MONTANA STATE UNIVERSITY

A computer graphic system for interactive display of land qualities and potentials
by Gary Lee Ford

A thesis submitted in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Crop and Soil Science
Montana State University
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Abstract:
Maps showing quality and potential of agricultural lands are not readily available for much of the world. The objective of this study was to develop a system for interactive computer analysis of pedologic, geologic, vegetative, and climatologic information. The system produces plotter drawn maps of Montana, an area of 235,421 square kilometers, showing the distribution of agriculturally or environmentally similar areas. The use of 1:1,000,000 map scale facilitates composite analysis because many environmental variables are mapped at this intensity. The average cost of preparing a map for computer storage is less than $70, for plotting a map $5 to $20. Examples of system applications include site selection for a new experiment station, analysis of seven research centers to determine similar environments, and soil classification studies on the distribution of lands with cryic and frigid soil temperature regimes. This system promotes increased awareness of the characteristics and potentials of Montana's agricultural land.

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by

GARY LEE FORD

A thesis submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

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Approved:

Chairperson, Graduate Committee

Head, Major Department

Graduate Dean

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd.)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (cont'd.)

ABSTRACT

Maps showing quality and potential of agricultural lands are not readily available for much of the world. The objective of this study was to develop a system for interactive computer analysis of pedologic, geologic, vegetative, and climatologic information. The system produces plotter drawn maps of Montana, an area of 235,421 square kilometers, showing the distribution of agriculturally or environmentally similar areas. The use of 1:1,000,000 map scale facilitates composite analysis because many environmental variables are mapped at this intensity. The average cost of preparing a map for computer storage is less than $70, for plotting a map $5 to $20. Examples of system applications include site selection for a new experiment station, analysis of seven research centers to determine similar environments, and soil classification studies on the distribution of lands with cryic and frigid soil temperature regimes. This system promotes increased awareness of the characteristics and potentials of Montana's agricultural land.

INTRODUCTION

The purpose of this research was to design, develop, and test a computer graphic system for Montana. The system which was developed displays the spatial distribution of land qualities and management opportunities within the state. The following section discusses the need for such a system.

Description of the Land Resources of Montana

Montana is the fourth largest state in the nation. It has an area of 235,421 square kilometers (147,138 square miles). The east-west dimension is just over 550 miles at the Canadian border; the greatest north-south distance is approximately 325 miles in the west and 280 miles in the east (Taylor et al. 1974). The complex pattern of geology, landforms, soils, climate, and vegetation found within the area interact to produce a land surface which has a wide range of qualities, potentials, and limitations for use by man.

Physiographically the state can be divided into three north-south trending zones. The western third is part of the Rocky Mountains, the eastern third is on the Great Plains, and the central portion is a transition zone of plains with isolated low mountain ranges (Figure 1).

Elevations vary from 12,799 feet at Granite Peak in the Beartooth Plateau to 1,800 feet in the valley of the Kootenai River near Troy in the northwestern part of the state.

Geologically the state consists of flat lying sedimentary beds in the east, with complex units of folded, faulted, and otherwise

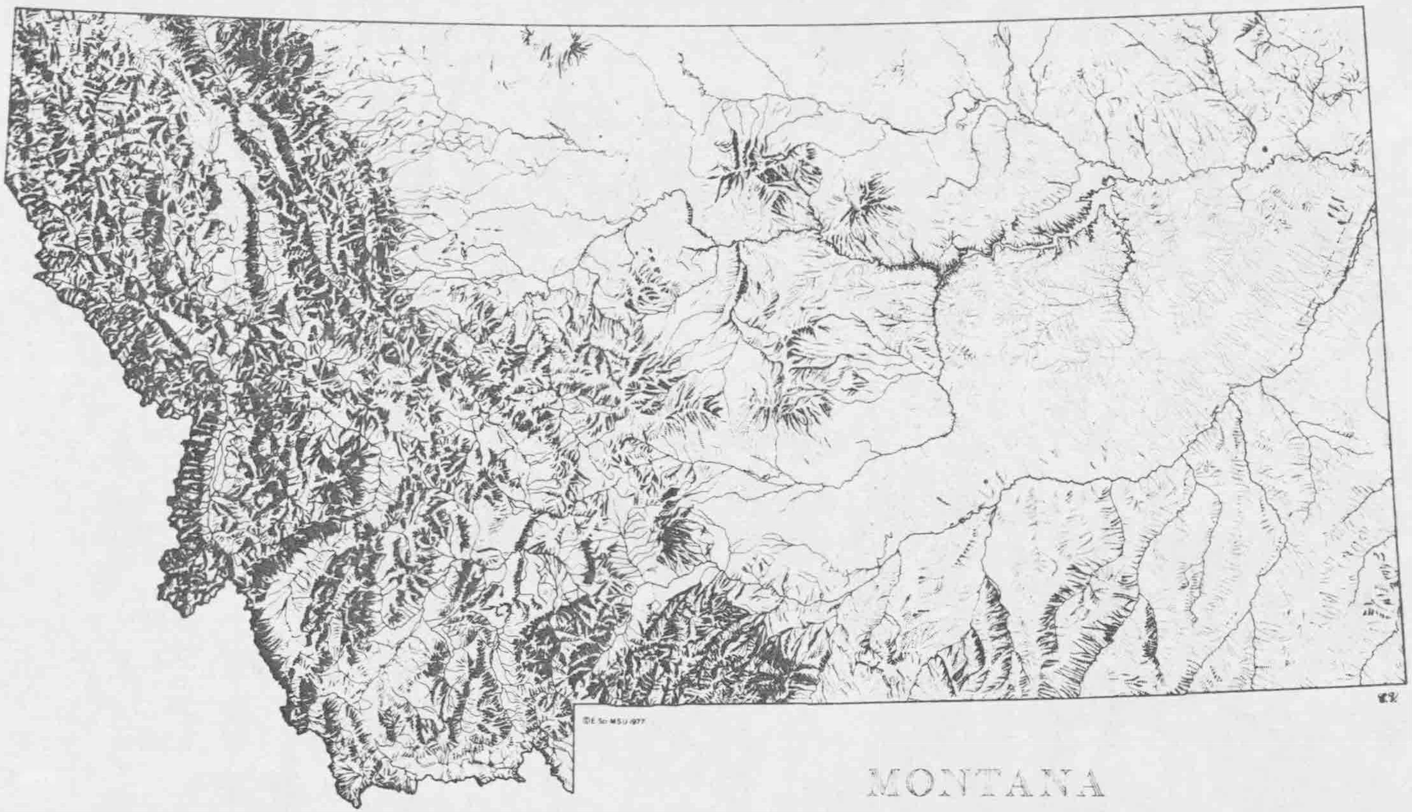


Figure 1. Physiographic diagram.

disturbed igneous, sedimentary, and metamorphic material in the west. Some portions of western Montana as well as the area north of the Missouri River in the east were extensively glaciated.

Temperatures range from a high of 117°F at Medicine Lake in 1937 to a low of -70°F at Rogers Pass in 1954. Although snowfall is great in many areas, more precipitation occurs as rain. Annual precipitation varies from less than 12 inches in southcentral Montana to over 100 inches in the mountains of the west. The average length of the frost-free season ranges from less than 30 days at high mountain locations to over 135 days in eastern Montana. Wind may be an important agent in some areas in the deposition of snow as in a blizzard or in its removal by a chinook.

The natural vegetation of the area covers a precipitation and elevation transect from xerophytic species through grasses to coniferous forest and finally alpine tundra. A recent climax vegetation map of the state by Ross and Hunter (1976) identified 62 different units based upon soils and climate.

The complex pattern of parent material, climate, relief, and vegetation found within the state interact to produce extensive amounts of five of the soil orders listed in Soil Taxonomy (USDA 1976). These are: Entisols, Aridisols, Inceptisols, Mollisols, and Alfisols.

The major land uses in the eastern two-thirds of the state include livestock raising on the more arid portions, with small grain production where precipitation is more favorable. In the west, the timber industry is an important part of the economy of many communities.

The Need for Land Resource Information

This brief description of Montana's land resources illustrates the complexity and diversity of the physical geography of the state. This wide spectrum of surface features complicates land management since each area will respond to a treatment in a slightly different manner. Resource inventories must be accomplished to identify the qualities, potentials, and limitations of this diverse area. In addition to this landscape complexity there are also ethical, legal, and economic justifications for these inventories.

There was a time in our nation's past when the practice was to remove the resources that could be easily extracted from a location and then move on to a less-populated area, often leaving a badly degraded landscape behind (Udall 1969). However, since little frontier remains in the 48 contiguous states to escape to, our society must learn how to use its fixed land base without impairing its productivity.

Nearly 30 years ago Aldo Leopold (1949) was advocating a land ethic: "A land ethic . . . reflects the existence of an ecological conscience, and this in turn reflects a conviction of individual responsibility for the health of the land. Health is the capacity of the land for self-renewal. Conservation is our effort to understand and preserve this capacity."

Only in recent years has this concept been given widespread attention. Proponents of the land ethic believe that an area should not be mindlessly manipulated but should be managed on the basis of its ecological characteristics. However, before this can be accomplished the manager must identify these characteristics, i.e., inventory the resources.

