



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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LAND QUALITIES AND POTENTIALS

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A thesis submitted in partial fulfillment
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in

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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.

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

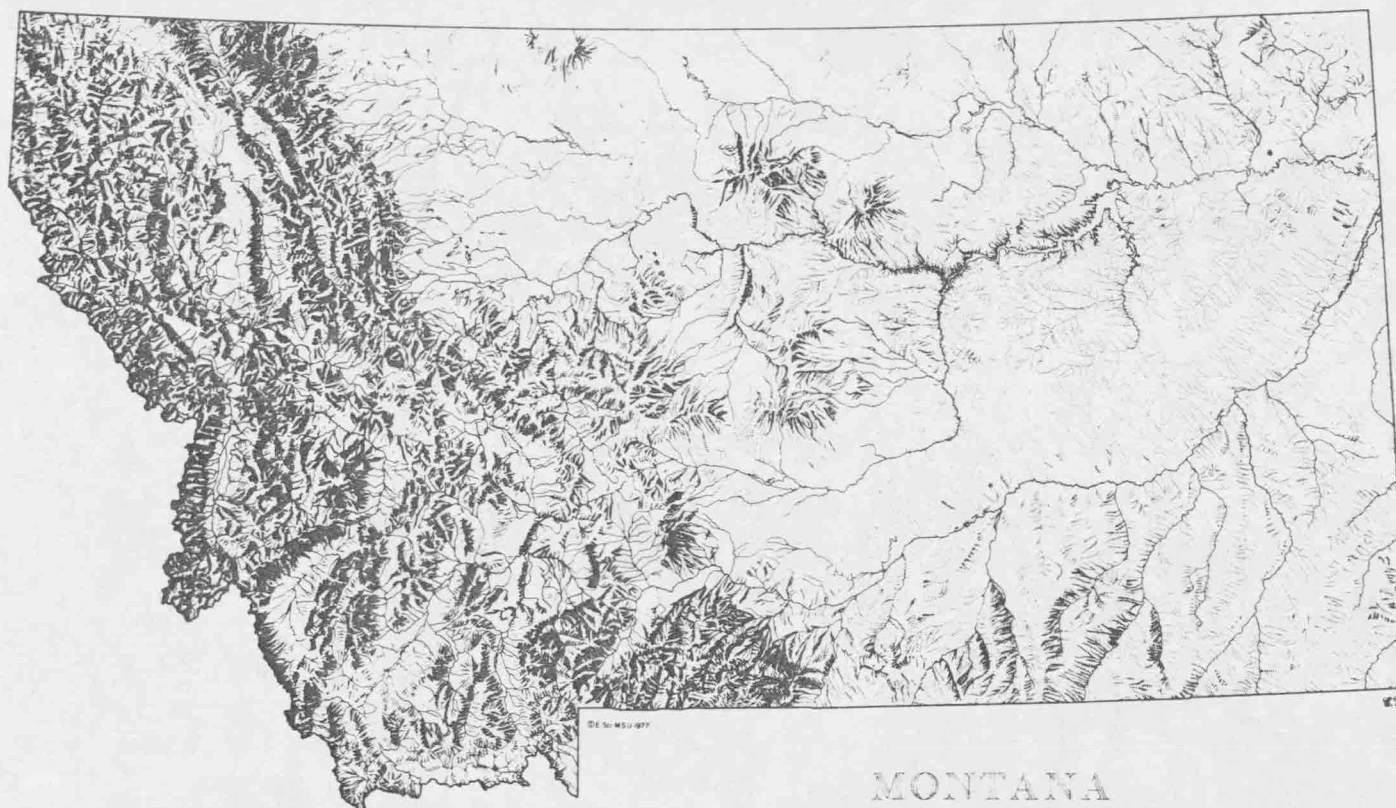


Figure 1. Physiographic diagram.

