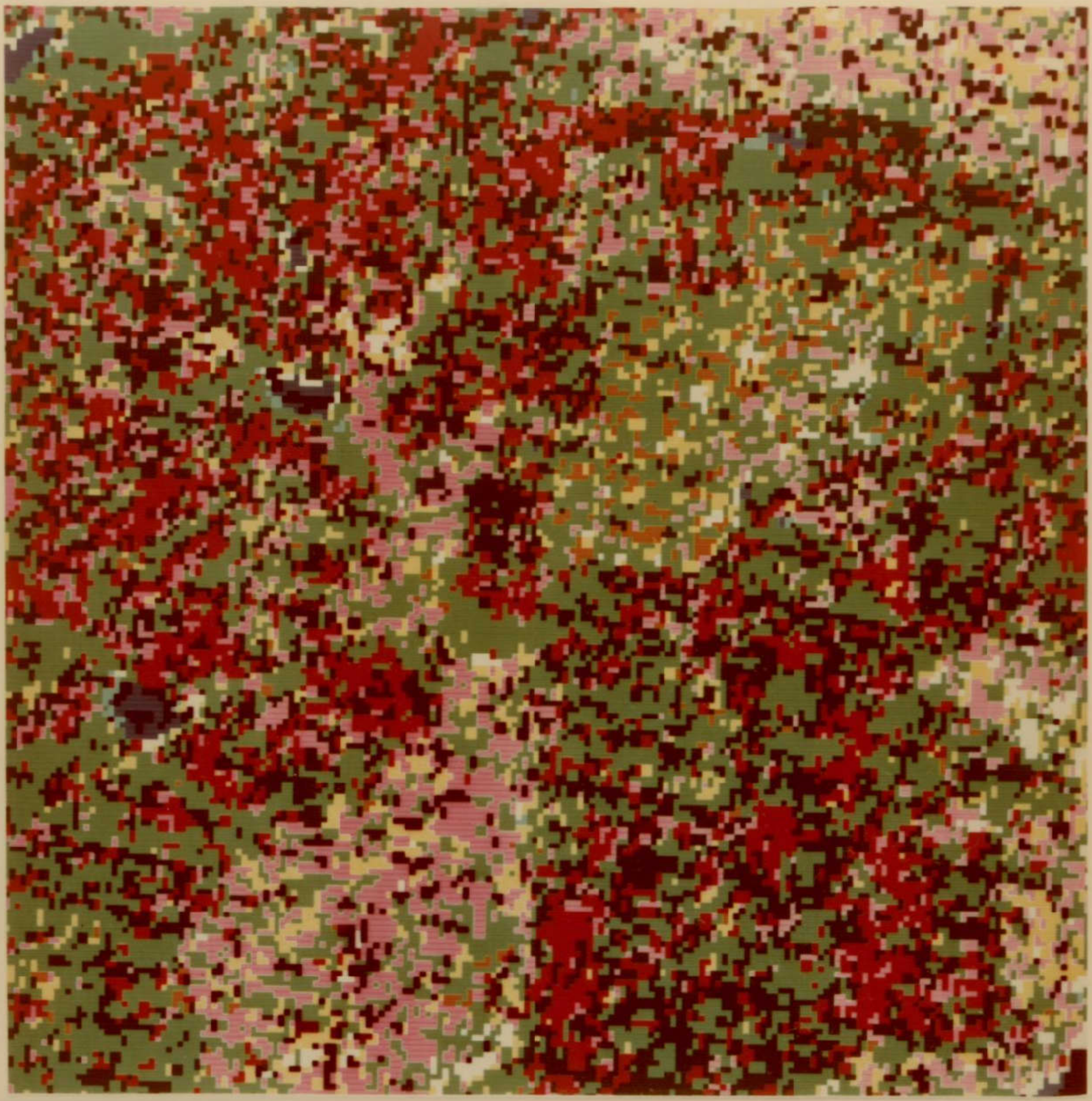
In addition to the use of the GEOREF tapes for making map products, the tapes can also be used as a data source for various application programs (shown as Activity E in Figure 1) which are used to extract and/or manipulate data on the tape for specific purposes. In the course of this application demonstration, only one of these special-purpose computer programs, "acreage compilation by land cover category", was demonstrated.

This computer program works in a manner that the UTM (northing, easting) coordinates defining the boundary of any polygon circumscribed unit (e.g., a county, a watershed, a township) are input with punched cards so as to allow a computer tally to show the acreage encompassed by each land cover type classified within the circumscribed land unit. The line printer output of the program shows the number of 50 meter by 50 meter cells, the percentage and square miles in each



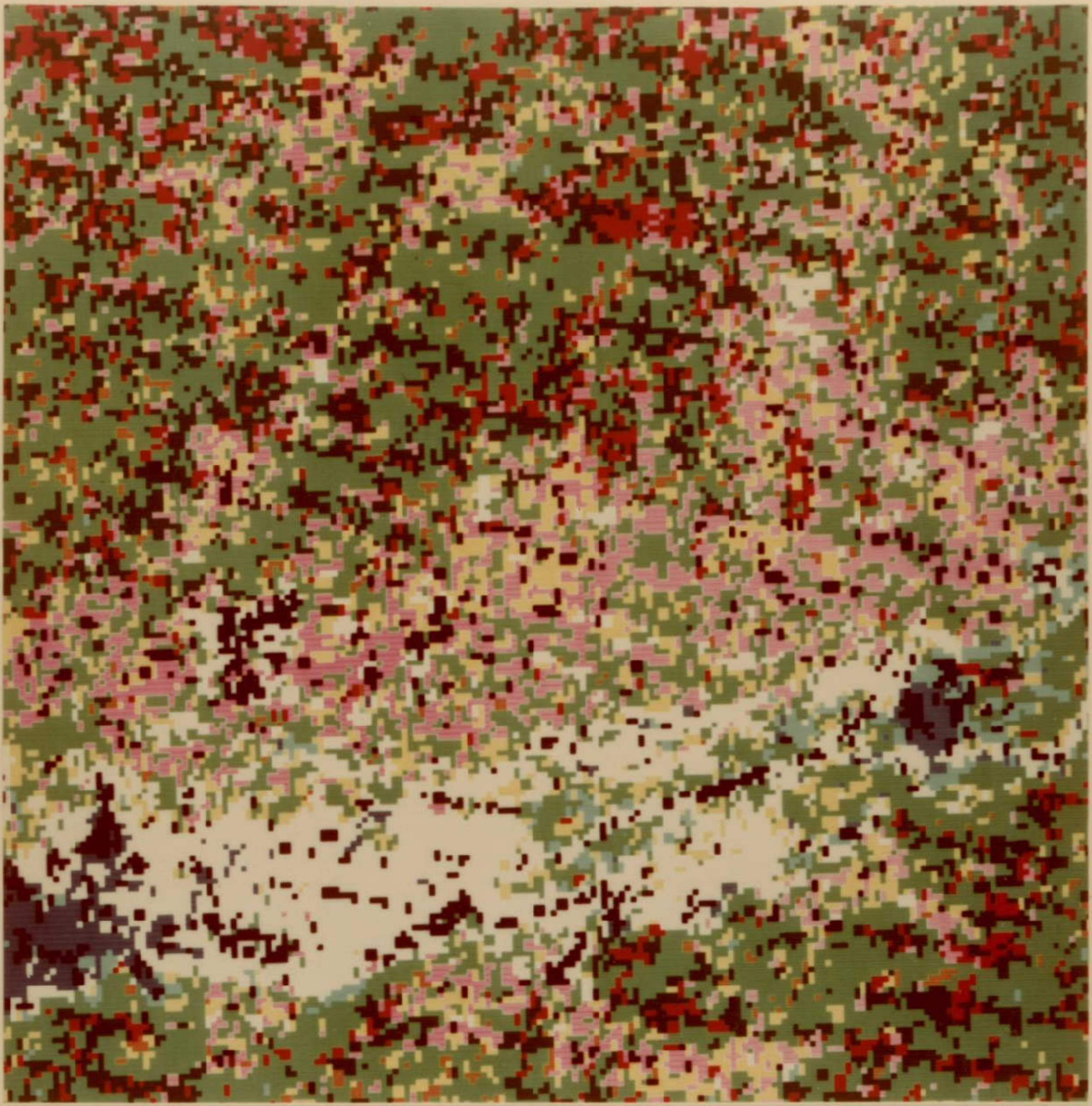
| | |
|---|---|
| BLUE | WATER |
| LIGHT BLUE | VEGETATED WETLANDS |
| GREEN | DECIDUOUS FORESTS |
| DARK GREEN | MIXED FORESTS |
| RED | PINE FORESTS |
| BROWN | BRUSH |
| PINK | WINTER GRASSES |
| YELLOW | PASTURE AND CROPLAND |
| WHITE | INERT MATERIALS |
| BLACK | UNCATEGORIZED MATERIALS |