Legislation has also been instrumental in the generation of land resource information. In particular, the National Environmental Policy Act of 1969 and the Montana Environmental Policy Act of 1971 require that any activity which will have a major impact on the environment must be thoroughly studied and documented and alternatives proposed. These acts also involve the public in the planning and review process. Litigation based upon these laws has frequently stopped a proposed activity because of insufficient resource data to justify the action.

Some areas of Montana have been badly degraded by man's use of the land. It is estimated that by 1974 140,000 acres of the state's farmland had been taken out of production by saline seeps (Miller et al. 1976). It is also estimated that by 1980 the strip mining of coal in eastern Montana will have disturbed 5,500 acres (Northern Great Plains Resource Program 1975) and it is not yet certain that reclamation will be successful. In some areas, wind and water erosion remain serious problems. In addition, each year more of Montana's farmland is converted to other uses because of urban sprawl, road construction, and other activities.

The population of the state will continue to increase and with competition between uses for this land it is essential that determinations be made of the qualities, limitations, and potentials of the area so it will be used wisely, without impairing its long-term productivity.

In this thesis land is considered to be the result of the synthesis of geology, soils, climate, and vegetation into a landscape which has a particular set of qualities or characteristics which influence how it can be used. In most cases, without enormous costs, these properties can only be slightly modified by man.

This definition suggests that before the limitations and potentials of land can be determined resource inventories will be necessary in many different disciplines. Research of the Montana Agricultural Experiment Station has shown that even when consideration is limited to the natural landscape, the number of pedologic, geologic, biologic, hydrologic, and climatologic factors which may be significant exceeds 1,400 (Plantenburg et al. 1974). Of this large number approximately one-fourth may be determined or estimated from a modern soil survey (Nielsen 1977). However, decisions about the best use of land cannot be based upon soil qualities alone. Other aspects of the physical environment as well as economic and political considerations are also important.

The Present Status of Resource Inventory Mapping

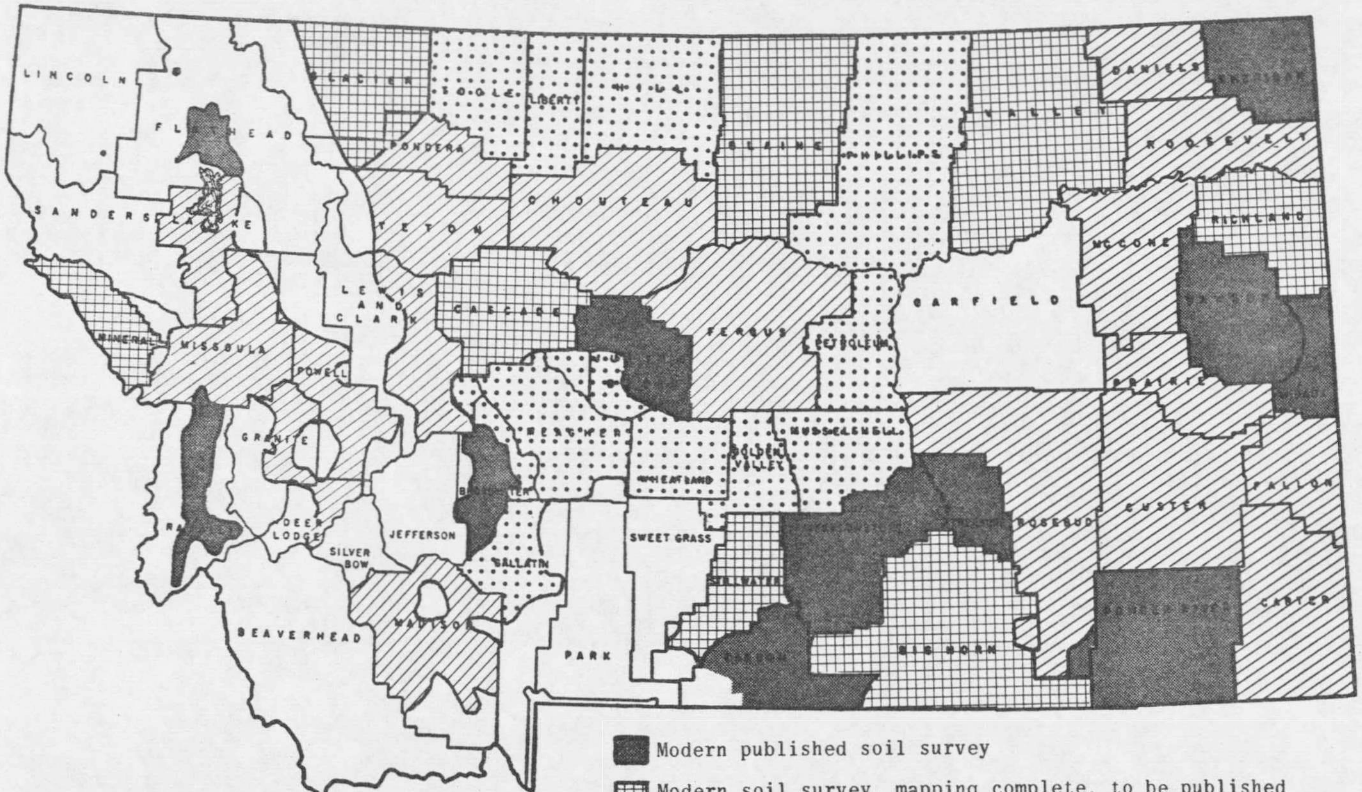
The amount and quality of natural resource information available for an area varies greatly. While some locations in the state have adequate detailed data for planning, most do not. Figure 2 shows the status of soil surveys in Montana. Detailed mapping in most other disciplines is similarly incomplete. Also currently unavailable is a statewide land use map.

Because of this paucity of detailed resource inventories it is imperative that existing generalized data be utilized until better information is available. This level of information can help prevent land degradation and facilitate wise land use if utilized properly. Furthermore, it is essential that this resource information be disseminated in a form which will communicate its meaning.

Planners, the public, and other users of resource information are often critical of inventory reports which are full of jargon and fail to communicate the significance of the data (Woolfe 1978). One of the best ways to present resource information is with clear, well-presented maps.

Land Resource Maps

Maps are an effective method of showing relationships because they display the spatial distribution of the resource. The user does not have to sort through pages of text or graphs and tables. A well-



Modern published soil survey

Modern soil survey, mapping complete, to be published

Modern soil survey being conducted, completion date set

Old published soil survey

No modern soil survey being conducted, and no old published survey

Figure 2. Soil survey areas (as of September 1977).

Source: United States Department of Agriculture. Soil Conservation Service.

prepared map makes it easier for the user to visualize and evaluate resource data.

From a land management perspective there are two basic types of maps: resource maps and interpretive maps. The first shows the spatial distribution of the resource without passing judgment on its suitability for use. The second displays the limitations of the land without identifying the resource unit responsible for the constraint.

A problem frequently encountered in using these types of maps is that since each survey, i.e., pedologic, geologic, climatic, etc., is usually conducted independently of the others, the completed maps are often at different scales and projections, cover different areas, and are thus difficult to integrate.

Overlays

One of the more effective ways in which maps can be used is by preparing all of them at a common scale and projection and then superimposing them. Renowned planner Ian L. McHarg was one of the first to demonstrate this technique in books such as Design With Nature (1971). The use of overlays permits increased understanding of resource relationships within an area since several parameters can be examined at the same time.

This technique has proven so valuable and useful in Montana that a handbook was prepared to instruct people in citizens groups and local government on how to collect and display resource information for planning purposes (Plantenburg et al. 1977). This handbook is designed for counties, other units of local government, and citizen groups which do not have professional planning staffs and yet feel the need to increase their understanding of the land resources of their area.

In addition to resource overlays, interpretive overlays are also used for planning. At Montana State University, interpretive overlays are used to effectively display soil limitations for selected uses.

The Use of Computers for Processing Land Resource Data

The need for resource data has increased significantly in recent years. To handle the large amount of data being generated and process it rapidly, computers are increasingly being used.

Montana was one of the leaders in the nation in the use of the computer to process soil survey data. Computers are used to store, process, and print out soil pedon descriptions on an operational basis for all new surveys in Montana (Decker et al. 1975). Computers are being used to generate not only resource data but interpretive soil maps as well (Nichols and Bartelli 1974).

Other disciplines are also making use of the computer, for example a new crop information system has been developed to help agronomists and plant breeders match crops with the right environment (Duke 1977).

Requirements for Computer Processing of Resource Data

Not all resource data or problems require computer processing. If the problem involves a relatively small amount of data, only a few parameters, or is a one-time effort, computer graphic systems have no advantage over hand-overlay methods because there is a large, fixed cost for input of data into the computer.

However, if large amounts of data must be processed, and/or the analysis is complex, a computer graphic system can perform the necessary calculations and generate a map in less time and at less expense than with manual operations. Computer processing can also be more efficient for frequently reoccurring tasks. Thus, the number of variables, the need for re-use of the data, speed, analytical complexity, and cost are all factors which must be considered before selecting a method for analyzing data (Johnston et al. 1978).