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-

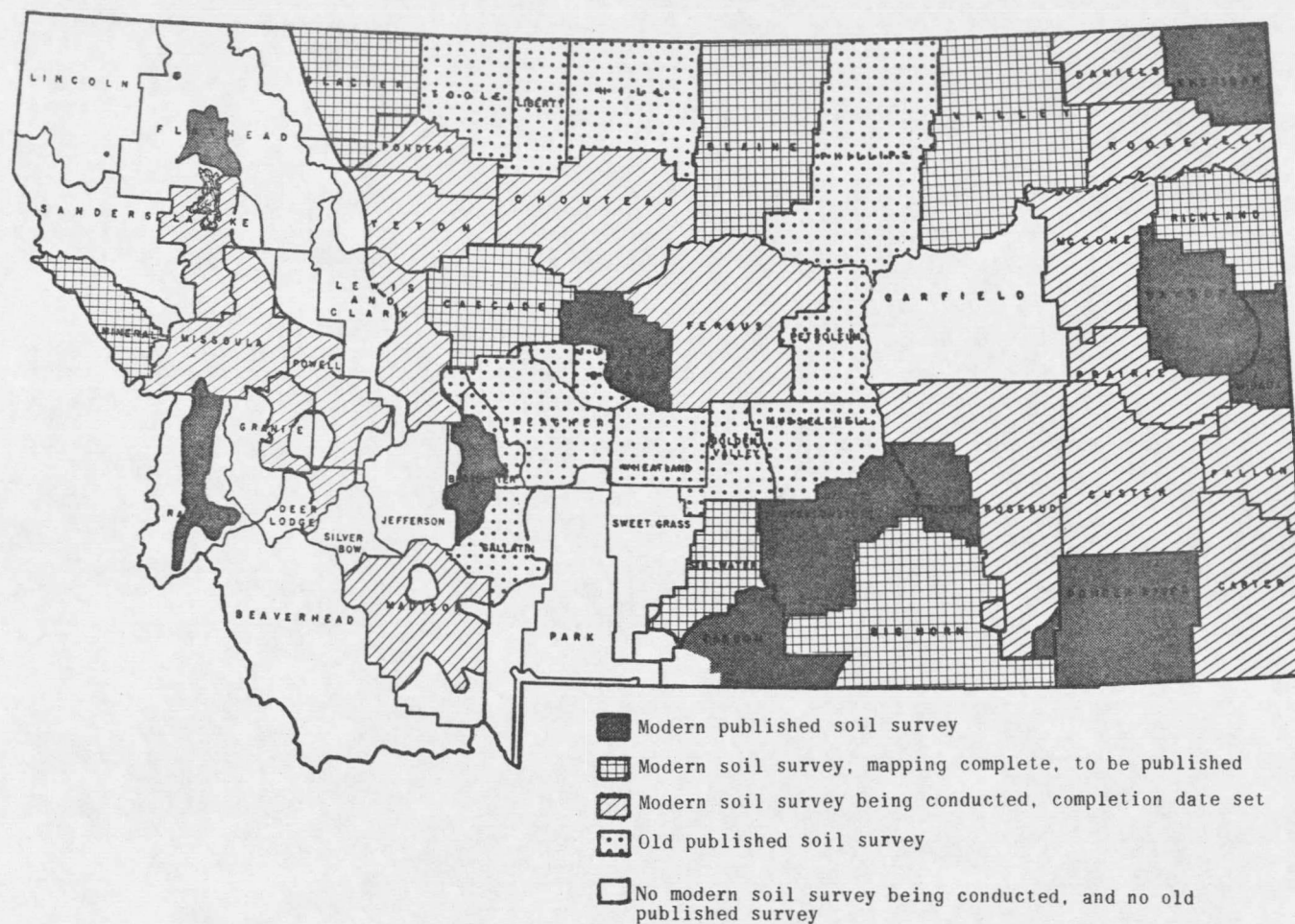


Figure 2. Soil survey areas (as of September 1977).

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 devices 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 inter-character 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 $1\frac{1}{4}$ 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 state-wide 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 $29\frac{1}{2}^{\circ}\text{N}$ and $45\frac{1}{2}^{\circ}\text{N}$ 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:

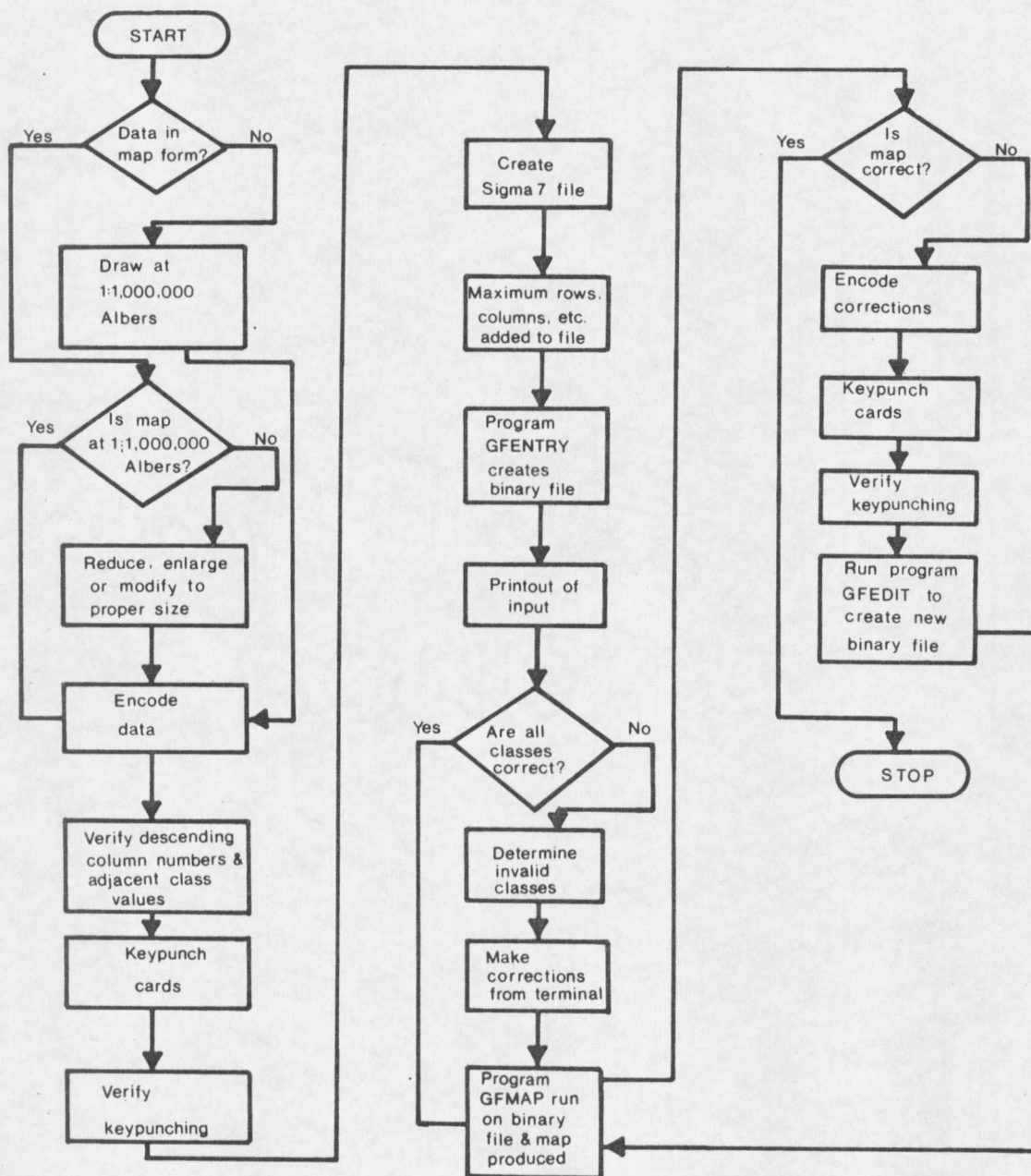


Figure 3. Flow chart of data processing.

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

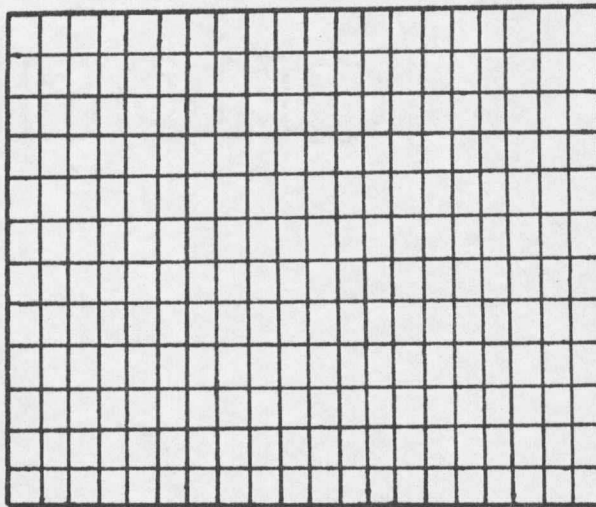


Figure 4. Portion of plotter-drawn grid.

