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A SYSTEM FOR PROCESSING LANDSAT AND OTHER GEOREFERENCED DATA FOR RESOURCE MANAGEMENT APPLICATIONS

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I. ABSTRACT

The NASA Earth Resources Laboratory (ERL) at the National Space Technology Laboratories, NSTL Station, MS, has developed a transferrable system for processing Landsat and disparate data with capabilities for digital data classification, georeferencing, overlaying, and data base management. This system is known as the Earth Resources Data Analysis System (ERDAS). The versatility of the system has been demonstrated with applications in several disciplines. A description is given of a low-cost data system concept that is suitable for transfer to one's available in-house minicomputer or to a low-cost computer purchased for this purpose. Software packages are described that process Landsat data to produce surface cover classifications and that geographically reference the data to the UTM projection. Programs are also described that incorporate several sets of Landsat derived information, topographic information, soils information, rainfall information, etc., into a data base. Selected application algorithms are discussed and sample products are presented. The types of computers on which the low-cost data system concept has been implemented are identified, typical implementation costs are given, and the source where the software may be obtained is identified.

II. INTRODUCTION

A. BACKGROUND

Several years ago ERL personnel surveyed the needs of a number of Federal, state, and local organizations who appeared to have a need for remotely sensed data and the information that could be derived from it. The survey revealed that there were needs for baseline surface cover maps and for resource management information that could only be derived from a combination of Landsat data and data from disparate sources. The survey confirmed that the system for producing the products needed to be as low-cost as possible and easy and inexpensive to use. These needs were translated to a system with the following salient features:

1. Low cost to implement and operate.

2. Modular in design so that users may incorporate available in-house components into a data processing system.

3. Proven off-the-shelf hardware components.

4. Software written in Fortran for ease of transfer to other computers.

5. Efficient classifier of Landsat multispectral scanner data.

6. Geographically references imagery data to the UTM map projection.

7. Overlays temporal data accurately.

8. Features a data base program where parameters from selected disparate sources may be layered to describe a given cell or polygon.

9. Accepts data from maps, tapes, cards, etc., to accommodate the many existing types of data that are needed to derive resource management information.

10. Incorporates a number of applications algorithms that are designed to derive resource management information from data base parameters.

11. Produces tabular information and inexpensive color or black and white map images.

A system with these features has been designed, implemented, and evaluated at the Earth Resources Laboratory at NSTL. The concept for this system was described by Whitley[1] in 1976. The system's software (systems and applications modules) has been entered into COSMIC, NASA's software dissemination facility at the University of Georgia, Athens, Georgia, and is available to the public at a modest price. Selected software components have been entered into COSMIC for use with UNIVAC 1108 computers and V-70 Series Varian Data Machines (now Sperry Univac) computers. Versions will soon be entered into COSMIC for PDP-11/70 and Interdata 8/32 computers.

III. SYSTEM DESCRIPTION

A. HARDWARE

The system hardware can be logically divided into five subsystems: input, display, computer, output, and support. Figure 1 shows a typical layout of a complete system as described in this paper.

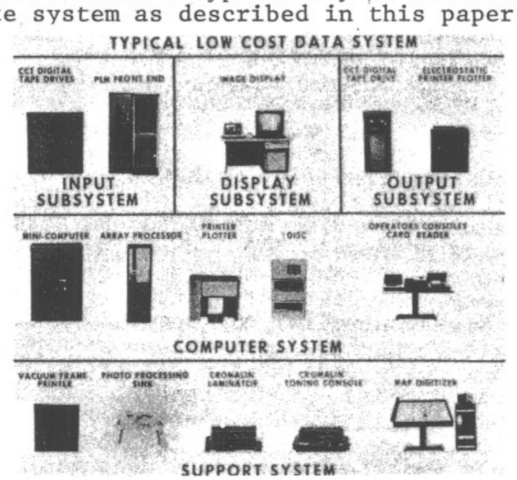

Figure 1. Typical system layout.

The system may be configured for either batch processing or interactive processing. Certain batch processing configurations can be implemented easily by transferring the Fortran software to the computer selected and accumulating the necessary hardware components. The implementation of interactive systems must be accomplished with greater care as the software becomes more hardware dependent.