LITERATURE REVIEW

Geographic Information Systems

One of the major recent developments in the processing of resource data has been the creation of computer-based geographic information systems. These commonly contain data on soils, geology, vegetation, water features, land use, transportation, political units, and many other factors.

There are two basic reasons for the proliferation of these systems in recent years: (1) there has become an increased technological capability for manipulating large quantities of data, and (2) there is a reduced per unit cost for information provided (Dangermond and Antenucci 1974).

One of the common techniques used to convert mapped resource data into a form which can be processed by the computer involves superimposing a grid on the map. This divides the resource map into a matrix of rectangles or unit cells. The process of converting the resource data into a form suitable for computer storage and retrieval is called encoding or digitization.

Computer Storage

There are two basic procedures for encoding or digitizing. These are (1) a manual process of identifying attributes or priority of attributes in each grid cell and (2) the automated method of using an electronic digitizer to measure the outline coordinates of polygon map data and associate attributes to each of these polygons.

Manual encoding techniques usually involve overlaying an acetate grid onto a resource map and recording all numeric codes described on the base map to an assigned row and column location within the matrix grid system. The code for each cell is written on a coding form and then keypunched and used to create the automated files.

Automated digitizing requires the determination of the x and y coordinate locations of the lines which form the polygon perimeters. An electromechanical device called a digitizer is used to convert horizontal and vertical movements of its cursor into computer compatible characters. The cursor is moved around each polygon, recording a series of x and y coordinates on paper tape. This data is subsequently transferred to magnetic tape for easier and more efficient processing (Dangermond and Antenucci 1974).

Data Retrieval

There are two output devices commonly used in these geographic information systems to produce computer-drawn maps--the standard line printer and the plotter.

The most commonly used output device is the line printer. Maps can be output on this device using each letter or character as a cell. Because the line printer does not print square characters, the map output will be scale distorted; that is, a square area will not come out as a square map on this device. The line printer commonly uses an overstrike process to produce patterns of varying shades.

There are several different types of plotters such as drum or electrostatic. Since a pen or other device is used to draw lines and print characters the plotter can produce nearly any size of letter or number and is not limited to the conventional symbols used by a line printer.

Johnston et al. (1978) made the following assessment of the suitability of these dvices for use with computer graphic systems. Plotter output is extremely expensive and not technically suited for the production of maps that combine a large number of variables. Standard high-speed printers are not aesthetically pleasing because the intercharacter spaces are too great, the lines are not straight, and the ribbon quality varies from map to map. New special printer terminals are slower, but produce relatively high-quality maps.

In the computer processing of resource data it is important to distinguish between computer mapping systems, such as SYMAP and LUMP, and geographic information systems, such as NARIS and LUNR. In the literature the frequent use of this symbol terminology causes confusion and it is important to understand the meaning of each.

Computer mapping system refers to the specialized computer programs which produce the maps. Terms such as geographic information systems or computer graphic systems refer to the total system for storage, processing, and retrieval of resource data.

Numerous computer geographic information systems are currently in operation in the country. A few of the more significant features of several of the larger systems will be briefly discussed. These systems include: (a) Land Use and Natural Resources Inventory (LUNR); (b) Maryland Automated Geographic Information System (MAGI); (c) Natural Resource Information System (NARIS); (d) Minnesota Land Information System (MLIS); (e) Other systems.

a. LUNR (Land Use and Natural Resources Inventory) system.--This was developed by the Center for Aerial Photographic Studies at Cornell University in collaboration with the Laboratory for Computer Graphics of Harvard University for the New York State Office of Planning Coordination.

A detailed inventory of land use and natural resources for all of New York State was accomplished using aerial photographs as the source of information and computers to store and analyze the data. Fifty different land uses were recognized. The grid system used was the Universal Transverse Mercator which permitted working within a framework of square cells. A 1-kilometer square cell (247.1 acres) was selected as a useful summary unit and approximately 140,000 cells were required for statewide coverage. Land use decisions were based on areas as small as 1¼ acres in size.

LUNR provides point, linear, or area information on 11 major categories of land use: agriculture, forest land, water resources, nonproductive land, residential land use, commercial areas, industrial areas, extractive industry, outdoor recreation, public and semi-public land uses, transportation, soils, bedrock geology, and agricultural economics. Each category contains more detailed classification units.

Products include overlay maps of area, point, or linear data, printouts that list information about each cell, and computer maps that indicate the location and results of quantitative analyses of the data. All products are available at moderate or low cost (Hardy and Shelton 1970).

b. Maryland Automated Geographic Information (MAGI) System.--This system was developed by Environmental Systems Research Institute, Redlands, California and sponsored by the Maryland Department of State Planning. The purpose was to develop a data bank of natural and cultural resources for land use planning.

MAGI converts maps depicting polygons, lines, and points of geographic distinction into digital data readable by the computer. The grid cell used for digitizing was approximately 91 acres. The dominant, secondary, and tertiary data of each cell are recorded.

A total of 15 variables were encoded: soils, geology, slope, mineral resources, aquifers and recharge areas, natural features, vegetation, surface water quality, state and federally owned properties, sewer and water service areas, transportation facilities, historic sites, existing land use, watersheds, and electoral districts. Data were encoded at the county level and then assembled into regional and statewide files. Several interpretive models were developed to depict the suitability and capability of the land to support various uses. Examples include a mining/extraction model, a productive agriculture model, and several urban models (Dangermond and Antenucci 1974).

c. NARIS (Natural Resources Information System).--The system was developed at the Center for Advanced Computation of the University of Illinois at Champaign-Urbana in collaboration with the Northeast Illinois Natural Resources Service Center and the Northeastern Illinois Planning Commission.

The system contains data for portions of eight counties in northeast Illinois and uses a grid system based upon the dominant feature within cells that are each 40 acres in size. Townships, sections, and quarter-quarter sections are used as the coordinate system for the grid. The system is designed for natural resources management and contains resource data such as geology, soils, forestry, water, and land use. These data are manually coded for each dominant cell and an overlay technique is used for data manipulation (Tsao 1975).

d. Minnesota Land Information System (MLIS).--A system developed by the Center for Urban and Regional Affairs at the University of

Minnesota and the State Planning Agency. Data stored include information on political jurisdictions, land ownership, bedrock geology, geomorphic regions, mineral potential and leases, soil landscape units, land use, forest cover, water orientation, and highway orientation. For state or county-owned land the following data are also stored: type of acquisition, highest recommended use, recommended disposition, and management unit status. Some areas of the state have additional information. There are 9 land use types and 50 different public ownership types. Forty-acre data cells were used that were based upon the United States Public Land Survey. The state is composed of 1.4 million 40-acre data cells. MLIS is also developing a large file of information at the 500 meter scale (approximately the size of a quarter-township), less than 10,000 cells being required for state coverage. Data are encoded based upon the dominant type found within the cell. It is organized by region, county, and township. Information can be retrieved in tabular, statistical, map, or computer file form. Alternative cell sizes are being used for some purposes.

e. Other systems.--There are other computer-based geographic information systems mentioned in the literature. A few of these include: (1) Texas Natural Resource Information System (TNRIS); (2) Land Information System for Texas (LIST); (3) Canada Geographic Information System (CGIS); (4) Illinois Resource Information System (IRIS); (5) Colorado Environmental Data System (CEDS).

Computer Mapping Systems

Many sophisticated programs have been developed to produce computer maps. Those in use today vary from older systems which have received a great deal of use to those written in the last few years.

Synagraphic Mapping (SYMAP) is one of the better known programs. It was written in 1963 at Northwestern University and is currently maintained by the Laboratory for Computer Graphics of Harvard University. Many of the early systems used SYMAP or a modification of it.

While a thorough discussion of the programs in use today to make computer maps is beyond the scope of this paper, a brief discussion of some of the capabilities of one of the more recent systems will illustrate the state of the art.

Land Use Mapping Programs (LUMP) was developed by the Division of Environmental Studies at the University of California at Davis. The system was developed to meet the needs of researchers in many disciplines on the campus and of land use planners in northern California. It has continued to be improved since the system was first designed in 1971.

LUMP has several uncommon capabilities. An input procedure called GRID/BASE makes it possible to enter cell data by using interactive terminals and bypassing the coding of sheets and the punching of cards. If point data, such as precipitation measurements, exist for only a small number of cells, values for the other grid cells can be generated by the use of contouring programs that fill in the missing data. Another capability of LUMP is that the optical distortion of aerial photos can be rectified and maps can be transposed from one projection to another.

Maps are produced by standard line printers or by more specialized typewriter printers that use letters, numbers, or shaded characters.

Data can be handled as choropleths rather than cells. A choropleth is an area where all the information is uniform. Choroplethic mapping is less expensive than cell mapping because data are not stored cell by cell.

MATERIALS AND METHODS

Figure 3 is a flowchart of the data processing procedures followed in developing the system. The initial phase of this research involved the preparation of a series of maps of environmental parameters at a common scale and projection which is a prerequisite to the overlay process. In this study it was found that there were more factors mapped at 1:1,000,000 than at any other scale. While this is a small scale map, it was the best available for overlaying the many parameters necessary to determine the land qualities of an area. The Albers Equal Area projection with standard parallels of $29\frac{1}{2}^{o}$N and $45\frac{1}{2}^{o}$N was selected. An advantage of this scale and projection was that the maps could be overlain on Landsat photos. It was also the scale and projection recommended by the National Bureau of Standards.