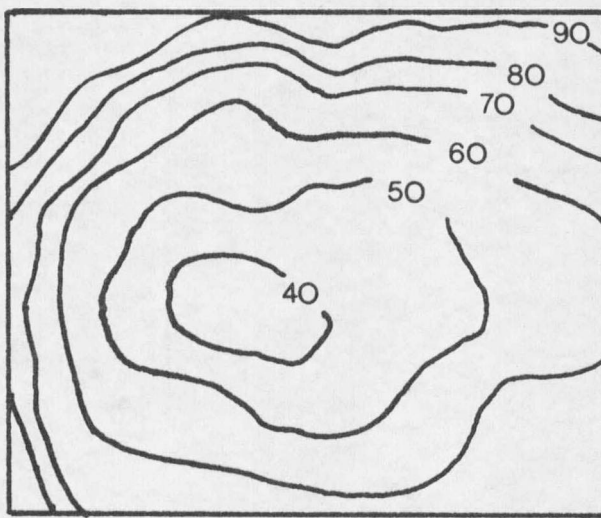


Figure 5. Portion of resource map to be encoded.

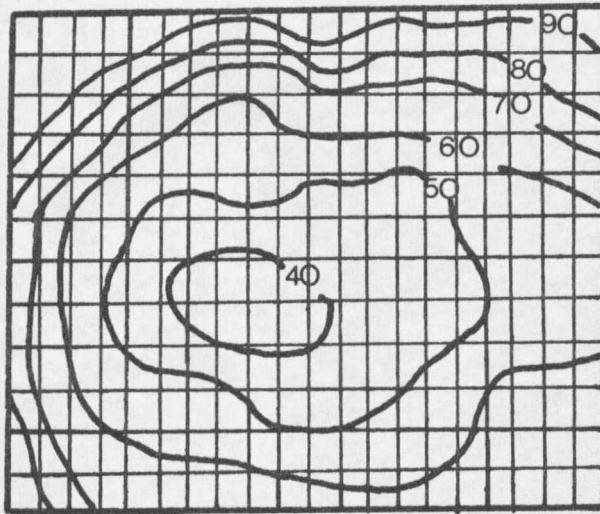


Figure 6. Grid superimposed on resource data.

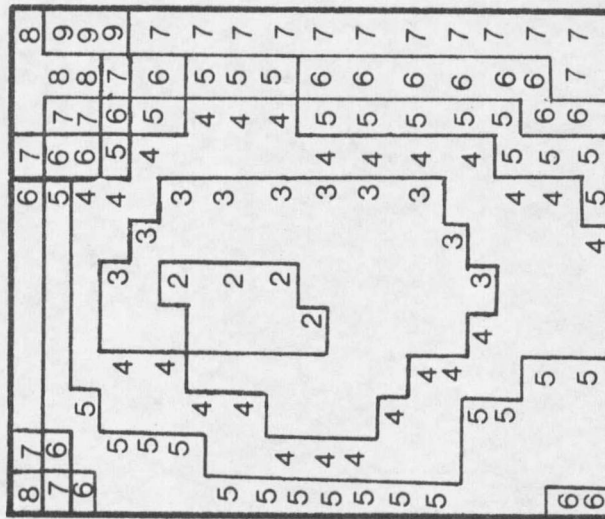


Figure 7. Final plotter map.

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 $\frac{1}{4}$ " 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.

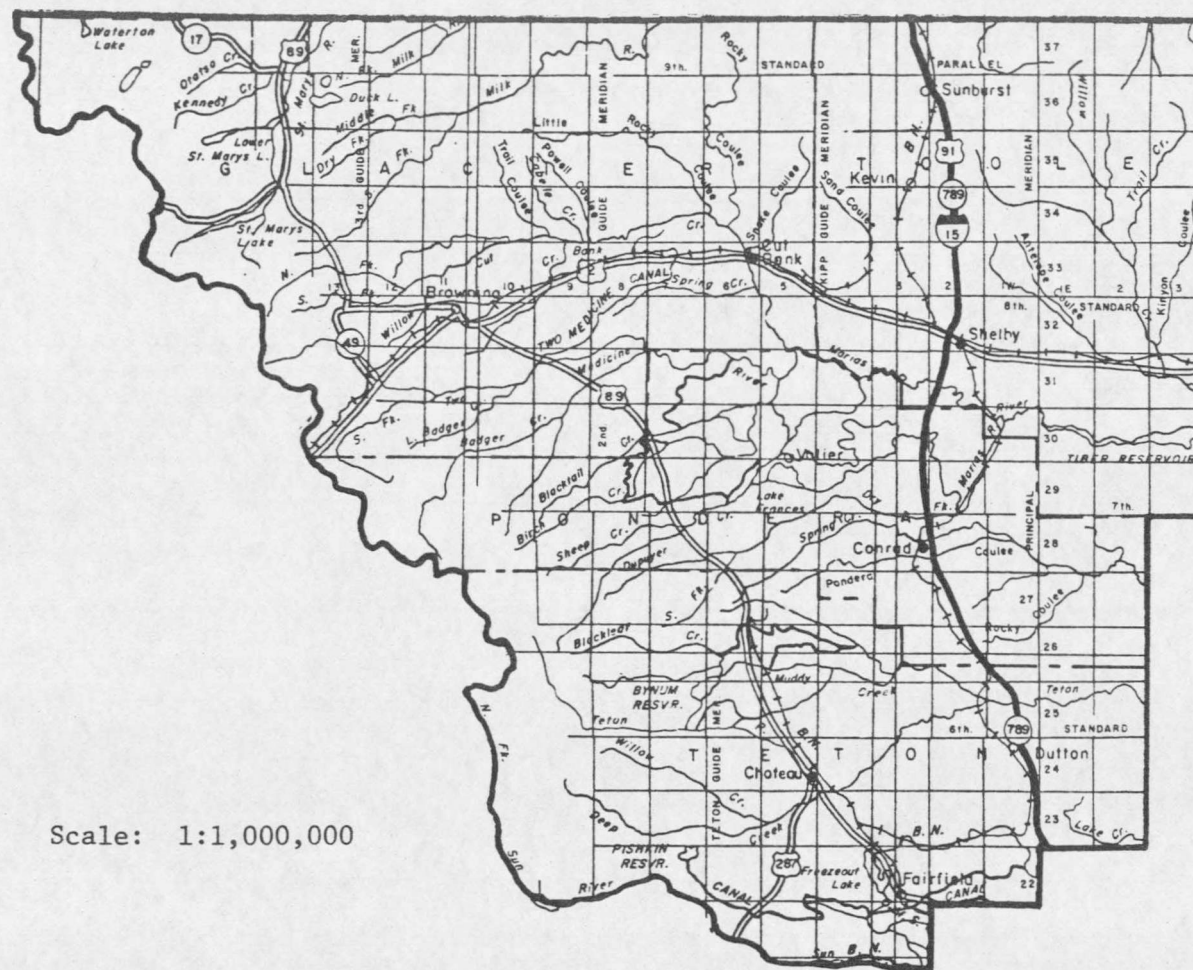


Figure 9. Larger scale view of study area.*

*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.