Input Subsystem. Input subsystems have been built and tested for reading standard computer-compatible tapes at 800 or 1600 bytes per inch packing densities in the "band interleaved by line" format available from the EROS Data Center, and for reading 1-inch-wide pulse code modulated (PCM) recorded data tapes from airborne multispectral scanner systems. A high-density-digital tape (HDDT) front-end has been designed for minicomputers to enable users to read the interim tape produced by the GSFC. This system consists of off-the-shelf hardware components, a specially designed interface unit, and a special software driver written for the computer on which the HDDT recorded data are to be read. The HDDT input subsystem was designed in anticipation of the high volumes of data expected from Landsat D, but has not yet been implemented.

Standard computer-compatible tapes are read with widely used 9-track tape drives at 800 or 1600 bytes per inch. Tape drive speed is of little concern if the data are read into a disk prior to data processing, but the tape drives should be as fast as the user can afford if data are to be processed from tape.

Input subsystems designed for reading PCM recorded airborne multispectral scanner data into a computer are available but only a limited community of users has a need for such devices. The necessary specifications, drawings, etc., can be provided by the ERL for building this type of input subsystem. The hardware costs for implementing an excellent PCM input subsystem is about $80,000. The design is well proven and has been incorporated into five systems over the past five years.

Display Subsystem. The display subsystem consists of a color CRT monitor, a control section, a memory module for elements, display refresh circuitry, a cursor system for interactively outlining desired areas or designating points of interest in the data, and a standard CRT/keyboard terminal to allow the user to interact with computer programs. A number of suitable display systems are available, but the ERL competitively procured a Comtal Series 8000 single image display system with two graphic overlays. The cost of all hardware components and optional features required to implement a display is slightly less than $40,000 including the computer interface unit and cables.

In preparation for Landsat D with its much greater data volume and resolution, the ERL is purchasing a 1024 x 1024 x 8-bit display system. Although the cost for the higher resolution display is not yet known, it is anticipated that it will be only slightly higher than the cost for a 512 x 512 element display.

Each display system permits selection of a subset of the displayed data and "zooming" by digital techniques to give the user a closer look at a selected area. Similarly, by subsampling the data stored in computer or disk memory, one can display a much larger area.

Although it is possible to implement a system using an electrostatic printer-plotter or a standard line printer as a display subsystem, few users are interested in this very low-cost approach.

Computer Subsystem. This system can be implemented on almost any 16- or 32-bit minicomputer equipped with adequate memory, floating point processor, hardware multiply and divide, tape drives, adequate random memory disk drives and a Fortran Compiler. If the prospective user is willing to convert available Fortran IV programs to run on his computer, then almost any kind of computer can be used to implement a "batch" version of the system. If, however, a potential user chooses to implement an "interactive" version of the system or is not willing to transfer the software to a different kind of computer, one may opt to implement a system using one of the types of computers on which the system is now operational. The system has been implemented on the Sperry Univac (or Varian Data Systems) V-70 series computers, the Perkin Elmer Interdata 8/32 computer and on the Digital Equipment Corporation's PDP 11-70 computer.

Due to the extensive use of floating point numbers in the software packages, it is highly recommended that the system be equipped with preferably a hardware floating point capability, or at least a firmware floating point capability. The selected minicomputer should be equipped with a multi-task operating executive (time sharing) as a number of the interactive tasks do not use much of the minicomputer's capacity. Thus, capability exists in the computer to support two or three users and image display systems, as well as a few batch jobs if adequate memory and disk space is provided.

The minimum amount of computer memory required to support an interactive data system is 131,072 bytes. The manufacturers' systems packages have grown in power and flexibility, and currently require approximately 60,000 bytes of memory. No ERL program module uses over 65,536 bytes of memory, but extensive use is made of software overlays. Computer memory costs have been reduced so drastically that some manufacturers now sell 524,288-byte solid state memory modules on a single board for under $10,000. This amount of money will support a number of tasks of the type discussed here.

Organizations with a need for monitoring the natural resources for a state-sized area will probably need the added processing speed of an array processor during the Landsat D era. Selected slower running programs are presently being converted at the ERL to run on an array processor. The ERL is using a Floating Point Systems AP120B array processor which was procured competitively, as a type that could be used with 16- or 32-bit computer systems. Prior to the launch of Landsat D, techniques will be presented in technical symposia describing the array processor's use and software will be made available to the public through COSMIC. It is anticipated that the array processor will increase throughput rates by a factor of 5 to 10.

