THE APPLICATION OF A GEOGRAPHIC INFORMATION SYSTEM TO THE MANAGEMENT OF SURFACE COAL MINES

By

LARRY MELVIN BUNSE

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Northwest Missouri State University

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Thesis Approved:

Stephen J. Walsh
Thesis Adviser

John D. Vitek

Stephen J. Stadler

Norman N. Durham
Dean of the Graduate College

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INTRODUCTION

Introduction

Resource management is a critical problem in the world. The use of environmental resources by affluent nations is expected to sharply increase in the coming decades (Miller,1979). As less affluent nations advance in technology and wealth, the demand on the dwinding resource base will further increase. The need for energy and mineral resources is inherent in all modern industrial societies (Brown et al., 1971). The rampant exploitation of energy and mineral resources, however, is under increasing attack from those who wish to preserve the environmental quality of the land and water. The efficient utilization of energy and mineral resources, while, at the same time, protecting the quality of the environment, is a task which requires very prudent resource management.

An intimate knowledge of all environmental variables that interact with a particular resource is necessary for effective management. The information needs of resource management are, therefore, many and diverse. Proper resource management requires an information source that can effectively organize the necessary data for display and analysis. The optimum format for such an information source which can incorporate numerous variables and synthesize their relationships is a computer-based geographic information system.

Statement of Research

In June 1981, the Oklahoma Department of Mines contracted the Center for Applications of Remote Sensing (CARS), Oklahoma State University, to develop an information system that would assist in the management of surface coal mines. The pilot project resulting from this contract provided an opportunity to develop and evaluate a geographic information system. This research involves the development of the Oklahoma Geographic Information Retrieval System (OGIRS) and an evaluation of its effectiveness for supplying the information needs of the managers of surface coal mines in eastern Oklahoma.

A review of the literature indicates that geographic information systems have been applied to a wide variety of resource management problems. Any mention of the application of such information systems to the management of surface coal mines, however, is noticeably lacking. As in all resource management, the operation of a surface coal mine requires information on many environmental variables. A geographic information system should be able to organize this information in a manner which can be readily utilized by mine personnel in their management decisions.

Research Methodology

A methodology with a structured design should be followed in the development of any geographic information system (Calkins and Tomlinson, 1977). The first task in this design process involves the determination of system objectives. This task is often difficult to complete, but it is essential in the development of any information system. Users of the system and their needs must first be determined. The Oklahoma Geographic Information Retrieval System was designed for use by managers of surface coal mines in eastern Oklahoma. The data needs of such managers include information on many different aspects of the physical environment. The variety of data needs required the development of an information system with flexible data input and storage capabilities. After the general data needs are determined, decisions must be made regarding data format, scale, and resolution. The OGIRS was developed as a grid information system with a ten acre resolution.

The next major task in the development of a geographic information system involves the assessment of available hardware and software resources. The Oklahoma Geographic Information Retrieval System was developed at the Center for Applications of Remote Sensing, Oklahoma State University. At the time of system developement, the available hardware at the Center included a Perkin Elmer 8/32 mini-computer with one half megabyte of core memory. This base unit was supported by two tape drives and a 300 megabyte disk system with multiple disk packs. CRT terminals provided access to the computer, while output was directed to either the terminals or a line printer. A Comtal Image Processing System, an Altek graphic digitizer, and a Versatec electrostatic printer/plotter were also available. The principle software package utilized at CARS was the Earth Resources Laboratory Applications Software (ELAS), which was developed at the National Space Technology Laboratories in Bay St. Louis, Mississippi (Junkin et al., 1980). This software package provided the capability for processing and analyzing satellite digital data and related ancillary information.

After the system objectives and available resources are determined, the actual development of the necessary software can commence. The system software must provide capabilities for data input and storage, manipulation, and display. All software development for the Oklahoma Geographic Information Retrieval System utilized the computing facilities at the Center for Applications of Remote Sensing.

The last major task in the development of a geographic information system involves the selection and acquisition of specific data. The selection of data should be based upon the initial objectives determined at the beginning of system development. The acquired data must be converted to a format which is compatible with the information system and then entered as layers of information.

Summary

Effective resource management requires a data source capable of organizing many diverse types of information. Such a data source can be supplied by a geographic information system. This research describes the development of the Oklahoma Geographic Information Retrieval System, which was designed for specific use in the management of surface coal mines in eastern Oklahoma. Chapter II examines geographic information systems, in general, and their applications to resource management. Chapter III briefly outlines the subject of surface coal mining in eastern Oklahoma and the data management needs of such operations. Chapter IV examines the development and operation of the Oklahoma Geographic Information Retrieval System. Chapter V describes the data which have been input into the information system. Chapter VI presents a general evaluation of the OGIRS with recommendations for future development.

CHAPTER II

GEOGRAPHIC INFORMATION SYSTEMS

Introduction

A geographic information system can be defined as an "information system that can input, manipulate, and analyze geographically referenced data in order to support the decision making processes of an organization" (Rocky Mountain Systems Technical Laboratory, 1977, p. 39). Geographic information systems can be distinguished from other types of information systems by the fact that the stored data is "geographically referenced." Guinn and Kennedy (1975, p. 867) described such systems as "primarily concerned with the manipulation of data which can be associated with points, lines, or areas below, on, or above the earth's surface." In other words, each bit of information in a geographic information system is referenced to a specific location.

Each data set that is input into a geographic information system can be viewed as a distinct layer of information (Cicone, 1977). Various layers of data can be overlaid to create new information regarding the co-occurrence of data. For example, a data set which describes the soil erodibility of an area could be combined with data describing slope angles to delineate areas which would experience the greatest potential soil erosion (Figure 1).

Any type of information that can be spatially referenced can be entered into a geographic information system. Remotely sensed data can, therefore, be included. Such data sources are being increasingly utilized as input to geographic information systems. Satellite sensing platforms are especially useful in supplying the data requirements for information systems that describe large regions, such as counties or states (Alexander, 1974). Remotely sensed data alone, however, cannot be expected to provide all the information required for most resource management applications. A wide variety of mapped data, both remotely sensed and conventionally collected, must be included in order to construct a functional data base designed to support resource management decisions.

Geographic information systems have been implemented in many resource management situations. Despite the diversity of applications, the physical structure of most systems are similar. The following sections briefly describe the data formats and functional operations currently utilized in geographic information systems.

Data Formats

Geographic information systems can be distinguished by the spatial character of the input data. The points, lines, and polygons representing desired geographical entities must

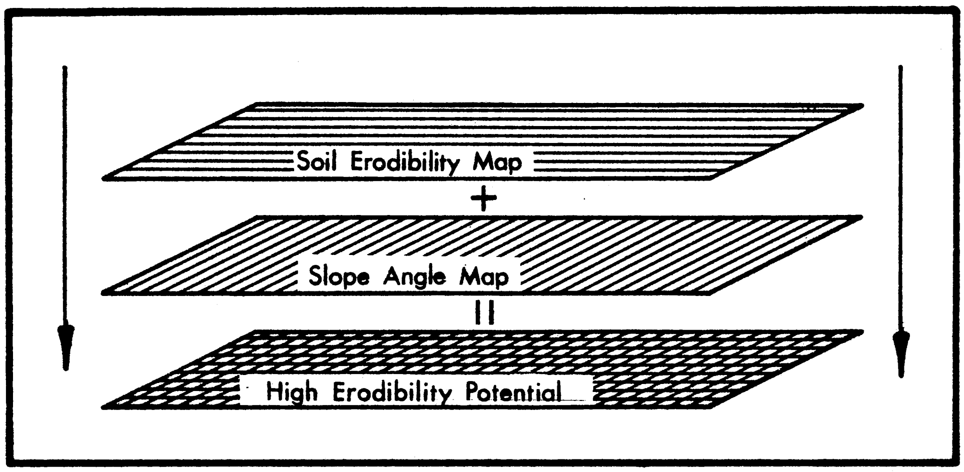


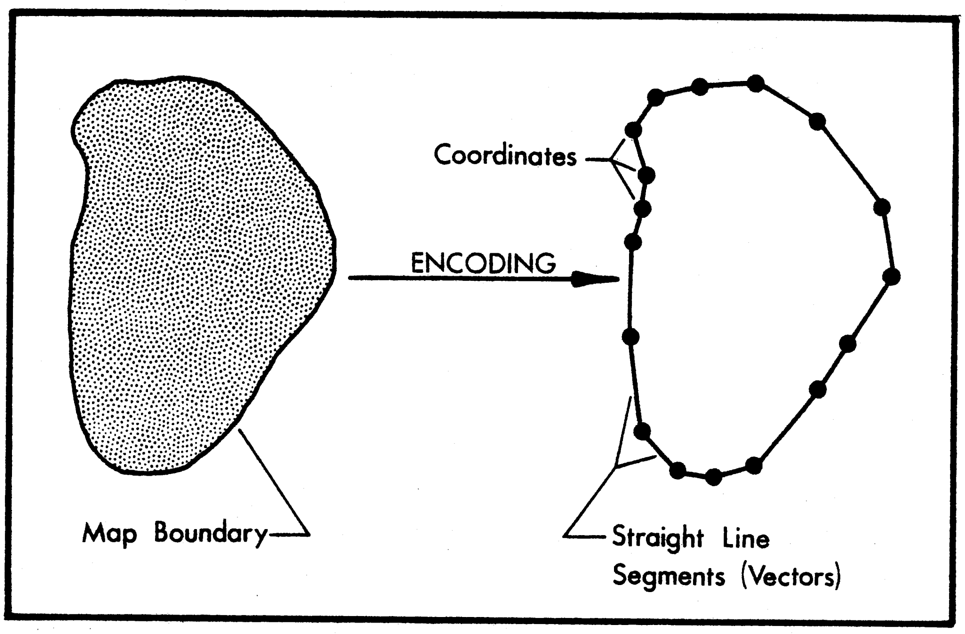
Figure 1. Overlaying Capability of Geographic Information Systems

be converted to a format which can be stored, manipulated, and displayed by a computer-based information system. The spatial information represented on a map must first be transformed into an array of X-, Y-, and Z-coordinates which describe the data. This transformation is commonly performed through the use of a graphic digitizer. The computer-compatible array of X-, Y-, and Z-coordinates must next be stored in the computer and arranged in an ordered data structure. Two types of data structure formats are utilized in geographic information systems: 1) line encoding, resulting in the storage of polygon data; and 2) cell encoding, resulting in the storage of grid data (Cicone, 1977).

Polygon Information Systems

The actual boundaries of geographic units are stored and manipulated in a polygon information system. Such boundaries are described by coordinates located at positions where line directions change (Figure 2). The set of line segments, or vectors, which describe the polygons are generally stored in the computer as lists. Four types of data structures are generally utilized in the listing procedure: 1) Location Lists, 2) Point Dictionaries, 3) DIME Files, and 4) Chain Files (NASA, 1980).

A Location List is the simplest polygon data structure. Each polygon is a separate entity, and is stored with an identifying name and a list of its coordinates. This type



Source: D. Monte Pascoe. Energy and Resource Management Techniques for Northwest Colorado: An Introduction to the Colorado Resource Information System. Denver: Colorado Department of Natural Resources, 1981.

Figure 2. Transformation of Original Map to Vector Data

of data structure is simple, but requires considerable storage space as the boundaries of adjacent polygons must be stored twice.

A Point Dictionary records each coordinate, or vertex, only once. Each vertex is stored with an identifying number. Polygons are described by the appropriate list of vertex identifiers. Point Dictionaries require less storage space than Location Lists, and updating and editing are easier. Data input, however, requires more effort as each vertex must be entered with an identifying number.

The DIME (Dual Independent Map Encoding) File was developed by the U.S. Bureau of the Census in 1967 (U.S. Bureau of the Census, 1970). DIME Files are constructed by storing the vectors, or line segments, of geographic boundaries as a unit. The method of data storage is similar to Point Dictionaries as each vector is stored with an identifying number or name. Polygons are described by linking together the appropriate list of vectors. These vectors must be located by searching the entire file, which hampers the efficiency of the data structure. DIME Files are very useful, however, for mapping urban areas, since streets can be stored as individual vectors.

Chain Files are the most complicated of the polygon data structures. The points stored in a Chain File are assigned to a hierarchy based upon their position relative to polygon edges. The points which serve as junctions for two or more polygon edges are termed nodes. The points between nodes describe a chain. Polygons are then described by the appropriate chain of points. Chain Files simplify editing and are more efficient than Point Dictionaries and DIME Files, since the need to store every vertex or vector with an identifier is eliminated.

Grid Information Systems

The actual boundaries of geographic units are not stored in a grid information system. Such systems are developed by converting the geographic units into an array of grid cells. All data are summarized by the grid cell, so the cells become the key to all data storage, manipulation, and display (Swanson, 1969).

The array of data cells in a grid information system is constructed by overlaying the desired map with a grid. Each grid cell is then examined to determine which geographic unit occupies the majority of the cell's area. The value of the geographic unit is then applied to the entire grid cell (Figure 3). The degree of detail of the resulting map is dependent upon the size of the grid cell utilized. The concept of resolution is involved; smaller grid cells can portray greater spatial variation. The array of grid cells is stored in the computer by describing each cell by X-, Y-, and Z-coordinate values. The X- and Y-coordinates describe the position of the cell relative to the entire array, while the Z-coordinate is a numeric value describing the content of the cell.

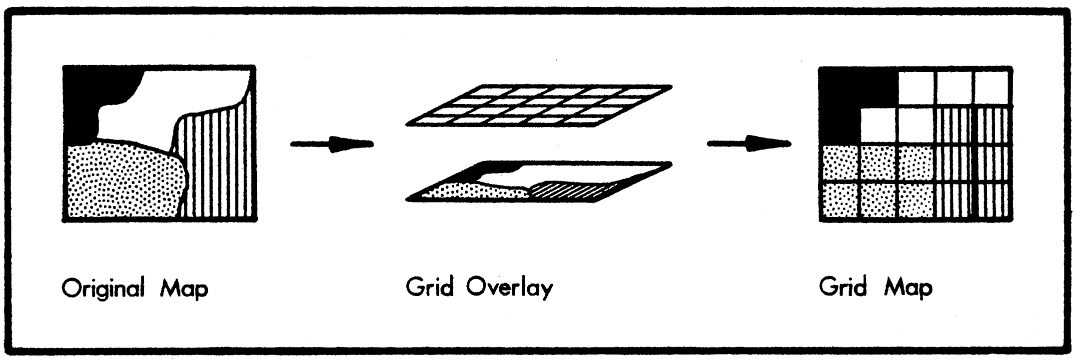


Figure 3. Transformation of Original Map to Grid Data

Polygon Versus Grid Information Systems

Polygon information systems and grid information systems both have advantages and disadvantages in various situations. Polygon systems have advantages in situations where small study areas with irregular boundaries are involved. Vector data can better delineate small, irregular areas, since actual boundaries are traced (Cicone, 1977). Situations requiring the representation of linear data, such as road and stream networks, are particularly suited to polygon information systems. Such linear features can be accurately described by a network of open line segments.

Grid information systems have a distinct advantage when large study areas are considered. The description of regional study areas usually requires the storage of large amounts of data. This often leads to storage problems, especially when small computers are utilized. The data resolution of a grid geographic information system can be varied to conform the amount of data to the storage capacity of the computer being utilized. It is also easier to store large amounts of geographic information with a grid format, since actual boundaries are not traced.

Data manipulation is usually facilitated by the use of a grid data format (NASA, 1980). When overlaying data sets, corresponding grid cells can be precisely paired which greatly assists many data manipulations. Grid information systems, however, have limitations when the representation of linear data is required. Grid cells represent area information and therefore cannot adequately describe linear data.

Geographic Information System Data Base Functions

Nearly all geographic information systems, regardless of their intended applications, have the same basic data base functions. These common data base functions include the capability to: 1) input and store data, 2) manipulate stored data, and 3) display stored data. Each of these data base functions will be briefly discussed in the following sections.

Data Storage

All geographic information systems must have the capability of accepting mapped data as input, and storing such data in a readily retrievable form (Lewis, 1972). Mapped information can be entered into a geographic information system as either polygon data or as grid data. The choice of data format depends upon individual system capabilities, characteristics of the mapped data, and the intended data applications.

Techniques of data input vary from system to system. The simplest method involves manually encoding the mapped information, and then inputting the data into the computer through peripheral terminals. More advanced techniques of data input involve semi-automatic and automatic digitizers which can prepare and input mapped information into the computer with a minimal amount of user involvement (Shelton and Hardy, 1974).

Data Manipulation

An important function of geographic information systems is the manipulation of stored data. Without data manipulation functions, a geographic information system would serve only as a computer-based library designed to store maps. Most geographic information systems, however, go beyond merely storing mapped data, and provide the capability to manipulate the data for a variety of purposes.

Most common data manipulation functions can be grouped into one of two categories: 1) statistical analysis, or 2) spatial analysis (NASA, 1980). Statistical analyses are performed to determine the relationships between the various data sets stored in the information system. For example, correlation and regression coefficients can be calculated in order to determine the degree of spatial similarity between data sets.

Spatial analysis is probably the most useful data manipulation function of geographic information systems. Spatial analyses can be designed for many specific applications. Single data sets can be manipulated to identify areas with or without a certain attribute, or areas having a certain range of attributes. Multiple data sets can be overlaid to create new maps which portray the spatial associations and relationships between desired layers of data.

Data Output and Display

The last important data base function of geographic information systems involves the retrieval and display of stored data. Storage and manipulation functions have little utility unless the products derived from such functions can be viewed and used for further analysis. As a result, the ultimate success or failure of a geographic information system is often judged by the quality of its output products.

Output products vary from system to system, dependent upon the types of stored data, retrieval programs, and display devices available to the information system (Shelton and Hardy, 1974). Tabular lists of non-spatial information can be output to allow analysis of the range of data within a study area. Reports and data summaries can also be produced. An important output product of a geographic information system is maps which display the various stored layers of data in graphic form. Such maps can portray the original spatial data that were input into the system, or the products resulting from various manipulation functions. Maps vary from simple line printer maps, composed of alpha-numeric symbols, to intricate, color maps produced on image display devices.

Geographic Information System Applications to Resource Management

Geographic information systems can be used "to support the decision making processes of an organization" (Rocky Mountain Systems Technical Laboratories, 1977, p. 39). This broad statement suggests the variety of applications for geographic information systems. Such systems have been developed on a municipal level to support the planning departments of a number of cities in the United States (Reeves, Anson, and Landen, 1975). The United States Geological Survey has developed a geographic information system designed to facilitate the publication of geologic index maps (Fulton and McIntosh, 1977). The greatest use of geographic information systems has been in the field of resource management. Computerized information systems are ideally suited for organizing the diverse information needs of resource managers. Geographic information systems have been developed at a variety of scales to handle many different types of resource management problems.

Statewide inventories of land use and natural resources have been conducted to develop natural resource information systems for a number of states. New York was one of the first states to develop a geographic information system designed to assist resource management (Swanson, 1969). In the late 1960's, the New York State Office of Planning Coordination conducted a statewide inventory primarily utilizing aerial photography. The information gained from this inventory was used to develop the New York Land Use and Natural Resource (LUNR) information system. This grid information system provided statewide resource data at a resolution of one square kilometer. A grid with a smaller cell size was used for mapping urban areas to increase the resolution to one quarter of a square kilometer.

In the early 1970's, the South Carolina Land Use Information System was developed. This system utilized a grid with a 92 acre cell size to portray land use, soil associations, population density, and elevations across the state (Hite, 1972). Data output from this system included computer printed maps and tabular listings of the number of grid cells containing a particular attribute. This information was primarily used to support initial planning decisions in the state. Also in the early 1970's, a land use information system was developed for the state of Maryland (Wahbe, 1972). The primary data source for this information system was high altitude color infrared aerial photography.

In 1972, Texas began developing the Texas Natural Resources Information System (TNRIS) (Interagency Council on Natural Resources and the Environment, 1973). TNRIS was developed "to provide the maximum availability of natural resource data and information consistent with cost and efficiency" (p. 1). This system included information on geographic base data, meteorology, biologic resources, water resources, geologic resources, and socio-economic resources.

In 1973, the Louisiana State Planning Office obtained computerized land use overlays for the entire state from the United States Geological Survey (Schwertz, Jr., 1975). This land use information was combined with flood data, soils data, and socio-demographic data to form the Louisiana Comprehensive Planning Information System. This system has been utilized for urban and regional planning and various resource management applications.

An extensive geographic information system was developed for Montana and Wyoming in the late 1970's (Information Systems Technical Laboratory, 1977). This information system included data on soils, geology, climate, land ownership, vegetation, land use, topography, socio-economic resources, wildlife, water resources, mineral resources, and land management plans. This information was organized to provide a data source designed to assist statewide planning and management of natural resources.

Development of the Colorado Resource Information System (CRIS) began in 1979 (Pascoe, 1981). Initial coverage of this system was limited to northwest Colorado. This region contains substantial reserves of oil shale, oil, natural gas, coal, and uranium. At the present time, the primary purpose of the CRIS is to provide a tool for assisting energy resource management in the region. Data categories incorporated into the system include regional information on geographic base data, wildlife, vegetation, minerals, and land use.

The Kentucky Department for Natural Resources and Environmental Protection is currently developing a geographic information system designed to assist in a variety of planning applications in the state (Croswell, 1982). In particular, the Kentucky Natural Resources Information System (KNRIS) is being designed to evaluate claims that certain areas of the state are unsuitable for surface coal mining. The KNRIS consists of a map and document library, a remote sensing support center, and an automated geographic information system. The KNRIS presently covers the eastern and western coal regions of Kentucky which encompass 40 percent of the state's total area. Landcover and land use information is currently interpreted from aerial photography. Future efforts will be directed toward integrating satellite data with the information system.

Geographic information systems designed for resource management have also been constructed for use at larger scales. An information system developed at the Jet Propulsion Laboratory in Pasadena, California was modified for use in monitoring the Lake Tahoe Watershed, situated on the California and Nevada boundary (Smith and Blackwell, 1980). This system utilizes satellite multispectral scanner data, digital terrain data, conventional maps, and ground data. The information system will be used to study environmental changes in the watershed which directly affect the water quality of Lake Tahoe.