<u>Soil Unit</u>	<u>No. of Cells</u>	<u>Soil Unit</u>	<u>No. of Cells</u>
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:

<u>Precipitation (in.)</u>	<u>No. of Cells</u>
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:

<u>No. of Days</u>	<u>No. of Cells</u>
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:

<u>No. Per 100 Yrs.</u>	<u>No. of Cells</u>
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 $1\frac{1}{2}$ miles west of Brady (T26N R2W, NW $\frac{1}{4}$ 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, SE $\frac{1}{4}$ 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.

<u>Research Center</u>	<u>Years of Record</u>	<u>Avg. Annual Precipitation</u>	<u>Avg. Length Frost-Free Season</u>
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.

<u>Research Center</u>	<u>Soil Survey of</u>
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:

<u>Research Center</u>	<u>Series</u>	<u>Classification</u>
Huntley	Lohmiller	Torrifluvents
	Fort Collins	Haplargids
	Thurlo	Haplargids
Moccasin	Danvers	Argiborolls
	Judith	Calciborolls
Creston	Flathead	Haploborolls
	Corvallis	Xerifluent <u>1/</u>
	Creston	Haploborolls
Corvallis	Burnt Fork	Argiboroll <u>1/</u>
	Ravalli	Natrargid
	Riverside	Haploboroll
Havre	Attewan	Argiboroll
	Telstad	Argiboroll
	Joplin	Argiboroll
Sidney	Savage	Argiboroll
	Williams	Argiboroll
Bozeman	Bozeman <u>2/</u> or	(Argiborolls)
	Amsterdam <u>2/</u>	(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	Torrifluent	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
	Xerifluent	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 multiplied 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 Sodid 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.

<u>Process</u>	<u>Cost</u>
Plotter Paper	\$.22/foot
Encoding by work study students: 12½ hrs/team or 25 man hrs. @ \$2.30/hr	57.50
Key punching & 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,

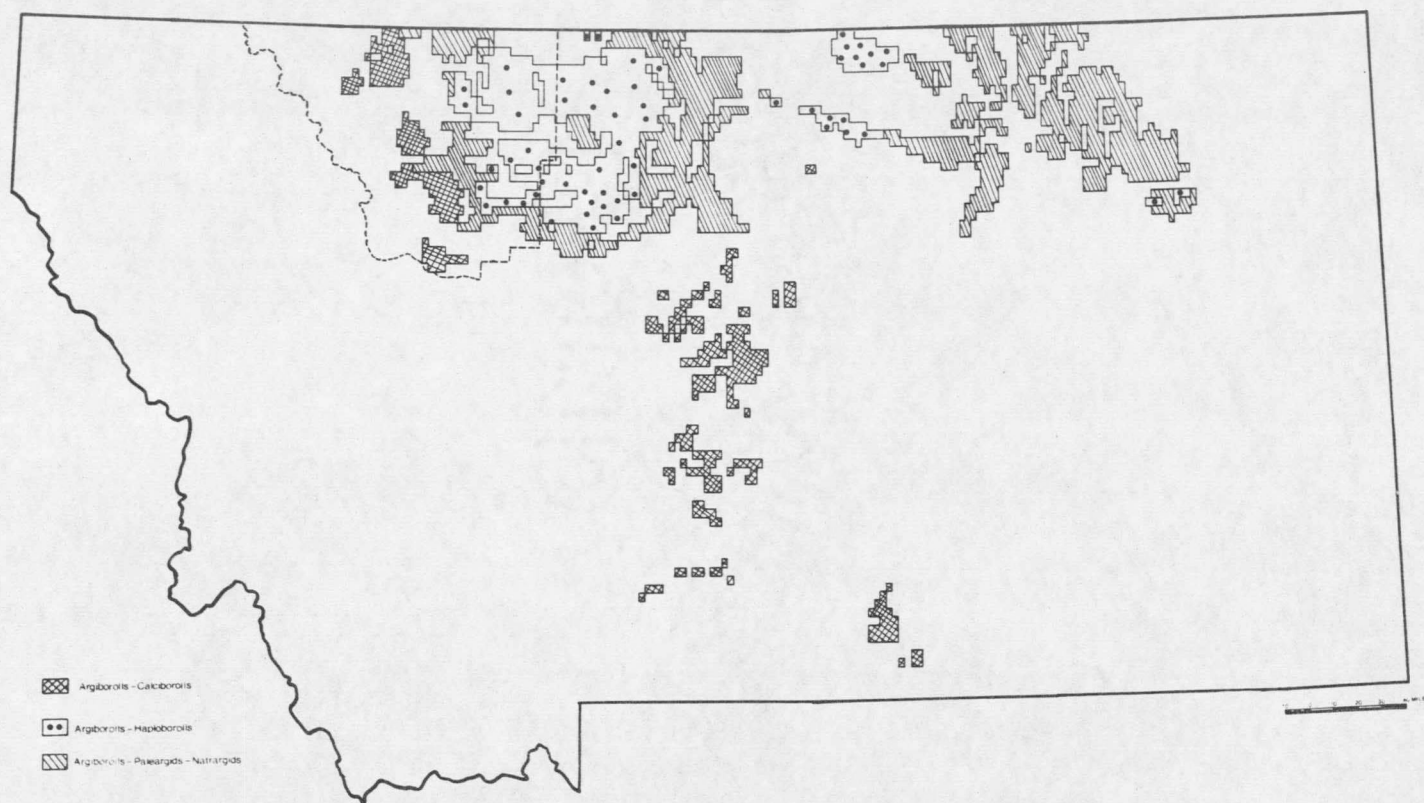


Figure 11. Distribution throughout the state of the most extensive soils of the western Triangle area.