Figure 3. Computer Implemented Land Cover Classification of Township 11 South, Range 5 West, Yalobousha County, MS.



| | |
|---|---|
| BLUE | WATER |
| LIGHT BLUE | VEGETATED WETLANDS |
| GREEN | DECIDUOUS FORESTS |
| DARK GREEN | MIXED FORESTS |
| RED | PINE FORESTS |
| BROWN | BRUSH |
| PINK | WINTER GRASSES |
| YELLOW | PASTURE AND CROPLAND |
| WHITE | INERT MATERIALS |
| BLACK | UNCATEGORIZED MATERIALS |

Figure 4. Computer Implemented Land Cover Classification of Township 24 North, Range 5 East, Yalobousha County, MS.



| | |
|---|---|
| BLUE | WATER |
| LIGHT BLUE | VEGETATED WETLANDS |
| GREEN | DECIDUOUS FORESTS |
| DARK GREEN | MIXED FORESTS |
| RED | PINE FORESTS |
| BROWN | BRUSH |
| PINK | WINTER GRASSES |
| YELLOW | PASTURE AND CROPLAND |
| WHITE | INERT MATERIALS |
| BLACK | UNCATEGORIZED MATERIALS |

Figure 5. Computer Implemnted Land Cover Classification of Township 24 North, Range 7 East, Yalobousha County, MS.

land cover type in addition to acreage in each land cover type.

The acreage compilation program was implemented for the 3 townships selected for the potential erosion hazard-reforestation needs assessment application demonstration. The resulting acreage calculations by land cover type are shown in Table 1. The class referred to as "uncategorized" in Table 1 includes those land cover classes for which signatures were not developed and/or were outside the imposed statistical level of confidence. The bulk of the uncategorized acreage for Twp. 11 South, Range 5 West corresponds to water areas within the lake in the upper left corner in figure 3 for which signatures were not developed.

The next major activity in the data processing flow (Activity F in Figure 1) involves data base building, the purpose of which is to integrate land cover information from the GEOREF tapes with information that is digitized from other sources. Although it will become obvious later in this paper, the reader should be aware at this point that the objective of the data base building activity is not to create a data bank containing all conceivable information. Rather, it is concerned with the efficient access of information required by the applications programs (Activity H in Figure 1).

The design of the computer programs developed at NASA/ERL provides for two options for data base building. One option is called the "gridded option" in which the land cover information from the GEOREF tapes and any information digitized

TABLE 1 - Acreage Compilation for Three Townships in Yalobusha Co., MS

| Class | ACREAGES Twp. 11S, Rge. 5W | Twp. 24N, Rge. 5E | Twp. 24N, Rge. 7E |
|---|---|---|---|
| Agriculture | 4419 | 4316 | 3888 |
| Forest | 15381 | 17903 | 16053 |
| Water | 281 | 146 | 499 |
| Inert | 683 | 280 | 2221 |
| Uncategorized | 2577 | 510 | 917 |
| TOTALS | 23340 | 23154 | 23578 |

from other sources, e.g., soils maps, is assigned to cells that are subdivisions of the UTM grid in multiples of 50 meters. The other option, called the "non-gridded" option, allows the UTM gridded information on the GEOREF tapes to be input to the data base for units of the public land survey system (e.g., the forty-acre subdivisions of a given section) by identifying the center Northing/Easting UTM coordinate of each unit. Although either option may be used in addressing various applications for a particular land area that has been surveyed by the public land survey system, it is anticipated that the "gridded option" would usually be used for land areas surveyed by "metes and bounds."[3] The advantage of using the "non-gridded option" for public land surveyed areas has to do with the relationship of ownership to the use of land. For example, a farmer may buy forty acres as defined by the boundaries of the NW¼ of the NW¼ of Section 33, Township 9 South, Range 6 West and subsequently decide to plant that entire forty to a specific crop. Likewise a logging operation in a forested area is likely to be conducted for a specific "forty" as defined by the public land survey. However, since the size of the cell is optional (in even multiples of 50 meters up to 400 X 400 meters) the advantage of the non-gridded approach is progressively less as cell sizes smaller than forty acres are elected. For either option, gridded or non-gridded, the

[3]Most land areas in the United States west of Ohio, with the exception of Texas, have been surveyed with the public land survey system.

design of the data base provides for storing up to thirty elements of information (variables) for each of the cells.

It was anticipated that six of these variables would be land cover information extracted from GEOREF tapes including four land cover classifications made with data acquired during each of the four seasons of the year, one land cover classification derived by merging the four seasonal classifications, and one land cover classification used to address temporary phenomena, e.g., flooding. The remaining twenty-four variables would include locational and other-than-land-cover information such as soils, slope, elevation, etc.

As mentioned earlier in this paper, the size of the cell can be any multiple of fifty meters up to 400 by 400 meters (approximately 40 acres). The choice of cell size, made prior to implementation, must take account of the combined effect of various factors. Among the factors are (1) the accuracy of the information other than the land cover information derived from satellite acquired data, e.g., soils maps; (2) the cost and effort involved in digitizing map source information for a particular cell size; (3) the size of the land area to be addressed as would relate to computer disc memory capacity, data storage, and retrieval time, (4) the accuracy needed for the applications to be addressed and decisions to be made in the ultimate use of the information, and (5) the positional accuracy in the GEOREF tape data. It is anticipated that the resulting choice will usually result in a data base cell size of 200 meters by 200 meters (approximately 10 acres) or larger being chosen for statewide data bases. In the case of the Mississippi data base design, a forty-acre cell was chosen which would result in about 30 million elements of information (1 million cells times 30 variables) if 30 variables were to be stored for the entire state. This information could be stored on two computer compatible tapes, one for the area east of $90^{o}$ longitude and one for the area west of $90^{o}$ longitude.