Summary

The use of geographic information systems has increased dramatically, since their initial development in the late 1960's. The applications briefly outlined in this chapter demonstrate the utility of such systems for resource management. In Oklahoma, one of the primary resources requiring careful management is the coal deposits located in the eastern third of the state. Little research has been conducted on the application of geographic information systems to coal mining. The Kentucky Natural Resources Information System covers the coal regions of Kentucky, but is primarily being designed to evaluate the suitability of land for surface coal mining. The Oklahoma Geographic Information Retrieval System was developed to assist the management of surface coal mines, so this study should provide insights into a new use for geographic information systems.

CHAPTER III

COAL PRODUCTION IN EASTERN OKLAHOMA

Introduction

As was mentioned in Chapter I, this research has grown out of a pilot project which developed a geographic information system designed to assist in the management of surface coal mines in eastern Oklahoma. This region provides an ideal setting for a project of this type. The coal reserves in eastern Oklahoma have been mined since 1872, and surface mining has gradually become the primary method of coal extraction (Johnson, 1974).

This chapter examines the coal producing region in Oklahoma. The first section describes the two study areas covered by the Oklahoma Geographic Information Retrieval System. The last two sections outline the subjects of coal production in eastern Oklahoma and the data management needs of surface coal mine operations.

Study Areas

Two small watersheds in northeastern Oklahoma were chosen as study areas for this research. The watersheds are located in western Craig County, 55 miles (89 kilometers) northeast of Tulsa, Oklahoma (Figure 4). The eastern watershed, consisting of the drainage of a fifth order stream of the Arkansas River drainage system (map order, USGS 1:24,000 topographic map), covers 978 acres (396 hectares) and contains an operational surface coal mine. The western watershed, containing a third order stream of the same drainage system, covers 1,403 acres (568 hectares) and contains no surface coal mining activity at the present time.

The watersheds are located in the Claremore Cuesta Plains Geomorphic Province (Johnson et al., 1979), an area characterized by gently rolling topography with low ridges of resistant Pennsylvanian sandstones and limestones rising from broad shale plains. The elevation in the eastern watershed ranges from 770 feet (235 meters) to 925 feet (280 meters), while the western watershed varies from 760 feet (233 meters) to 820 feet (252 meters).

Average annual precipitation for Vinita, located 15 miles (24 kilometers) southeast of the watersheds, is 42.0 inches (106.7 centimeters) (National Oceanic and Atmospheric Administration, 1981). The average temperature in July is 81.1 degrees Fahrenheit (27.3 degrees Celsius), while January temperatures average 36.0 degrees Fahrenheit (2.2 degrees Celsius).

The soils in the watersheds vary from fine sandy loams to silty clay loams (Soil Conservation Service, 1973). Most of the soils are deep and formed under a cover of mid to tall grasses. Many of the soils in the area are mildly

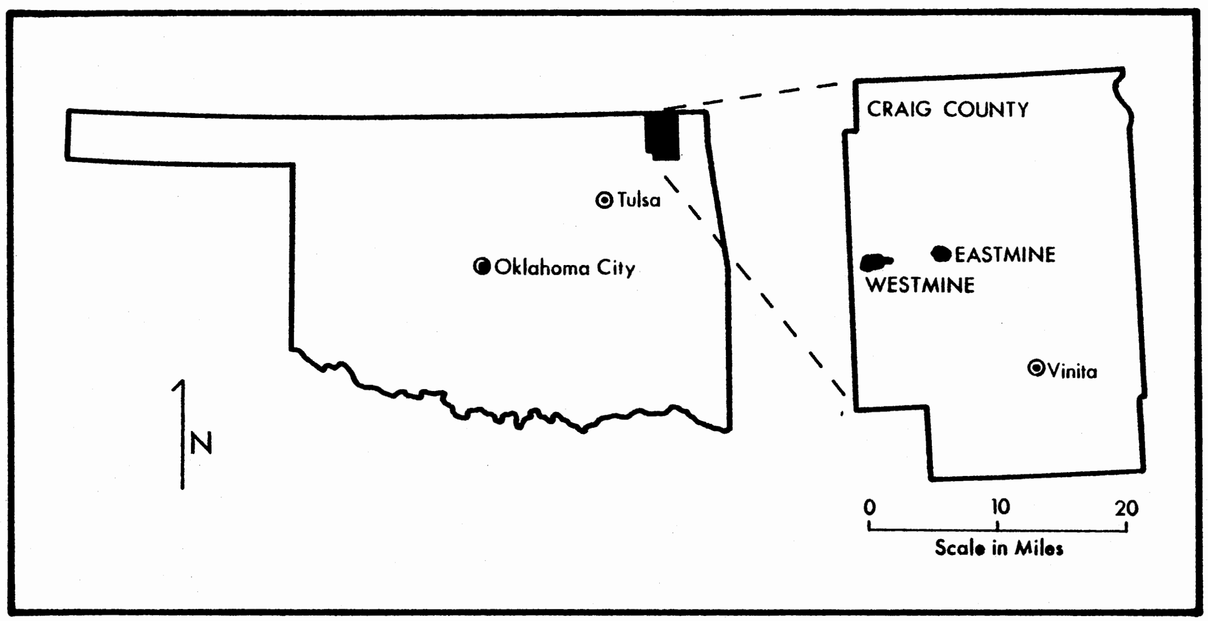


Figure 4. Location of Study Areas in Craig County, Oklahoma

acidic.

Agriculture is the primary land use in the study areas (Soil Conservation Service, 1973). Leading cash crops include wheat, grain sorghum, and soybeans. Livestock production, principly the raising of beef cattle, is also important.

Landcover in the study areas is governed largely by the agricultural uses of the land. Much of the eastern watershed is covered by sparse grass used for grazing. Small acreages have been planted in wheat and alfalfa. Narrow bands of bottomland forest follow the drainage channels, while small stands of upland forest appear on the surrounding hills. Surface mining activities have removed much of the vegetation in the south central portion of the eastern watershed.

Cultivated acreage accounts for a larger percentage of the area in the western watershed. As in the eastern watershed, much of this acreage is planted in wheat and alfalfa. Pastureland is also found in the western watershed. Forests have been almost entirely removed from the area.

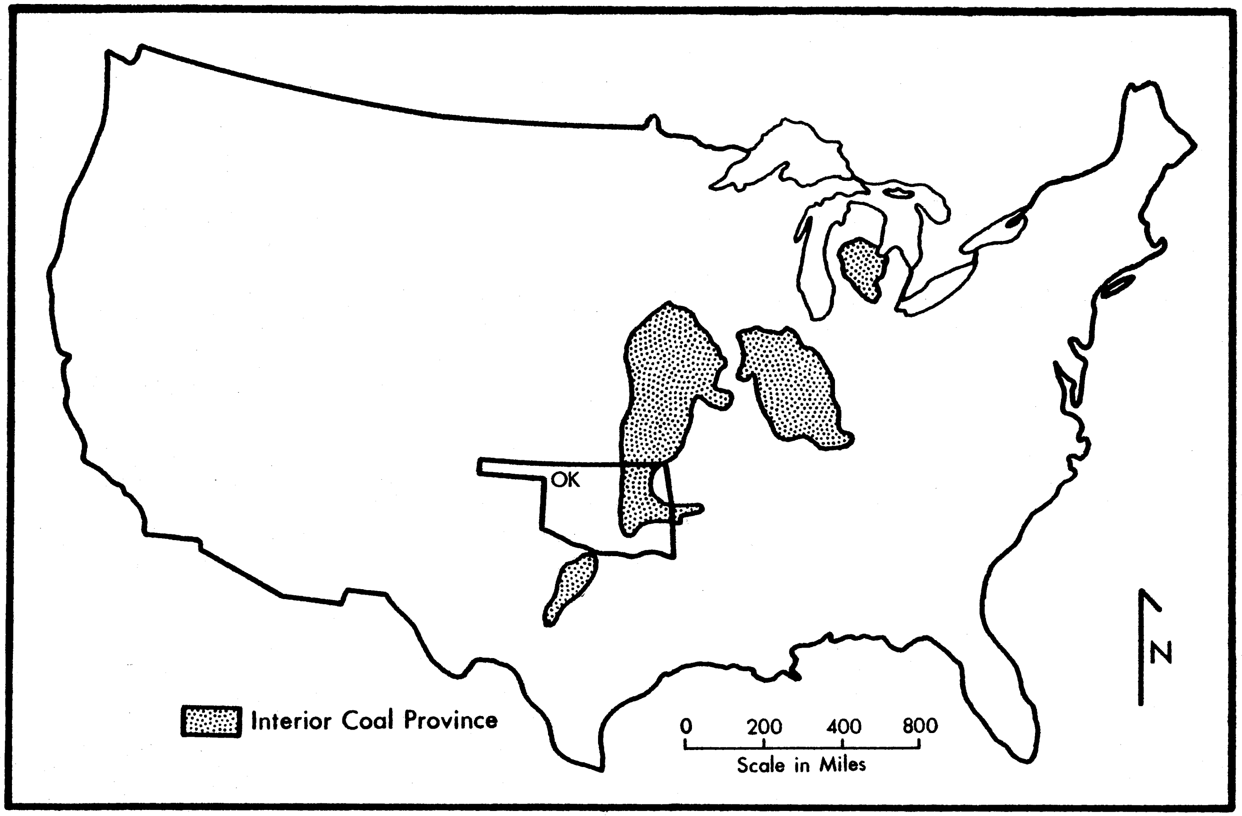
Coal Production in Eastern Oklahoma

The bituminous coal resources of Oklahoma span an area of nearly 8,000 square miles (20,725 square kilometers) in the eastern third of the state (Friedman, 1975). This area is the southern extension of the Western Region of the

Interior Coal Province of the United States (Figures 5 and 6). The Oklahoma coal reserves are found in beds of Middle and Late Pennsylvanian age rock (270 to 300 million years old). Stratigraphically, the Hartshorne coal is the lowest exploited coal bed in Oklahoma. It is found at the top of the Hartshorne formation, which varies in thickness from three to 316 feet (one to 96 meters). The Dawson coal is the highest exploited coal bed, stratigraphically, in Oklahoma. It is located in the Seminole formation, which varies from ten to 240 feet (three to 73 meters) thick.

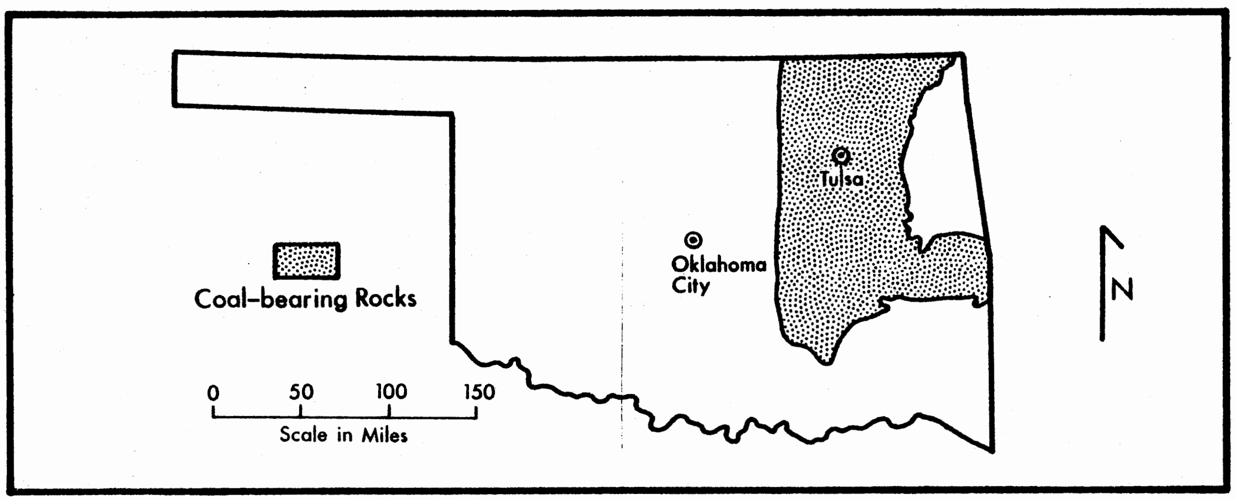
The strippable coal reserves in Oklahoma have been estimated at 695 million tons (630 million metric tons), of which 504 million tons (457 million metric tons) are considered recoverable (Haigh, 1978). Mining of these reserves began in 1872 with the arrival of the railroad. Underground mining accounted for nearly all of the early coal extraction. Surface mining has become increasingly important, however, as the large earth-moving equipment necessary for such operations were developed (Figure 7). By 1943, surface mining accounted for 50 percent of Oklahoma's annual production, and by the mid-1960's, this percentage had risen to over 99 percent (Johnson, 1974). By the end of 1973, surface mining accounted for 100 percent of Oklahoma's coal production, as the last underground mine in Oklahoma closed in that year.

Coal production in Oklahoma reached an all-time high of 5,428,678 tons (4,923,811 metric tons) in 1978 (Northeast



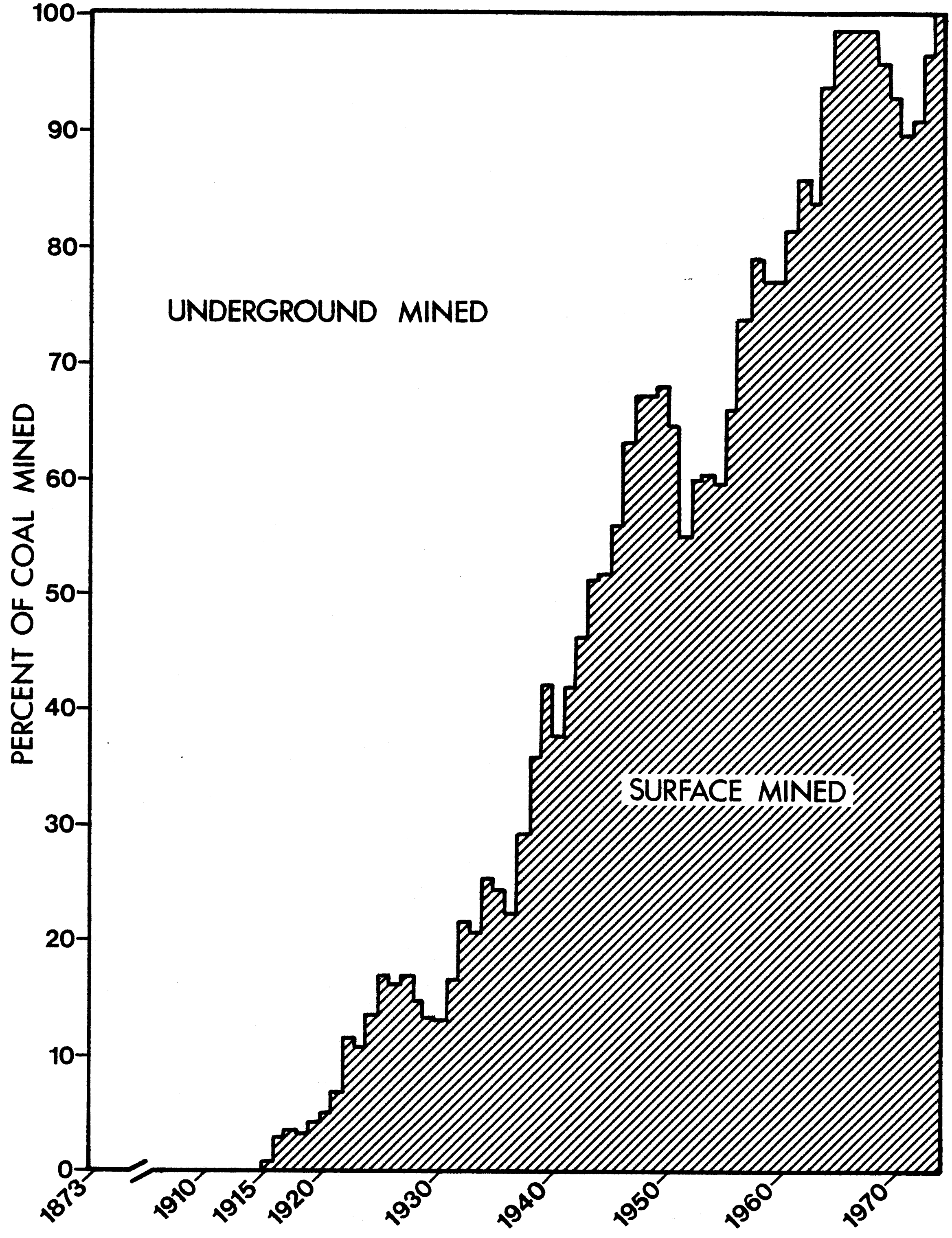
Source: S. A. Friedman. Investigation of the Coal Reserves in the Ozarks Section of Oklahoma and their Potential Uses. Norman: Oklahoma Geological Survey, 1975.

Figure 5. Interior Coal Province of the United States



Source: S. A. Friedman. Investigation of the Coal Reserves in the Ozarks Section of Oklahoma and their Potential Uses. Norman: Oklahoma Geological Survey, 1975.

Figure 6. Location of Coal-bearing Rocks in Oklahoma



Source: S. A. Friedman. Investigation of the Coal Reserves in the Ozarks Section of Oklahoma and their Potential Uses. Norman: Oklahoma Geological Survey, 1975.

Figure 7. Percentage of Underground Mined to Surface Mined Coal in Oklahoma, 1873 - 1970+

Counties of Oklahoma Economic Development Association, 1981). Production decreased in 1979, as only 4,797,156 tons (4,351,021 metric tons) were mined. Coal production in 1980 was 5,335,805 tons (4,839,575 metric tons); an increase over 1979 figures, but still below the 1978 production.

In 1978, Craig County led the state in coal production (Northeast Counties of Oklahoma Economic Development Association, 1981). Mining in the county in that year yielded 1,924,131 tons (1,745,187 metric tons), contributing over 35 percent of Oklahoma's total production. As with state production, Craig County's coal production dropped in 1979, amounting to 1,709,497 tons (1,550,514 metric tons). In 1980, Craig County continued to follow state trends, as coal production increased to 1,738,772 tons (1,577,066 metric tons).

Surface mining basically involves two operations: 1) removal of the overburden to expose the coal seam, and 2) extraction of the coal. Although these two tasks are basic to all surface mining operations, the exact manner in which they are performed may vary from site to site, depending upon the nature of the overburden, thickness of the coal seam, and the topography of the mine site.

Surface mining has disturbed large tracts of land in eastern Oklahoma. Land disturbed by surface mining provides potential sources of pollution to the air and water (Persse, 1975). Toxic materials are often exposed that cause acid conditions in local water bodies. The barren land is vulnerable to water and wind erosion. The disturbed land in Craig County, alone, covered 4,485 acres (1,815 hectares) in 1973 (Johnson, 1974). By 1980, the area of disturbed land in the county had increased to 10,787 acres (4,365 hectares) (Northeast Counties of Oklahoma Economic Development Association, 1981). Of the 1980 figure, only 6,831 acres (2,764 hectares) had been reclaimed. This left 3,956 acres (1,601 hectares) still in need of reclamation efforts.

Data Management Needs of Surface Coal Mine Operations

Many variables are associated with the management of a surface coal mine. The environmental aspects of the mine site, itself, must be constantly analyzed during the mining operation to maintain the efficient extraction of the coal reserves. Coal seam depth, thickness, and configuration are important considerations in determining the economic viability of the mining venture (Breslin and Anderson, 1974). Other aspects of the physical environment also affect the mining operation. The general geologic characteristics of the mine site will have an important influence on mine management decisions. The depth to bedrock and type of bedrock will largely determine the ease of overburden removal. Other characteristics of the bedrock will influence such factors as highwall stability. The engineering properties of the soil play a large role in determining the stability of access roads and embankments.

Hydrologic characteristics, such as the height of the water table, must also be considered. All surface mine operations are directly exposed to the weather, so local climatic patterns are another important consideration in any surface mining venture.

Until recently, activity at many surface coal mines terminated with the removal of the economically recoverable coal. Concern over the environmental degradation caused by surface mining, however, has led to state and federal reclamation laws regulating current mining operations and the reclamation of past mining sites. Examples of these laws include Oklahoma's Mining Lands Reclamation Acts of 1968 and 1971 and the Federal Surface Mining Control and Reclamation Act (PL95-87), which was signed into law on August 3, 1977. These laws have produced additional considerations for the surface coal mine manager. Section 515 of the 1977 Surface Mining Control and Reclamation Act outlines performance standards which must be met by the operators of surface coal mines. The approximate original contours of the land disturbed by surface mining must be restored. Surface areas must be protected from wind and water erosion. Topsoil must be removed separately during the mining operation, and then replaced after mining is completed. Other standards regulating the disposal of waste materials, the use of local hydrologic resources, and other engineering aspects of the mining operation are also specified.

Many of the environmental factors affecting the actual mining operation, such as climatic patterns and the engineering properties of the soil, also influence reclamation potentials. Successful reclamation, however, also requires new data needs. Information on the pre-mining topography of the mine site must be recorded for consideration during post-mining regrading efforts. Redistribution of the topsoil over the spoil material requires knowledge of the pre-mining soil profile. Soil characteristics relating to plant growth are important considerations for determining the re-vegetation potential of the mine site (Packer, 1974).

Paragraph D, Section 101, of the 1977 Surface Mining Control and Reclamation Act states:

> Surface mining and reclamation technology are now developed so that effective and reasonable regulation of surface coal mining operations by the States and Federal Government in accordance with the requirements of this Act is an approppriate and necessary means to minimize so far as practical the adverse social, economic, and environmental effects of such mining operations (p. 4).

The many data requirements of surface coal mine management suggest that geographic information systems need to be included in the new technologies mentioned in the 1977 Act. The diverse data types could be efficiently organized through an information system format, and the tabular and graphic output products from such a system could provide valuable analysis tools for the mine manager.