Disk memory size should be based on a user's requirements. Disk memory cost has plummeted along with other electronic hardware costs. 300 megabyte disks (without controllers) can be procured directly from disk manufacturers at a cost of under $15,000. When those same disks are purchased through a computer company, the costs frequently are doubled. One disk controller can normally accommodate about four disk drives making disk memory quite inexpensive as more than one drive is added. Users tend to become very wasteful of disk space because it is so convenient to be able to call upon vast quantities of imagery data with very little effort; therefore, disk space management is necessary.

In summary, computer systems should also be equipped with one or more digital tape drives, one or two line printers, a card reader, one or more computer display terminals, disk memory, and an electrostatic printer-plotter. Table 1 is a cost matrix of typical low-cost data systems for processing multispectral and disparate sets of data.

Table 1. Typical costs for competitively priced data analysis systems based on 16- and 32-bit computers are as follows:

	16-Bit	32-Bit
Computer and Peripherals	$125,000	$155,000
Image Display System and Controller	37,000	40,000
Electrostatic Printer-Plotter	23,000	23,000
Digitizer (Hang-on type)	15,000	15,000
Totals	$200,000	$233,000

Obviously, sizeable savings can be realized if a suitable computer system is available that could be adapted to this task.

Output Subsystem. The output devices of the Earth Resources Data Analysis System are: line printers, electrostatic printer-plotters, tape drives, and display devices.

The electrostatic printer-plotter (EPP) has proven to be the most frequently used output device on the ERL data system. The EPP's used at the ERL are 200 dot/inch, high speed, high contrast systems. Two were procured competitively by the ERL and both have been found to be very reliable. The ERL has a Varian Graphics Statos 4222 EPP that is connected on line with the computer through a parallel interface device and a stand-alone Versatec EPP whose input is read from CCT. The Statos and the Versatec EPP systems cost $23,000 and $30,000, respectively.

Electrostatic printer-plotters are particularly useful for producing inexpensive gray shade images on 22-inch wide paper from scan lines of digital data. Each image element (pixel) is represented by a four dot square array. The computer is programmed to provide the EPP with accurately scaled data that can produce a gray shade map. The gray shade maps may be converted to high quality color maps via the Cromalin process. Each theme, or classification category, is printed as a separate breakout by the EPP, then each theme is converted to a different color by the Cromalin process described in appendix B of NASA TR R-467 by Whitley.[1] The computer can also produce different dot patterns making ground surface materials easily distinguishable even though only one color is used in the Cromalin process. Through the clever use of dot patterns and multiple color layers one can produce a highly useable color-coded surface cover map inexpensively. With careful maintenance and system setup one can produce maps with the electrostatic printer-plotter that meet national map accuracy standards at 1:250,000 scale.

The color CRT of the display subsystem can also produce color output products if a camera is used to photograph the display screen. Such products sometimes meet a users needs, but are not recommended when high quality is desired or large areas are involved.

Data may be tabulated on either a line printer or the electrostatic printer-plotter, but one should be aware that the cost of paper for the electrostatic printer-plotter is much more than paper for a standard line printer.

Supporting Subsystem. The data system requires support subsystems for preparing both input and output data in the required formats. Some kinds of disparate data are available only in map format, some in only digital tape format, and some in punched card format. A digitizer is needed to convert the map data into a format that can be read into the computer. Map digitizers used for this purpose should have a precision of approximately .001 inch. The data are normally read in polygon format where given materials are enclosed within a boundary and labeled, or in cell format where one reading is made to represent the most frequently occurring material in a given cell. The data is read by digitizers in such a way that it can be entered into the data base program in UTM coordinates. Digitizers are available as "hang-on" device or as "stand-alone" devices. Good digitizers of these types range in cost from about $7.5K to $30K. The main attractions of hang-on digitizers are low-cost and flexibility in use. One must, however, develop his own software before the "hang-on" digitizer can be used, thus increasing implementation cost. The stand-alone digitizer is either hard-wired or controlled by its own minicomputer or microcomputer. The cost of the stand-alone computer covers all components needed to convert the map data to a computer-compatible tape. Programs have been developed at the ERL to edit digitizer output, and to enter the data into the data base program.