The map scale and projection of the original data varied considerably. Some were at 1:1,000,000 Albers Equal Area projection and only required copying. Others were at the right scale but the Lambert Conformal Conic projection which necessitated modifications. Where the best available data were mapped at a smaller scale than 1:1,000,000 a Map-O-Graph projector was used to enlarge it to the required scale.

The following maps were prepared at 1:1,000,000 Albers Equal Area Projection:

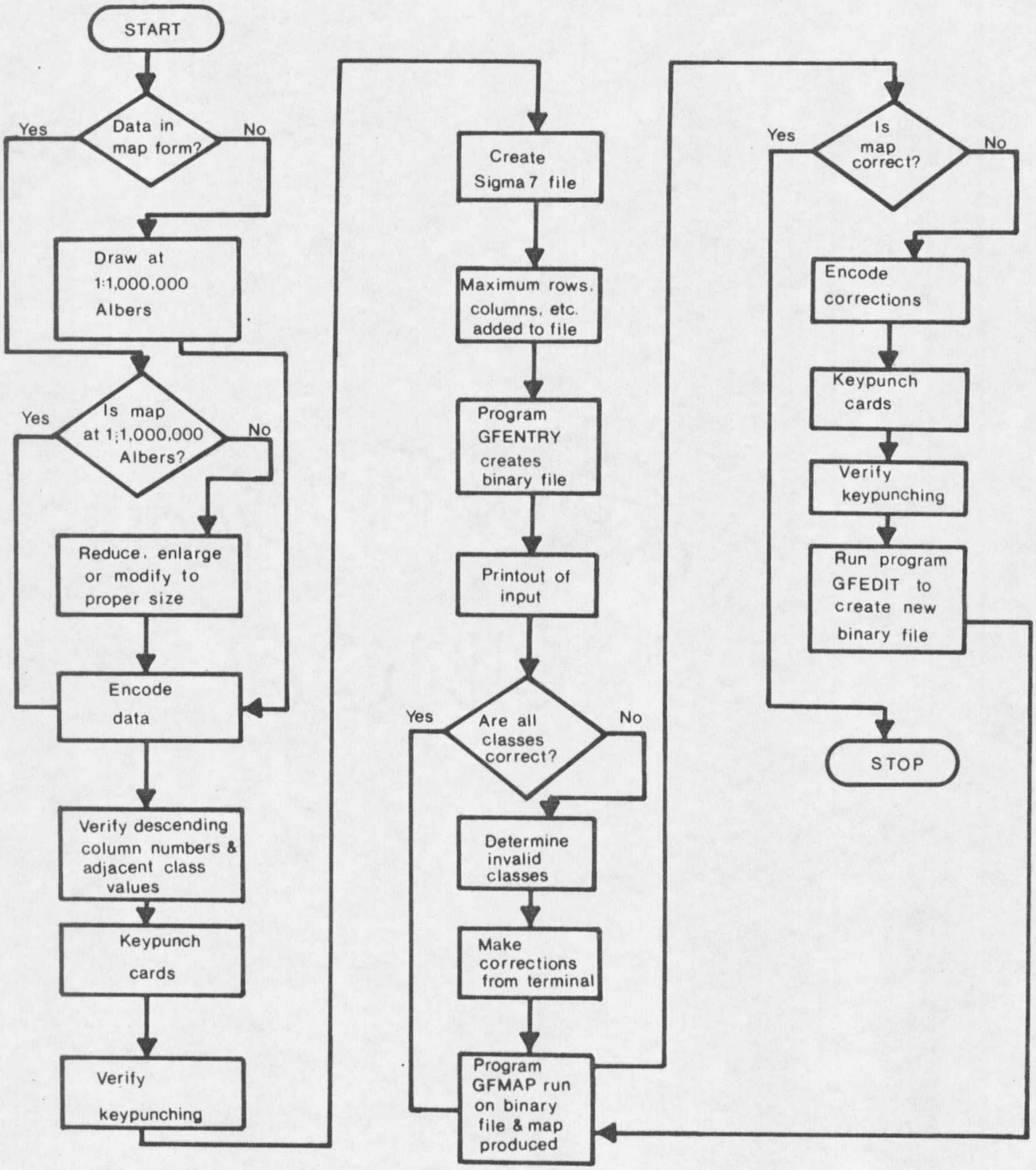


Figure 3. Flow chart of data processing.

1. Soils
2. Irrigated Lands*
3. 1953-67 Average Annual Precipitation*
4. 50 Year Peak Precipitation
5. Number of Strong Chinooks per 100 Years
6. Potential Evapotranspiration
7. Average Annual Effects of Erosive Rain
8. Average Length of Frost-Free Season
9. Average Date of First Freeze
10. Average Date of Last Freeze
11. Sediment Yield*
12. Consumptive Use of Water
13. 1958-72 Average Annual Snowfall
14. Geology
15. Percent of Annual Precipitation Falling from April 1 Thru July 31
16. Percent of Annual Precipitation Falling from May 1 Thru July 31
17. Climax Vegetation
18. Elevation

*Not stored in the computer

Appendix I describes these maps in greater detail. A new map of Average Annual Precipitation, 1941-70 was produced after the one listed above was drawn, so only the newer map was encoded to store in the computer.

Construction of the Data Bank

After a map was drawn at the proper scale and projection the next step was to convert this resource data into a form which could be processed by the computer. The method employed in this study was to lay a grid of chosen size over a resource map and analyze each cell created by that grid.

Grid systems are often used by researchers because of their relatively simplistic storage, retrieval, data overlay, and graphics capabilities. Furthermore, much of the computer mapping software has been designed for grid systems (Ferris and Fabos 1974).

The cells created by the grid should be keyed to a common ground reference system to facilitate overlay analysis. In this study the cells were based upon latitude and longitude. Each unit cell is 3 minutes on a side or 1/20th of a degree.

There are two important considerations in selecting the cell size for computer-based land resource information systems. These are the level of detail of information that is available or desired and the costs that are incurred when more cells of a smaller size are required. Using a smaller cell size increases the volume of data and the precision of detail but significantly increases the cost of encoding because of the greater time involved (Hicks and Hauger 1977).

The cell size used in this study was a compromise between the need for smaller cells in the mountainous western third of the state and that of the eastern two-thirds of Montana where a larger cell would have been sufficient. Many of the resource maps show a pattern of great complexity of detail in the mountainous areas with a simplified and more uniform pattern in the plains area. If a larger cell size had been used little accuracy would have been lost on the plains but the data encoded from the mountains would have been so generalized as to be of little value. Conversely, if a small enough cell size were used to maintain the accuracy of the mountainous detail, the time and costs required for encoding would have been prohibitive. It is felt that the 3-minute-on-a-side grid used for encoding provides good accuracy for the plains portion of the state, which is where Montana's agriculture occurs, and still provides sufficient detail for the mountains to show general patterns. The computer graphic system has its greater reliability in the plains areas of the eastern two-thirds and the intermontane valleys of the west. Its use in mountainous areas is limited and the output should only be used after verifying its accuracy.

Originally the township and range survey system was to be used for the coordinate system since many people are familiar with these values for their location. However, the many correction lines and units of unequal size in this system would have made the computer programming more difficult and time consuming.

At the scale of 1:1,000,000, 1 inch equals approximately 15.78 miles. Because of the curvature of the earth, the size of the cells varies slightly from the top of the map (.15 inch x .22 inch) to the bottom (.16 inch x .22 inch). Using the values of .15 inch (east-west) and .22 inch (north-south) is equivalent to 2.37 miles in an east-west direction by 3.47 miles in a north-south direction. Thus, the average area of a cell is approximately 8.22 square miles.

There are approximately 18,060 unit cells in an individual map and 288,960 total in the data bank.

Before encoding could occur it was necessary to make a plotter-drawn grid based on latitude and longitude at the 1:1,000,000 Albers Equal Area Projection. No local references could be found to explain how this projection is made. Finally, by corresponding with Mr. Doyle Smith of the United States Geological Survey in Reston, Virginia (1976) the mathematical equations were identified which were necessary to generate the map. This procedure is included in Appendix II.

Once the plotter-drawn grid was produced, a copy was made on mylar drafting film to facilitate data encoding since it is necessary to see through the grid to the resource map being encoded. In transferring the plotter grid onto the mylar some slight shrinkage resulted which caused a small displacement in cell location between the encoding grid and the eventual plotter-drawn resource maps. This was to cause problems when the maps were corrected.