Summary

Surface mining has become the primary method of coal extraction in the coal producing region of eastern Oklahoma. The many environmental aspects associated with surface coal mining illustrate the need for effective data management. A geographic information system could provide a means for organizing the diverse data requirements of surface coal mine managers. The next chapter examines the development and operation of such an information system.

CHAPTER IV

OPERATION OF THE OGIRS

Introduction

A major task in the development of a geographic information system involves writing the software package. The system software must provide the capability to input and store data, manipulate it for various applications, and then produce display products. All software development for the Oklahoma Geographic Information Retrieval System utilized the computing facilities at the Center for Applications of Remote Sensing. The OGIRS was programmed in Fortran-VII, and consists of a main program and subroutines. The program uses system dependent subroutines for dynamic assignment of logical units and for interactive allocation of disk files. This chapter examines the method of data input into the OGIRS, and the system capabilties for data manipulation and display.

Data Entry

Data can be entered into the information system in two formats: 1) as grid coordinate points from a graphic digitizer, and 2) as polygon data in the NASA Earth Resources Laboratory Applications Software (ELAS) type data file (Junkin et al., 1980). The attributes of grid and polygon formats were discussed in Chapter II. Although the small sizes of the study areas suggest the use of a polygon format, a grid system was developed to store and manipulate areal features. This decision was made for a number of reasons. As was mentioned in Chapter II, grid data is easier to manipulate in an information system than is polygon data, as corresponding grid cells can be precisely paired when grid data sets are overlaid. Also, a geographic information system designed to assist the management of surface coal mines in eastern Oklahoma must have the ability to store data over a relatively large region. The coal reserves in Oklahoma span an area of nearly 8000 square miles (Friedman, 1975). A grid format with a relatively large cell size is required when describing large study areas in order to keep the volume of data within manageable limits. A grid format with a ten acre (four hectare) cell size was chosen to demonstrate the degree of detail which can be expected from a geographic information system describing a county, or a multiple county area.

Data entry into the OGIRS, in a grid format, requires two steps. First, the desired mapped data must be converted to an array of ten acre grid cells. This task is accomplished by overlaying the desired map with a grid of ten acre cells. Each cell is analyzed and assigned a value based upon the geographic unit occupying the majority of the cell's area (Figure 3). The resulting array of values is then digitized on a graphic digitizer. This process assigns an X-, Y, and Z-coordinate value to each cell. As the array of grid cells is digitized, a system subroutine automatically stores the coordinate data in a disk file which can then be accessed by other system subroutines.

Linear features can also be stored within the OGIRS through its interface with the Earth Resources Laboratory Applications Software (ELAS). The storing of linear features requires two basic steps. First, the desired linear pattern is digitized so that each line segment is converted to a set of X- and Y-coordinate values described by the Universal Transverse Mercator (UTM) coordinate system. Next, the UTM coordinate information is entered and stored in an ELAS polygon file. The stored linear features can then be overlaid on any of the OGIRS grid data and viewed upon the Comtal Image Processing System. The ELAS software includes polygon editing capabilities so linear patterns, such as road networks, can be periodically updated.

Organization of data within the Oklahoma Geographic Information Retrieval System is relatively simple. Data sets are grouped into broad categories, termed libraries. Each library is an open-ended file containing data describing similar environmental phenomena. Individual data sets are stored as channels within the appropriate library. As grid data is digitized and stored on disk, the user is prompted to input the appropriate library name and channel number. Five libraries were developed within the OGIRS: Geology, Landcover, Soils, Topography, and Climate (Figure 8).

Data Output

The Oklahoma Geographic Information Retrieval System can generate output in a number of formats. Line printer maps can be viewed on a CRT terminal or obtained as hard copy printout from a line printer (Figure 9). These maps are composed of alphabetic symbols representing the data value of each ten acre grid cell.

The OGIRS data sets can also be viewed as color image display maps. A subroutine in the information system generates a data set which is compatible with the NASA Earth Resources Laboratory Applications Software (ELAS). The ELAS-compatible data set can then be displayed on the Comtal Image Processing System. The graphics capability in ELAS allows the display of titles and legends with each data set. The images on the display screen can be viewed in a wide variety of user-controlled colors, in addition to black and white. The ELAS-compatible data set can also be used to generate hard copy maps on the Center's Versatec electrostatic printer/plotter. Although these maps are available as black and white products only, a variety of scales can be chosen.

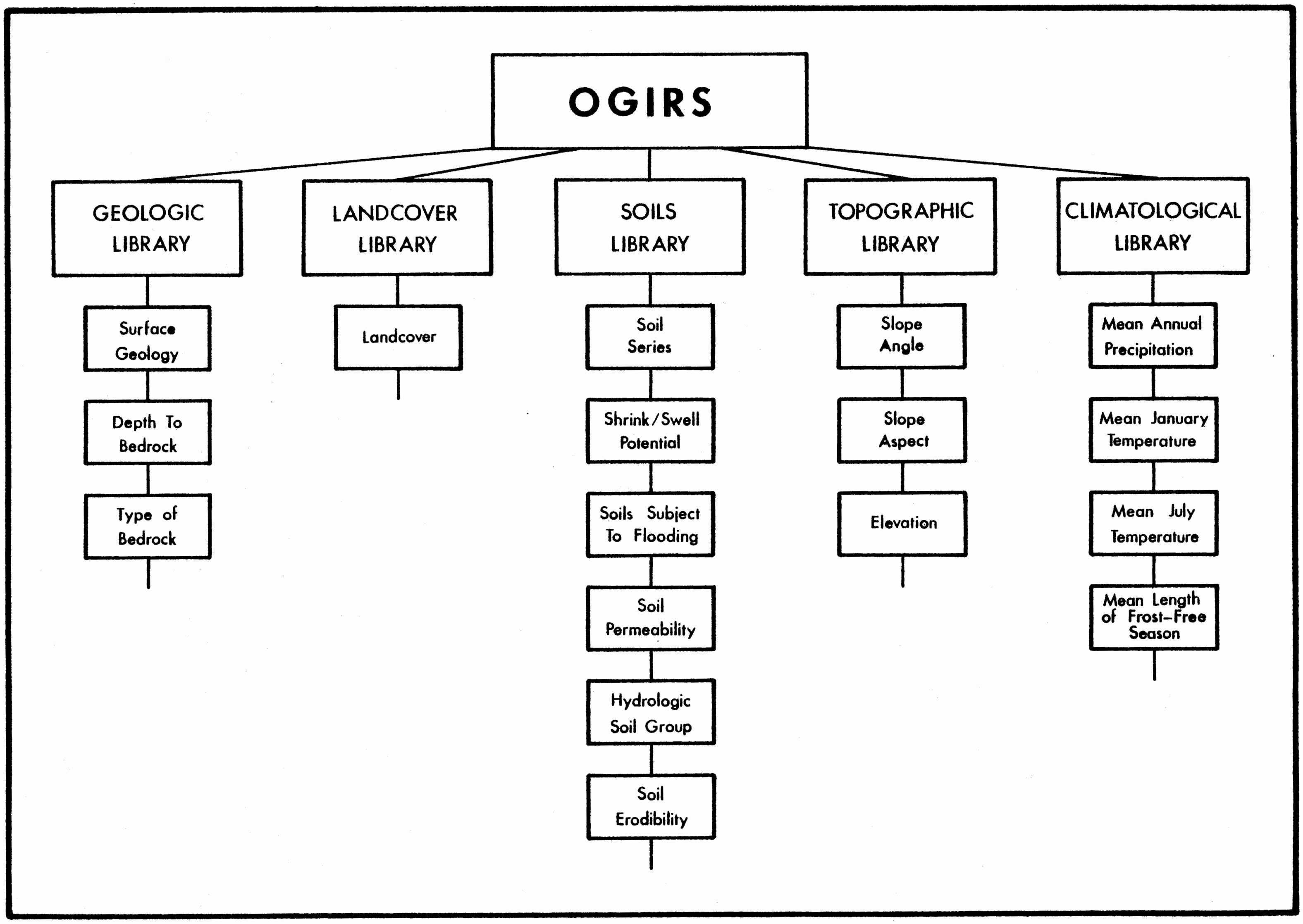


Figure 8. Data Organization and Contents of the Oklahoma Geographic Information Retrieval System

```
EASTMINE SLOPE ANGLE
CRAIG
IL =     1       LL =    10
IE =     1       LE =    13
CH =     1
DATE: 19/02/82      LIBRARY DESCRIPTOR: TOPO
```

```
          A B C D
    E F F F G H I A J
  E F F K I I J J E I
E F F H F I J E E A A E
E H G F L H I I L L E I
  E D F H B L F K M E A E
  N A I K L M B F K E E H
    A H D G K F F F J J L
      F D K B C B K K G M
        J J H M H O O
```

LEGEND

CAT #	FREQ	VALUE	SYMBOL
1	7	2	A
2	5	10	B
3	2	13	C
4	4	15	D
5	14	3	E
6	16	8	F
7	4	11	G
8	9	6	H
9	9	5	I
10	8	4	J
11	8	9	K
12	6	7	L
13	4	12	M
14	1	1	N
15	2	14	O

15 CATEGORIES 99 CELLS 990A AREA

Figure 9. Line Printer Map of Slope Angle in the EASTMINE Watershed

Data Manipulation Functions

Data manipulation functions and models are an important part of any information system. Typically, decisions are based upon the structured manipulation of pertinent, stored data (Haseman, Holsapple, and Whinston, 1976). The Oklahoma Geographic Information Retrieval System provides a set of very flexible data manipulation functions. These functions operate on two levels: 1) single data sets, and 2) multiple data sets.

Single data sets may be processed to select values from the total data set. Five modes are available, including: equal values, greater than, less than, greater than and less than, and greater than or less than. In the "equal values" mode, a user may select up to 12 individual values to be selected from the total data set. The result is a map showing only those cells having the selected values. The "greater than" and "less than" functions prompt the user for a value, and the resulting map displays values greater than or less than the input value, respectively. The "greater than and less than" and the "greater than or less than" functions prompt the user for two values and then produce maps which isolate the values on either side of the input values, or between the input values, respectively.

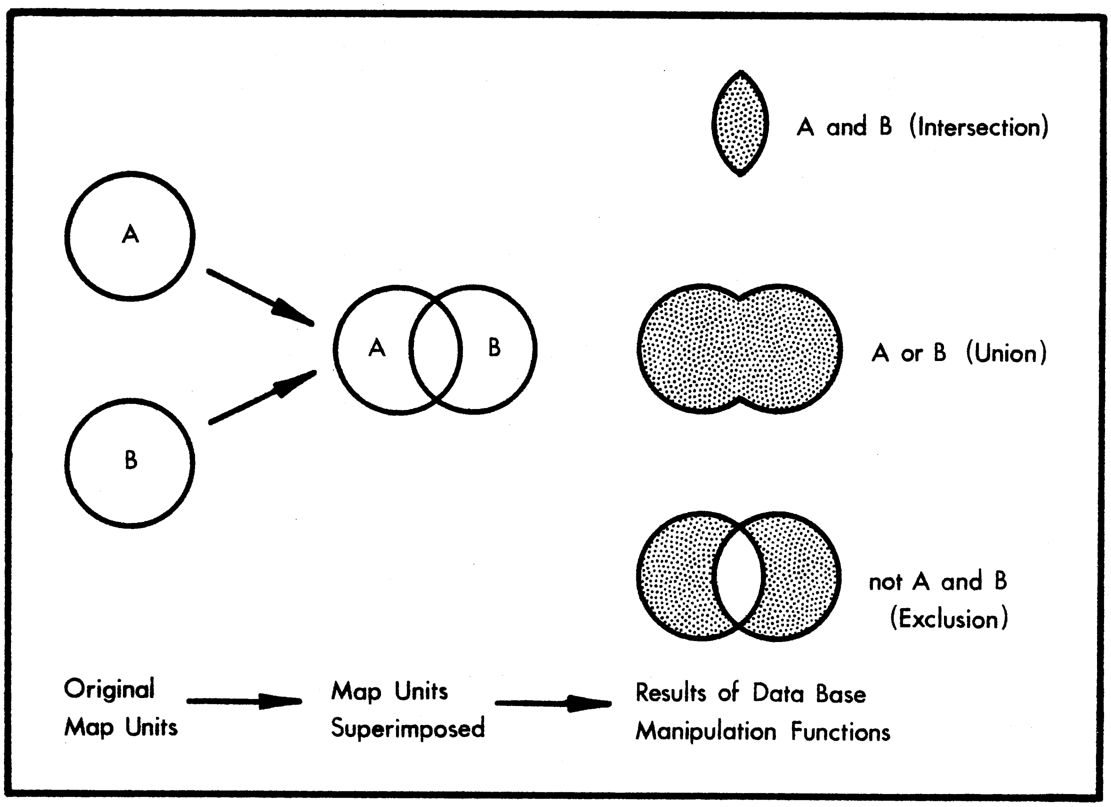
Multiple data sets can also be processed with the data manipulation functions through a series of set theory models. The user has three modes to select from, including: intersection, union, and exclusion (Figure 10). Once one of the basic modes is selected, the user is prompted for the total number of data sets to be processed and the library and channel numbers of the selected data sets. At this point, each of the data sets can be processed through one of the manipulation functions designed for single data sets. Examples of the use of the data manipulation functions will be outlined in Chapter VI.

Additional Data Manipulation Models

Additional data manipulation models, aside from the data manipulation functions previously described, can be included in the software of the Oklahoma Geographic Information Retrieval System. One such model has been developed and is described in the following section. An example of its possible use will be outlined in Chapter VI.

Coefficient of Areal Association Model

The Coefficient of Areal Association Model is a statistical model which generates, as output, a value describing the areal correspondence of the information from two data sets. This value, called the Coefficient of Areal Association, ranges in value from "0" to "1", depending upon the spatial similarity between the two data sets. A value of "0" indicates that the two data sets are completely dissimilar, while a value of "1" indicates that the data sets are spatially identical. The coefficient is generated by dividing the total number of grid cells involved in the



Source: Boeing Computer Services, Inc. Natural Resource Information System. Seattle, Washington: Boeing Computer Services, Inc., 1972.

Figure 10. Illustration of Common Set Theory Functions

intersection of two data sets by the total number of grid cells involved in their union (Taylor, 1977).

The Coefficient of Areal Association Model can be applied to any combination of data sets stored within the OGIRS data libraries. Each of the desired data sets is first processed through one of the functions designed to manipulate single data sets. The intersection and union of the two data sets are then calculated, and the number of grid cells involved in these operations are utilized to generate the Coefficient of Areal Association.

Summary

The Oklahoma Geographic Information Retrieval System was designed to assist the management of surface coal mines in eastern Oklahoma. The grid information system accepts and stores digitized data, and then provides various functions for data manipulation. Output products include line printer maps, electrostatic printer/plotter maps, and color images. A variety of data describing the physical environment of the two study areas was collected and stored within the OGIRS. These data are briefly described in the following chapter.

CHAPTER V

DESCRIPTION OF ARCHIVED DATA

Introduction

The selection and acquisition of data is a very important task in the development of a geographic information system. The utility of any information system depends upon the relevancy of the stored data. As mentioned in Chapter I, the selection of data should be based upon the initial system objectives. A poor definition of data needs can result in the encoding of unnecessary data, or the exclusion of necessary data, both of which can lessen the efficiency and effectiveness of an information system (Information Systems Technical Laboratory, 1977).

Lewis (1972) describes various characteristics which should be considered when the data are selected. The data should represent the resource management situation and account for the components of the environment which affect management. The data should be objective to assure the utility of the data for a variety of users. The data should be spatially interrelatable to allow effective analysis of information. The data should also be stored in a format which allows for quantification. Finally, the data should be uniformly available.

The data which have been entered and stored within the Oklahoma Geographic Information Retrieval System were selected with the goal of developing an information system designed to assist the management of surface coal mines. Data needs were determined through research and interviews with individuals associated with surface mining and general resource management. This information was utilized to develop the five basic data libraries for each of the two study areas utilized in this research. The specific data which were selected are outlined in Figure 8, and are described in more detail in the following sections on the OGIRS library contents. Electrostatic printer/plotter maps of the data (Figures 18 to 51) are included in the Appendix.

Soils Library

The Soils Library within OGIRS contains the largest amount of data of any of the libraries which have been developed. The size of this library indicates the importance of soil data to surface coal mine management. The engineering properties of the soil at a mine site have a great influence upon the stability of spoil piles and highwalls, the construction of access roads, and the many other engineering aspects of surface mining. The structure and morphology of the soil can give estimates of the potential sediment yield in lands disturbed by surface mining (Haigh, 1978). Soil properties should also be considered in post-mining activities at mine sites, as soil productivity and stability are important factors in determining the probability for successful reclamation (Packer, 1974). The following sections describe the contents of the data channels that are located within the Soils Library.

Channel 1

Soil Series (Figures 18 and 19, in Appendix). The name of the soil series that is found in each ten acre grid cell within the watersheds was stored in Channel 1 of the Soils Library. Thirteen different soil series are found within the eastern watershed, while twelve soil series are found within the western watershed. The soil series were digitized from the soil maps (1:20,000) included within the Craig County Soil Survey (1973) issued by the Soil Conservation Service.

Channel 2

Soil Shrink-Swell Potential (Figures 20 and 21, in Appendix). The shrink-swell potential of each soil series found within the watersheds was stored in Channel 2. The entire soil horizon was considered in determining an average for the soil series. The soil shrink-swell potentials range from low to high in the eastern watershed, while only moderate and high shrink-swell potentials are found in the western watershed (Soil Conservation Service, 1973).

Channel 3

Soils Subject to Flooding (Figures 22 and 23, in Appendix). The soils in each watershed that are subject to periodic flooding were stored in Channel 3. Small areas of potential flooding are found within each watershed (Soil Conservation Service, 1973).

Channel 4

Soil Permeability (Figures 24 and 25, in Appendix). The degree of permeability of the least permeable soil horizon for each soil series found within the watersheds was stored in Channel 4. The degree of permeability ranges from slow (.06 to .20 inches/hour) to moderately rapid (2.0 to 6.0 inches/hour) in the eastern watershed. In the western watershed, the degree of permeability ranges from very slow (less than .06 inches/hour) to moderate (.60 to 2.0 inches/hour) (Soil Conservation Service, 1973).

Channel 5

Hydrologic Soil Groups (Figures 26 and 27, in Appendix). The hydrologic soil grouping of each soil series in the watersheds was stored in Channel 5. This parameter rates soils according to their infiltration and transmission rates, which directly affect the runoff potential of a soil (Soil Conservation Service, 1975). The runoff potentials of the soils range from moderate to high for both watersheds (Soil Conservation Service, 1973).

Channel 6

Soil Erodibility (Figures 28 and 29, in Appendix). The erodibility potentials of each soil series in the watersheds were stored in Channel 6. The erodibility potentials were calculated by utilizing an abbreviated form of the Universal Soil Loss Equation (Soil Conservation Service, n.d.). This equation states:

$$A = RKLSC$$

A = the predicted average annual soil loss
R = the rainfall factor
K = the soil-erodibility factor
L = the slope length factor
S = the slope-gradient factor
C = the plant cover factor

Potential soil erodibility ranges from low to very high in the eastern watershed, and from low to high in the western watershed.

Geologic Library

The Geologic Library contains data describing the bedrock of the study areas. The design of the mine pit, the selection of mining techniques, and, ultimately, the profitability of the mining venture largely depend upon the character of the bedrock (Breslin and Anderson, 1974). The following sections describe the contents of the channels found within the Geologic Library.

Channel 1

Surface Geology (Figures 30 and 31, in Appendix). The geologic units found within the watersheds were stored in Channel 1. Both watersheds contain units of the Fort Scott and Senora Formations (Miser, 1974).

Channel 2

Depth to Bedrock (Figures 32 and 33, in Appendix). The average depth to bedrock in each of the ten acre cells located within the watersheds was stored in Channel 2. In the eastern watershed, the depths to bedrock range from less than ten inches to greater than 60 inches. In the western watershed, these depths range from ten inches to greater than 60 inches (Soil Conservation Service, 1973).

Channel 3

Type of Bedrock (Figures 34 and 35, in Appendix). The type of bedrock underlying each soil series found in the watersheds was stored in Channel 3. The "Alluvium" category describes the underlying material for the floodplain soils delineated in Channel 3 of the Soils Library. The type of bedrock was not described for these soils. In addition to the "Alluvium" category, the eastern watershed contains shale, limestone, and sandstone. The western watershed contains alluvium, shale, and limestone (Soil Conservation Service, 1973).

Topographic Library

As with other aspects of the environment, the topography of the mine site plays a role in determining the management decisions of surface mining operations. Data describing slope angle, slope aspect, and elevation, outlined in the following sections, are found in the Topographic Library.

Channel 1

Slope Angle (Figures 36 and 37, in Appendix). The slope angle (percent) of the dominant slope within each ten acre cell located in the watersheds was stored in Channel 1. Slope angles in the eastern watershed vary from one percent to 15 percent. The western watershed has gentler slopes as the slope angles vary from one percent to five percent. Slope angles were determined from the 1:24,000 United States Geologic Survey (USGS) topographic maps for the areas (Centralia and Sanders quadrangles).

Channel 2

Slope Aspect (Figures 38 and 39, in Appendix). The slope aspect of the dominant slope within each ten acre cell located in the watersheds was stored in Channel 2. Slope aspects were recorded as North, Northeast, East, Southeast, South, Southwest, West, or Northwest. Slope aspects were determined from the Centralia and Sanders 1:24,000 USGS topographic maps.

Channel 3

Elevation (Figures 40 and 41, in Appendix). The average elevation of each ten acre cell located within the watersheds was stored in Channel 3. Elevations in the eastern watershed range from 770 feet to 925 feet. The western watershed has less relief, as the elevations vary from 760 feet to 820 feet. Average elevations were calculated from the Centralia and Sanders 1:24,000 USGS topographic maps.