Electrostatic printer output products will require the services of a modest photographic laboratory. The gray shade images are converted to black and white positives by contact printing. This process is accomplished by use of a standard vacuum frame printer equipped with a tungsten light source. A sink is required for processing the black and white positive. The black and white positive image is translated to color products via the Cromalin system. Cromalin printing may be accomplished as a service, or may be done in-house using equipment that can be purchased for less than $4,000.

B. SOFTWARE

The greatest challenge in developing software for the Earth Resources Data Analysis System has been to establish and maintain the proper relationship between software transferability, software efficiency, ease of use, and ease of adding applications algorithms. After having assisted a number of users as they transferred ERL's ERDAS software to their own computers it became apparent that there was a need for the development of a special Fortran operating subsystem that operates within the operating system of a computer to easily accommodate those functions that are highly machine dependent. Such a subsystem has been developed for use on either 16- or 32-bit computers. Through this approach some of the especially nice features of a given computer are ignored at the expense of ease of transfer. No common blocks are used, but extensive use is made of software overlays. This Fortran Operating Subsystem will be described more fully in the near future by Mr. Ronnie Pearson, who developed it.

Within the framework of this Fortran Operating Subsystem, the following data processing programs are executed:

Program REFORMAT reads the standard Band Interleaved by Line format available from the EROS Data Center at Sioux Falls, SD. By the use of a reformat program one can reduce the impact of accommodating new sensor systems as they become available.

Program DESTRIPE compensates for the banding effects caused by nonuniformity in the six detectors used on Landsat whenever such corrections are needed.

Program SIGNATURE DEVELOPMENT derives signatures from the data by either a fully automated process known as SEARCH by which signatures are derived from uniform data windows of selectable size and are distinguishable in the maximum likelihood ratio sense, or a manually operated training sample selection and/or a point cluster technique. Significant improvements have been made in classification accuracy and repeatability as a result of these algorithms.

Program DIMENSIONALITY REDUCTION permits the translation of axes in such a way that maximum data content is forced into a small number of data bands. Such techniques are very helpful if several sets of data are overlaid. Such dimensionality reduction reduces the computer time required to process multidimensional data. This program is presented as an option for the user.

Program OVERLAY provides an automated technique for overlaying two or more sets of Landsat multispectral scanner data. The program has a measured average error of 25 meters. This program will play a major role in multitemporal analysis and change detection.

Program CLASSIFY exists in two forms, a table lookup form, and a general purpose "N-band" classifier. The table look-up program contains options for a 2, 3, or 4 band classification based precisely on maximum likelihood ratio and obtaining exactly the same answers as one would get in the more generalized N-band classifier for a given computer. The chief advantage of the 2, 3, and 4 band table look-up classifiers is that such classifiers run extremely fast in standard digital computers. The N-band general classifier runs much more slowly in the computer mainframe. Therefore, the N-band classifier is being programmed to run on the AP120B array processor. The four band table look-up program has been reported before under the name of MAXL4X by Pearson.[2]

Program GEOREF is a module consisting of programs to determine transformation coefficients for mapping to the UTM projection based on ground control points. Resampling is performed on raw or classified data to produce a corrected map to a precision of better than a pixel (RMS accuracy), and to produce maps at standard map scales to the UTM projection. Program GEREF4 produces up to 2500 rows and 5000 columns of selectable-size pixels oriented along lines of northings and eastings. Program SUPERG produces geographically corrected maps of complete Landsat scenes oriented along the flight path of Landsat, and the absence of the rotation to north allows SUPERG to run several times faster than GEREF4. If only a corrected map is desired, SUPERG is recommended. If the data are to be entered into a Data Base program, use of GEREF4 is recommended. Graham[3] described the geographical referencing technique used in NASA TM-58200.

Program DATA BASE stores data from disparate sources--Landsat, land ownership, soil types, elevation, slope, slope length, aspect, rainfall, etc., or as many parameters as one desires or can afford to store--in a regular grid of cells. The cell size may be any size the user desires, limited only by the amount of disk storage available to the user. The data base program is equipped with commands to read, store, write, display, update, calculate, etc., giving the user much flexibility in manipulating parameters interactively to produce displays of linear combinations or to step through a sequence of operations to answer a given complex question about a polygon shaped region.