No particular digitizing method is assumed for the digitizing of information other than land cover information (Activity G in Figure 1). Anyone familiar with digitizing land cover information (which is dynamic and ever-changing) from maps would discount the use of manual techniques. However, this system does not involve digitizing land cover from maps because the data is in digitial form from the start. Consequently, one may wish to employ manual techniques for the digitizing of such stable variables as soils, slope, elevation, aspect, average annual rainfall, etc., for which baseline information would be digitized only once in a life time. However, one who chooses to employ a system that revolves around using satellite acquired digital data for land cover information, may also choose, as part of the system, a semi-automated method (X Y digitizer) of digitizing other information such as soils.[4]

[4]This statement is not to imply that an either/or choice must be made in respect to use of satellite-acquired digital data for land cover information, because the data base building computer programs can be employed in a manner that ground acquired information can be input for small areas, e.g., urban areas, small parks, etc., with reliance on satellite coverage for the bulk of the land area.

In addition to digitizing map source information, an X Y digitizer could be used effectively for the digitizing of northing/easting UTM coordinates that define areas of special interest for which "Acreage by land cover" compilations are to be made from the GEOREF tapes. It is not anticipated that anyone other than agencies that engage in nation-wide digitizing of information would employ more sophisticated methods of digitizing.

In the case of this particular application demonstration, the non-gridded data base building option was utilized. This involved determining the northing/easting UTM coordinate in the center of each "forty" in each of the 3 demonstration townships as defined by the public land survey system. The data base building computer program takes the coordinate information as card input and functions in a manner that a "forty" mid-point is located on a GEOREF tape and a 7-cell by 7-cell matrix of 50 meter cells around each midpoint is examined to determine the predominant land cover for each "forty".

In addition to the predominant land cover type for each "forty", the digitized slope and soils mapping unit were read into the data base. Slope for each "forty" was determined from 7½' topo maps using a transparent "slope scale". This scale was used to determine the average slopefor the 10 acre area of greatest slope within each "forty" which was then digitized. Soils information was digitized from SCS county soils maps.

The final step in the data processing flow of this application demonstration was to use one of the special purpose computer programs to which the data base was designed to feed information (Activity H in Figure 1). In this case, the main function of the computer program was to integrate land cover information with soils, slope, and rainfall factors in such a manner that the potential erosion hazard for all "forties" within the three demonstration townships could be calculated. This was accomplished through the implementation of the computer version of the Modified Musgrave's Equation.

In its basic form, the Modified Musgrave's Equation is:

$$E = KCR \frac{(S)^{1.35}}{10} \frac{(L)^{.35}}{(72.6)}$$

where E - Sheet erosion in tons/acre/year
K = Soil erodability value
C = Cover factor (Crop Management Factor)
R = Rainfall Index
S = Land Slope in Percent
L = Length of Slope in Feet

Actual values for each of the independent variables (right hand side of the equation) were obtained from an SCS publication (USDA-SCS, 1963). The soils erodability value (K) varies with soil type and expresses a relative "erodability potential" index. Soil types encountered in this study and their corresponding K values are presented in Table 2.

The cover factor (sometimes referred to as the crop management factor) relates to the capacity of the cover type to prevent or suppress erosion. Bare soil has a "C" value of 1.0, which, when taken in context with its functions as a linear multiplier in the Modified Musgrave's Equation, represents the least amount of erosion protection or suppression possible. All

TABLE 2 -- Soils Erodability Values for Soils Encountered in the 3 Township Demonstration Areas.

| Data Base Code | Soil Type | "K" |
|---|---|---|
| 142 | Ariel silt loam, occasionally flooded | .32 |
| 143 | Arkabutla silt loam, occasionally flooded | .32 |
| 144 | Arkabutla silt loam, frequently flooded | .37 |
| 145 | Bonn silt loam | .49 |
| 148 | Calloway silt loam, 0 to 2% slopes | .49 |
| 150 | Cascilla silt loam, frequently flooded | .43 |
| 151 | Collins silt loam, occasionally flooded | .43 |
| 152 | Collins silt loam, frequently flooded | .43 |
| 153 | Deerford complex, 0 to 2% slopes | .37 |
| 154 | Gillsburg silt loam, occasionally flooded | .43 |
| 155 | Gillsburg silt loam, 0 to 2% slopes | .43 |
| 157 | Grenada silt loam, 2 to 5% slopes | .43 |
| 158 | Loring silt loam, 2 to 5% slopes, eroded | .37 |
| 159 | Loring silt loam, 5 to 8% slopes, eroded | .37 |
| 160 | Loring silt loam, 5 to 8% slopes, severely eroded | .37 |
| 162 | Loring silt loam, 8 to 12% slopes, severely eroded | .37 |
| 163 | Loring Complex, gullied areas | .37 |
| 168 | Oaklimeter silt loam, occasionally flooded | .43 |
| 169 | Oaklimeter silt loam, frequently flooded | .43 |
| 170 | Providence silt loam, 2 to 5% slopes, eroded | .37 |
| 171 | Providence silt loam, 5 to 8% slopes, eroded | .37 |
| 172 | Providence silt loam, 8 to 15% slopes, eroded | .37 |
| 174 | Providence-Smithdale Complex, 8 to 12% slopes, severely eroded | .37 |
| 176 | Providence-Smithdale Complex, gullied areas | .32 |
| 177 | Providence-Smithdale Association, hilly | .32 |
| 178 | Sweatman-Smithdale Association, hilly | .32 |

other "C" values are less than 1.0 (but non-negative) and hence, when incorporated into the basic equation, serve to reduce the predicted soils loss. The land cover categories as derived from Landsat data for this study, with their corresponding "C" values are presented in Table 3.

Rainfall index (R) for the entire county was given as 350 (USDA-SCS, 1963). This value relates the duration and intensity of storms over a time period to their ability to cause erosion of exposed soils. The larger the "R" value, the greater the ability to create erosion.

Land slope (S) was derived, as was previously mentioned, from 7½' topographic maps using a slope scale. It was decided to find the worst 10 acre area in each "forty" (with respect to percent slope) and use this value as the "S" factor in equation (1) when the predicted erosion was calculated. In addition, slope length was established as 660', which corresponds to one side of the 10 acre area used to determine the slope percent.