Landcover Library

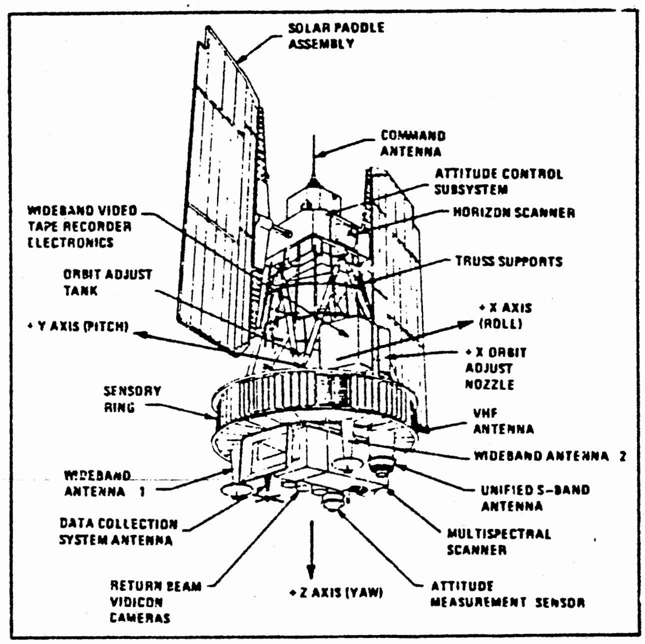
Landcover also affects the management decisions involved with surface mining. Runoff is directly related to landcover, and reclamation decisions must be based, in part, on the landcover of the mine site and surrounding landscape. The following section describes the landcover categories found in the watersheds, and explains the manner in which these categories were determined.

Channel 1

Landcover (Figures 42 and 43, in Appendix). The dominant landcover of each ten acre cell within the watersheds was stored in Channel 1. The landcover information was obtained from classified Landsat Multispectral Scanner (MSS) digital data, which was processed at the Center for Applications of Remote Sensing.

The Landsat series of satellites orbit the earth at an altitude of 570 miles (920 kilometers) in a circular, near-polar, north to south orbit that passes over the same geographic location on the earth's surface every 18 days (NASA, 1979). Three satellites have been launched in the Landsat series: Landsat-1, launched July 23, 1972; Landsat-2, launched January 22, 1975; and Landsat-3, launched March 5, 1978. Each of the satellites has the same basic configuration and carries the same sensor packages (Figure 11). The Multispectral Scanner (MSS) is a line-scanning system that utilizes an oscillating mirror to continually scan the surface of the earth in a 115 mile (185 kilometer) swath perpendicular to the direction of the satellite orbit. The MSS aboard Landsats 1 and 2 sense reflected solar radiation in four spectral bands, while a fifth band, in the thermal portion of the electro-magnetic spectrum, was added to the scanning system aboard Landsat 3.

For this research, Multispectral Scanner digital data (sensed on September 23, 1978) were obtained as a computer-compatible tape from the EROS Data Center at Sioux Falls, South Dakota. Unsupervised clustering of the Landsat data yielded 48 statistical classes. These classes were grouped into five landcover categories: 1) Grassland, 2) Forest, 3) Agriculture, 4) Bare Ground, and 5) Water. All five landcover categories were found within the eastern watershed. Grassland accounted for nearly 70 percent of the acreage, followed by Bare Ground (12 percent), Forest (nine percent), Agriculture (eight percent), and Water (one



Source: U.S. Geological Survey. Landsat Data Users Handbook. Arlington, Virginia: U.S. Geological Survey, 1979.

Figure 11. Landsat Satellite

percent). Grassland was also the dominant landcover in the western watershed, covering 74 percent of the total area. Agriculture accounted for 25 percent of the acreage, while Forest and Water each accounted for less than one percent. Bare Ground did not appear in the western watershed.

Climate Library

Climate plays a vital role in the management of surface coal mines. All mining activity is exposed to the local weather conditions. Successful reclamation requires specific knowledge of the climate over the mining region.

In this research, the climatological information can be regarded as single point data, since the macro-climatic parameters, which were included in the data libraries, will not vary over the small study areas being considered. For this reason, all climate data maps will have only one value. Variations will be noted in study areas covering larger regions. The information that was utilized was recorded at Vinita, Oklahoma, located 15 miles (24 kilometers) southeast of the study areas. The contents of the Climate Library are described in the following sections.

Channel 1

Average Annual Precipitation (Figures 44 and 45, in Appendix). The average annual precipitation (42 inches) was stored in Channel 1 (National Oceanic and Atmospheric Administration, 1981). As was mentioned above, this amount is the same for both watersheds.

Channel 2

Average January Temperature (Figures 46 and 47, in Appendix). The average January temperature of the study areas is stored in Channel 2. This temperature value is 36.0 degrees Fahrenheit for both watersheds (National Oceanic and Atmospheric Administration, 1981).

Channel 3

Average July Temperature (Figures 48 and 49, in Appendix). The average July temperature of the study areas was stored in Channel 3. This temperature value is 81.1 degrees Fahrenheit (National Oceanic and Atmospheric Administration, 1981).

Channel 4

Average Length of the Frost Free Season (Figures 50 and 51, in Appendix). The average length of the frost free season in the study areas was stored in Channel 4. The average frost free season lasts 205 days in each watershed (Soil Conservation Service, 1973).

Summary

Relevant data is an important component of any information system. The data stored within the Oklahoma Geographic Information Retrieval System was chosen with the goal of providing an information source which would assist in the management of surface coal mines in eastern Oklahoma. The next chapter presents an evaluation of the OGIRS with recommendations for future development.

CHAPTER VI

OGIRS EVALUATION AND RECOMMENDATIONS

Introduction

The Oklahoma Geographic Information Retrieval System was developed to provide an information source which would assist the managers of surface coal mines in eastern Oklahoma. A software package was written which allows the input, manipulation, and display of data. Relevant data were determined, acquired, and entered as layers of information. The physical construction of the information system has been completed. The next task involves the evaluation of the system's utility to serve as a management tool.

A proper evaluation of the Oklahoma Geographic Information Retrieval System can only be made by the surface coal mine managers who ultimately utilize the system. Such an appraisal cannot be formulated until the information system is consulted on a working basis in the coal fields of eastern Oklahoma. This chapter, however, presents a general evaluation of the OGIRS from the developer's point of view. Such an evaluation is also valuable, because those who design and construct an information system can often best determine specific applications for the system and features that should be included in the future. The first section in this chapter describes several specific applications for the Oklahoma Geographic Information Retrieval System in the management of surface coal mines. The later sections present an evaluation of the information system and provide recommendations which could increase the system's utility.

Practical Use of the OGIRS

The Oklahoma Geographic Information Retrieval System can be applied to a wide variety of management situations involved in surface coal mining. The stored data can be utilized as it exists, or processed by the data manipulation functions and models, to produce answers to many surface mining questions. These questions may range from the initial engineering problems of the mining operation to final reclamation procedures. Although actual applications must be determined by the mine officials who ultimately use the information system, the following examples should demonstrate the types of applications that are possible.

Example 1

The stored data sets can be used to supply information in situations requiring simple mapped data. For example, a mine manager may need to know the range and location of elevations within a study area. For this situation, the elevation map of the desired study area could be output and utilized (Figure 12). The information system can be used as a library for storing all the maps that may be required by the manager of a surface coal mine.

Example 2

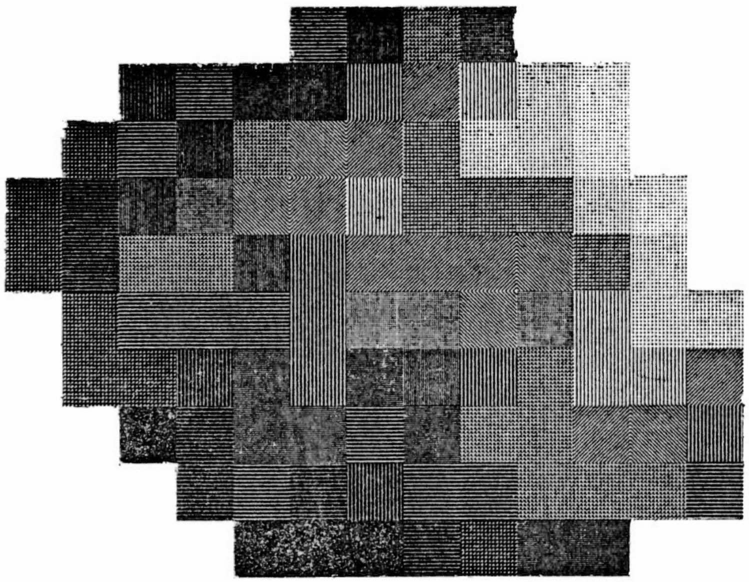
The OGIRS data manipulation functions provide a valuable information tool for many management situations. The mine manager may be interested in delineating those areas that have soils with high runoff potentials. To determine this information, the Hydrologic Soil Group data set can be manipulated by the "greater than" function to create a map which displays only those areas that have Hydrologic Soil Group D, which are the soils that have the greatest runoff potentials (Figures 13 and 14). In the same manner, a map which displays only those areas with relatively steep slopes can be generated from a general slope angle map (Figures 15 and 16).

The functions designed to manipulate multiple data sets can be utilized to determine the relationship between two different data sets. For example, the intersection of the runoff potential data set and slope angle data set can display those areas that have soils with high runoff potential that are located on steep slopes (Figure 17). These examples illustrate the utility of the OGIRS beyond merely storing and outputting mapped data.

Example 3

The Coefficient of Areal Association Model, described

EASTMINE ELEVATION
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 4
DATE: 02/03/82 LIBRARY DESCRIPTOR: TOPO



LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		3	770 - 779 FEET ABOVE SEA LEVEL
2	2		7	780 - 789 FEET ABOVE SEA LEVEL
3	3		5	790 - 799 FEET ABOVE SEA LEVEL
4	4		5	800 - 809 FEET ABOVE SEA LEVEL
5	5		8	810 - 819 FEET ABOVE SEA LEVEL
6	6		5	820 - 829 FEET ABOVE SEA LEVEL
7	7		5	830 - 839 FEET ABOVE SEA LEVEL
8	8		6	840 - 849 FEET ABOVE SEA LEVEL
9	9		10	850 - 859 FEET ABOVE SEA LEVEL
10	10		6	860 - 869 FEET ABOVE SEA LEVEL

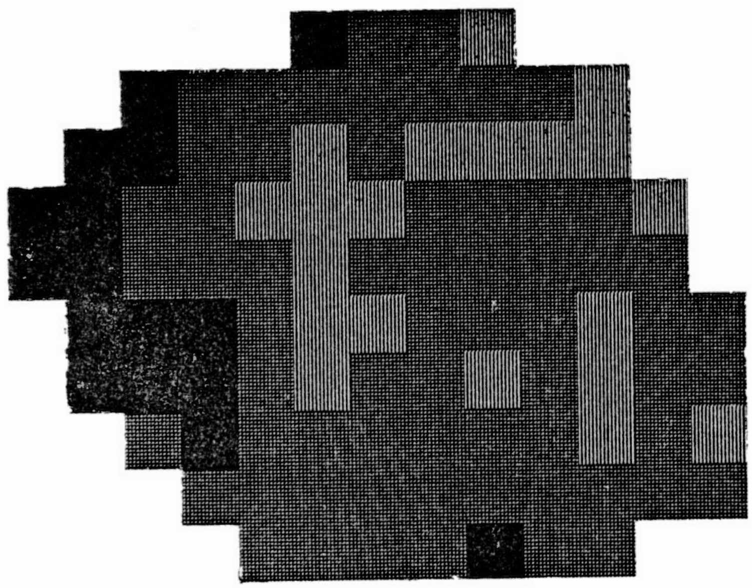
Figure 12. Elevation Map of the EASTMINE Watershed
(continued on the next page)

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
11	11		8	870 - 879 FEET ABOVE SEA LEVEL
12	12		11	880 - 889 FEET ABOVE SEA LEVEL
13	13		6	890 - 899 FEET ABOVE SEA LEVEL
14	14		3	900 - 909 FEET ABOVE SEA LEVEL
15	15		7	910 - 919 FEET ABOVE SEA LEVEL
16	16		4	920 - 929 FEET ABOVE SEA LEVEL

16 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 12. Continued

EASTMINE HYDROLOGIC SOIL GROUPS
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 4
DATE: 25/02/82 LIBRARY DESCRIPTOR: SOIL



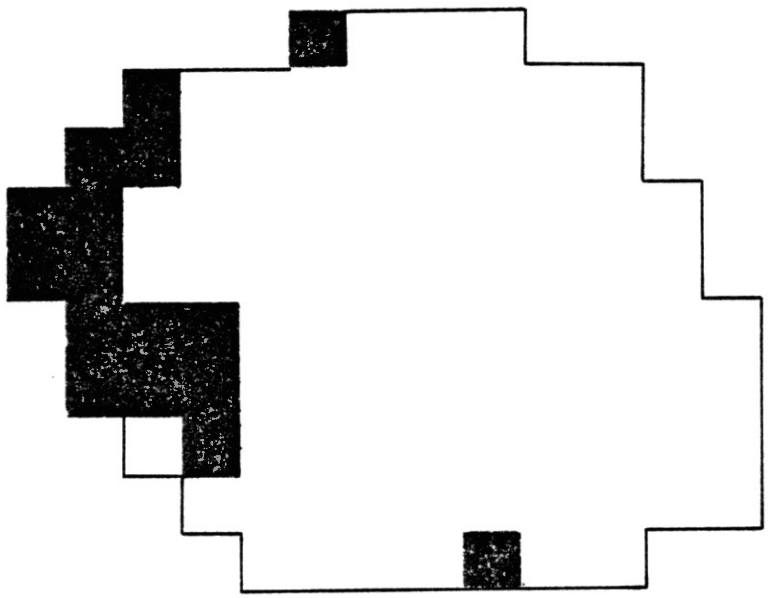
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	2		20	MODERATE RUNOFF POTENTIAL
2	3		63	MODERATELY HIGH RUNOFF POTENTIAL
3	4		16	HIGH RUNOFF POTENTIAL

3 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 13. Hydrologic Soil Group Map of the EASTMINE Watershed

EASTMINE HYDROLOGIC SOIL GROUP D
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 4
DATE: 25/02/82 LIBRARY DESCRIPTOR: SOIL



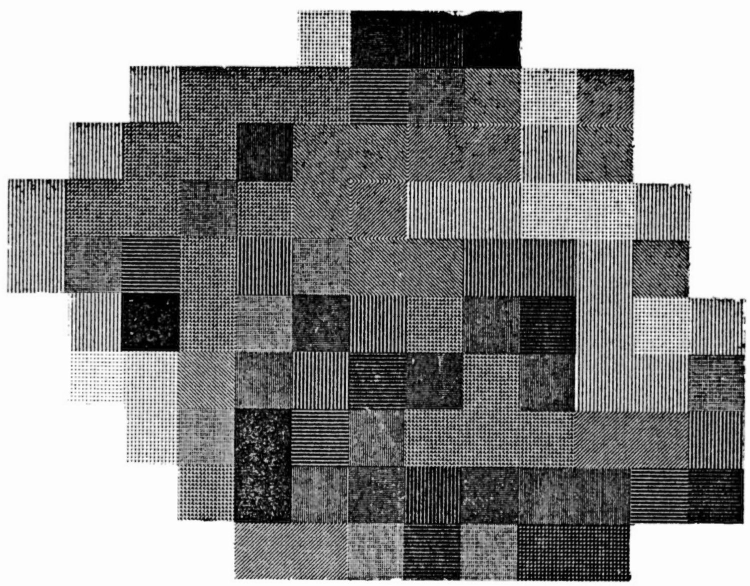
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	4	■	16	HIGH RUNOFF POTENTIAL

1 CATEGORIES 16 CELLS 160 ACRE AREA

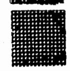
Figure 14. Map Delineating Soils with High Runoff Potential

EASTMINE SLOPE ANGLE
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 1
DATE: 19/02/82 LIBRARY DESCRIPTOR: TOPO



CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		1	0 - 1 %
2	2		7	1.1 - 2 %
3	3		14	2.1 - 3 %
4	4		8	3.1 - 4 %
5	5		9	4.1 - 5 %
6	6		9	5.1 - 6 %
7	7		6	6.1 - 7 %
8	8		16	7.1 - 8 %
9	9		8	8.1 - 9 %

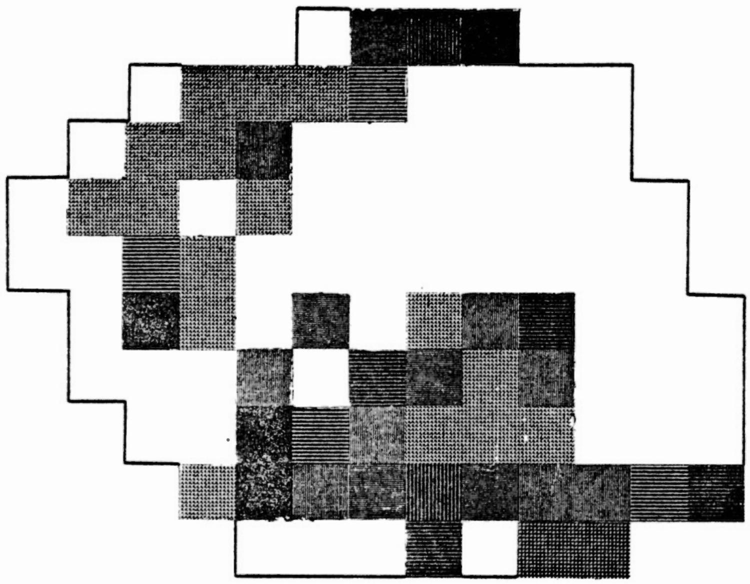
Figure 15. Slope Angle Map of the EASTMINE Watershed (continued on the next page)

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
10	10		5	9.1 - 10 %
11	11		4	10.1 - 11 %
12	12		4	11.1 - 12 %
13	13		2	12.1 - 13 %
14	14		2	13.1 - 14 %
15	15		4	14.1 - 15 %

15 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 15. Continued

EASTMINE STEEP SLOPES
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 1
DATE: 19/02/82 LIBRARY DESCRIPTOR: TOPO



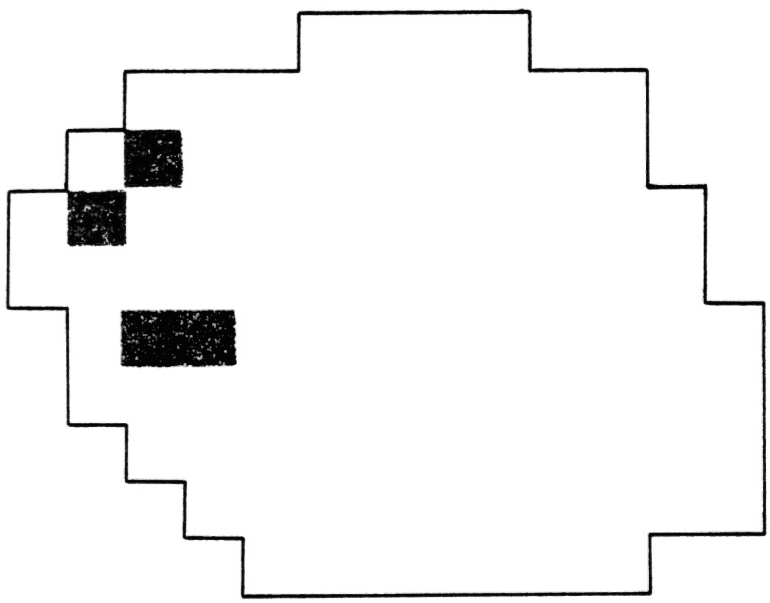
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	8		16	7.1 - 8 %
2	9		8	8.1 - 9 %
3	10		5	9.1 - 10 %
4	11		4	10.1 - 11 %
5	12		4	11.1 - 12 %
6	13		2	12.1 - 13 %
7	14		2	13.1 - 14 %
8	15		4	14.1 - 15 %

8 CATEGORIES 45 CELLS 450 ACRE AREA

Figure 16. Map Delineating Areas with Steep Slopes

COMPOSITE MAP
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 1
DATE: 19/02/82 LIBRARY DESCRIPTOR: TOPO



LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		4	INTERSECTION OF SOILS WITH HIGH RUNOFF POTENTIAL AND SLOPES GREATER THAN 7 PERCENT

1 CATEGORIES 4 CELLS 40 ACRE AREA

Figure 17. Map Delineating the Intersection of Soils with High Runoff Potential and Areas with Steep Slopes

previously, can be utilized in situations requiring knowledge of the degree of relationship between two characteristics of the environment. For example, the mine manager may be interested in determining which type of bedrock is most commonly associated with higher elevations. In this situation, a map delineating only those areas with high elevations can be compared to maps delineating those areas with a particular type of bedrock. The value of the Coefficient of Areal Association can then be used to determine which bedrock type in the study area is most commonly associated with higher elevations.

Evaluation of the OGIRS

The Oklahoma Geographic Information Retrieval System has the potential to provide valuable information to the managers of surface coal mines. The wide variety of data required for effective management of surface coal mines was discussed in Chapter III. The OGIRS has the capability of storing any type of information that can be spatially referenced to the earth's surface. The storage capabilities of the OGIRS, however, is not limited to surface phenomena. Subterranean features can also be referenced to a surface location and stored within the OGIRS. The location of features in three-dimensional space can, thus, be specified. The contents of the Geologic Library, which was described in Chapter V, illustrate this capability. Channel 3 (Type of Bedrock) describes the location of various types of bedrock in a horizontal plane. Channel 2 (Depth to Bedrock) describes the vertical location of the bedrock. This information could be stored in one channel of data, if desired, as the type of bedrock could be entered with a qualifier describing its depth. Spatial descriptions of data in three-dimensional space could also be applied to phenomena located above the surface of the earth, if such information was required.