The formats of the various types of data that may be entered into the data base storage include the classified Landsat data tapes, data from maps or cards (e.g., soil surveys and rainfall), data from tapes (e.g., Defense Mapping Agency (DMA) topographic tapes), etc.

Although some data stored in the data base are in polygon format, all data processing is accomplished by manipulating data points within the polygon in the storage tiers involved.

Program TOPO derives elevation, slope, slope length, and aspect from DMA topographic tapes. The input data to this program are derived by DMA from a standard 1:250,000-scale quad sheet, with one tape for each half ($1^{o} \times 1^{o}$) of the map. The original quad sheets are referenced to a polyconic selction, but the TOPO program translates the data to the UTM projection. The data are prepared in the format expected by the data base program. The details of this procedure have been documented by Junkin.[4]

Program SOILS accepts soil survey data that are available from the Soil Conservation Service and enters it into the data base. In cases where soil type is only available in a map format, the data are read and processed by the map digitizer program as described below.

Program MAP DIGITIZER reads, edits, and formats data that have been converted from map format to digitial tape format by the ALTEK stand-alone digitizer. The data are displayed on the display screen for manual editing, and the corrected data are entered into the data base. This procedure has been reported by Junkin.[5]

Program SCALE reformats the output data from various programs described above so that the data can be printed by the electrostatic printer-plotter at a standard map scale. The user inputs the necessary conversion factor at run time for a given printer-plotter.

Program SYS403 is a systems level program that prepares digital output data in the dot pattern format expected by the electrostatic printer-plotter. Each picture element to be printed is converted to a dot pattern consisting of from 0 to 4 dots. If all four dots are "on," a solid gray shade is printed. By clever use of this program one can print out individual themes, a number of coded themes, and either single or multiple themes that are to be printed as color coded maps via the Cromalin process.

C. APPLICATIONS ALGORITHMS

A number of applications algorithms have been developed to derive specific resource management information from either data base output parameters or the output from specific programs. These algorithms are not normally complicated, but are very useful in preparing data in a format that is easy to interpret. Some of the programs developed are described below.

Program CROP PRODUCTION ESTIMATE evaluates data extracted from a polygon-shaped region of the data base to estimate crop production under the assumption that good agronomic cropping practices are used. The parameters extracted from the data base and used in the algorithm are surface cover, soil series, and rainfall. The productivity is determined by table look-up from a user input table of productivity vs. soil series, vs. rainfall. The same algorithm can be used for cotton, corn, soybeans, etc., depending on the table values entered. The results are particularly useful on a local basis.

Program EROSION HAZARD calculates tons of soil per acre per year lost from a polygon shaped region using the universal soil loss equation. The data base parameters used are surface cover, soil series, slope, slope length, and rainfall. The output can be a color coded erosion hazard map, or the tons of lost material can be calculated for an area and tabulated. An example of the use of this algorithm was reported by Anderson and Joyce in 1977.[6]

Program ACREAGE determines the total acreage of each surface cover type included within a polygon shaped region using the output data of either program CLASSIFY or the DATA BASE. The output data are tabulated.

Program WILDLIFE HABITAT ASSESSMENT evaluates the capacity of an area to support wildlife of a specific type. An evaluation algorithm has been developed for evaluating whitetail deer habitat. The data base parameters used are overstory (surface cover), understory (derived from soil type), elevation, and aspect. The algorithm produces a capacity index map showing the relative ability of each data cell to support whitetail deer. Similar algorithms may be developed for other types of wildlife.

Program CHANGD attempts to detect the change that has occurred in an area over a given timeframe. Two sets of data are precisely registered by Program OVERLAY. The land use is compared in a data window to determine areas of change. Several approaches have been implemented. One approach involves comparing two registered classifications and determining which areas have changed. Another approach is to determine change by detecting shifts in the radiance from one data set to the other.

Program SUITABILITY determines the suitability of a polygon shaped region for a specific use. The program may be used to evaluate the suitability of an area to be a recreational area, a housing development, a city dump, etc., using information stored in the data base.

IV. IMPLEMENTATION HISTORY

Data Analysis Systems based on the low-cost concept have been implemented in the states of Mississippi, Georgia, Texas (Parks and Wildlife Division), Missouri, and Louisiana. Systems have also been implemented by EPA in Las Vegas, Nevada, and the Navajo Indian Nation at Window Rock, Arizona. Because the low-cost data system concept stresses modularity and utility of available in-house components, each system implemented to date is somewhat different in makeup, but the products are the same.