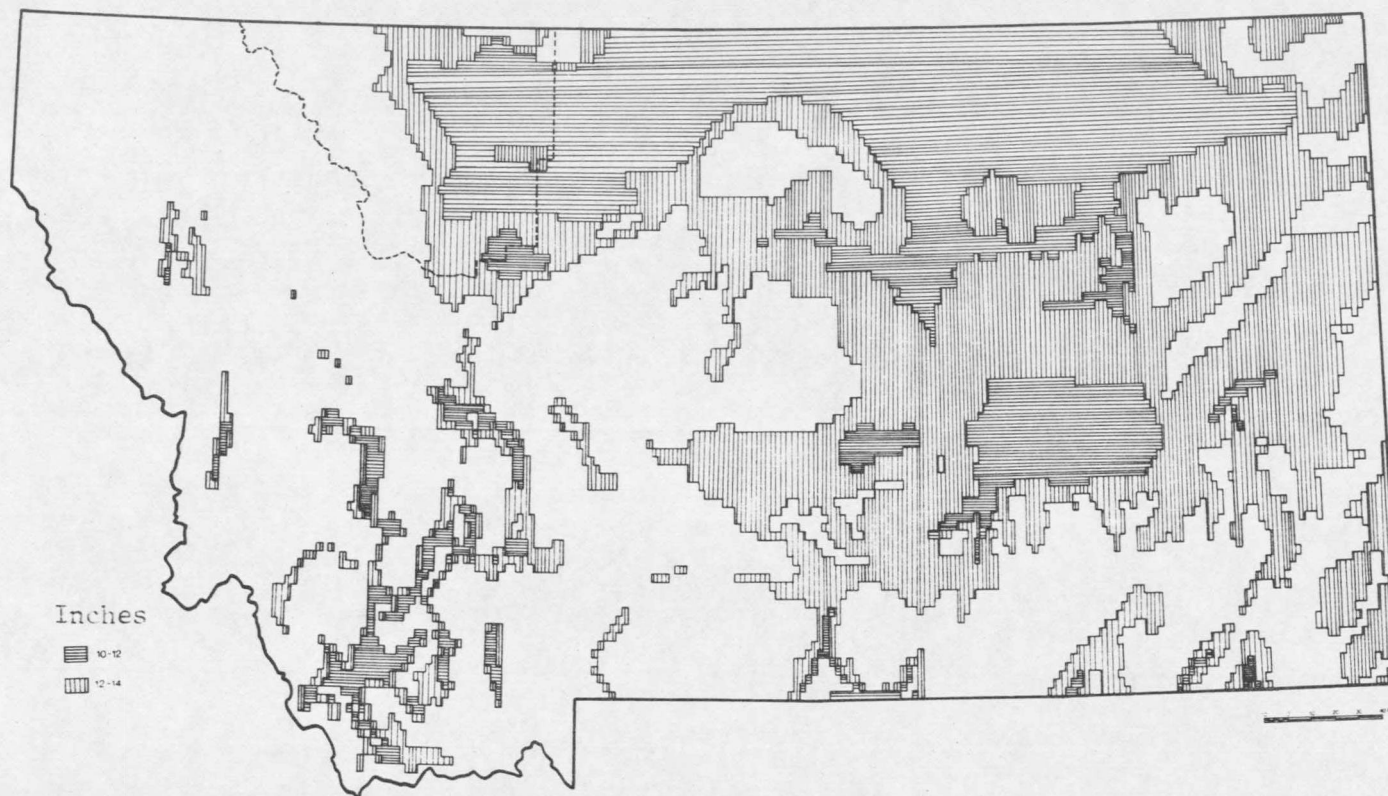


Figure 12. Distribution throughout the state of the most extensive precipitation conditions of the western Triangle area.

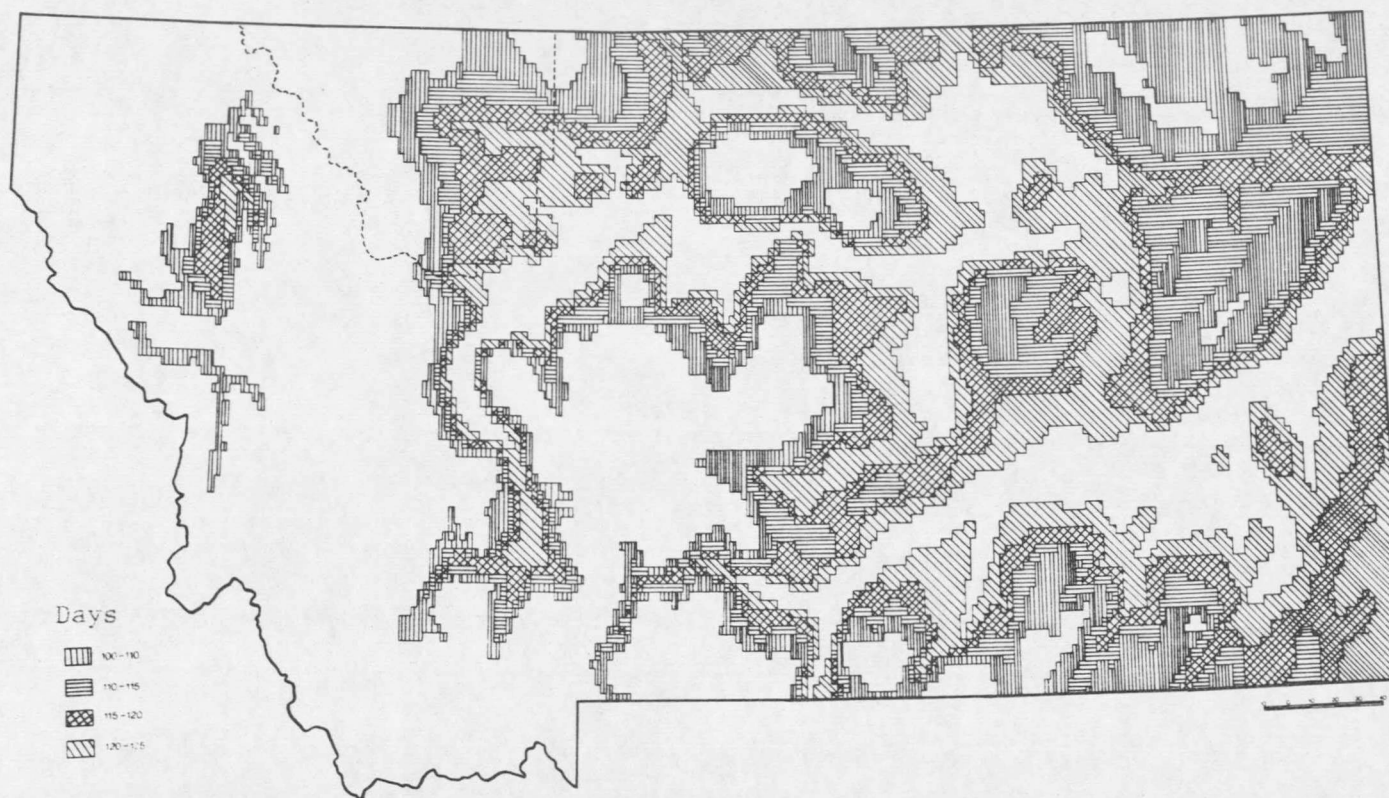


Figure 13. Distribution throughout the state of the most extensive growing season lengths of the western Triangle area.



1/ Number of strong chinooks per 100 years.

Figure 14. Distribution throughout the state of the most extensive chinook conditions of the western Triangle area.