One disadvantage of many grid geographic information systems lies in their inability to accept and store linear features, such as road and stream networks. Such information could be of vital importance to the managers of surface coal mines. For example, the determination of the environmental impact of a mining operation would certainly require knowing the proximity of the mining activity to the streams in the area. The location of transportation networks, such as highways, railroads, and rivers, is an important consideration when determining the economic viability of a mining venture. As was mentioned in Chapter 4, the Oklahoma Geographic Information Retrieval System solves the problem of storing linear patterns through its interface with the Earth Resources Laboratory Applications Software (ELAS) and the Comtal Image Processing System. The graphic overlay capability provided by ELAS and the image processing system allows the display of all linear patterns on any color image display map.

The flexibility of the Oklahoma Geographic Information

Retrieval System is illustrated by not only the variety of system-compatible data, but also by the variety of possible data resolutions. The ten acre resolution was chosen to demonstrate the degree of detail which could be expected from an information system describing large, regional study areas. A coarse resolution is required in such cases to keep the volume of data within manageable limits. The resolution required by regional systems, however, would probably not provide adequate detail for managing individual surface mines. Information can be stored in the OGIRS at finer resolutions, such as one acre, when smaller study areas are involved. This task simply involves digitizing the data with a grid having a smaller cell size. The Oklahoma Geographic Information Retrieval System can, therefore, be used to describe large study areas, such as the coal producing region of Oklahoma, and smaller areas, such as individual mine sites. Data sets with variable resolutions can easily be stored within the OGIRS, but, at the present time, data layers with different cell sizes cannot be manipulated with the intersection, union, and exclusion functions.

Much of the data needed to describe surface coal mine sites is dynamic and subject to change. The topography of the mine site changes constantly during the mining activity and later reclamation. Stream and road networks are altered as the surface mine expands. Landcover will also change as the mine advances. The Oklahoma Geographic Information

Retrieval System is well-equipped to adequately describe change in the environment. The editing capabilities of ELAS, which can be used to update road and stream networks, was mentioned in Chapter 4. An edit subroutine is also included within the OGIRS software. The Z-value describing the content of any grid cell can easily be edited to reflect any change in the environment over time. Multi-temporal data can also be stored to record environmental changes. The utilization of Landsat satellite data is especially applicable for delineating large-scale changes in landcover as mining progresses, since the Landsat satellites pass over the same location on the earth's surface every 18 days. Anderson, Schultz, and Buchman (1975) demonstrated the feasibility of using Landsat MSS data to monitor surface coal mines in western Maryland. They found that landcover changes could be monitored to within five acres (two hectares) with a 93 percent classification accuracy. They also demonstrated the feasibility of temporally extending reflectance signatures to other Landsat data. It should be noted that Landsat data cannot be expected to provide immediate information on the landcover changes associated with surface mining. Acquisition of current digital data requires at least three weeks. The imaging capabilities of the Landsat satellites, however, can still provide valuable landcover information for monitoring long-term expansion of the mine site and for assessing reclamation success.

The data manipulation functions included in the OGIRS software should provide a very useful analysis tool for the managers of surface coal mines. The examples of possible applications that were outlined earlier in this chapter indicate the wide variety of data analyses that can be performed. As additional data are entered and stored in the information system, the number and types of possible analysis procedures should greatly increase. New data manipulation models, such as the Coefficient of Areal Association Model, can also be included within the software as new needs and uses for the information system are determined. More advanced data manipulations, such as those required for predictive modeling, should provide the necessary information for evaluating the impact of surface mining on the environment.

The output products from the Oklahoma Geographic Information Retrieval System should be of considerable use in the management of surface coal mines. Line printer maps of various data sets can be rapidly viewed on a CRT terminal. Hard copy maps can be obtained quickly and relatively economically from line printers. These maps can be taken into the field and utilized for a variety of management applications. Electrostatic printer/plotter maps and photographs of the color image display maps can be utilized in reports and presentations that require more refined display products.

The data storage, manipulation, and display capabilities of the Oklahoma Geographic Information

Retrieval System can be utilized by individuals who have limited prior experience in the use of computer information systems. User inputs are generally in plain English or integer values. Lists of directives which describe required input commands can be recalled and viewed at any point in the program. Such user-oriented attributes allow quick familiarization of all system capabilities and are important in assuring the widest possible utilization of the information system.

Recommendations for Future Development

The Oklahoma Geographic Information Retrieval System should not be regarded as a finished product with immediate applications to all management situations. The OGIRS can be improved in several areas. The recommendations discussed in this section will hopefully provide direction for future system development.

The first series of recommendations involve increased utilization of the current system capabilities and do not require new software development. A wider variety of data should be collected and stored to develop a more effective management tool. Current system libraries can be expanded. For example, climatic extremes may provide more useful information to mine managers than the climatic averages which are presently stored in the Climate Library. New libraries should also be developed. Stream and road networks need to be digitized and stored for utilization as overlays. Socio-economic data are noticeably lacking. Information on land ownership and land use should be considered in any expansion of mining activities. Data on special interest areas, such as natural areas and historic and archeological sites, also need to be included.

It may be useful to include error statements when storing data. For example, the erodibility potential of a generalized ten acre cell may differ considerably from a specific location within the ten acre area. Statements of possible error could provide a basis for judging the optimum level of analysis for a particular data set.

Further development of the system software will also increase the utility of the Oklahoma Geographic Information Retrieval System. The storage capabilities of the OGIRS should be expanded. For example, the inclusion of data from digital terrain tapes could provide an efficient means for storing topographic information for regional areas. Digital terrain tapes, produced by the Defense Mapping Agency Topographic Center (DMATC) and distributed by the National Cartographic Information Center (NCIC), provide digital representation of elevations obtained from 1:250,000 and 1:24,000-scale topographic maps (National Cartographic Information Center, 1979).

Data sets with variable resolutions should be included in the OGIRS, if the system is to adequately describe regional areas, as well as individual surface mine sites. Further software development will be required to expand the use of data manipulation functions, such as intersection, union, and exclusion, to data sets having different resolutions. Such data manipulations may first require re-sampling the data sets to produce corresponding resolutions. This re-sampling could be automatically performed by a system subroutine.

Consideration should be given to the increased manipulation of linear features within the OGIRS. At the present time, grid data can be overlaid with linear patterns for purposes of visual analysis only. The development of models which effectively manipulate grid data sets and linear patterns would be useful in determining the relationships between surface mining and local hydrologic and transportation networks.

Additional types of output products should be included in the OGIRS. For example, tabular products could provide a useful supplement to the mapped information currently produced for display by the information system. Lists of data for a particular study area could be quickly scanned to determine the range of variation of such variables as slope angle, soil permeability, and depth to bedrock.

Attention should also be directed toward increasing the range and ease of user access to the Oklahoma Geographic Information Retrieval System. The use of telephone modems could greatly increase the range of direct access to the OGIRS. These modems can connect remote terminals to a base computer and transfer information along telephone lines.

The use of telephone modems could, therefore, greatly increase the possible utilization of the information system capabilities. It may also be useful to develop an abbreviated version of the OGIRS software for utilization by micro-computers. A micro-computer information system could then be used to handle the data requirments of individual mining operations.

Concluding Remarks

The Oklahoma Geographic Information Retrieval System should provide a data base that can efficiently organize the diverse types of information required for the effective management of surface coal mines. A variety of data, considered pertinent to the management of surface coal mines in eastern Oklahoma, were collected and entered into the grid information system. This data included information on the soils, geology, topography, landcover, and climate of two small watersheds in northeastern Oklahoma, one of which contains an operational surface coal mine. The system software provides the capability for useful data manipulations involving single data sets and multiple data sets. A variety of output products can be generated for display and analysis. These products include line printer maps, electrostatic printer/plotter maps, and color image display maps. Even in its present stage of development, the Oklahoma Geographic Information Retrieval System should provide solutions to many of the data management problems currently facing mine personnel.

A geographic information system, however, should not be regarded as a static management tool. In order to insure maximum effectiveness, an information system, such as the OGIRS, must continually evolve to handle new data needs and user requirements. Flexibility is a major asset of the Oklahoma Geographic Information Retrieval System and should assure its continued development. Data were entered into the grid information system at a ten acre resolution, but the OGIRS will accept data at any resolution. The open-ended library files can store additional data whenever new needs are determined. New data manipulation models can be incorporated within the system at any time. The recommendations outlined in this chapter indicate the potential of the OGIRS beyond its present capabilities.

The extraction of the coal reserves in eastern Oklahoma without permanently scarring the land is a difficult task which requires very careful management. Prudent management requires information on all environmental variables that interact with the mining operation and later reclamation. The Oklahoma Geographic Information Retrieval System should provide a valuable tool for organizing the data needs of the managers of surface coal mines, and will hopefully become an integral part of future surface coal mining operations in eastern Oklahoma.

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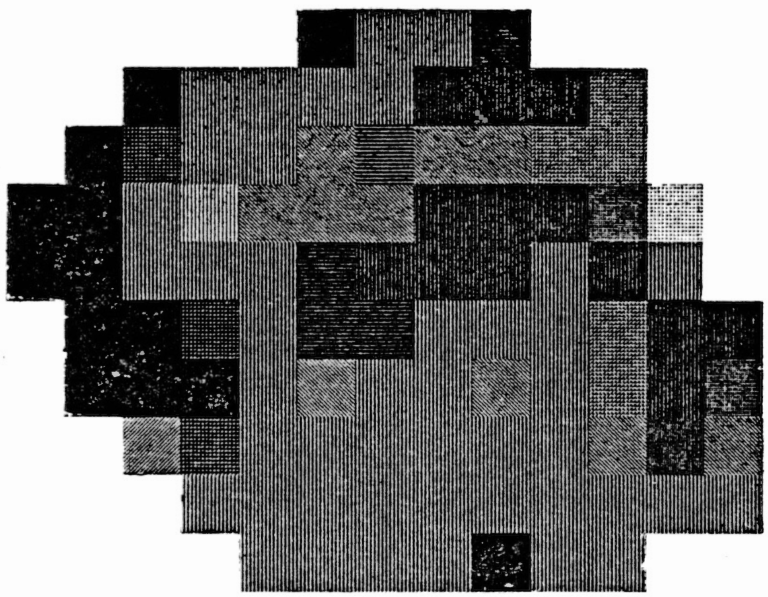
APPENDIX

EASTMINE SOIL SERIES
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 1
DATE: 28/02/82 LIBRARY DESCRIPTOR: SOIL



LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		4	BATES (BaC)
2	2		1	BONHAM (BoB)
3	3		44	COLLINSVILLE (CoF)
4	4		13	DENNIS (DnB)
5	5		1	DENNIS (DnC)
6	6		1	DENNIS (DnC2)
7	7		2	DENNIS (DnC3)
8	9		1	SUMMIT (SuB)
9	10		13	TALPA (T1B)

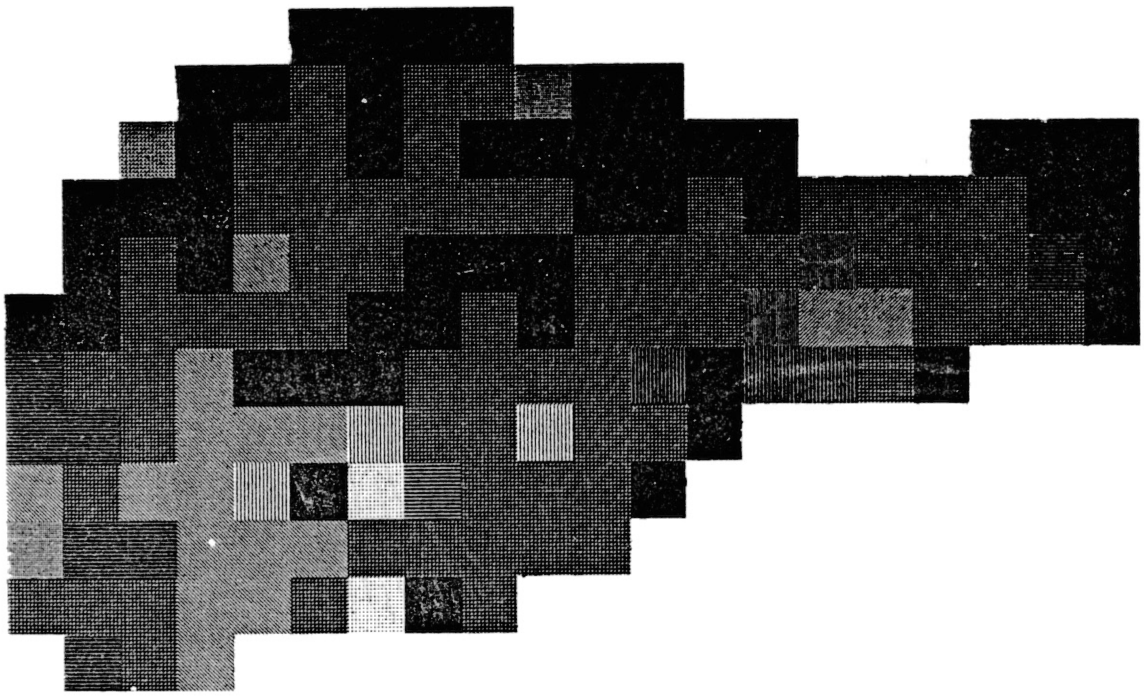
Figure 18. Soil Series Map of the EASTMINE Watershed (continued on the next page)

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
10	11		3	TALPA (TsD)
11	12		5	VERDIGRIS (Ve)
12	13		10	VERDIGRIS (Vt)
13	14		1	VERDIGRIS (Vs)

13 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 18. Continued

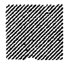
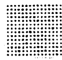
WESTMINE SOIL SERIES
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 1
DATE: 25/02/82 LIBRARY DESCRIPTOR: SOIL



LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		49	BATES (BaC)
2	2		2	BONHAM (BoB)
3	3		3	COLLINSVILLE (CoF)
4	4		3	DENNIS (DnB)
5	5		1	DENNIS (DnC)
6	6		7	DENNIS (DnC2)
7	7		14	DENNIS (DnC3)
8	8		65	LENAPAH (LeB)

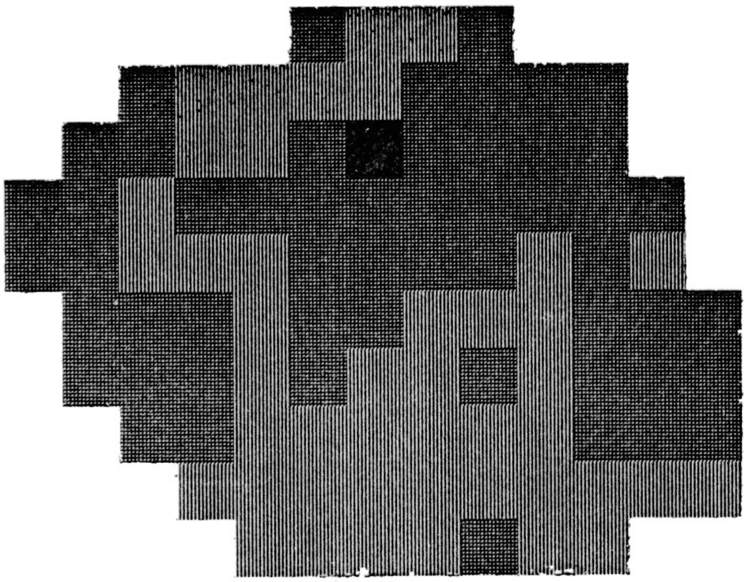
Figure 19. Soil Series Map of the WESTMINE Watershed
(continued on the next page)

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
9	9		2	SUMMIT (SuB)
10	10		2	TALPA (T1B)
11	11		2	TALPA (TsD)
12	12		1	VERDIGRIS (Ve)

12 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 19. Continued

EASTMINE SOIL SHRINK-SWELL POTENTIAL
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 2
DATE: 20/02/82 LIBRARY DESCRIPTOR: SOIL



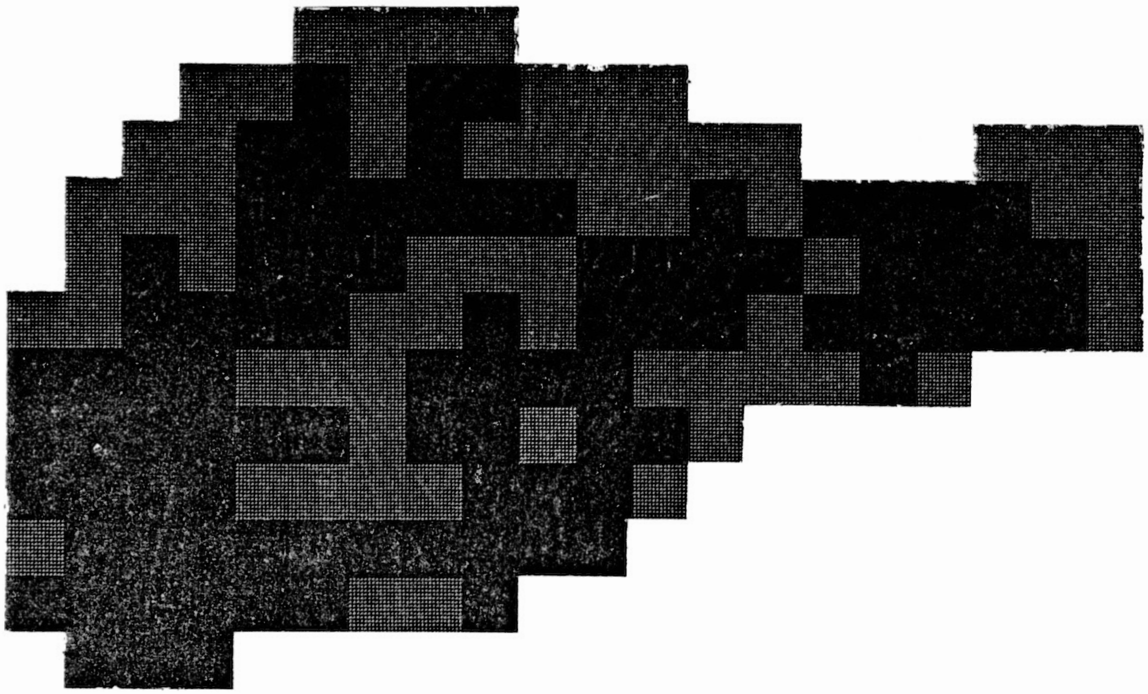
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		44	LOW
2	2		54	MODERATE
3	3		1	HIGH

3 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 20. Soil Shrink-Swell Potential Map of the EASTMINE Watershed

WESTMINE SOIL SHRINK-SWELL POTENTIAL
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 2
DATA: 26/02/82 LIBRARY DESCRIPTOR: SOIL



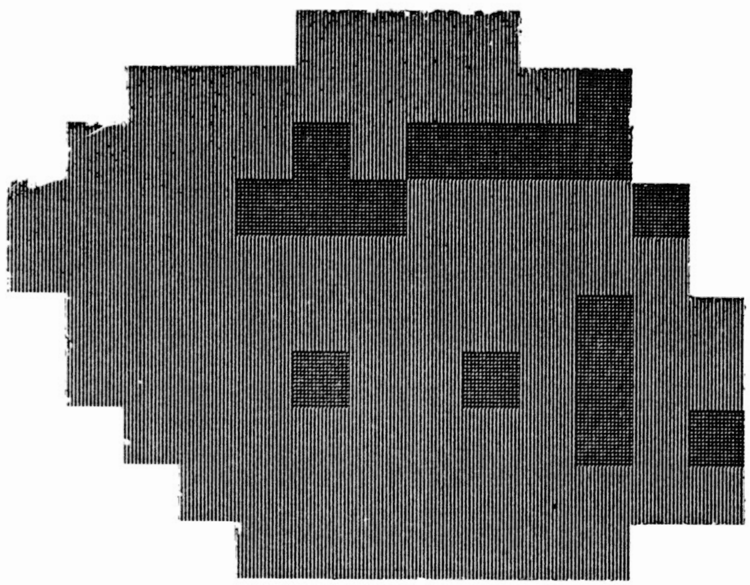
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	2		63	MODERATE
2	3		88	HIGH

2 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 21. Soil Shrink-Swell Potential Map of the WESTMINE Watershed

EASTMINE SOILS SUBJECT TO FLOODING
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 3
DATE: 20/02/82 LIBRARY DESCRIPTOR: SOIL



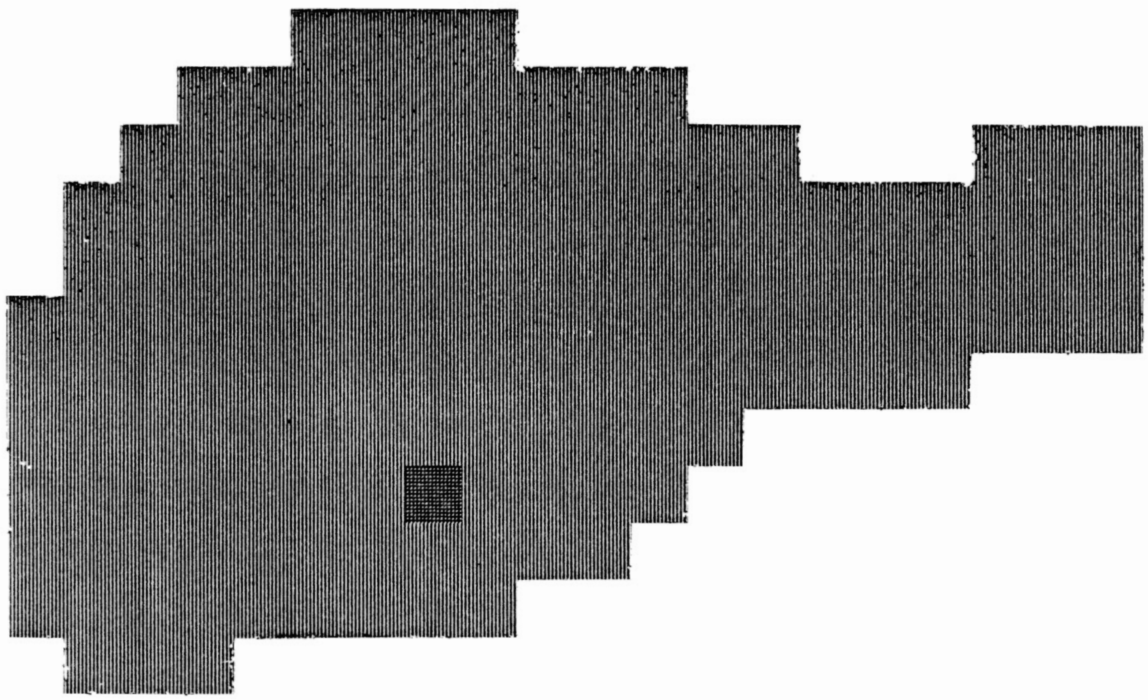
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		83	NOT SUBJECT TO FLOODING
2	2		16	SUBJECT TO FLOODING