The actual computer program may compute two values for potential erosion (E) for any particular "forty". The first calculation assumes that there is no vegetative cover on a particular area and hence sets "C" = 1.0. The resulting calculation of "E" reflects a "baseline" erosion potential for the soil type, slope, etc. for that particular forty. This value for "E" is compared to a "critical" value of

TABLE 3 -- "C" Values for the Land Cover Categories Used In this Demonstration.

| Land Cover Category | "C" |
|---|---|
| Forest, Dense (70% to 100%) | .001 |
| Forest, Sparse (10% to 70%) | .004 |
| Pine Plantations (less than 20% covered) and Brushland | .014 |
| Pasture/Grass, Dense (40% to 100%) | .02 |
| Pasture/Grass, Sparse (10% to 40%) | .20 |
| Cropland | .35 |
| Barren/Extractive | 1.0 |

erosion (set at 25 tons/acre/year for this demonstration). If it is less than this critical value (which may be changed) computation ceases, for the critical value defines that point above which reforestation is to be considered. Since the "baseline" value for "E" was calculated with maximum "C" (1.0), any inclusion of land cover would reduce "E". Unless specific values for each forty are desired (which would result in a voluminous amount of computer output), such a recalculation of "E" with the true "C" value is unnecessary. No printout is made at this time. If the calculated value of "E" is greater than the critical value when "C" = 1.0, the computer prints the township and forty number, incorporates the true "C" value, and recalculates "E". If, at this time, the recalculated "E" falls below the critical value, the computer moves on to the next forty. If on the other hand, "E" still exceeds the critical value, the computer "flags" the forty by printing out the calculated "E" value. This procedure is repeated until all forties in the area of interest have been examined. An example output is included as Table 4. This output shows a potential erosion hazard. These numbers, ranging from 1 to 8, refer to various ranges of predicted soil losses and are used to simplify the output. The corresponding predicted erosion range values used are given in Table 5.

TABLE 4 -- Output from Applications Software Designed for the Reforestation-Erosion Potential Demonstration.

| Township Code [1] | Forty Number [2] | Potential Erosion Hazard [3] | (Soil Loss Calculated in Tons/Acre/Year)[4] |
|---|---|---|---|
| 996 | 305 | 8 | |
| 996 | 306 | 8 | |
| 996 | 307 | 8 | |
| 996 | 308 | 6 | |
| 996 | 309 | 8 | |
| 996 | 310 | 8 | |
| 996 | 311 | 8 | |
| 996 | 312 | 8 | |
| 996 | 313 | 8 | |
| 996 | 314 | 8 | ** Erosion Hazard - 5 Calculated Soils Loss = 30. |
| 996 | 315 | 8 | |
| 996 | 318 | 7 | |
| 996 | 319 | 7 | |
| 996 | 320 | 8 | |
| 996 | 322 | 8 | ** Erosion Hazard - 5 Calculated Soils Loss = 27. |
| 996 | 323 | 8 | ** Erosion Hazard - 5 Calculated Soils Loss = 30. |
| 996 | 324 | 8 | ** Erosion Hazard - 8 Calculated Soils Loss = 40. |
| 996 | 325 | 8 | |
| 996 | 326 | 8 | |
| 996 | 327 | 8 | |

[1] Townships are identified with a code rather than with the public land survey designation. In this example, township 996 is Twp. 11S, Rge. 5W.

[2] "Forties" are coded according to the scheme shown in Figures 6, 7, and 8.

[3] "C" value equals 1 (bare soil).

[4] "C" value corresponds to actual land cover.

TABLE 5

Potential Erosion Hazard Values and Their

Assigned Erosion Potential Ranges

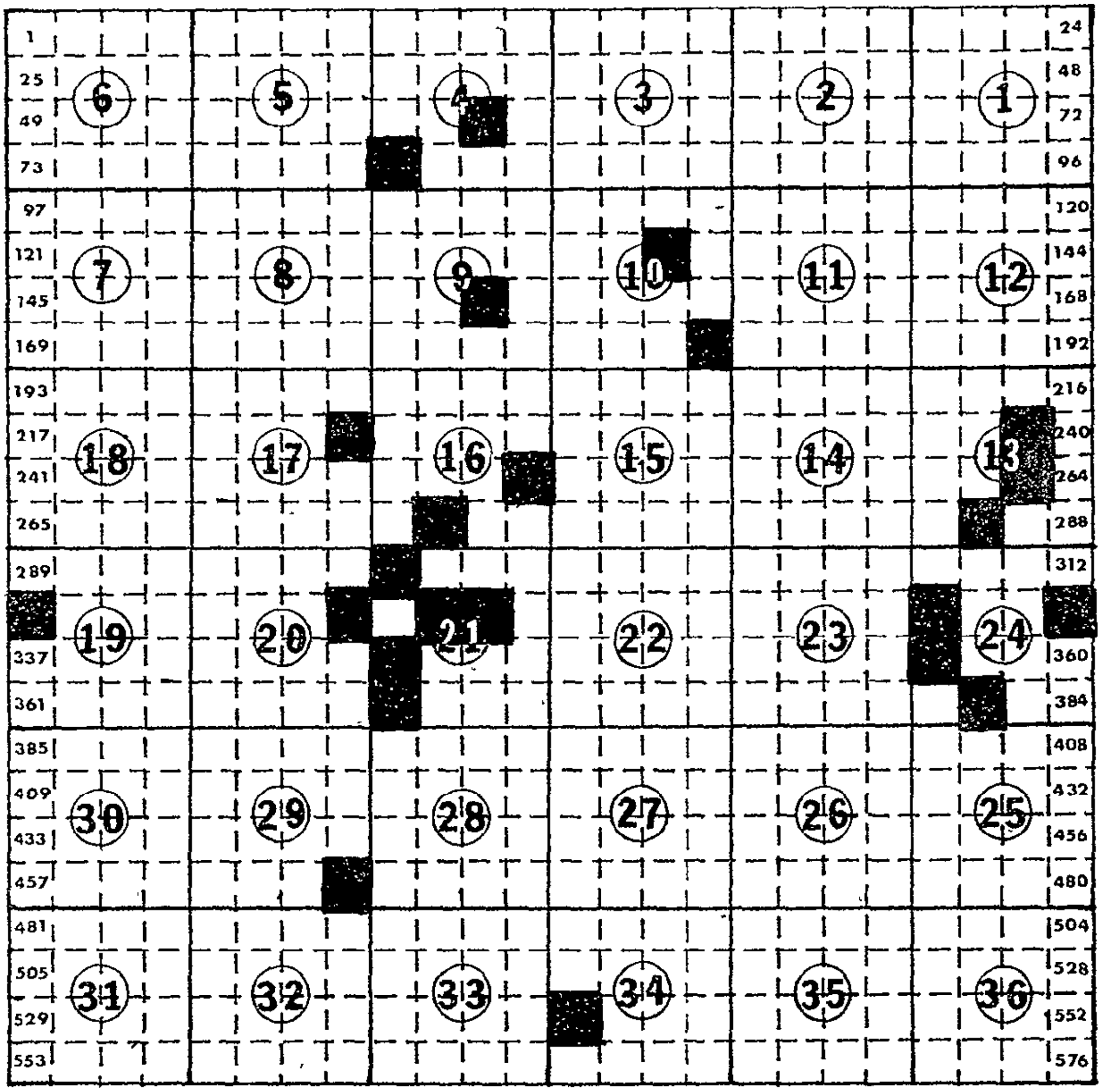
| | Potential Erosion Hazard | Potential Erosion Range (T/AC/YR) |
|---|---|---|
| | 1 | 0 - 10 |
| | 2 | 10 - 15 |
| | 3 | 15 - 20 |
| | 4 | 20 - 25 |
| ↑ CRITICAL ↓ | 5 | 25 - 30 |
| | 6 | 30 - 35 |
| | 7 | 35 - 40 |
| | 8 | 40+ |

In addition, on the output shown, the critical value was set at 25 tons/acre/year (potential erosion hazard = 5), such that all forties with potential erosion hazards of 5 or greater were flagged (after incorporation of the true "C" value). This value, as well as the potential erosion hazard ranges were specified for this demonstration and could be changed to a different value by simply replacing one input card.