To digitize the resource data the mylar grid was overlain on the map to be encoded. Figures 4-7 illustrate the process. Data were coded by rows from the top (north) of the map down, from left to right. This was recorded and keypunched to form the data deck. Two methods (dominant or central feature) were used to digitize the cells. Data were coded for a cell based upon the map class that dominates

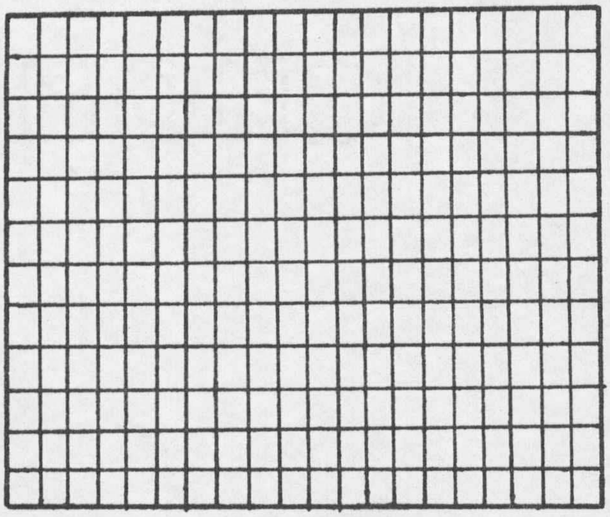


Figure 4. Portion of plotter-drawn grid.

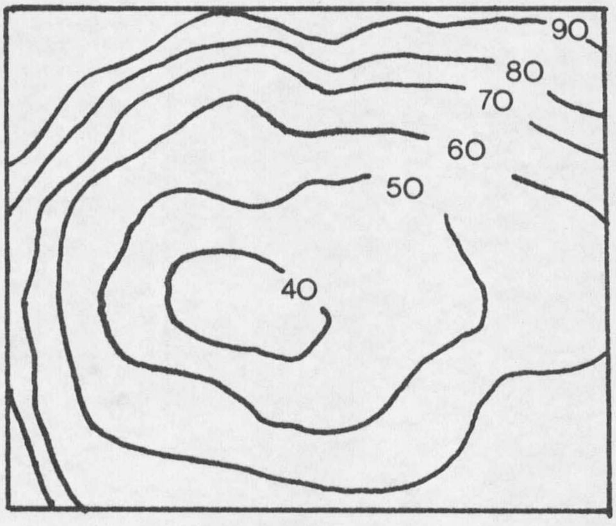


Figure 5. Portion of resource map to be encoded.

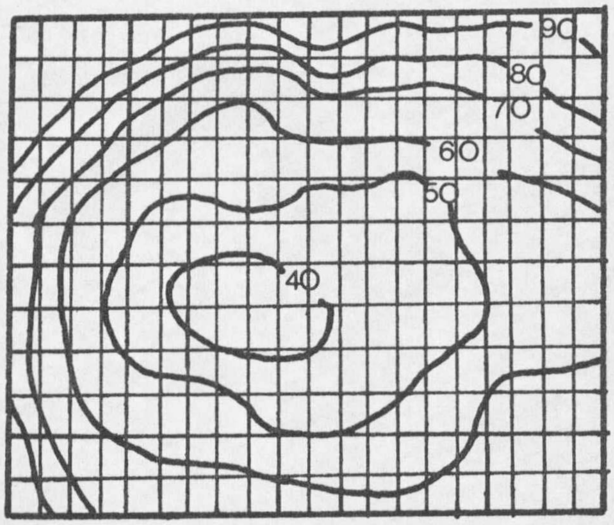


Figure 6. Grid superimposed on resource data.

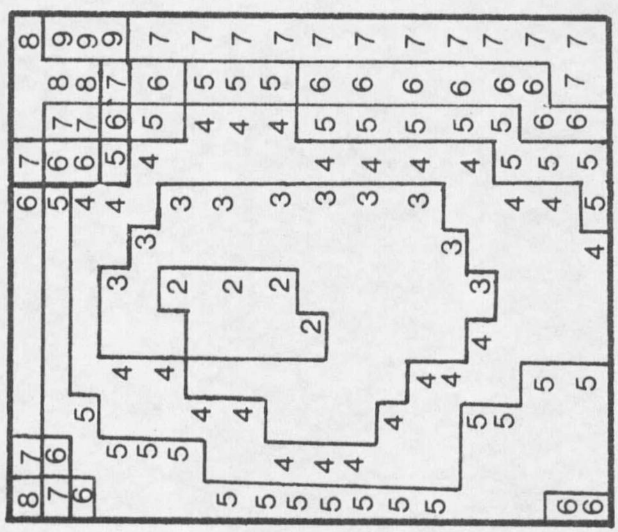


Figure 7. Final plotter map.

the unit. Where no class was clearly dominant the datum at the center of the cell was encoded.

A change point method was used to digitize the data. This technique requires the identification and recording of those cells where value changes occur. Thus, rather than encoding values for each cell in a row only those where map classes change require digitization.

The encoding process was most efficient when two individuals were utilized, one to read from the grid while the other recorded the values on fortran coding sheets. The two individuals took turns reading and recording, switching positions periodically. This relieved the monotony of the process and increased the accuracy of the encoded data.

After a map had been encoded, the fortran sheets were checked for several types of encoding errors and then taken to the computer center to be keypunched and verified. The cards were then ready for computer processing.

All computer programs used were in FORTRAN IV language and were utilized on a Xerox Sigma 7 Computer. The plotter which produced the maps was a Calcomp Drum Plotter 563.

Computer processing consisted of the following sequential operations:

1. After keypunching and verification, the data cards were used to create a Sigma 7 file.

2. Additional descriptive information on the resource parameter being processed was added to the file.
3. Program GFENTRY was used to create a binary file.
4. Program GFMAP was run on this binary file and the plotter map was produced.

To produce a composite map the following procedure was followed:

1. Program GFMERGE was run to combine the smaller binary files (from the individual parameters being combined for composite analysis) into one large binary file.
2. Program GFMAKE was used to create a new smaller, composite binary file.
3. Program GFMAP was run on this binary file and the composite plotter map was produced.

Problems Encountered in System Development

All maps plotted were compared to the original hand-drawn maps and corrections were made. When the first plotter map was produced it was learned that there were two possible causes of error. The first was that the grid used to digitize the maps had shrunk slightly when it was transferred onto the mylar and thus the same cell on the grid would cover a slightly different area from the final map.

The other type of error was related to the process of superimposing the plotter-drawn map onto the original to check the accuracy of the coding. If the map was put in a slightly different position from where it was when the encoding was done, it would be enough to cause error. Eventually registration symbols were used to insure that the maps were lined up in the precise way that the corrections were made. Once this was done only minor errors were observed on the second plotter-drawn maps.

Another recurring problem with the plotter-drawn maps was the inconsistency of the map scale. For reasons that were never determined, occasionally the north-south distance on the plotter-drawn maps would be ≈¼" shorter than the actual distance on the base map.

Development of System Applications

After all data had been encoded and stored in the computer it was necessary to test the system. Several applications were undertaken, these were to:

1. Assist in the initial determination of where in a four-county area a new research center should be located;
2. Determine the location of lands with agricultural environments similar to those found at the seven existing Agricultural Experiment Station research centers;
3. Prepare computer maps showing the location of lands with cryic or frigid soil temperature regimes;
4. Use two of the files to mathematically generate two new files and maps of growing season precipitation;

5. Plot a map of sodium influenced soils; and

6. Use two of the resource maps to prepare a map of areas where summer fallow may not be recommended.

Each of these will be discussed in turn.

Establishment of New Branch Research Center

In 1977 the 45th Montana Legislature passed the following bill:

HOUSE BILL NO. 282
INTRODUCED BY MANUEL, JOHNSTON,
KENNERLY, J. GUNDERSON, UNDERDAL

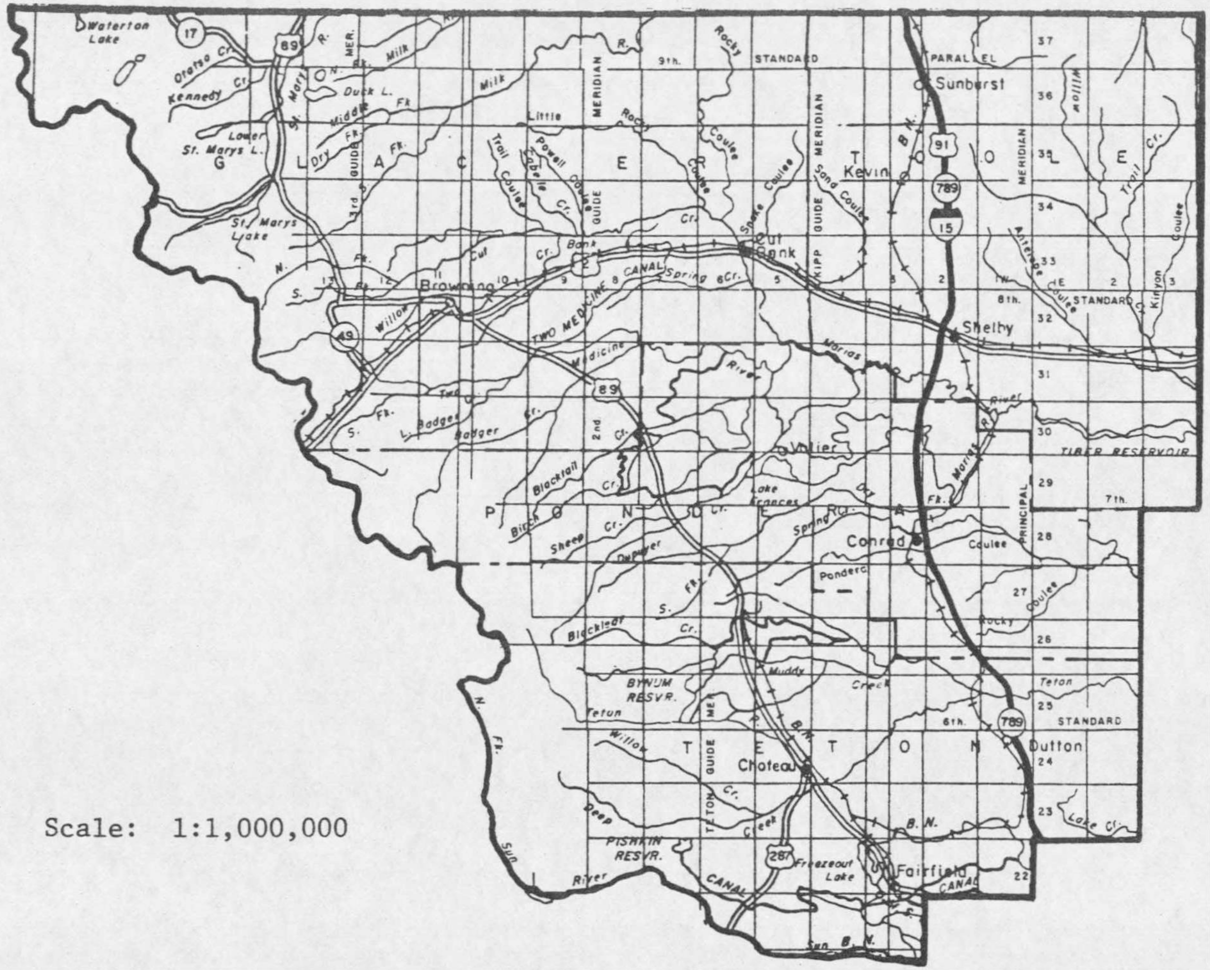
A bill for an act entitled: "An act appropriating funds for the establishment of a satellite agricultural experiment station to serve the general area of Glacier, Toole, Pondera, and Teton Counties."