Strong interest in implementation of data systems has been shown by the states of Florida, North Carolina, South Carolina, Oklahoma, Kentucky, Iowa, and New Mexico. Some of these states have funds set aside at this time to proceed with the implementation of a system.

Anyone who has an interest in learning more about the software used in this approach can acquire a set of program abstracts from the NASA Earth Resources Laboratory at the National Space Technology Laboratories, NSTL Station, MS 39529, or a set of program documents may be purchased from COSMIC, University of Georgia, 112 Barrow Hall, Athens, Georgia 30602.

V. SAMPLE PRODUCTS

ERDAS output products may be produced in the form of tabulations, gray scale or color coded images. Most users specify color coded output products. Due to report printing limitations the sample products shown here will be presented in gray shades. Product distinguishability is reduced or lost by this approach because the ERDAS normally capitalizes on the fact that the same dot patterns presented in different colors greatly extends the number of uniquely identifiable material classes. Figure 2 is an example of a geographically referenced land cover classification of the Big Thicket National Preserve in Texas. Note that roads, contours, city and town names, pipelines, etc., have been optically superimposed over basic data greatly enhancing one's ability to analyze and interpret the data.

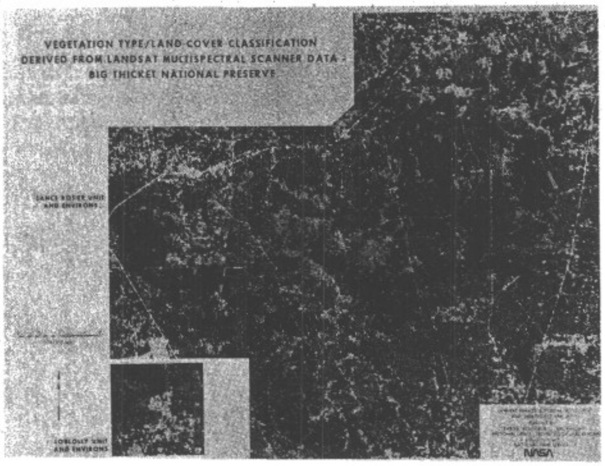

Figure 2.- Land cover classification of the Big Thicket National Preserve.

Figure 3 is a color coded land cover classification that was photographed from the CRT display screen of the image display system. The system's graphic overlays are used to produce figures for reports and presentations. This sample came from a very fruitful urban classification study conducted by Dr. Paul Baumann.[7]

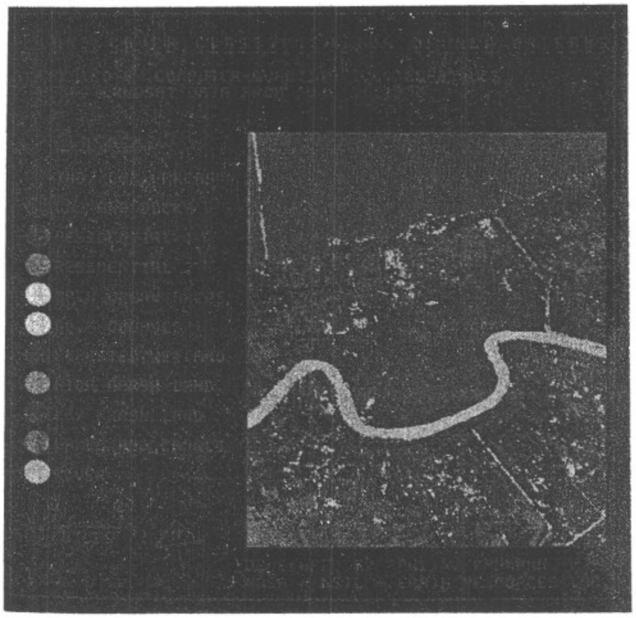

Figure 3.- Urban land cover map as produced on the Image Display CRT.