The results of the complete output for the 3 townships are presented in Figure 6, 7, and 8. In these figures, those forties "flagged" by the computer as exibiting a potential erosion hazard with actual land cover as previously described are shaded. The figures also indicate the scheme for computer coding of "forties" within a township. It is expected that these figures would be used in conjunction with field maps to determine the actual reforestation needs in the field. While the computer flags forties, areas less than this may actually be in need of reforestation, since slope related features were developed for a 10-acre sub-unit of the "forty". However, by directing the field personnel to a specific "forty", the utility of the system would be reflected in a significant reduction in the cost of field operations.

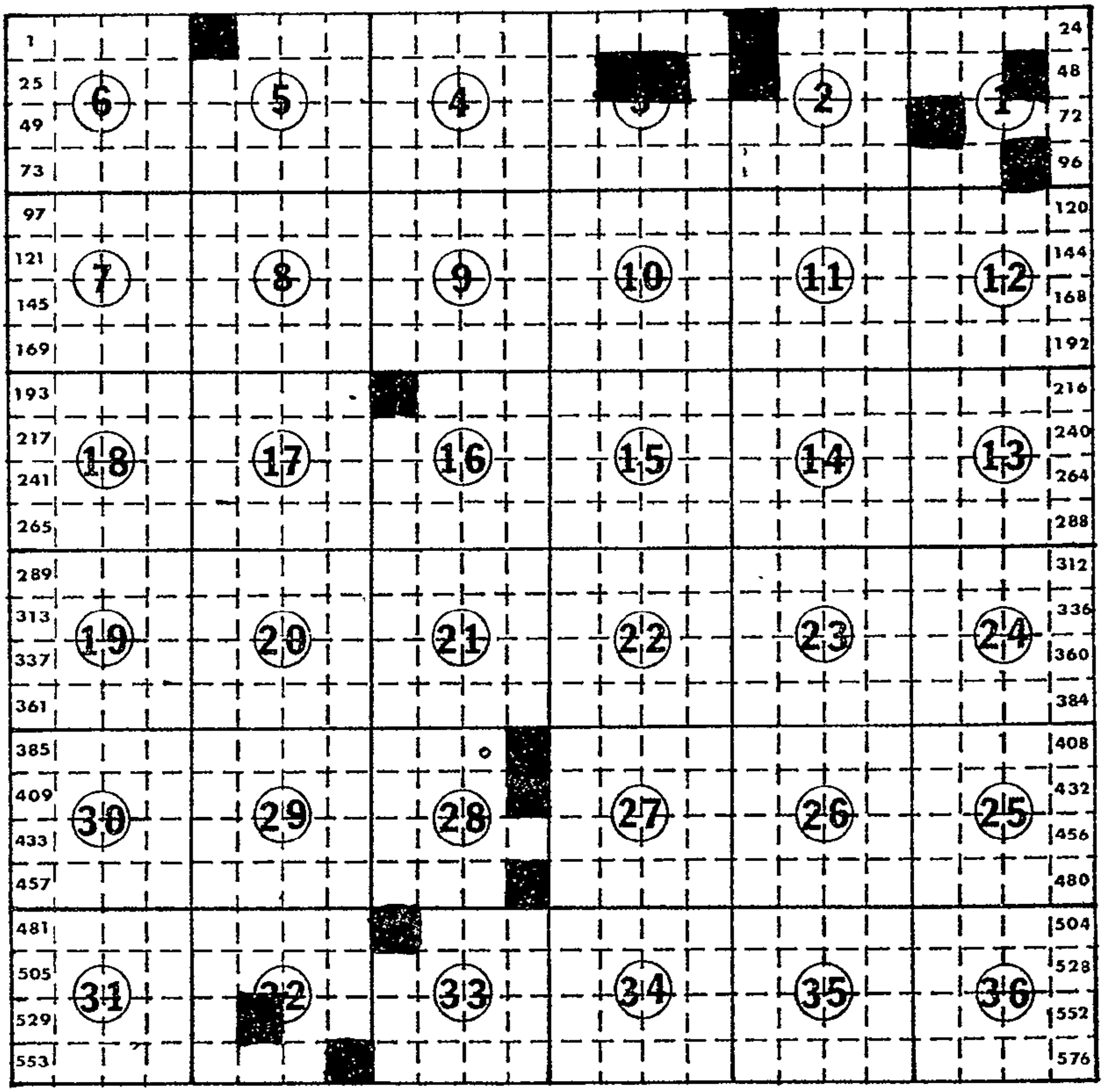
Several additional calculations can be made at this time, based on the information pertaining to the three townships, which point out some interesting relationships between the variables in the modified Musgrave's equation. Two cases will be considered:

FIGURE 6 -- Chart showing forties (shaded squares) that were flagged for field examination of reforestation needs in Twp. 11S, Rge. 5W.