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF MONTANA:

Section 1. There is appropriated the sum of $206,000 for the biennium ending June 30, 1979, from the general fund to the Montana Agricultural Experiment Station for the purpose of establishing a satellite agricultural experiment station serving Glacier, Toole, Pondera, and Teton counties and surrounding areas.

Figure 8 is a map which shows the location of the four-county area, sometimes called the western "Triangle," while Figure 9 is a larger scale view. Local people had initiated the movement for a research facility within their area because they believed the research done at other centers did not apply to their region. Once the bill was signed into law the problem was to first determine the criteria to use in selecting the site and then see if available land could be found which fit these requirements.

Figure 8. Location map for the four-county area.



Scale: 1:1,000,000

Figure 9. Larger scale view of study area.*

*Source: U. S. Department of Agriculture, Soil Conservation Service.

Several meetings were held in the area to determine the most significant factors to be considered in selecting a location for the center. Some of those considered most important were: (1) it should be on a site which has soil and climatic characteristics which are representative of a large portion of the area; (2) irrigation water should be present; (3) the site should be easily accessible by the public; (4) it should be close to a town for a service center; (5) it should be centrally located in the four-county area; and (6) there should be room for expansion.

On May 31, 1977 a meeting was held at Conrad at which time Dr. Gerald Nielsen and the writer presented maps and charts on the general soils, climate, and vegetation of the area. As part of this presentation graphic material was displayed illustrating the range of several of the environmental parameters found within the four-county area and where Conrad was on this spectrum. The purpose of this material was to communicate to those people attending the meeting the variability of the land resources of the four-county area.

Discussion with experiment station personnel had indicated that four environmental parameters were considered to be most important in the four-county area. These were: (1) soils, (2) average annual precipitation, (3) average length of the frost-free season, and (4) frequency of strong chinook winds.

To determine the most extensive units of these factors within the area, the computer was used to calculate the number of cells of each class for each of these parameters. This technique provided estimates of the relative amounts of each mapping unit present. This is a capability of the computer graphic system which can be very useful since this type of information can be difficult to estimate on a hand-drawn map which has a complex pattern.

In the following data, those numbers which are followed by an asterisk indicate the most extensive units and those which were used in the subsequent land resource analysis. The soil mapping units within the area had the following distribution. To determine the characteristics of these units consult the legend for the soils map in Appendix I.

Soil Unit	No. of Cells	Soil Unit	No. of Cells
ME1	34	VB5	1
LG1	3	GF2	7
R	48	PP2	12
LG2	23	GB2	1
IG	54	VB2	75
IB3	39	PH2	35
GB5	122*	GG2	39
SG2	119*	ME4	52
GB4	42	IF4	14
AW	24	GB6	33
OG3	25	VB1	1
MO4	4	GF4	25
SG1	162*	PB2	11
AV4	24	PB3	21
ST	22	GG4	1

The distribution for average annual precipitation was as follows:

Precipitation (in.)	No. of Cells
10- 12	351*
12- 14	270*
14- 16	89
16- 18	54
18- 20	50
20- 30	141
40- 60	60
60- 80	18
80-100	19
100-120	21

The average length of the frost-free season had the following distribution:

No. of Days	No. of Cells
10- 30	8
30- 50	75
50- 70	138
70- 90	153
90-100	147
100-110	165*
110-115	114*
115-120	182*
120-125	88*
125-130	3

The number of strong chinooks per 100 years was:

No. Per 100 Yrs.	No. of Cells
70-100	42
100-150	69
150-175	127
175-200	234*
200-225	311*
225-250	117
250-275	69
275-300	104

The western boundary of the four-county area is adjacent to the continental divide. The influence of the mountains is evident in the higher precipitation classes, complexity of soil units, shorter growing seasons, and lower chinook frequencies found in the western portion of the area compared to the more uniform eastern plains.

The first analytical technique utilized was to prepare clear acetate maps of the four parameters and overlay them to see if any natural regions were evident. A trend observed in both this process and in subsequent computer overlays was that only a few parameters could be superimposed before the resulting composite map displayed only individual, relatively unique areas with no large homogeneous regions having all of these characteristics.

The next methodology employed was to overlay these four factors and locate areas which had soil, precipitation, growing season, and chinook characteristics which were representative of a condition which existed for much of the area. Expressed another way the object was to locate the station on land which had more in common with the rest of the agricultural area than any other location within the region.

Computer maps were generated of the most extensive units of each of the four parameters (indicated by asterisks on the previous lists). These maps show the distribution of these factors within the entire state and not just within the four-county area.

A composite map of the most extensive units of these parameters was manually prepared using acetate overlays. While the computer produced map would have shown essentially the same areas, viewers would not have been able to visualize how the map was produced. With manual overlays each factor is overlain one at a time with less extensive areas being "blackened out" leaving clear "windows" indicating possible areas on which to locate the station. As each map is overlain, the area suitable becomes less until all parameters have been examined. This process permits the viewer to better understand the methodology employed.

It will be noted from the computer summary of the average length of the frost-free season map that no intervals were clearly dominant, the frequency distribution of the classes were fairly uniform. For this reason the final composite map was constructed using only the other three parameters. When the intervals in the frost-free season map were superimposed on the composite of the other three, 20 subclasses were delineated. However, it was not clear how important the differences were between these subclasses. For this reason the composite map was based only upon soils, average annual precipitation, and frequency of chinook winds.

In mid-March of 1978 the writer was contacted by the superintendent of the new station. At this time the selection committee had narrowed their field of possible sites down to two parcels of land. The first was 1½ miles west of Brady (T26N R2W, NW¼ Sec. 4) while the other was approximately 9 miles north of Conrad immediately adjacent to the junction of Interstate 91 and Montana Highway 216 (T30N R3W, SE¼ Sec. 36). The soils on both sites were Scobey-Kevin complexes. A study of the two sites was requested to determine which of them was representative of more of the state's land.

Kevin is an Aridic Argiboroll, fine loamy, mixed while Scobey is an Aridic Argiboroll, fine, montmorillonitic. Since both have the same great group classification, Argiboroll, a map was made showing the location of those units which contain Argiborolls. As a test, this map was made by hand to determine the amount of time required (ca. 5 hrs.).

Weather records were next examined to determine the location of the nearest station to the two possible sites. While a weather observation station was listed for Brady AZNOE a check with Dr. J. M. Caprio, Agricultural Climatologist for the Montana Agricultural Experiment Station, disclosed that this site was 23 miles east-southeast of Brady. The station closest to the site north of Conrad was at the Conrad Airport. In both cases Dr. Caprio advised against using data from these observation stations since they were too far from the proposed sites to be reliable.

This paucity of climatic data resulted in the final site selection being made without knowledge of the extensiveness throughout the state of the composite characteristics found on the site of the new station.

Environments of Agricultural Research Centers in Montana

Montana currently has seven branch research centers throughout the state (Figure 10). These are the Southern Agricultural Research Center at Huntley, Eastern Agricultural Research Center at Sidney, Northern Agricultural Research Center at Havre, Northwestern Agricultural Research Center at Kalispell, Western Agricultural Research Center at Corvallis, and Field Research Laboratory, west of Bozeman.