Figures 4,5,6 and 7 are examples of data from disparate sources that may be entered into the data base and processed through applications algorithms to produce, for example, an erosion hazard map, as shown in figure 8. Figure 4 is a land cover map of the Fort Defiance Chapter of the Navajo Indian Nation. Land cover is presented here in 10-acre pixels. Roads and town names have been superimposed by graphic overlay. Figure 5 shows soil taxonomic units. Figure 6 is a rainfall map that was derived from a map by the Altek map digitizer and converted to digital format. Figure 7 is a slope map that was derived from DMA topographic tapes covering the Fort Defiance Chapter. Using land cover, soil type, soil erodability (from soil type), slope, slope length, rainfall, and the universal soil loss equation, one can derive erosion hazard in tons/acre/year. This may be translated to slight, moderate, and severe erosion hazard, as was done in figure 8.

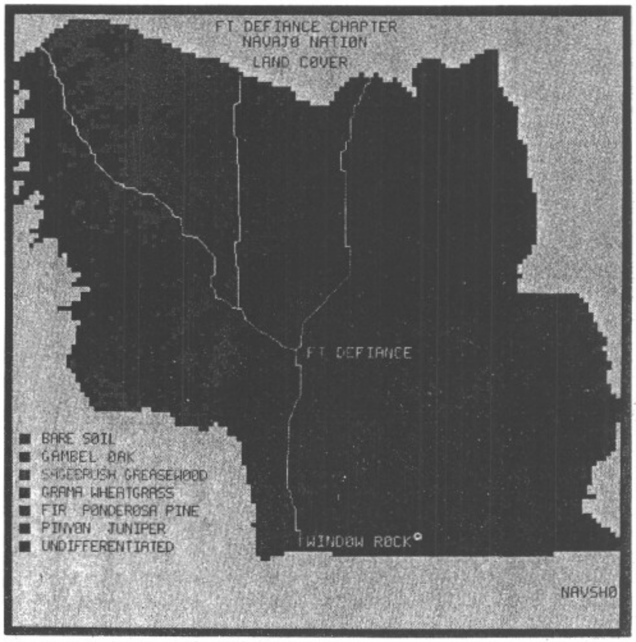

Figure 4.- Land cover map of Fort Defiance Chapter.

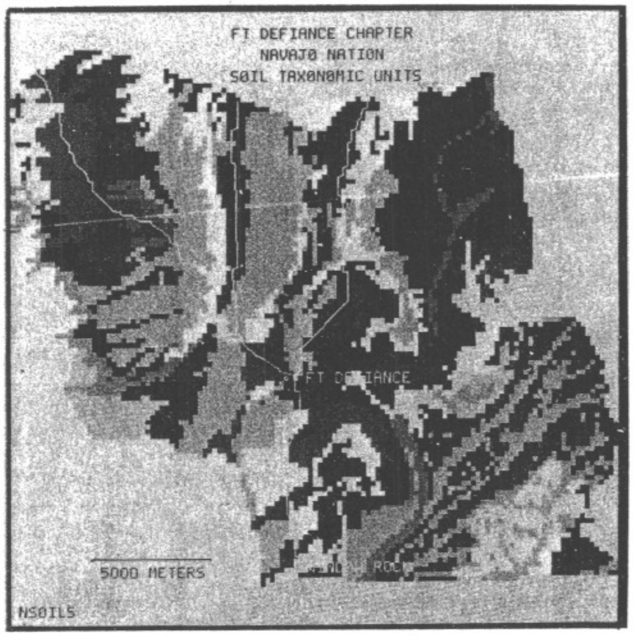

Figure 5.- Soils map of Fort Defiance Chapter.