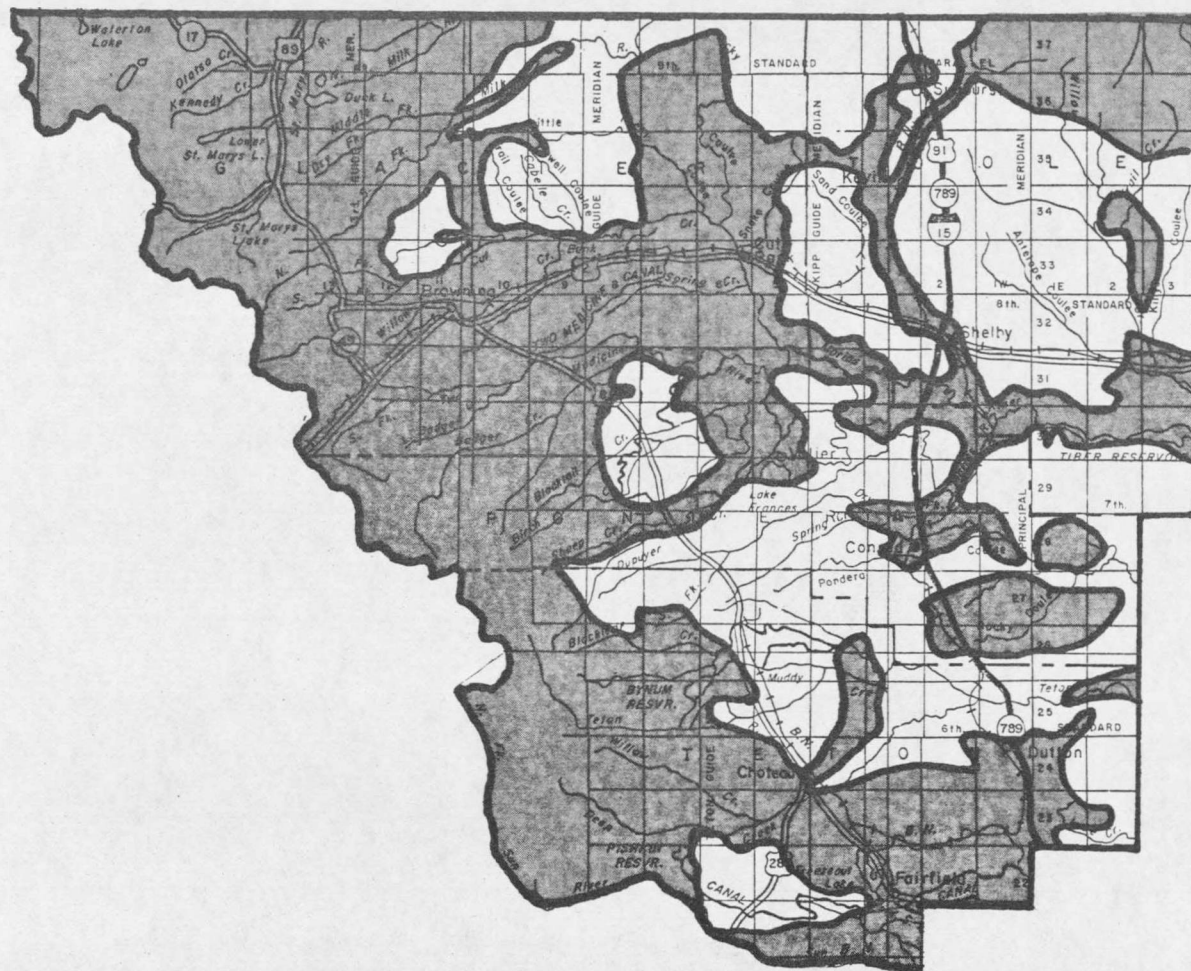


Figure 15. Extensive soils of the western Triangle area.

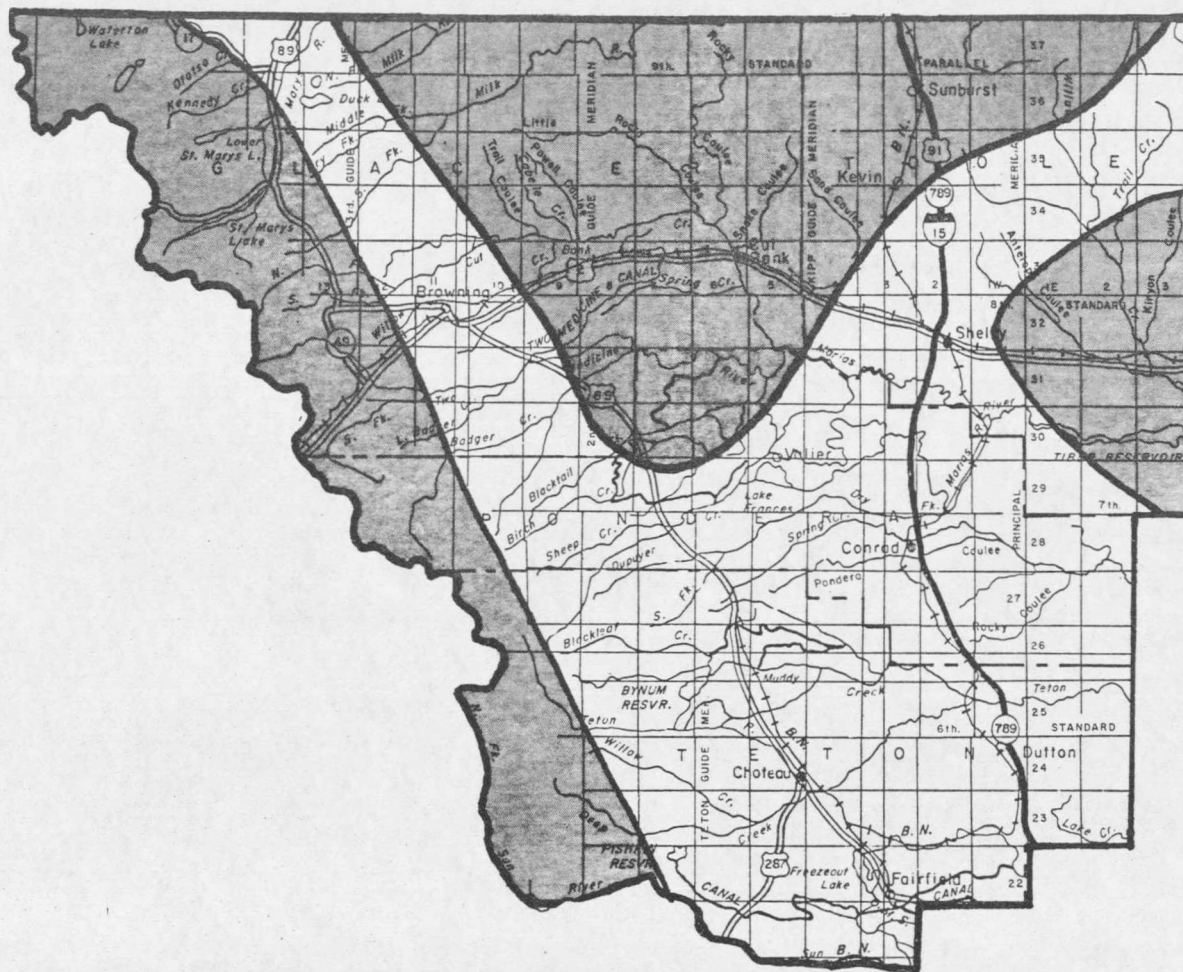


Figure 16. Extensive precipitation conditions of the western Triangle area.