The process of extrapolating research results from the field plots at these stations to other areas in the state has usually not been accomplished systematically or reliably. The reason for this is that those areas of the state with agricultural environments similar to those of the research centers had not been mapped. This seemed like a useful application for the computer graphic system.

The methodology employed was to examine the weather records and soils data for each station and then use the data bank to locate other areas with similar environments.

Weather observations are made and recorded daily at all research centers. With all the stations except Corvallis these data had been tabulated and averages generated (Caprio 1976). The following is a summary of those data:

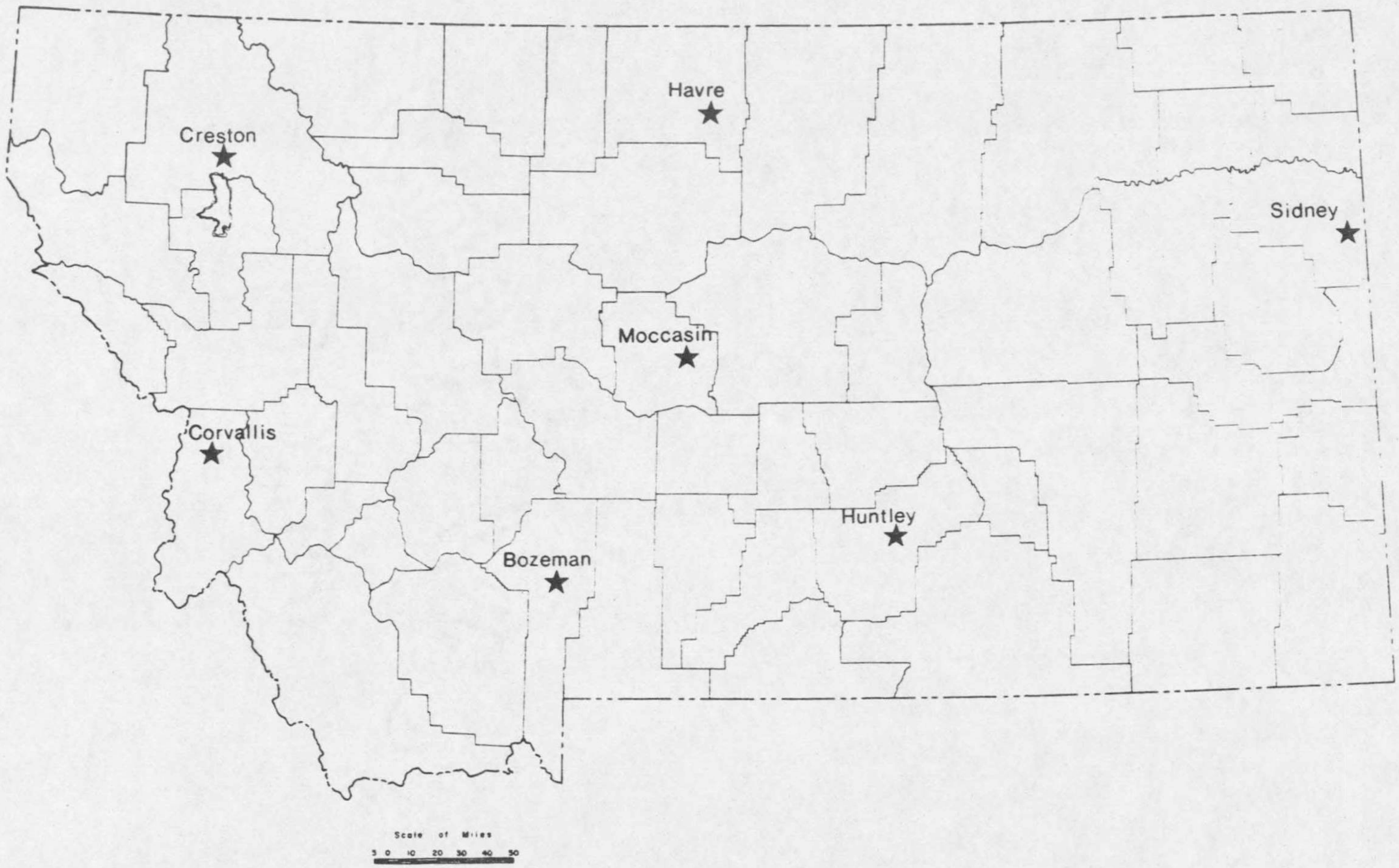


Figure 10. Location of agricultural research centers.

Research Center	Years of Record	Avg. Annual Precipitation	Avg. Length Frost-Free Season
Bozeman	1958-74	15.25	100
Kalispell	1949-76	19.01	108
Havre	1916-76	11.60	127
Huntley	1910-76	13.14	127 (1911-76)
Moccasin	1909-76	15.00	112
Sidney	1949-76	13.74	122

The Corvallis research center had climatological data from 1966-76 but averages for this period had not been generated. It was necessary to summarize the data to determine the average annual precipitation and average length of the frost-free season (Appendix III). These were found to be 10.8 inches (1966-76) and 106.5 days (1966-77), respectively.

To determine what soils were present at each center, detailed soil surveys were used where available. Five of the centers were covered by these surveys.

Research Center	Soil Survey of
Huntley	Yellowstone County (1972)
Moccasin	Judith Basin Area (1967)
Corvallis	Bitterroot Valley Area (1959)
Kalispell	Upper Flathead Valley Area (1960)
Bozeman	Gallatin Valley Area (1931)

Soil data on the Sidney and Havre centers were obtained from station records. While these data were not recent, they were the best available.

Summarized below are the dominant soils of each station and their great group classification:

Research Center	Series	Classification
Huntley	Lohmiller	Torrifluvents
	Fort Collins	Haplargids
	Thurlow	Haplargids
Moccasin	Danvers	Argiborolls
	Judith	Calciborolls
Creston	Flathead	Haploborolls
	Corvallis	Xerifluvent 1/
	Creston	Haploborolls
Corvallis	Burnt Fork	Argiboroll 1/
	Ravalli	Natrargid
	Riverside	Haploboroll
Havre	Attewan	Argiboroll
	Telstad	Argiboroll
	Joplin	Argiboroll
Sidney	Savage	Argiboroll
	Williams	Argiboroll
Bozeman	Bozeman 2/ or	(Argiborolls)
	Amsterdam 2/	(Haploborolls)

1/ Unclassified soils; these were the State Soils Correlator's best estimate.

2/ At present there is some disagreement as to whether these soils have a cryic or frigid soil temperature regime. The Argiborolls and Haploborolls used to characterize the center reflect the belief that frigid conditions exist and the original classification was incorrect.

After identifying the soil, precipitation, and growing season characteristics for each research center, it was necessary to select the appropriate intervals or classes of each parameter as they were stored in the computer. The task was to select the ranges of these characteristics which would identify those lands that have agricultural environments which are similar but not identical to those of the research centers and would thus respond to management in a similar fashion.

The ranges selected for this analysis were identified in a very subjective manner. Table 1 shows the site characteristics and the ranges used to characterize those conditions.

The following lists indicate the mapping units found on the new state soils map which contain some soils with the indicated great group classification. Appendix I should be consulted to determine the characteristics of these units.

Bozeman (Argiborolls and Haploborolls): AV4, AV5, GB1, GB2, GB3, GB4, GB5, GF1, GF2, GF3, GF4, GF5, GG1, GG2, HF1, HF2, HF3, HF4, JB, JF, KB2, KB3, KF MO4, MO6, AP4, AP5, AP6, AP7, NB1, NB2, NP1, NP2, NP3, NP4, NP5, NP6, NP7, NP8, NH1, NH2, NH3, NH6, NH7, OG1, OG2, OG3, OG4, OH, OT, PB1, PB3, PP1, PP2, PH1, SG1, SG2, SG3, ST, TB1, TP1, UG1, VB1, VB2, VH2.

Corvallis (Argiboroll, Haploboroll, Natrargid): Same as Bozeman plus CT2, KT, AP3, SG2, SG3, SH, TB2, TP5, TH6, UG2, VB3, VB4, VB5, VH1.

Creston (Haploborolls and Xerifluvents): Haploborolls--AV4, AV5, GB1, GB2, GF2, GF3, GF4, GF5, GG1, GG2, HF1, HF2, HF3, HF4, MO4, AP6, AP7, NB2, NP3, NP4, NP5, NP6, NP8, NH1, NH2, NH3, NH6, NH7, OT, PB3, PP1, SG1, ST, TB1, TP1. Xerifluvent--AV2.

Table 1. Site characteristics and ranges used to characterize these conditions.

Station	Soils	Avg. annual precipitation (in inches)		Avg. length frost-free season (in days)	
		Map interval	Site data	Map interval	Site data
Bozeman	Argiborolls	14-16	15.25	90-100	100
	Haploborolls	16-18		100-110	
Huntley	Torrifluvent	12-14	13.14	120-125	127
	Haplargid			125-130	
Moccasin	Argiborolls	14-16	15.00	100-110	112
	Calciborolls			110-115	
Havre	Argiborolls	10-12	11.60	120-125	127
		12-14		125-130	
Sidney	Argiborolls	12-14	13.74	115-120	122
		14-16		120-125	
				125-130	
Creston	Haploborolls	16-18	19.00	100-110	108
	Xerifluvent	18-20		110-115	
Corvallis	Haploborolls	10-12	10.80	100-110	107
	Natrargids	12-14		110-115	
	Argiboroll				

Moccasin: Argiborolls--AV4, AV5, GB1, GB2, GB3, GB4, GF1, GF2, GG1, HF1, HF3, JB, JF, KB2, KB3, KF, MO6, AP4, AP5, AP7, NB1, NP1, NP2, NP3, NP5, NP7, OG1, OG2, OG3, OG4. Calciborolls--GB5, GB6, GF3, GG2, NP4, NH1, NH2, NH3, PB2.