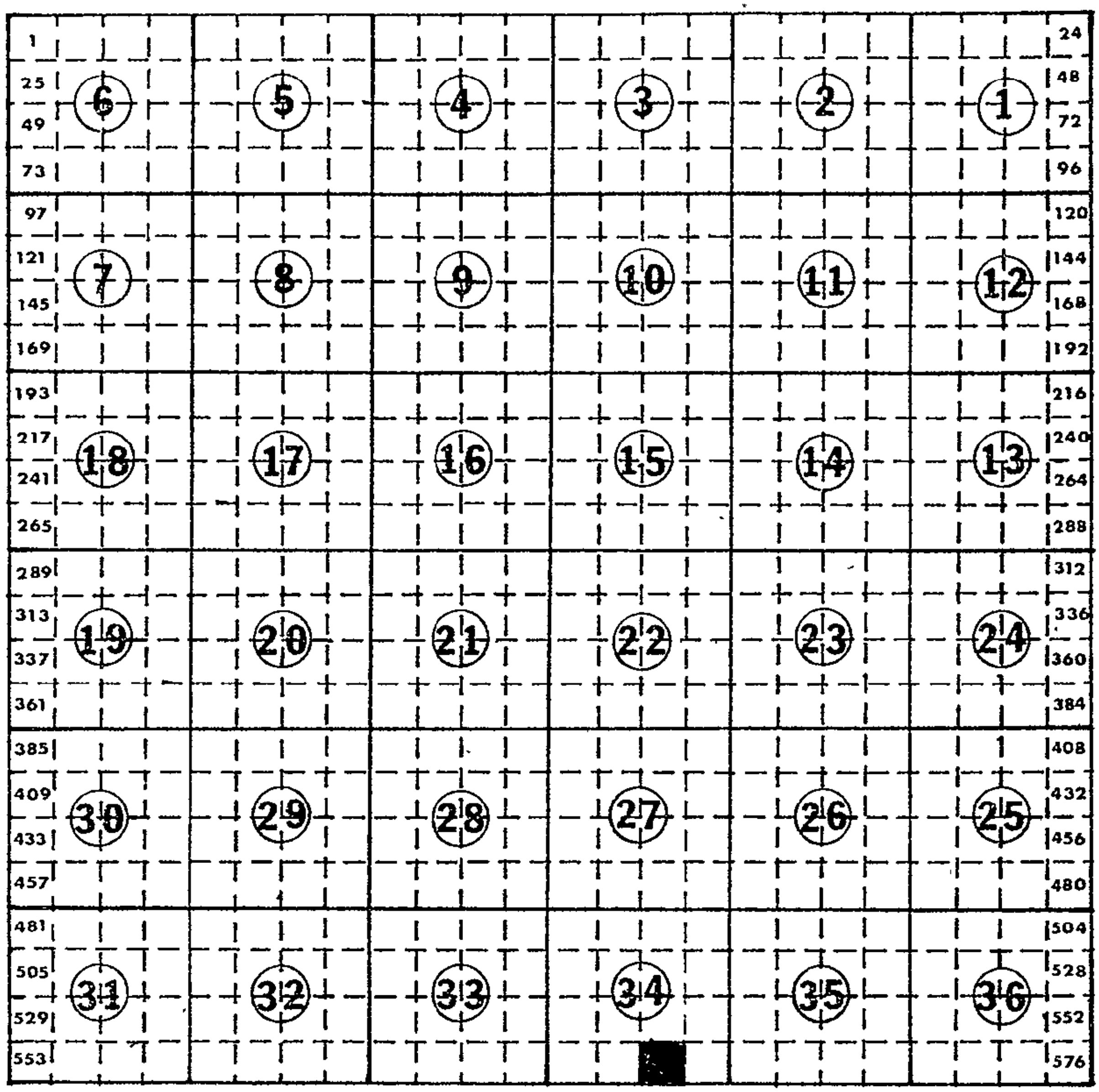

NOTE: Circled numbers are section numbers.

FIGURE 7 -- Chart showing forties (shaded squares) that were flagged for field examination of reforestation needs in Twp. 24N, Rge. 5E.




NOTE: Circled numbers are section numbers.

FIGURE 8 -- Chart showing forties (shaded squares) that were flagged for field examination of reforestation needs in Twp. 24N, Rge. 7E.




NOTE: Circled numbers are section numbers.

Case I

Given K = .49 (implies high erosion potential)
R = 400
S = 50%
L = 660'

Solve for "E" (sheet erosion in tons/acre/year)

When:

| C = | .001 | .004 | .014 | .02 | .2 |
|---|---|---|---|---|---|
| E = | .515 | 2.059 | 7.208 | 10.297 | 102.968 |

It should be noted in this case that all variables (K, R, S) were set to maximum with respect to influencing the amount of expected erosion. Even so, the only "C" value which would cause "E" to exceed the 25 tons/ac/yr critical value is 0.20 (or greater). This includes sparse pasture/grass (.20), cropland (.35) and Barren/Extractive (1.0). So for all forties in the three townships, the computer could only flag sparse pasture/grass, cropland, and barren/extractive land cover types.

Case II

Given: E = 25 t/ac/yr
K = .49
R = 400
L = 660

Solve for "S" (slope expressed as %)

When:

| C = | .001 | .004 | .014 | .02 | .20 |
|---|---|---|---|---|---|
| S = | 887 | 318 | 125 | 96 | 18 |

In the case of this demonstration area where slopes of greater than 50% were not encountered, the land slope becomes a critical factor (for E = 25 tons/acre/year) when the "C" value reaches .20 (same as in Case 1). This means that only croplands, pasture/grass (sparse), and barren/extractive areas would be flagged due to a slope manifested problem (even under the artificially poor conditions as imposed by the values of the other variables). Increasing "E" to values greater than 25 tons/acre/year will correspondingly increase allowable maximum slope in the above case.

From the above two cases, it can be concluded that only those areas designated as sparse pasture/grass, cropland, or barren/extractive will be flagged in the townships investigated as being in need of reforestation, due to high predicted erosion levels.

## III. Product Adequacy Assessment

The accuracy of the land cover classification was determined as follows.

First, the predominant land cover was photo interpreted using 1:120,000 scale color IR photography for every fifth "forty" in the three townships used in the demonstration. The resulting categorization of each "forty" was then compared with the results that were extracted from the GEOREF tapes and read into the data base through use of the computer programs mentioned earlier in this report. During this comparison, each "forty" for which there was disagreement between the photo interpretation and the Landsat data as to land cover category was flagged. The second step was to make a random selection of 10% of all "forties" flagged for each type of disagreement, and to locate these "forties" on 1:24,000 scaled maps for field verification. In all cases, the field verification revealed that one of the two sources (Landsat or aerial photography) was correct (as opposed to neither one being correct); substantiating that those "forties" in agreement and, therefore, not field checked, had a high probability of being categorized as the actual land cover. Results of the field verification were incorporated into results of the first step to arrive at an estimated composite land cover classification accuracy of 81%. After products had been generated for this demonstration, various Mississippi agencies were briefed on the results. Map products were disseminated along with an evaluation form which, among other things, asked the evaluators to assess the land cover classification accuracy. All evaluators who were able to address this question responded that the overall classification accuracy was better than the 81% estimate indicated by the ERL assessment.

The use of geographic signature extension techniques as was done for this demonstration can have two effects: (1) a reduction in cost, and (2) a possible reduction in classification accuracy. Consequently, conclusions on the adequacy of the geographic extension technique must be based on an analysis of the cost and accuracy trade-offs relative to a specific application. Such an analysis can be conducted for this project to illustrate a procedure by using costs that were developed in a research environment (as opposed to an operational activity) and extending results demonstrated for three townships to the area encompassed by the Landsat scene.

Past experience at ERL shows the total cost for producing a land cover classification on tape for an entire Landsat scene using standard procedures to range between $5,106 ($0.39/sq. mile) and $7,227 ($0.55/sq. mile), depending on the degree of ground truthing difficulty; and the classification accuracy to be 90% or better for the classification level required for this application (Joyce, A. T. and Derbonne, J. D., 1975; Anonymous, 1975; Joyce, A. T. and Griffin, R. H., 1976). The cost for producing a land cover classification of an entire scene using the geographic signature technique as used for this demonstration was calculated to be $3,117 ($0.24/sq. mile).