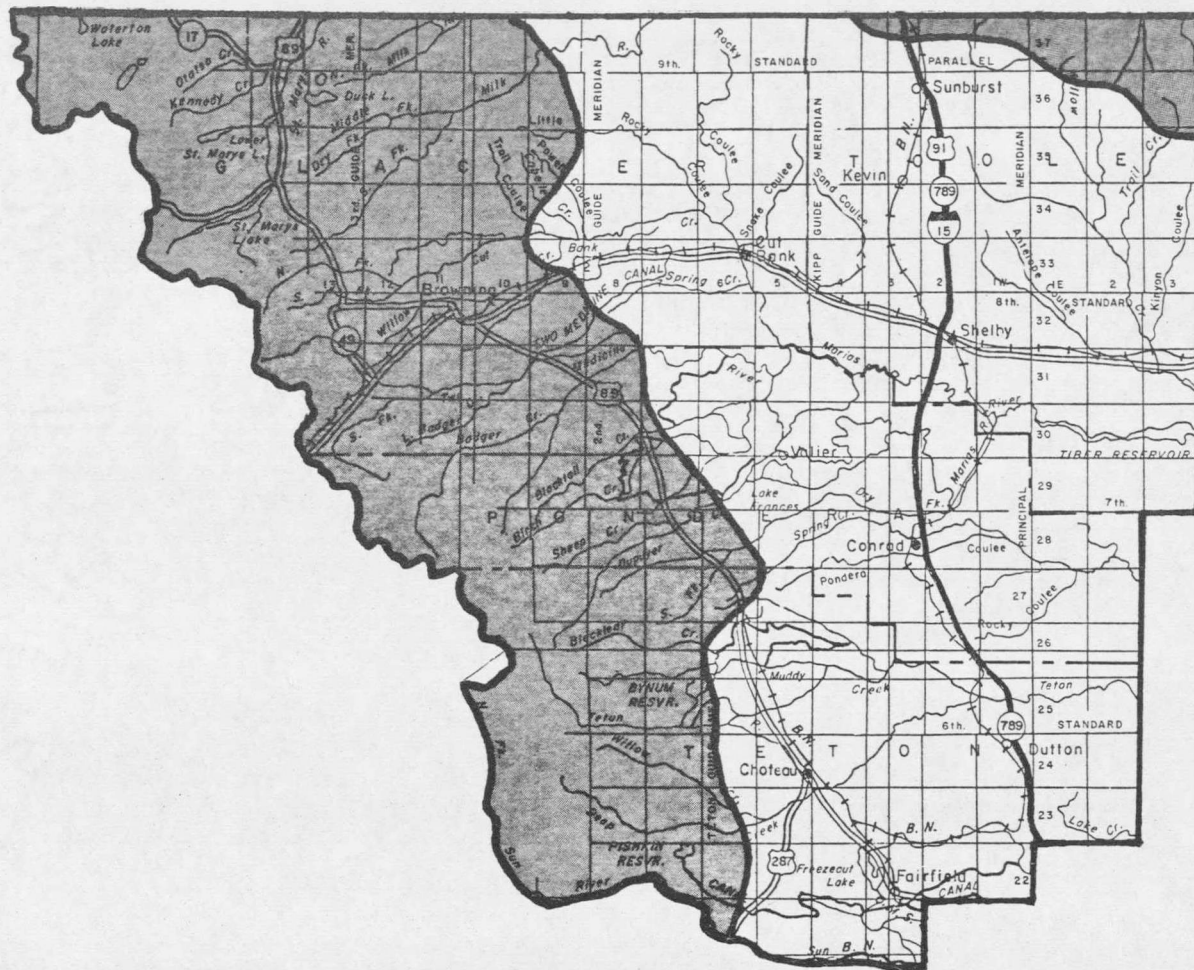


Figure 17. Extensive chinook conditions of the western Triangle area.

and two chinook frequency classes. Any portion of the unshaded area is, however, composed of extensive units of all three factors.