Havre: Argiborolls--AV4, AV5, GB1, GB2, GB3, GB4, GB5, GF1, GF2, GG1, GG2, HF1, HF3, JB, JF, KB2, KB3, KF, MO6, AP4, AP5, AP7, NB1, NP1, NP2, NP3, NP5, NP7, NH1, NH2, NH3, OG1, OG2, OG3, OG4, OH, OT, PB1, PB3, PP1, PP2, PH1, SG1, SG2, SG3, ST, TB1, TP1, UG1, VB1, VB2.

Huntley: Torrifluvent--AP1, AP2, AP3, PH2, VB5. Haplargid--JF, KB2, PP2, TB1, TB2, TP5, TH7.

Sidney: Same units as Havre.

Based upon this data it would seem that some of the centers such as Sidney and Havre have similar soils. However, this is at the generalized great group level of the classification. At the family or series level these soils and their management characteristics may be quite different. If detailed data for these lower categories are added to the system this weakness will be overcome.

Plotter-drawn maps were produced for each of the seven research centers showing the portions of Montana which have soil, average annual precipitation, and length of frost-free season conditions which are similar to those of each station.

Soil Temperature Research

The Montana Computer Graphic System was used in conjunction with a soil temperature model developed by L. C. Munn (1977). Using the elevation file and the latitude of the state, Munn utilized his model to produce maps showing cryic and frigid soil temperature regimes. These data were generated because of their importance in classifying the soils of the state. As defined by Soil Taxonomy (1976) these regimes have the following definitions:

Cryic - These soils have a mean annual temperature higher than 0°C (32°F) but lower than 8°C (47°F)

Frigid - These soils are warmer in summer than those in the cryic regime but its mean annual temperature is lower than 8°C (47°F) and the difference between mean winter and mean summer soil temperature is more than 5°C (9°F)

Plotter maps for north and south aspects and 45 percent slopes were produced by Munn.

Growing Season Precipitation Studies

At present, a published map of growing season precipitation does not exist for Montana. A new map of average annual precipitation was published by the Snow Survey Unit of the Soil Conservation Service in 1977. Dr. J. M. Caprio, Agricultural Climatologist for the Montana Agricultural Experiment Station, has compiled maps showing the percent of the annual precipitation that falls from April 1 through July 31 and May 1 through July 31. These were encoded and stored in the computer.

To aid Dr. Caprio in the preparation of a map of growing season precipitation, the data in each cell of the average annual precipitation file were multipled by the percentage value for each of the two periods (April-July and May-July). This resulted in two new files being created for the actual average amounts of precipitation which falls during these two periods. Plotter-drawn maps were generated for these two new parameters.

Delineation of Sodic Claypan Soils

A plotter-drawn map was produced to delineate those units of the new state soils map which contain Natrargids, Natrixerolls, or Natriborolls. These soils in their present condition require special management practice and it is important to identify the location of these soils.

This map displays the following soil mapping units: CT2, DT2, FG, KT, AP3, NP8, SG2, SG3, SH, TB2, TP5, TH6, UG1, UG2, VB3, VB4, VB5, and VH1.

Areas Where Summer Fallow May Not Be Recommended

Some areas of the state will not benefit from summer fallowing since the soils cannot store enough water to justify the practice. In addition, some areas receive sufficient moisture for annual cropping and summer fallowing for moisture conservation may not be necessary.

During the March 1978 Planning Conference held at Montana State University, researchers from the Plant and Soil Science Department and the Science and Education Administration, United States Department of Agriculture made the decision to identify those portions of Montana where summer fallowing may not be recommended for moisture conservation. The judgment was made that those agricultural areas which receive more than 14 inches of annual precipitation have sufficient moisture for recropping.

To identify these areas it was necessary to first delineate the mountain soils since some of these receive more than 14 inches of annual precipitation and yet are not suited for agriculture. The mountain soil units were: Et, Lt, Lg, Ma, Me, Mf, Mo, R. These areas were blackened out on the precipitation map, as were those lands receiving less than 14 inches of average annual precipitation. The clear area remaining on the map identified the agricultural areas of the state which receive more than 14 inches of average annual precipitation, which is sufficient for recropping.

The state office of the Soil Conservation Service was contacted to assist in the identification of those units of the new state soils map which contained series with a low water-holding capacity. The following units were selected: OT, PB2, PP1, PP2, GB6, NB2, NP9,

NP2, NP4, NH5, NH1, NH3, JB, KB1, KB4, HF4, TP4, TH8, TH5, TH3, GB2, GF5, GF3. These units were left as clear windows.

The windows from both the precipitation and soil maps were combined into a final hand-drawn composite map.

RESULTS AND DISCUSSION

The Montana Computer Graphic System (MCGS) was developed, tested, and found to have great potential as a research aid and as a device to communicate agricultural findings to the public.

The following sections discuss the MCGS and how it compares with larger systems, the costs associated with it, the importance of the new state soils map and Soil Taxonomy, the maps produced in this study, and the effectiveness of computer drawn maps.

Comparison of the Montana Computer Graphic System with Larger Systems

The research conducted for this thesis produced a geographic information system, the Montana Computer Graphic System. While it has many similarities to the systems described earlier, there are many ways in which MCGS is different.

Most of the Montana Computer Graphic System was developed by six people working on the project part time for one year. As expected from this information, the costs of constructing the data bank were relatively low.

By comparison, the Land Use and Natural Resources Inventory (LUNR) discussed earlier was developed with a full-time staff of 50 personnel. Similarly, the Minnesota Land Information System has had an average annual budget of $160,000.

With a smaller staff and less financial resources, the Montana Computer Graphic System does not have many of the advanced capabilities of these larger, more expensive systems. However, while many of these contain more detailed resource data and can perform sophisticated computations they are still usually hampered by a lack of available data. Thus, these systems can process large amounts of resource information when it is available but, as previously discussed, much of the country is still lacking detailed resource data.

If creation of a statewide geographic information system is the objective, the Montana Computer Graphic System which contains generalized long-term average data can be useful in visualizing and evaluating the land resources of the state. One of the positive aspects of the MCGS is that since the type of data it contains only requires infrequent updating and no full-time personnel to maintain the system, its cost to the Montana Agricultural Experiment Station is minimal.

A user's manual has been prepared for the Montana Computer Graphic System. A copy of it has been included in Appendix I. This document summarizes the most important aspects of the system. It includes descriptions of the data it contains as well as how to add more data or retrieve file information for a simple or composite analysis.

Costs of Computer Produced Maps

The following are some average costs for processing a map for computer storage and retrieval. Depending upon the complexity of the data being digitized the costs will vary accordingly.

Process	Cost
Plotter Paper	$ .22/foot
Encoding by work study students:	
12½ hrs/team or 25 man hrs.	
@ $2.30/hr	57.50
Keypunching & Verification:	
4 hrs @ $2.50/hr.	10.00
Plotter to produce map:	
Daytime processing	17.67
Night processing	4.41
Approx. Average Total Costs:	
Daytime	85.73
Nighttime	72.47

Importance of New State Soils Map and Soil Taxonomy

A new state soils map (1978) at 1:1,000,000 Albers Equal Area projection was developed concurrently with this project by Dr. G. H. Simonson and others of the Montana Agricultural Experiment Station with the cooperation of the Soil Conservation Service and the Forest Service.

This was the first state soils map for Montana which utilized the new Soil Taxonomy. This new method of soil classification defines very precisely the characteristics that a soil must have for a particular level of the taxonomy. It is a distinct improvement over the vague and often ambiguous terminology employed in the previous classification system.

The utility of the computer graphic system was greatly enhanced by the addition of the new state soils map based upon Soil Taxonomy.

Products of the System

The maps included in this section are photographically reduced versions of the original 1:1,000,000 plotter-drawn maps. These maps were redrafted and photo-reduced to meet thesis requirements.

Establishment of New Branch Research Center

On October 13, 1977 at a joint meeting in Conrad of the Experiment Station Advisory Committee and Agricultural Experiment Station personnel, several plotter- and hand-drawn maps were presented. Figures 11-14 display the distribution throughout the state of the most extensive units of soils, average annual precipitation, and chinook conditions found within the area. This was to increase public awareness of where else in the state these major units occur.

A series of overlays was used to delineate those portions of the area which had soil, precipitation, and chinook conditions which were representative of extensive portions of the four counties. Figures 15-17 display these distributions with the shaded areas being comprised of less extensive units and the clear or "window" portion showing possible site locations. Figure 18 is a composite of the three maps with the window being the recommended area for more detailed investigations.

The conditions within the window are not uniform since it is a composite of three soil mapping units, two precipitation intervals,