Extending the 13 "forties" indicated as being in need of reforestation in the 3 townships (figures 6, 7, and 8) to an entire Landsat scene indicates that 4,784 "forties" would be indicated for an entire scene when the conditions in that scene were typified by conditions within the three townships. The difference between the estimated accuracies of the two approaches is 9% (90-81) which when applied to the 4,784 "forties" shows that an additional 430 "forties" would be erroneously indicated for field inspection when using geographic signature extension techniques as opposed to standard techniques assuming that errors due to other variables would be the same for both methods. Applying a cost of $8.50 per "forty" for field verification (as derived from past ERL cost calculations) to these 430 "forties" erroneously indicated shows a total of $3,655 that would be essentially unnecessary effort. However, comparing this $3,655 with the difference in the costs of classification by the two techniques ($7,227 - $3,117 = $4,110) reveals a cost savings of $455 for the upper extreme. In other words, under difficult ground truthing conditions (steep and/or inaccessible terrain, lack of existing aerial photography or maps, etc.), it would be cost effective to use geographic signature extension for this application even though the accuracy dropped to 81% as opposed to 90% that could be attained with standard techniques. On the other hand, it can also be shown that geographic signature extension would not be cost effective at the lowest extreme of the range (the easiest of ground truthing conditions).

In addition to accuracy, other aspects of product adequacy assessment such as map product scale, color assignments for maps, formats of line printer output, etc., were addressed by the evaluators. The details of these evaluations will be incorporated into a final report on this ASVT project along with evaluations of products relating to other applications demonstrated during the project. In addition, to comments on product adequacy, all evaluators who commented on procedures expressed a preference for the Universal soil loss prediction equation rather than the Modified Musgrave's Equation used in this demonstration. The only factor used in the Universal equation that is not used in the Musgrave's Equation is the "erosion-control practice" factor (P) which relates to specific agricultural practices (e.g., contour plowing, up and down slope operations, etc.)[5]. This factor would have to be incorporated into the data base before the Universal equation could be applied in its intended form. It is the author's opinion that it would not be realistic to assume that information on this variable could be incorporated into the Mississippi data base because there are no existing source maps from which this information could be digitized nor are there any routine operations conducted to get this information. However, the factor could be dealt with by using a P factor that is considered to be appropriate for the agricultural practices that are typical for a given area, and holding it constant when data

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[5]See USDA-SCS 1973, for details of the Universal soil loss prediction equation.

is processed for that area. All other factors in the Universal equation appear in the Musgrave's equation. Consequently, the entire system and procedures described in this report through data base building (Activity G in Figure 1) could be used for either equation. To employ the Universal equation it would be necessary for a computer programmer to expend a small effort to modify the program for Activity H in Figure 1.

IV. Concluding Remarks

It is emphasized that the main consideration during the development of computer programs and techniques utilized in this demonstration was to establish the hardware/software system and associated procedures needed to utilize Landsat digital data and other digitized data (e.g., soils) to address specific applications. Consequently, no field studies were made to verify the accuracy of the soils information shown in Table 3 or to certify the cover factor values assumed for this application demonstration.[6] However, the computer programs were designed to use card input so that information from other sources, such as the soils information in Table 2 could be replaced by merely punching a new card should more accurate information become available without any need to make changes in the computer program.

It should be recognized that the results obtained during this study were derived from data classified through geographic extension of signatures. This technique involved the development of class statistics on one Landsat scene (used for another application in this ASVT project) and the subsequent use of these statistics to classify the Landsat scene within which this demonstration area fell. Although the accuracy was estimated to be 81% for the level of classification performed for the application being demonstrated, it was illustrated (using costs

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[6]Although no field studies were made for this purpose, there was no reason to suspect that the soils information or the cover factor values assumed were incorrect.

developed in a research environment) that this result would be adequate in view of trade-offs between cost and accuracy when applied to difficult ground truthing conditions.

As mentioned earlier, the costs for several possible configurations of system hardware are covered elsewhere (Whitley, S. L., 1976); however, in summary, these capital investment costs would be less than $50,000 (image display device and electrostatic printer-plotter) as a minimum, provided that a computer and peripherals are already available. (See Appendix B for computer specifications). Operating costs will be documented in the final report for this ASVT project.

Furthermore, there is considerable potential for substantial reductions in cost through development of faster computer algorithms and automated training sample selection. One of the main advantages, both cost-wise and time-wise, of the data processing system used for this application demonstration involves the use of satellite-acquired digital data for the land cover information component; thereby, eliminating the need to digitize such dynamic information from a map or photo base as is required by other approaches. The costs associated with digitizing other data, such as soils, from map sources are commensurate with the digitizing methods used. Although the system used in this application demonstration does not presuppose any particular digitizing technique, it is thought that even a system that employs manual encoding from the map source is a feasible alternative for such static variables as soils, slope, elevation, annual rainfall, etc. that would be digitized only once. However, some cost savings could be incurred by digitizing slope information from slope maps (if available) rather than from contour maps as used for this demonstration, and/or deriving slope from elevation information on National Cartographic Information Center tapes.

In conclusion, it is thought that the utility of satellite data as reported for this application demonstration can justify the operational use of data generated by the Landsat II satellite currently in orbit.

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APPENDIX

APPENDIX A

GROUND TRUTH DATA FOR CROPS AND PASTURE

TAKEN BY ________________________________ DATE ______________

TRAINING SAMPLE # ______________ MAP OR AIR PHOTO INDEX # ____________

ESTIMATED FIELD SIZE: ______ ft X ______ ft. or ______________ ACRES

LOCATION ____________________________________________________________
County 1/4 1/4 Section Township Range

GENERAL CONDITION[1] ________________________________________________

DESCRIPTION (if not crop or pasture) ________________________________

_____________________________________________________________________

CROP OR PASTURE SPECIES[2] ______________ VARIETY (if known) __________

PLANTING TECHNIQUE[3] ______________ PLANT HEIGHT (to closest ft) ______

ROW WIDTH ______________________ PHYSIOLOGICAL STATE[4] ______________

ROW DIRECTION __________________ VISUAL ASPECT[5] ____________________

PERCENT GROUND COVER ( ) 0% to 20% ( ) 40% to 60% ( ) 80% to 100%
( )20% to 40% ( ) 60% to 80%

WEED INFESTATION (species & %, if greater than 20%) __________________

DISEASE INFESTATION (kind & %, if greater than 20%) __________________

INSECT INFESTATION (kind & %, if greater than 20%) ___________________

SOIL CONDITION[6] ___________________________________________________

SOIL MOISTURE[7] ____________________________________________________

SOIL TYPE[8] (if available) _________________________________________

_____________________________________________________________________

OTHER COMMENTS (if needed) __________________________________________

_____________________________________________________________________

(1) e.g. crop, pasture, stubble, plowed, fallow.
(2) e.g. soybean, bahia grass, etc.
(3) e.g. row, skip row, drilled, broadcast.
(4) e.g. flowering, heading, mature, etc.
(5) e.g. chlorotic, wilted, etc.
(6) e.g. freshly cultivated, rough, smooth, etc.
(7) e.g. moist, dry, waterlogged, etc.
(8) series, texture, color, slope, etc.