2 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 22. Map Delineating the Soils Subject to Flooding in the EASTMINE Watershed

WESTMINE SOILS SUBJECT TO FLOODING
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 3
DATE: 26/02/82 LIBRARY DESCRIPTOR: SOIL



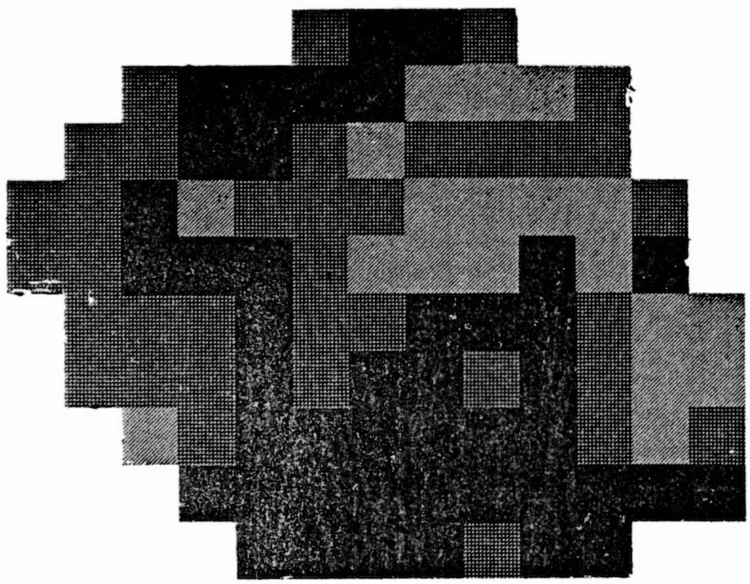
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		150	NOT SUBJECT TO FLOODING
2	2		1	SUBJECT TO FLOODING

2 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 23. Map Delineating the Soils Subject to Flooding in the WESTMINE Watershed

EASTMINE SOIL PERMEABILITY
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 5
DATE: 25/02/82 LIBRARY DESCRIPTOR: SOIL



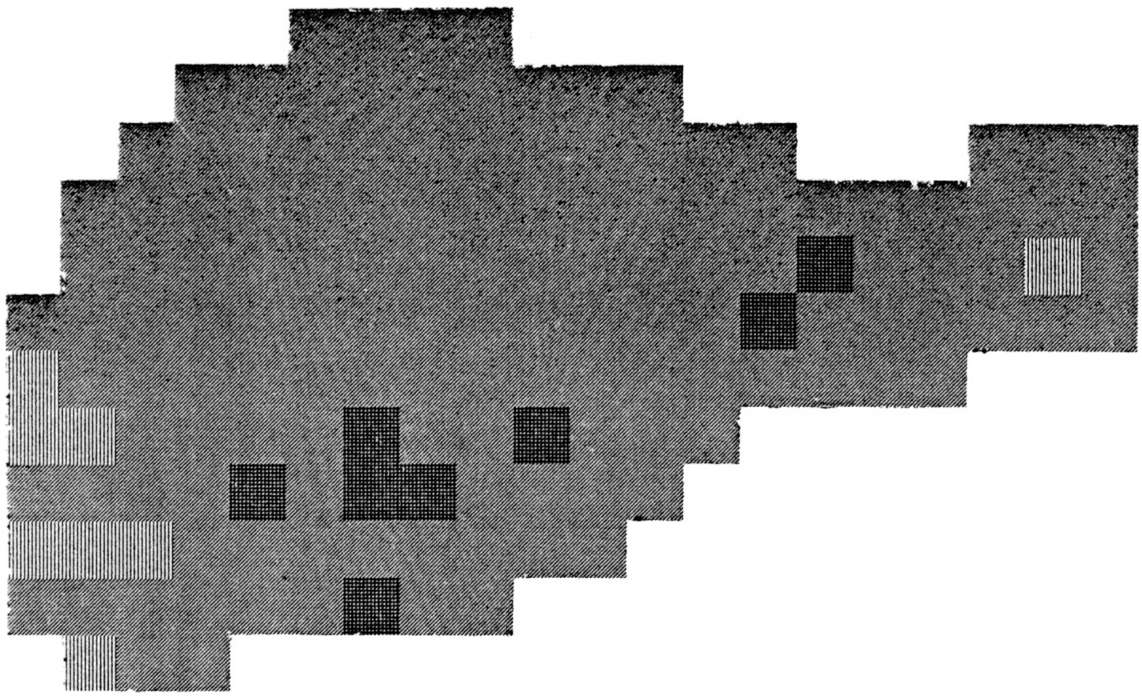
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	2		19	SLOW (.06 - .20 INCHES/HOUR)
2	4		36	MODERATE (.60 - 2.0 INCHES/HOUR)
3	5		44	MODERATELY RAPID (2.0 - 6.0 INCHES/HOUR)

3 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 24. Soil Permeability Map of the EASTMINE Watershed

WESTMINE SOIL PERMEABILITY
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 4
DATE: 26/02/82 LIBRARY DESCRIPTOR: SOIL



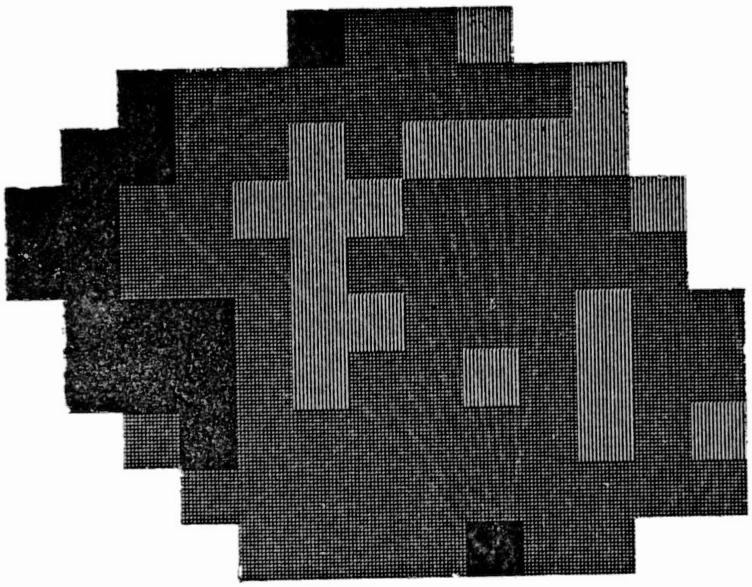
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		8	VERY SLOW (< .06 INCHES/HOUR)
2	2		135	SLOW (.06 - .20 INCHES/HOUR)
3	4		8	MODERATE (.60 - 2.0 INCHES/HOUR)

3 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 25. Soil Permeability Map of the WESTMINE Watershed

EASTMINE HYDROLOGIC SOIL GROUPS
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 4
DATE: 25/02/82 LIBRARY DESCRIPTOR: SOIL



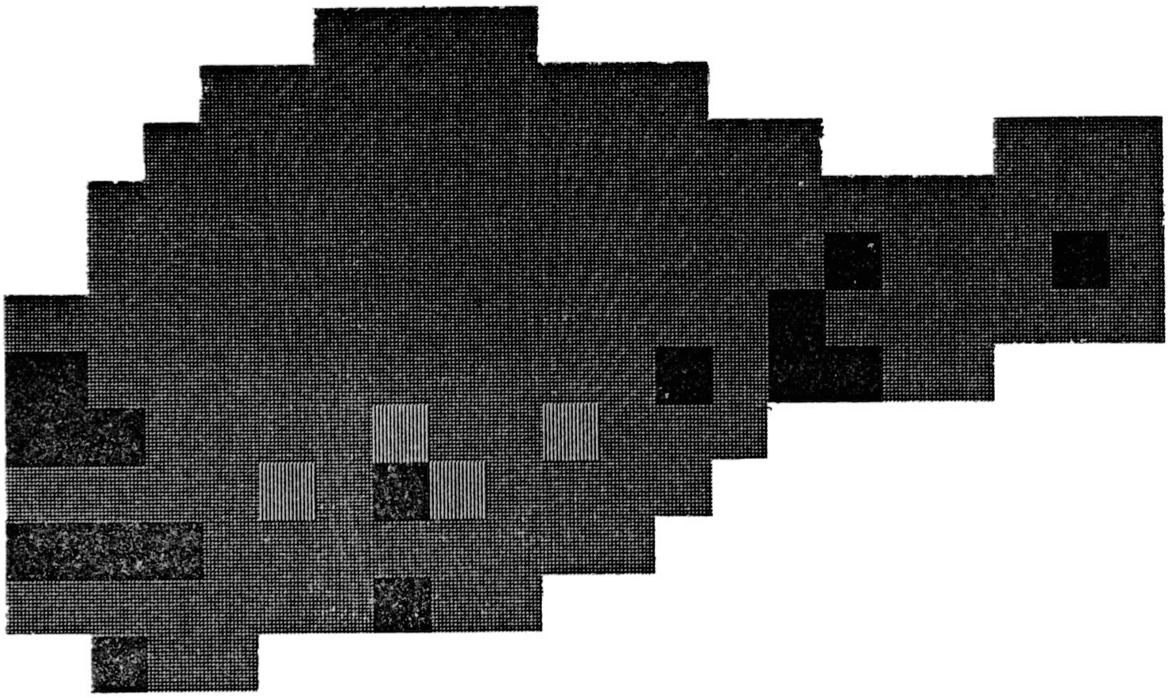
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	2		20	MODERATE RUNOFF POTENTIAL
2	3		63	MODERATELY HIGH RUNOFF POTENTIAL
3	4		16	HIGH RUNOFF POTENTIAL

3 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 26. Hydrologic Soil Group Map of the EASTMINE Watershed

WESTMINE HYDROLOGIC SOIL GROUPS
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 5
DATE: 26/02/82 LIBRARY DESCRIPTOR: SOIL



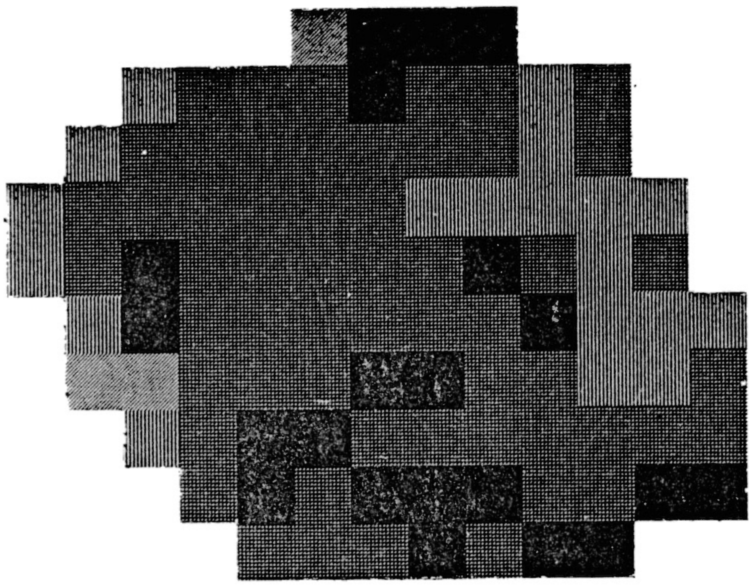
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	2		4	MODERATE RUNOFF POTENTIAL
2	3		132	MODERATELY HIGH RUNOFF POTENTIAL
3	4		15	HIGH RUNOFF POTENTIAL

3 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 27. Hydrologic Soil Group Map of the WESTMINE Watershed

EASTMINE SOIL ERODIBILITY
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 7
DATE: 25/02/82 LIBRARY DESCRIPTOR: SOIL



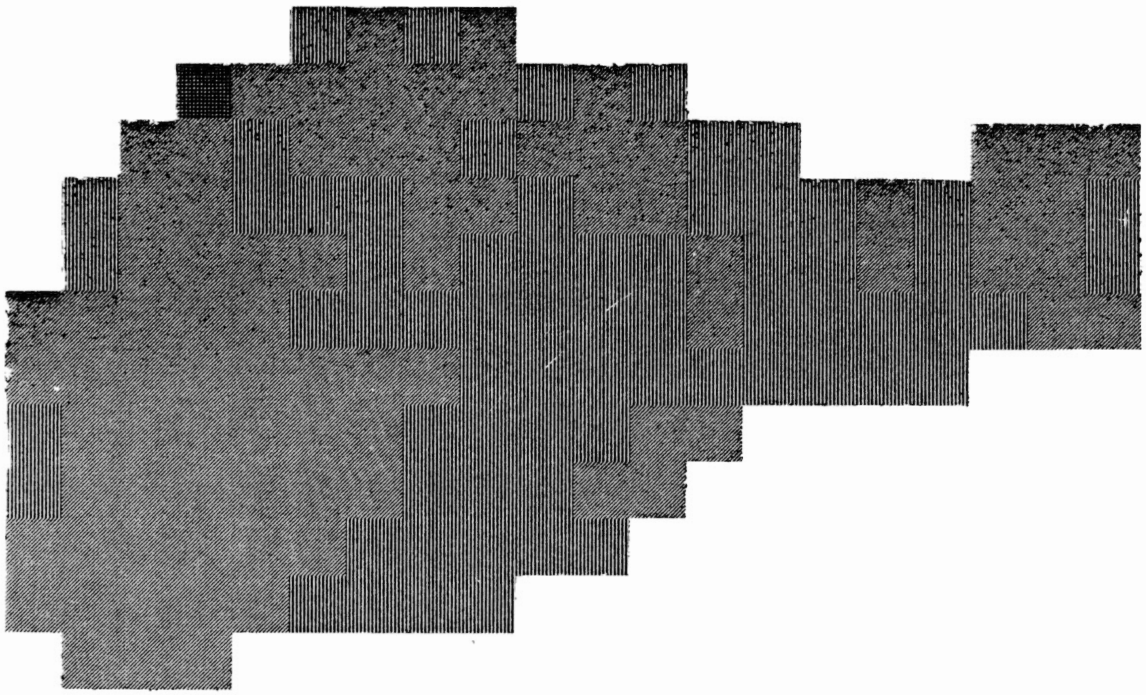
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		3	LOW
2	2		19	MODERATE
3	3		56	HIGH
4	4		21	VERY HIGH

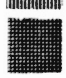
4 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 28. Soil Erodibility Map of the EASTMINE Watershed

WESTMINE SOIL ERODIBILITY
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 6
DATE: 26/02/82 LIBRARY DESCRIPTOR: SOIL



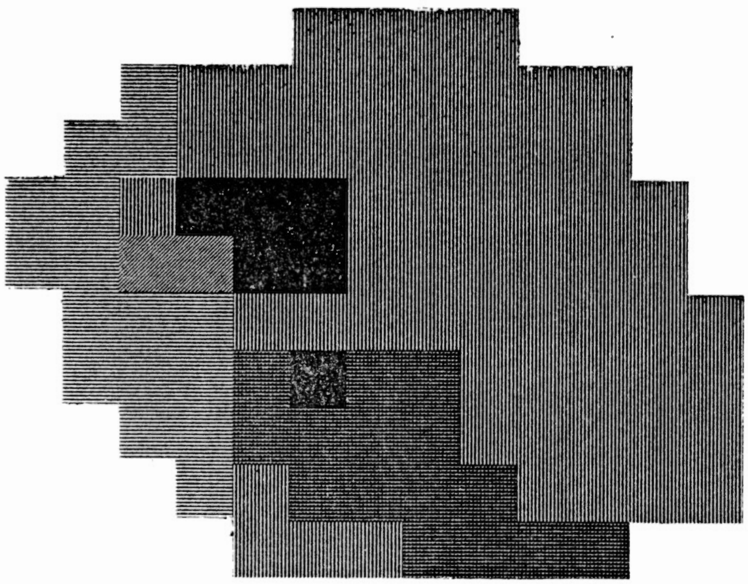
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		83	LOW
2	2		67	MODERATE
3	3		1	HIGH

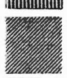
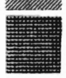
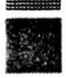
3 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 29. Soil Erodibility Map of the WESTMINE Watershed

EASTMINE SURFACE GEOLOGY
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 1
DATE: 20/05/82 LIBRARY DESCRIPTOR: GEOL



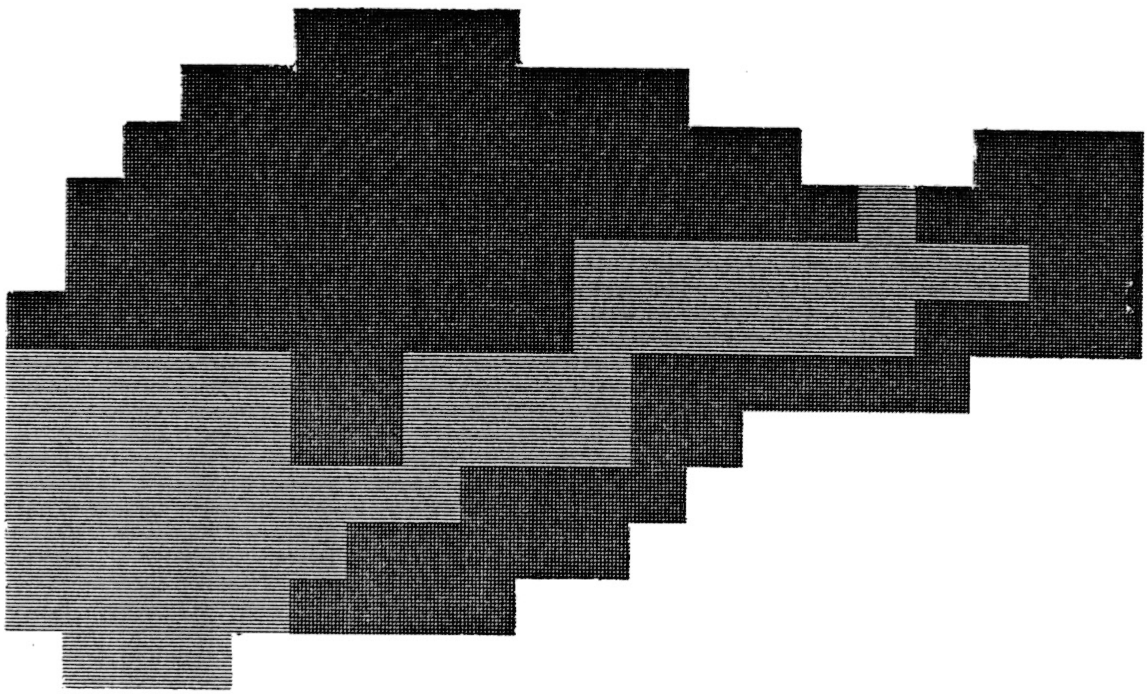
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	2		16	PFSB (LIMESTONE)
2	3		60	PSN (SHALE, COAL, SANDSTONE, LIMESTONE)
3	4		2	PSNB (SHALE, LIMESTONE)
4	5		15	PSNL (SHALE, COAL, SANDSTONE)
5	6		6	PSNV (COAL, LIMESTONE)

5 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 30. Surface Geology Map of the EASTMINE Watershed

WESTMINE SURFACE GEOLOGY
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 1
DATE: 20/05/82 LIBRARY DESCRIPTOR: GEOL



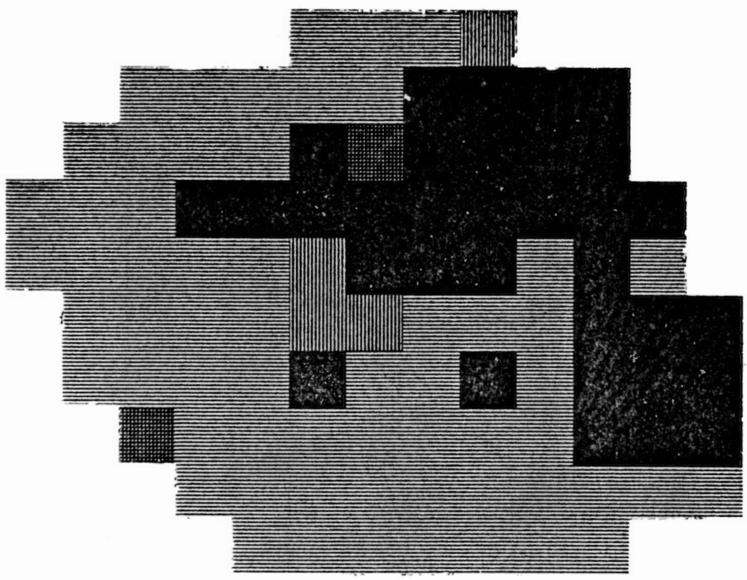
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1	(dark)	96	PFSH (LIMESTONE)
2	2	(lined)	55	PFSB (LIMESTONE)

2 CATEGORIES 151 CELLS . 1510 ACRE AREA

Figure 31. Surface Geology Map of the WESTMINE Watershed

EASTMINE DEPTH TO BEDROCK
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 2
DATE: 20/02/82 LIBRARY DESCRIPTOR: GEOL