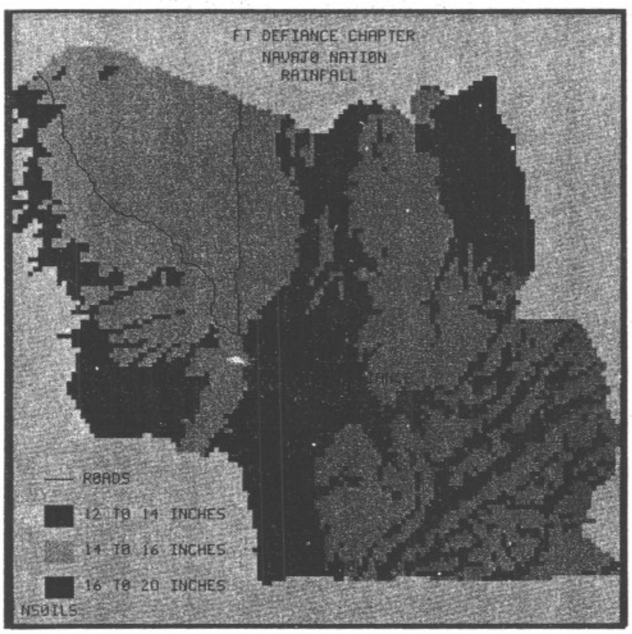

Figure 6.- Rainfall map of Fort Defiance Chapter

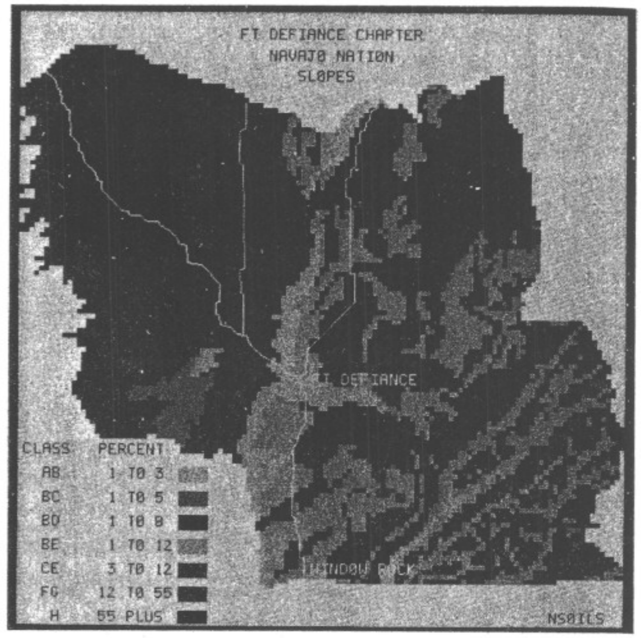

Figure 7.- Slope map of Fort Defiance Chapter.

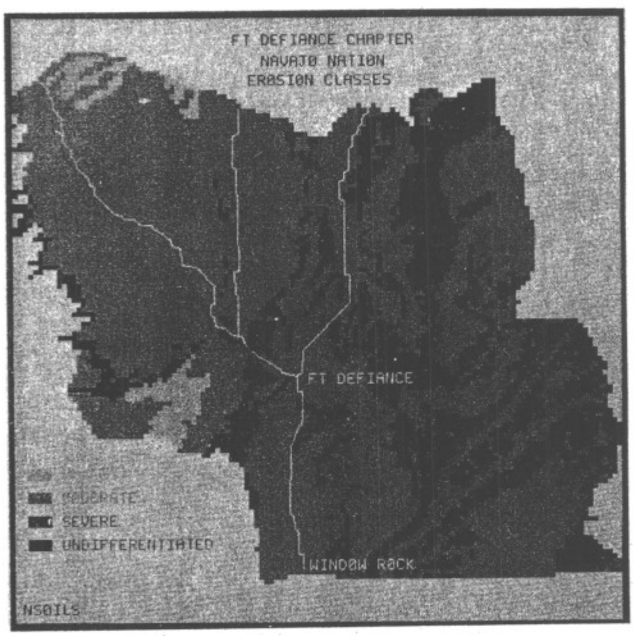

Figure 8.- Erosion hazard map of Fort Defiance Chapter

Figure 9 is a sample product produced in a mine safety investigation using land cover, extent of underground mining activity, 200-foot contour intervals, roads, and streams, all of which were stored in the data base. By simply superimposing the various parameters in a clever manner one can produce a map that gives considerable insight into potential water leakage problems under streams and roof cave-ins under roads. Addition of known faults, etc., would obviously provide mine safety personnel with a valuable analysis tool.

Figure 9.- Superimposed data providing a more definitive view of an underground coal mine.

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-Graduate study in mathematics and statistics from the Univ. of N.C., and Florida State U.
-Served in Earth Resources Remote Sensing Data Management positions since 1965.
-Member of NASA's Intercenter Committee on ADP.
-Experience in developing air and spaceborne data systems and ground data processing systems for remote sensor data.
-Developed configurations of interactive data systems for processing multiple sets of data and entering them into a data base with disparate data from which resource management information can be derived.
-Developing an easily transferrable system that can be afforded by states and cities for resource management.