# GROUND TRUTH DATA FOR FOREST/BRUSH VEGETATION

TAKEN BY:________________________________________DATE__________________

TRAINING SAMPLE #_________________________MAP OR AIR PHOTO INDEX #________

ESTIMATED FIELD SIZE:_______ft X ______ft. or ______________________ACRES

LOCATION______________________________________________________________
County 1/4 1/4 Section Township Range

KIND OF VEGETATION (check one)
( ) Natural Forest
( ) Forest Plantation
( ) Brush Vegetation

If Natural Forest, indicate:

(1) Major forest type (check one)

( ) Maple-Beech-Birch ( ) Elm-Ash-Cottonwood ( ) Aspen-Birch
( ) Oak-Hickory ( ) Loblolly-Shortleaf ( ) Oak-Pine
( ) Oak-Gum-Cypress ( ) Longleaf-Slash ( ) Mixed Hardwood

(2) Species composition (to nearest 25%)

| Species | % |
|---|---|
| | |
| | |
| | |
| | |

(3) Average age class of upper canopy trees (check one)

( ) Less than 20 years ( ) 50 to 100 years
( ) 20 to 50 years ( ) over 100 years

(4) Average height class of upper canopy trees (check one)

( ) Less than 20 feet ( ) 50 to 100 feet
( ) 20 to 50 feet ( ) over 100 feet

(5) Slope

( ) 0% to 10% ( ) 30% to 50%
( ) 10% to 30% ( ) 50% or more)

(6) Predominant Aspect

( ) North ( ) South ( ) East ( ) West

If Forest Plantation, indicate (1) Species________________(2) Spacing________
(3) Row Direction_________(4) Ave. age:______(5) Ave. height:________

If Brush Vegetation, indicate species composition to nearest 25%.

| Species | % | Species | % |
|---|---|---|---|
| | | | |
| | | | |

GROUND TRUTH DATA
Extractive Land Uses

OBSERVATIONS MADE BY ______________________________ DATE ______________

IDENTIFIER NO.* ______________ Approx. Size _____ X _____ (feet) or _______ acres.

COUNTY ______________________________

LOCATION (if known) ______________________________________________

| Township | Range | Section | Quarter | Forty |
|---|---|---|---|---|

ACTIVITY TYPE

( ) Sand pit
( ) Gravel pit
( ) Stone, dimension
( ) Stone, crushed
( ) Lime
( ) Cement
( ) Clay
( ) Chert & Tripoli
( ) Lignite
( ) Heavy mineral
( ) Other ____________________

____________________

Is area ( ) in-production or ( ) abandoned?

If abandoned, is area ( ) barren or ( ) revegetated?

Is the area likely to contain impounded water during all or a significant part of year ( ) yes ( ) no?

How much time did it take to make observations and fill out this form (min. and/or hours) ____________________.

*Observations should only be made on extractive areas that are at least 600 feet by 600 feet, or approximately 10 acres. Once such an area is located, its location should be delineated on an aerial photo or map sheet with colored pen or pencil, and an identifier cross-reference number should be recorded on the aerial photo or map beside the delineated area and on the ground truth data form.

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OF POOR QUALITY

# GROUND TRUTH FORM FOR MARSH VEGETATION

1. Sample number________________.
2. Date: ______________________.
3. Time: ______________________.
4. Vegetation type:

   (1) pure stand (monotypic)____________________.

   (a) species:______________________________.

   (2) intermixed (less than 6 vascular species present) ______________________.

   (a) dominant species:____________________________, ______________________.

   (3) intermixed (more than 6 vascular species present) ______________________.

   (a) dominant species:____________________________, ______________________.

   (NOTE: If a species comprises less than 5% of vegetation do not regard as major or dominant component.)

5. Homogeneity:

   (1) sub-elements (defined)

   (a) vegetation differences (clumps, patches, zones) ____________________.

   (b) barren areas ________________________________________________________.

   (c) open water __________________________________________________________.

   (d) sparse vegetation/barren __________________________________________.

   (e) sparse vegetation/water ___________________________________________.

   (f) other (describe) __________________________________________________.

   (sub-elements (size)

   (a) less than 10 feet _______________________________________________.

   (b) more than 10, but less than 20 ___________________________________.

   (c) more than 20, but less than 40 ___________________________________.

   (d) more than 40, but less than 60 ___________________________________.

(3) distribution (of sub-elements in study area).

(a) evenly ______________________________.

(b) center ______________________________.

(c) peripheral ______________________________.

(4) density (of vegetation as % of surface area).

(a) dense > 90 ______________________________.

(b) intermediate < 70 ______________________________.

(c) sparse < 50 ______________________________.

6. Height of plants (stands).

(1) approximate height of major units:

(a) species ______________, height ______________.

(b) species ______________, height ______________.

(c) species ______________, height ______________.

(2) approximate height of minor units:

(a) species ______________, height ______________.

(b) species ______________, height ______________.

7. Status of vegetation:

(1) approximate (%) of dead-standing material.

(a) major units (species) ______________________________.

(b) minor units (species) ______________________________.

8. Stage of growth:

(1) major units

(a) dormancy (winter-no leaves) ______________________________.

(b) dormancy (winter-leaves dead-standing) ______________________________.

(c) seedlings ______________________________.

(d) immature ______________________________.

(e) mature ______________________________.

(f) anthesis ______________________________.

(g) vigor ________________________________________________.

(1) excellent _________________________________________.

(2) fair ______________________________________________.

(3) poor ______________________________________________.

9. Surface of substratum:

(1) covered by algae _________________________________________.

(2) covered by small vascular plants ______________________________.

(3) covered by detritus _______________________________________.

(4) barren _________________________________________________.

(5) substrate type

(a) mud _______________________________________________.

(b) sand ______________________________________________.

(c) sandy/mud __________________________________________.

10. Water level.

(1) standing on surface of marsh ________________________________.

(a) covered by tidal water __________________________________.

(b) covered by river overflow _______________________________.

(c) combination of both (a & b) above __________________________.

(d) permanent or semi-permanent ______________________________.

(2) Depth of water on marsh surface ______________________________.

11. Comments:

APPENDIX B

B-1 - COMPUTER REQUIREMENTS FOR LOW-COST DATA ANALYSIS SYSTEM*

| CATEGORY | MINIMUM | DESIRED |
|---|---|---|
| Central Processor Unit with Operators Console | Yes | Yes |
| Memory | 16K, 16 bit words | 64K, 16 bit words (Dual Port) |
| Tape Drives, (CCT) | Two 7 or 9 track | Two 9 track, 3.05 MPS, (120 IPS), 315 Bytes/cm (800 BPI) |
| Disc (Rotating Memory Device) | 12M, 16 bit words | 46M, 16 bit words |
| Line Printer | Yes | Yes |
| Electrostatic Printer | --- | Yes |
| Card Reader | Yes | Yes |
| Floating Point Hardware | --- | Yes |
| Micro Programmable Writable Control Storage | --- | Yes |
| Operating Executive System | --- | Yes |
| Fortran Compiler | Yes | Yes |
| APPROXIMATE COST (1975 Prices) | $75 - 80K | $150K |

* Whitley, S.L., 1976.