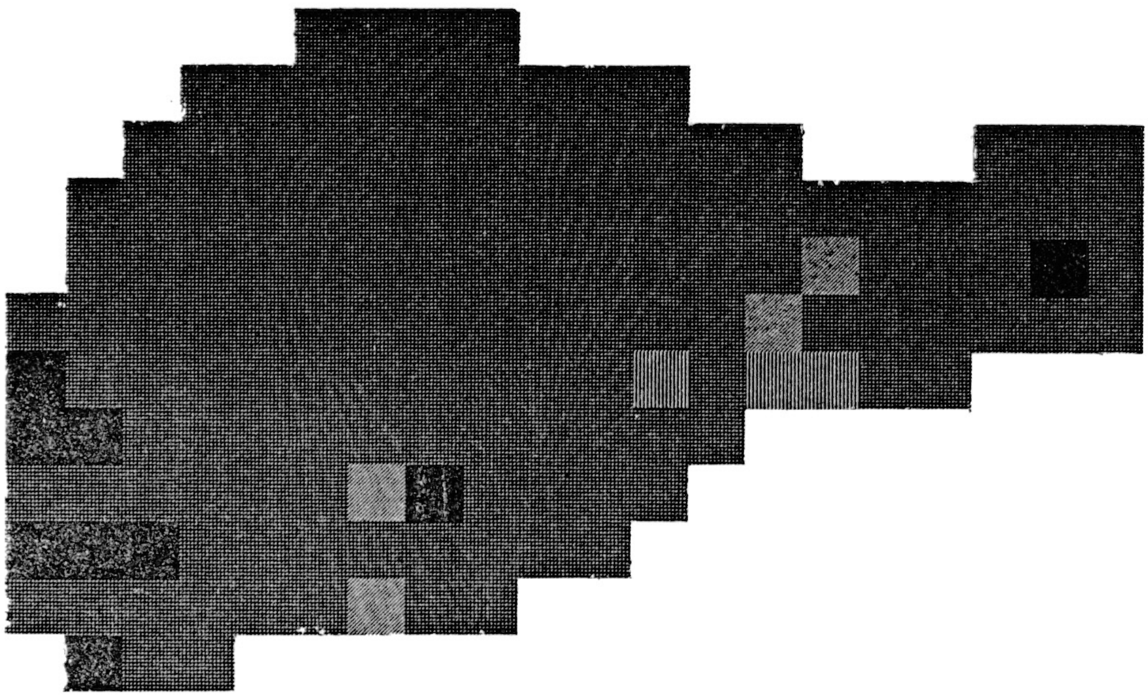
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		60	VERY SHALLOW (< 10 INCHES)
2	3		4	MODERATELY DEEP (21 - 40 INCHES)
3	4		2	DEEP (41 - 60 INCHES)
4	5		33	VERY DEEP (> 60 INCHES)

4 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 32. Depth to Bedrock Map of the EASTMINE Watershed

WESTMINE DEPTH TO BEDROCK
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 2
DATE: 25/02/82 LIBRARY DESCRIPTOR: GEOL



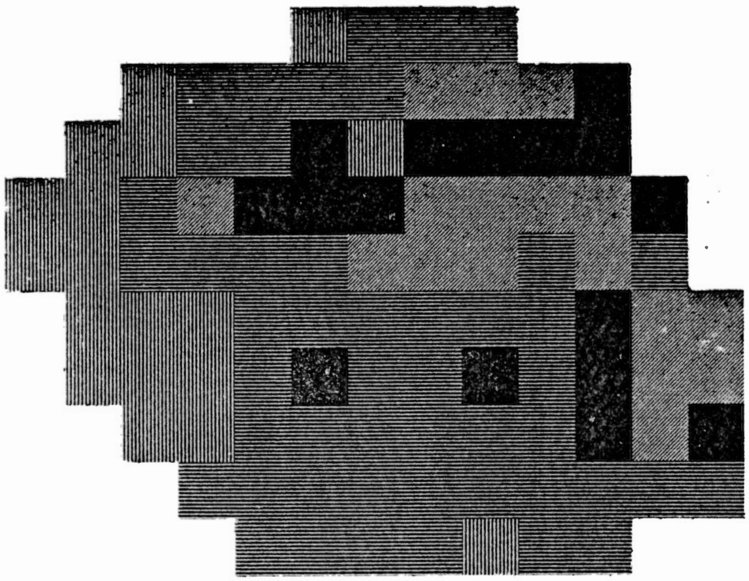
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	2		4	SHALLOW (10 - 20 INCHES)
2	3		3	MODERATELY DEEP (21 - 40 INCHES)
3	4		135	DEEP (41 - 60 INCHES)
4	5		9	VERY DEEP (> 60 INCHES)

4 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 33. Depth to Bedrock Map of the WESTMINE Watershed

EASTMINE TYPE OF BEDROCK
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 3
DATE: 20/02/82 LIBRARY DESCRIPTOR: GEOL



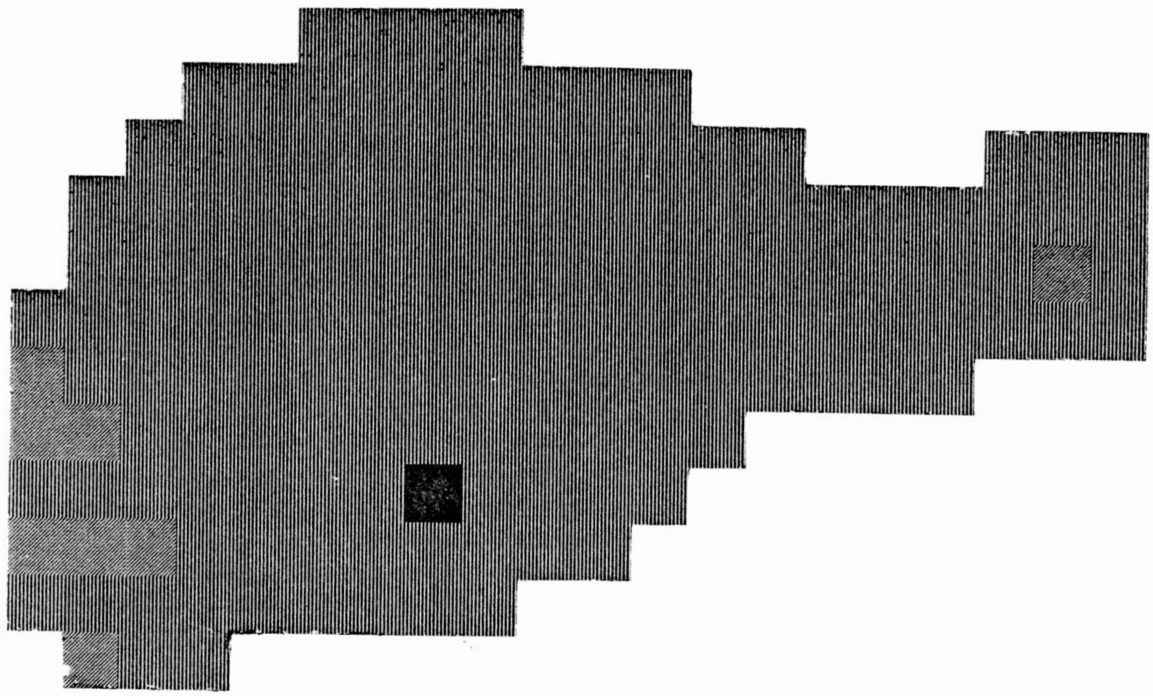
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		48	SANDSTONE
2	2		18	LIMESTONE
3	3		17	SHALE
4	4		16	ALLUVIUM

4 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 34. Type of Bedrock Map of the EASTMINE Watershed

WESTMINE TYPE OF BEDROCK
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 3
DATE: 26/02/82 LIBRARY DESCRIPTOR: GEOL



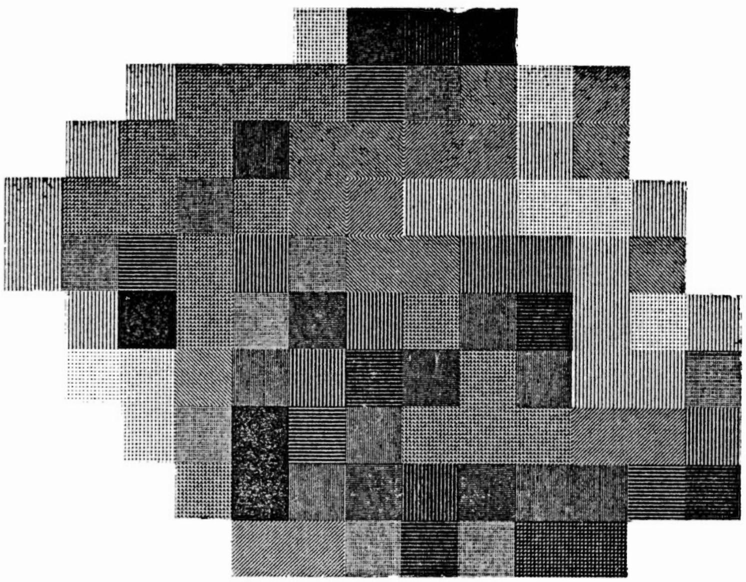
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	2		142	LIMESTONE
2	3		8	SHALE
3	4		1	ALLUVIUM

3 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 35. Type of Bedrock Map of the WESTMINE Watershed

EASTMINE SLOPE ANGLE
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 1
DATE: 19/02/82 LIBRARY DESCRIPTOR: TOPO



CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		1	0 - 1 %
2	2		7	1.1 - 2 %
3	3		14	2.1 - 3 %
4	4		8	3.1 - 4 %
5	5		9	4.1 - 5 %
6	6		9	5.1 - 6 %
7	7		6	6.1 - 7 %
8	8		16	7.1 - 8 %
9	9		8	8.1 - 9 %

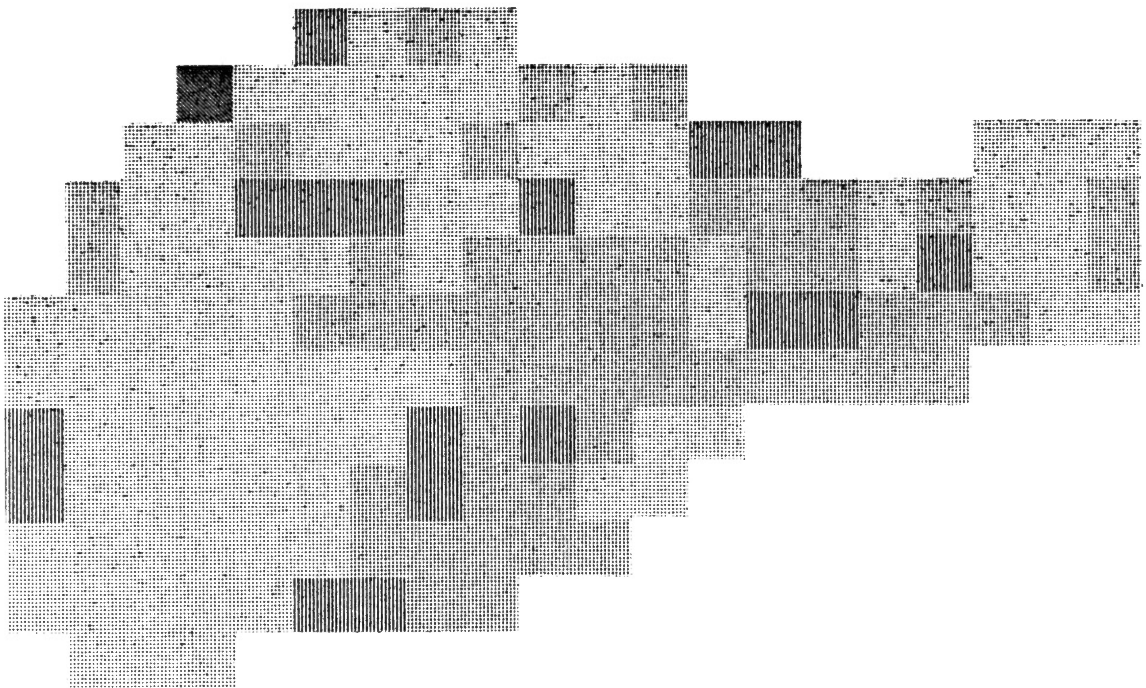
Figure 36. Slope Angle Map of the EASTMINE Watershed (continued on the next page)

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
10	10		5	9.1 - 10 %
11	11		4	10.1 - 11 %
12	12		4	11.1 - 12 %
13	13		2	12.1 - 13 %
14	14		2	13.1 - 14 %
15	15		4	14.1 - 15 %

15 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 36. Continued

WESTMINE SLOPE ANGLE
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 1
DATE: 28/02/82 LIBRARY DESCRIPTOR: TOPO



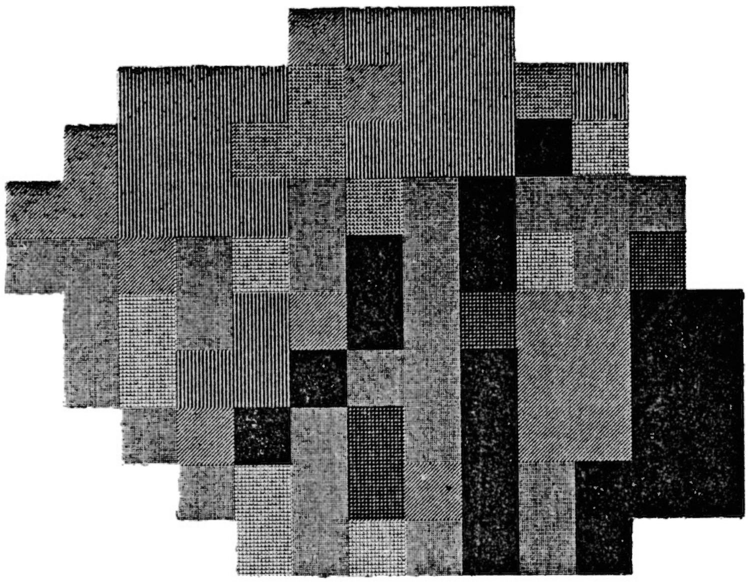
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		82	0 - 1 %
2	2		51	1.1 - 2 %
3	3		17	2.1 - 3 %
4	5		1	4.1 - 5 %

4 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 37. Slope Angle Map of the WESTMINE Watershed

EASTMINE SLOPE ASPECT
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 3
DATE: 19/02/82 LIBRARY DESCRIPTOR: TOPO



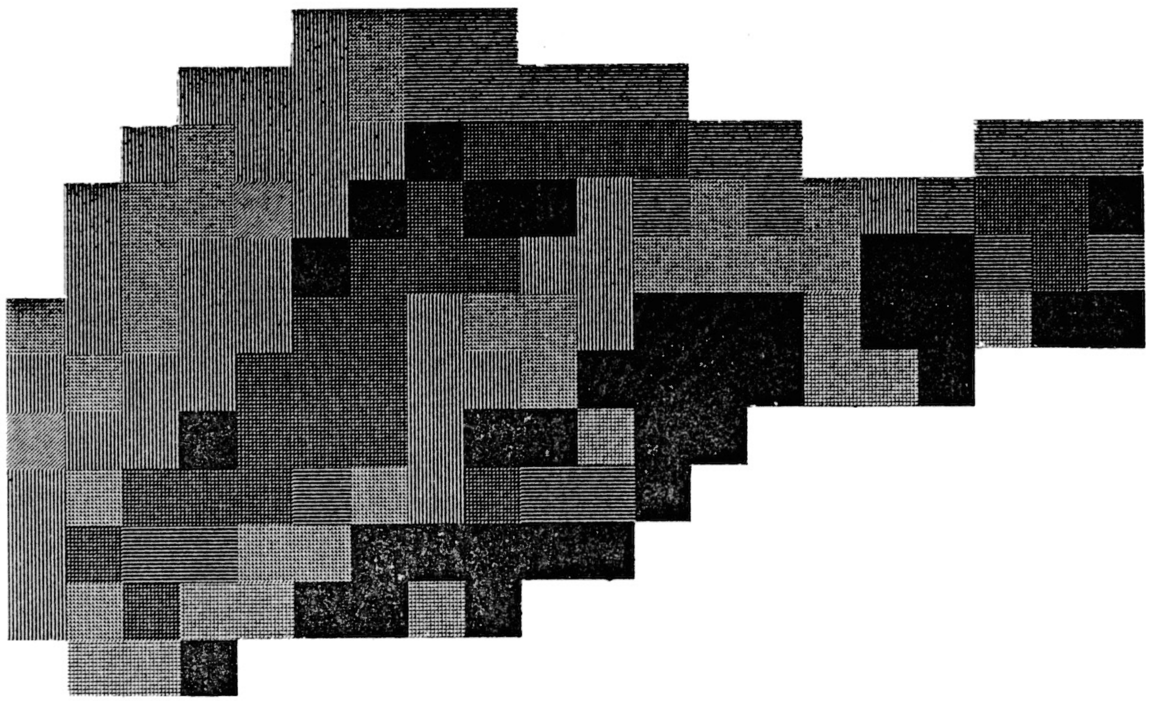
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		8	NORTH
2	2		26	NORTHEAST
3	3		15	EAST
4	4		20	SOUTHEAST
5	5		5	SOUTH
6	7		4	WEST
7	8		21	NORTHWEST

7 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 38. Slope Aspect Map of the EASTMINE Watershed

WESTMINE SLOPE ASPECT
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 2
DATE: 28/02/82 LIBRARY DESCRIPTOR: TOPO



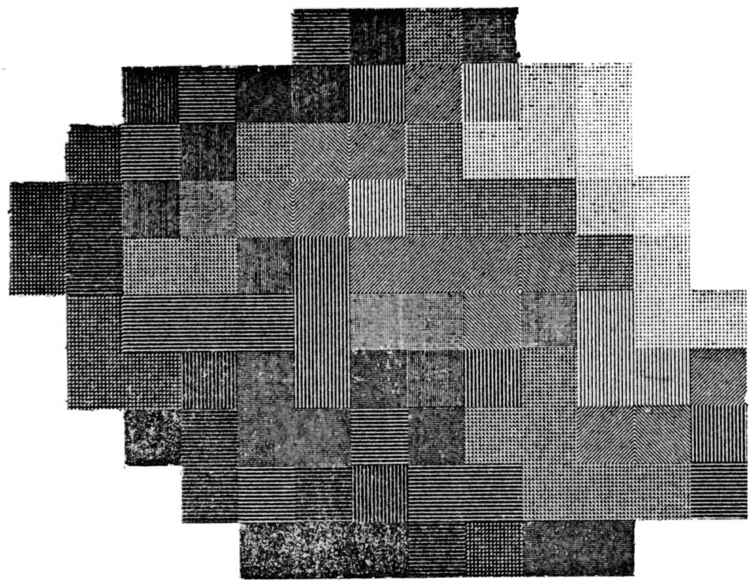
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		10	NORTH
2	3		2	EAST
3	4		34	SOUTHEAST
4	5		23	SOUTH
5	6		22	SOUTHWEST
6	7		25	WEST
7	8		35	NORTHWEST

7 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 39. Slope Aspect Map of the WESTMINE Watershed

EASTMINE ELEVATION
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 4
DATE: 02/03/82 LIBRARY DESCRIPTOR: TOPO



LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		3	770 - 779 FEET ABOVE SEA LEVEL
2	2		7	780 - 789 FEET ABOVE SEA LEVEL
3	3		5	790 - 799 FEET ABOVE SEA LEVEL
4	4		5	800 - 809 FEET ABOVE SEA LEVEL
5	5		8	810 - 819 FEET ABOVE SEA LEVEL
6	6		5	820 - 829 FEET ABOVE SEA LEVEL
7	7		5	830 - 839 FEET ABOVE SEA LEVEL
8	8		6	840 - 849 FEET ABOVE SEA LEVEL
9	9		10	850 - 859 FEET ABOVE SEA LEVEL
10	10		6	860 - 869 FEET ABOVE SEA LEVEL

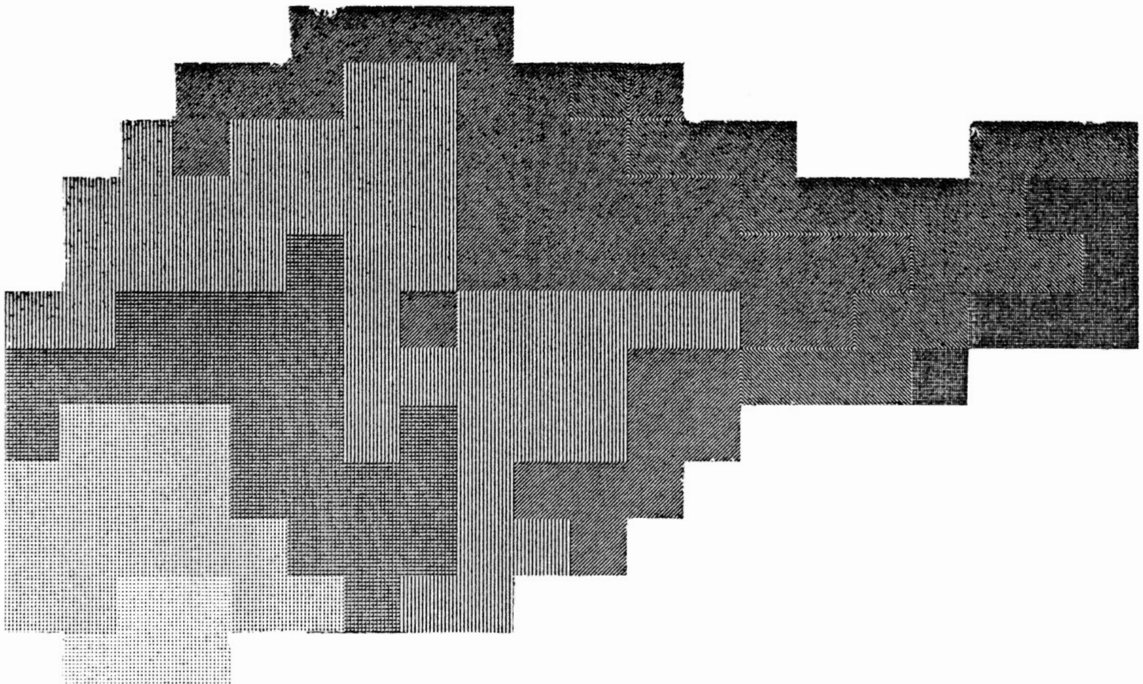
Figure 40. Elevation Map of the EASTMINE Watershed
(continued on the next page)

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
11	11		8	870 - 879 FEET ABOVE SEA LEVEL
12	12		11	880 - 889 FEET ABOVE SEA LEVEL
13	13		6	890 - 899 FEET ABOVE SEA LEVEL
14	14		3	900 - 909 FEET ABOVE SEA LEVEL
15	15		7	910 - 919 FEET ABOVE SEA LEVEL
16	16		4	920 - 929 FEET ABOVE SEA LEVEL

16 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 40. Continued

WESTMINE ELEVATION
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 3
DATE: 02/03/82 LIBRARY DESCRIPTOR: TOPO



LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		5	760 - 769 FEET ABOVE SEA LEVEL
2	2		16	770 - 779 FEET ABOVE SEA LEVEL
3	3		23	780 - 789 FEET ABOVE SEA LEVEL
4	4		42	790 - 799 FEET ABOVE SEA LEVEL
5	5		38	800 - 809 FEET ABOVE SEA LEVEL
6	6		20	810 - 819 FEET ABOVE SEA LEVEL
7	7		7	820 - 829 FEET ABOVE SEA LEVEL

7 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 41. Elevation Map of the WESTMINE Watershed

```
EASTMINE LANDCOVER
CRAIG COUNTY, OK
IL  =    1    LL  =   10
IE  =    1    LE  =   13
CH  =    1
DATE:  21/05/82     LIBRARY DESCRIPTOR:  LAND


          A A A B
    A A A C A A A A A
  A A A D C A C A C D
A A A E B C A A A D D D
A A C A A A A A A A A D
  A C A A A A A A A D C D
  A A A A A A B B B A A A
    A A A A A B B B A A A
      A A A A B B B A A A
        A A A C A B A
```

LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1	A	69	GRASSLAND
2	4	B	12	BARE
3	2	C	9	FOREST
4	3	D	8	AGRICULTURE
5	5	E	1	WATER

5 CATEGORIES   99 CELLS   990 ACRE AREA

Figure 42. Landcover Map of the EASTMINE Watershed

WESTMINE LANDCOVER
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 1
DATE: 21/05/82 LIBRARY DESCRIPTOR: LAND

```
          A B B B
      A A A B B B B A A
    A A A A B B B B A A A A       A A A
  B A A A A B B B B B B B B B B B B A A
  B B B B B B B B B B B B B B B B B B B
B B B B B B B B A A B B B B B A B B B B
B B B B B B B B A A A B B B B B B
B B B B B B A A B B A A A
B B B C B B B B B B A A
B B B B B B B B D B A
B B B B B B B B B
  B B B
```

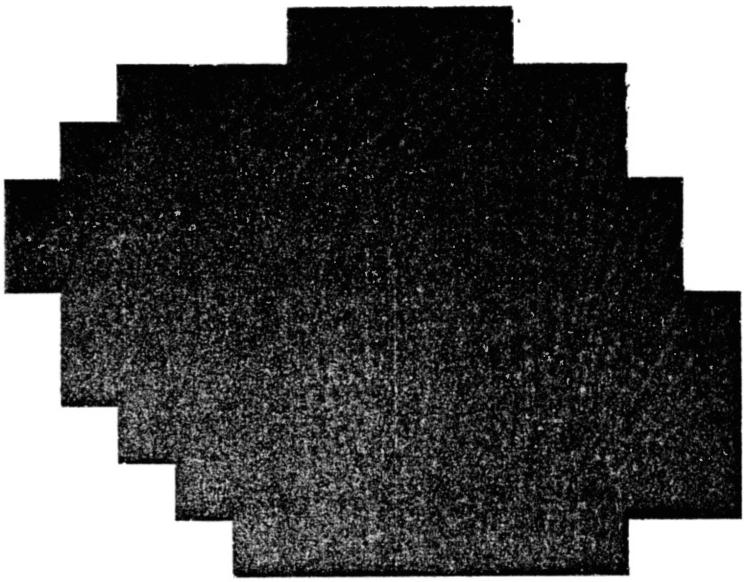
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	3	A	37	AGRICULTURE
2	1	B	112	GRASSLAND
3	2	C	1	FOREST
4	5	D	1	WATER

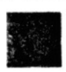
4 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 43. Landcover Map of the WESTMINE Watershed

EASTMINE AVERAGE ANNUAL PRECIPITATION
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 1
DATE: 20/02/82 LIBRARY DESCRIPTOR: CLIM



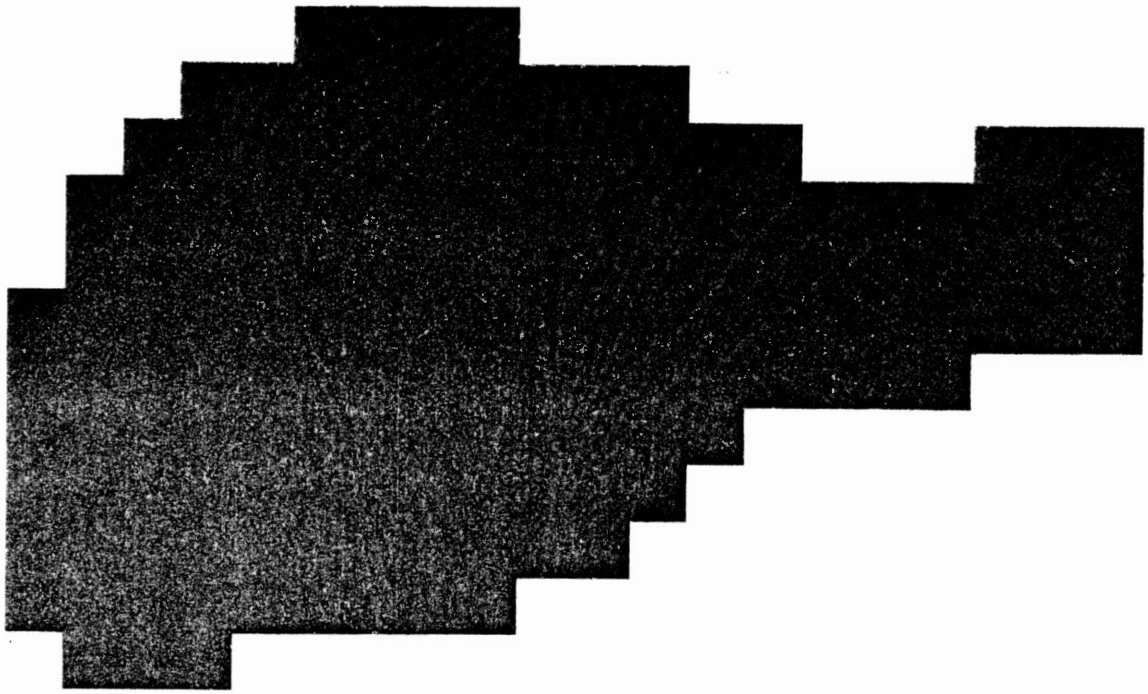
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		99	42 INCHES

1 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 44. Average Annual Precipitation Map of the EASTMINE Watershed

WESTMINE AVERAGE ANNUAL PRECIPITATION
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 1
DATE: 20/02/82 LIBRARY DESCRIPTOR: CLIM



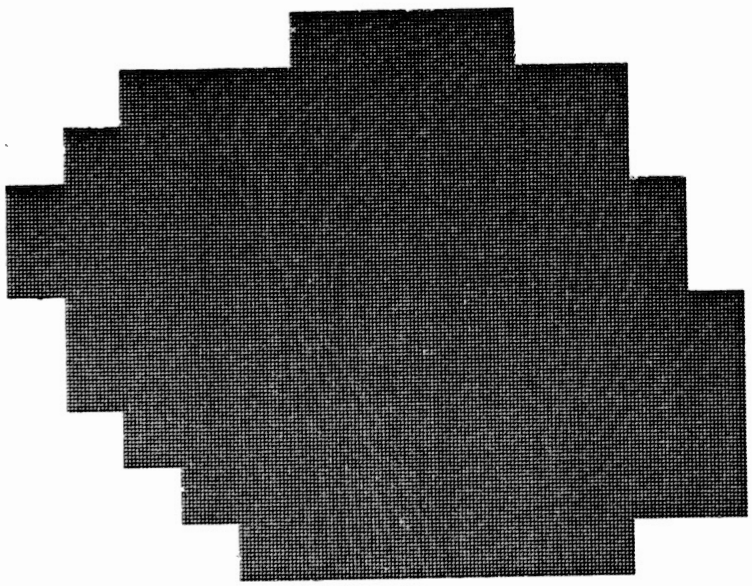
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		151	42 INCHES

1 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 45. Average Annual Precipitation Map of the WESTMINE Watershed

EASTMINE AVERAGE JANUARY TEMPERATURE
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 2
DATE: 20/02/82 LIBRARY DESCRIPTOR: CLIM



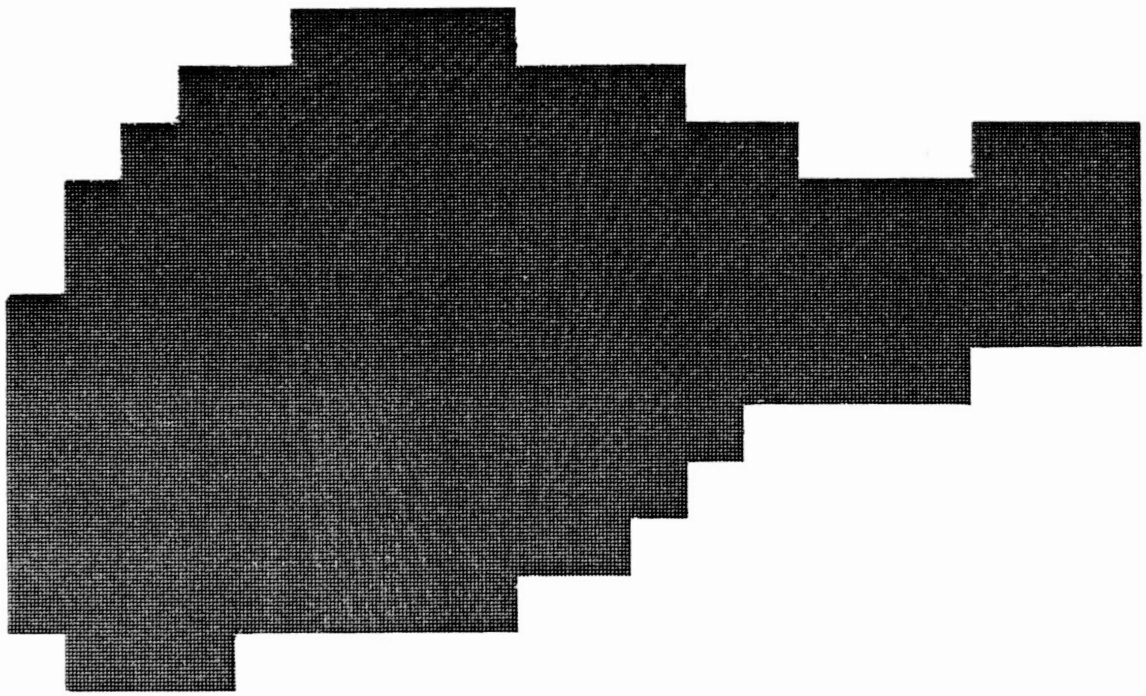
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1	■	99	36.0° FAHRENHEIT

1 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 46. Average January Temperature Map of the EASTMINE Watershed

WESTMINE AVERAGE JANUARY TEMPERATURE
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 2
DATE: 20/02/82 LIBRARY DESCRIPTOR: CLIM



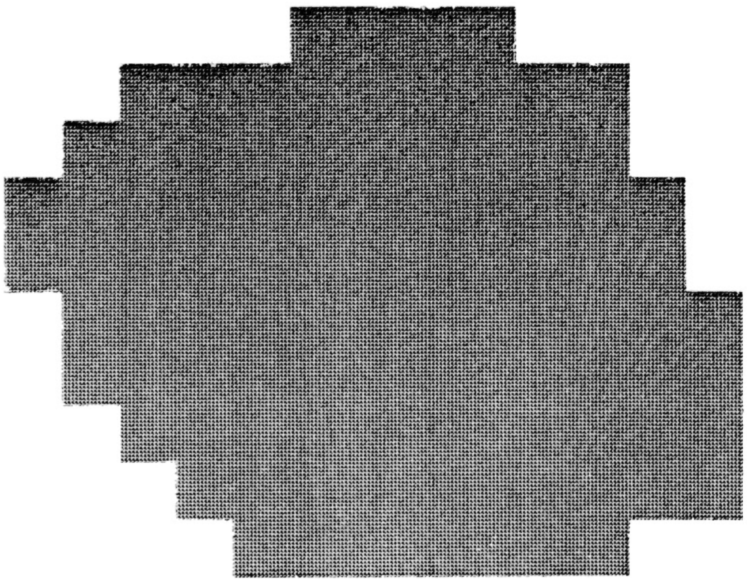
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1	■	151	36.0^{o} FAHRENHEIT

1 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 47. Average January Temperature Map of the WESTMINE Watershed

EASTMINE AVERAGE JULY TEMPERATURE
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 3
DATE: 20/05/82 LIBRARY DESCRIPTOR: CLIM



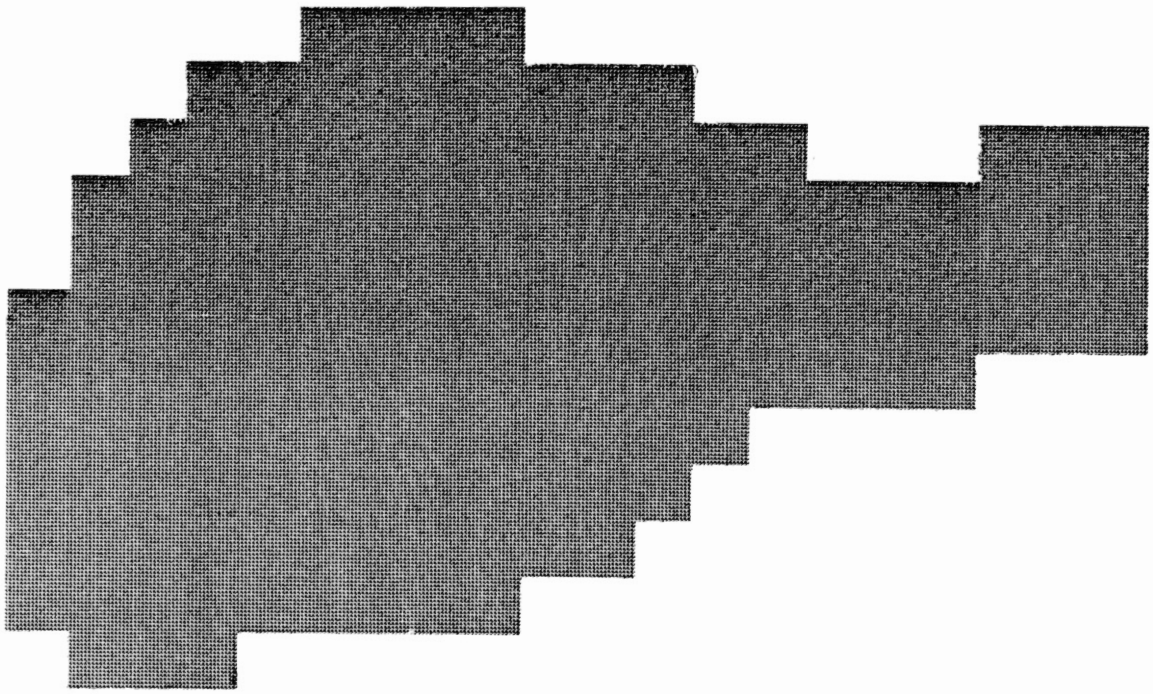
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1	▒	99	81.1° FAHRENHEIT

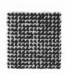
1 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 48. Average July Temperature Map of the EASTMINE Watershed

WESTMINE AVERAGE JULY TEMPERATURE
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 3
DATE: 20/05/82 LIBRARY DESCRIPTOR: CLIM



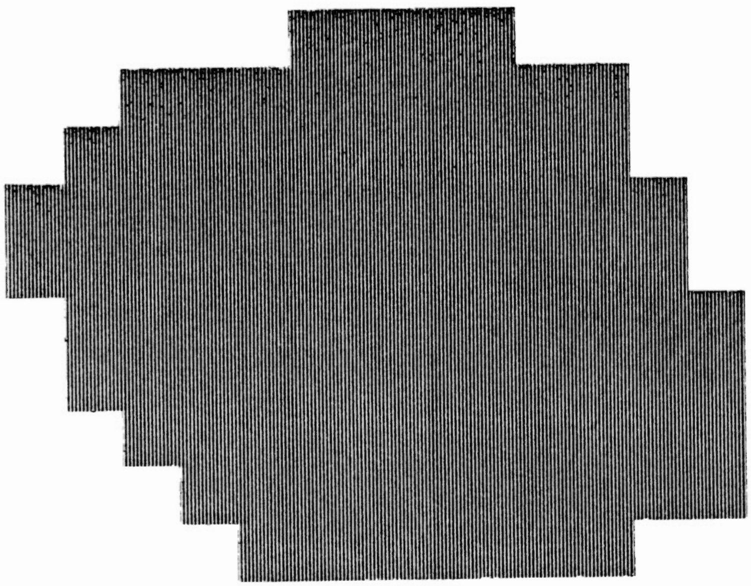
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		151	81.1° FAHRENHEIT

1 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 49. Average July Temperature Map of the WESTMINE Watershed

EASTMINE AVERAGE LENGTH OF FROST-FREE SEASON
CRAIG COUNTY, OK
IL = 1 LL = 10
IE = 1 LE = 13
CH = 4
DATE: 20/05/82 LIBRARY DESCRIPTOR: CLIM



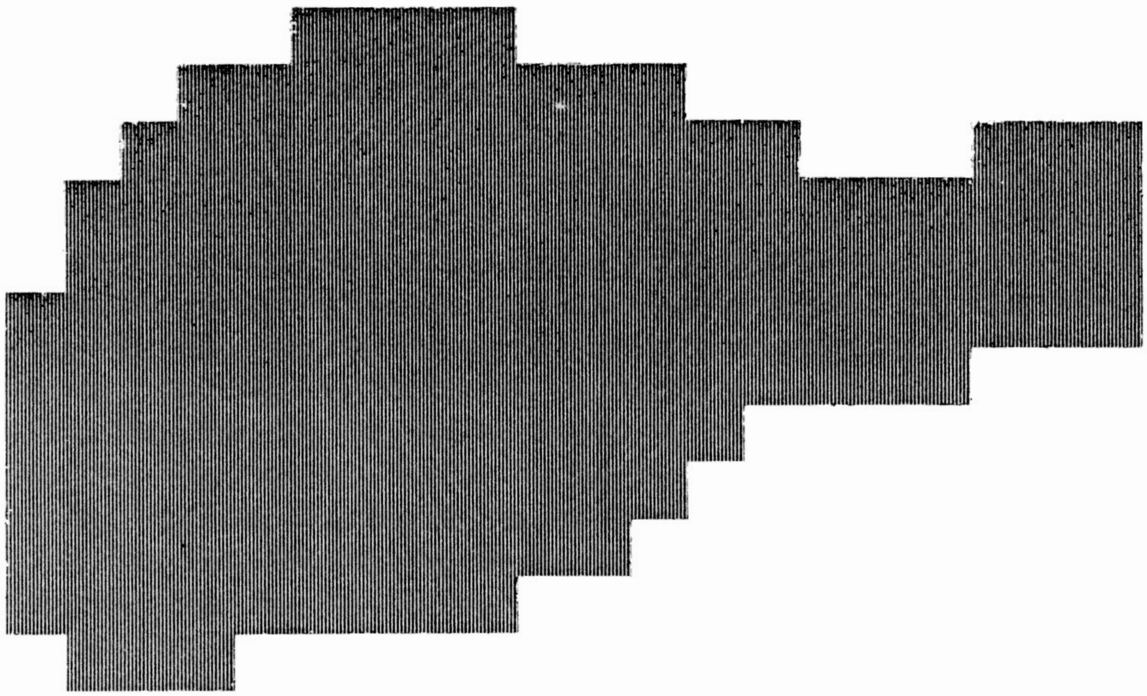
LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		99	205 DAYS

1 CATEGORIES 99 CELLS 990 ACRE AREA

Figure 50. Map Delineating the Average Length of the Frost-free Season in the EASTMINE Watershed

WESTMINE AVERAGE LENGTH OF FROST-FREE SEASON
CRAIG COUNTY, OK
IL = 1 LL = 12
IE = 1 LE = 20
CH = 4
DATE: 20/05/82 LIBRARY DESCRIPTOR: CLIM



LEGEND

CAT #	VALUE	SYMBOL	FREQ	DESCRIPTION
1	1		151	205 DAYS

1 CATEGORIES 151 CELLS 1510 ACRE AREA

Figure 51. Map Delineating the Average Length of the Frost-free Season in the WESTMINE Watershed

VITA

Larry Melvin Bunse

Candidate for the Degree of

Master of Science

Thesis: THE APPLICATION OF A GEOGRAPHIC INFORMATION SYSTEM TO THE MANAGEMENT OF SURFACE COAL MINES

Major Field: Geography

Biographical:

Personal Data: Born in St. Joseph, Missouri, January 25, 1958, the son of Mr. and Mrs. Melvin V. Bunse.

Education: Graduated from Savannah High School, Savannah, Missouri, in May, 1976; received Bachelor of Science degree in Geography from Northwest Missouri State University, Maryville, Missouri, in May, 1980; completed requirements for Master of Science degree in Geography at Oklahoma State University in December, 1982.

Professional Experience: Graduate research assistant, Center for Applications of Remote Sensing, Oklahoma State University, June 1980 to May, 1982.

Professional Organizations: Member, Association of American Geographers.