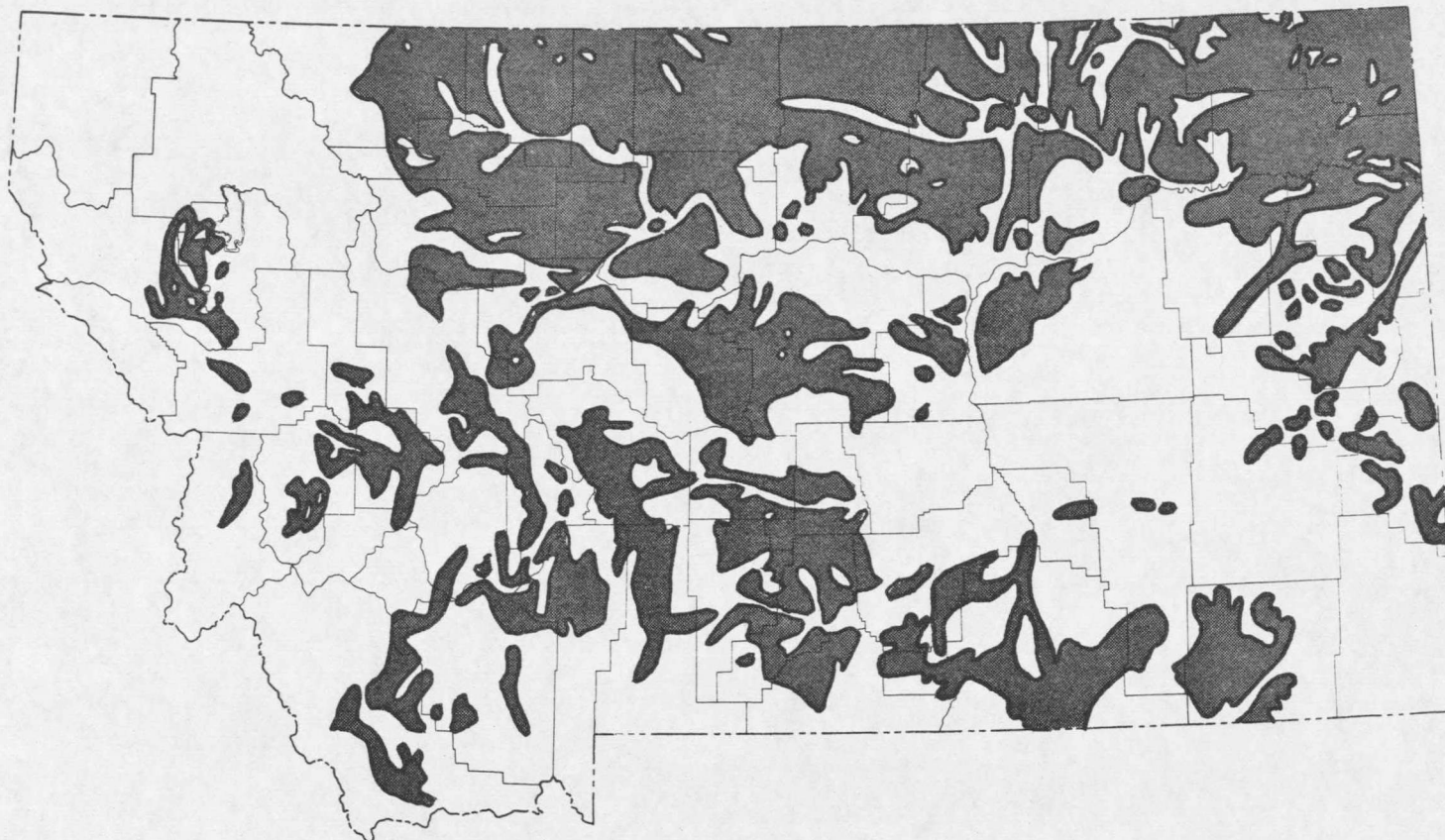
These maps were influential in the decision to locate land within a 10-mile radius of Conrad as a site for the research center (Prairie Star 1977). The objective was to locate 40 acres of irrigated and 80 acres of dryland preferably together.

Figure 19 was prepared for the new superintendent of the soon to be established station and shows the distribution of Argiborolls throughout the state. These cool soils with dark surfaces and subsoil accumulation of clay were present at both of the final sites considered as locations for the new center. The map indicates that soils classified at this great group level are very extensive throughout the state and would be suitable for the new station if the family and series criteria were favorable.

Environments of Agricultural Research Centers in Montana

Figures 20-26 show the lands with agricultural environments similar to those of the seven research centers.

Only two of the maps, Bozeman (Figure 20) and Moccasin (Figure 21) had patterns which were strikingly similar. Corvallis (Figure 26) was a surprise in that a large area in the northeastern part of the state has similar characteristics. Since these conditions only exist on a small parcel of land surrounding the center, cells are not displayed for that location.



Scale of Miles
0 10 20 30 40 50

Figure 19. Distribution of Argiborolls (shaded areas).

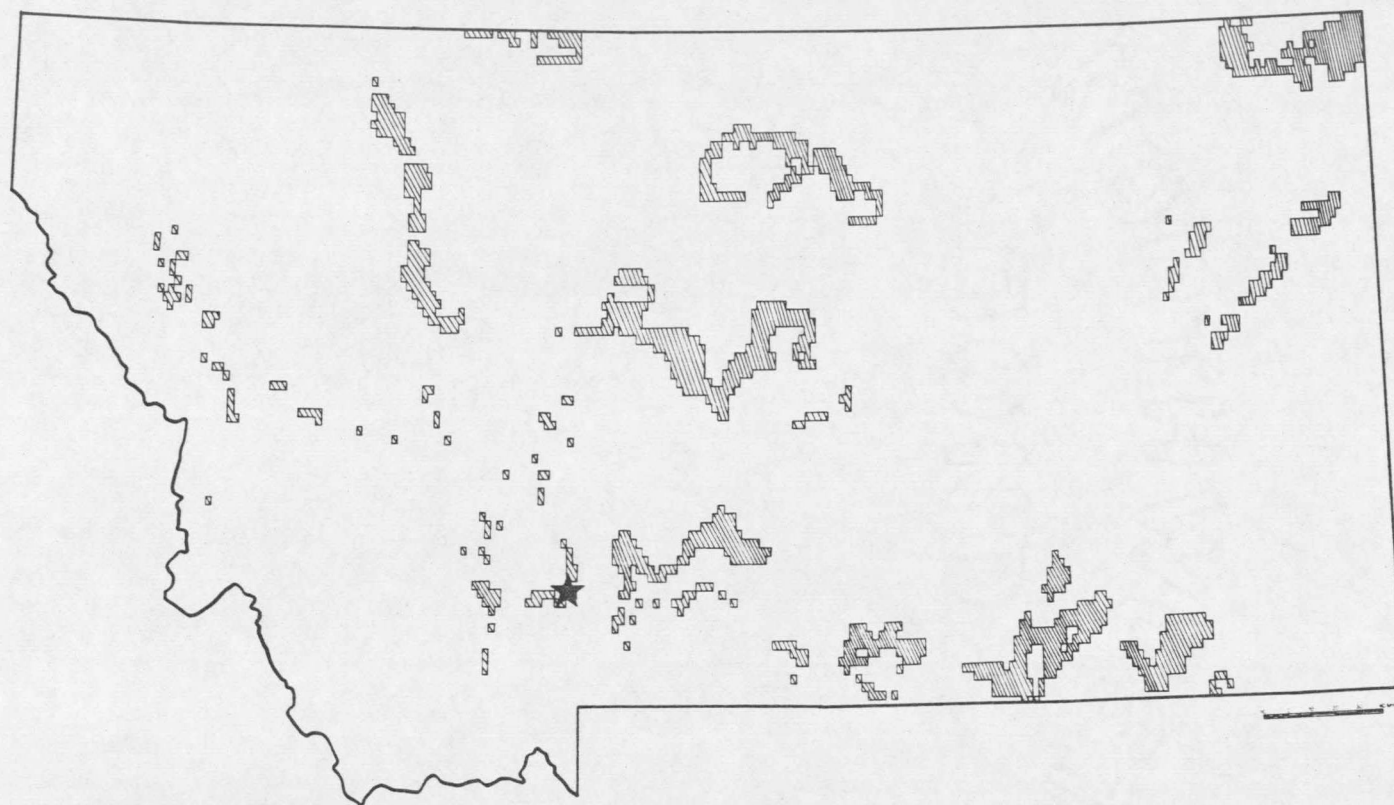


Figure 20. Agricultural environments similar to the Bozeman center.

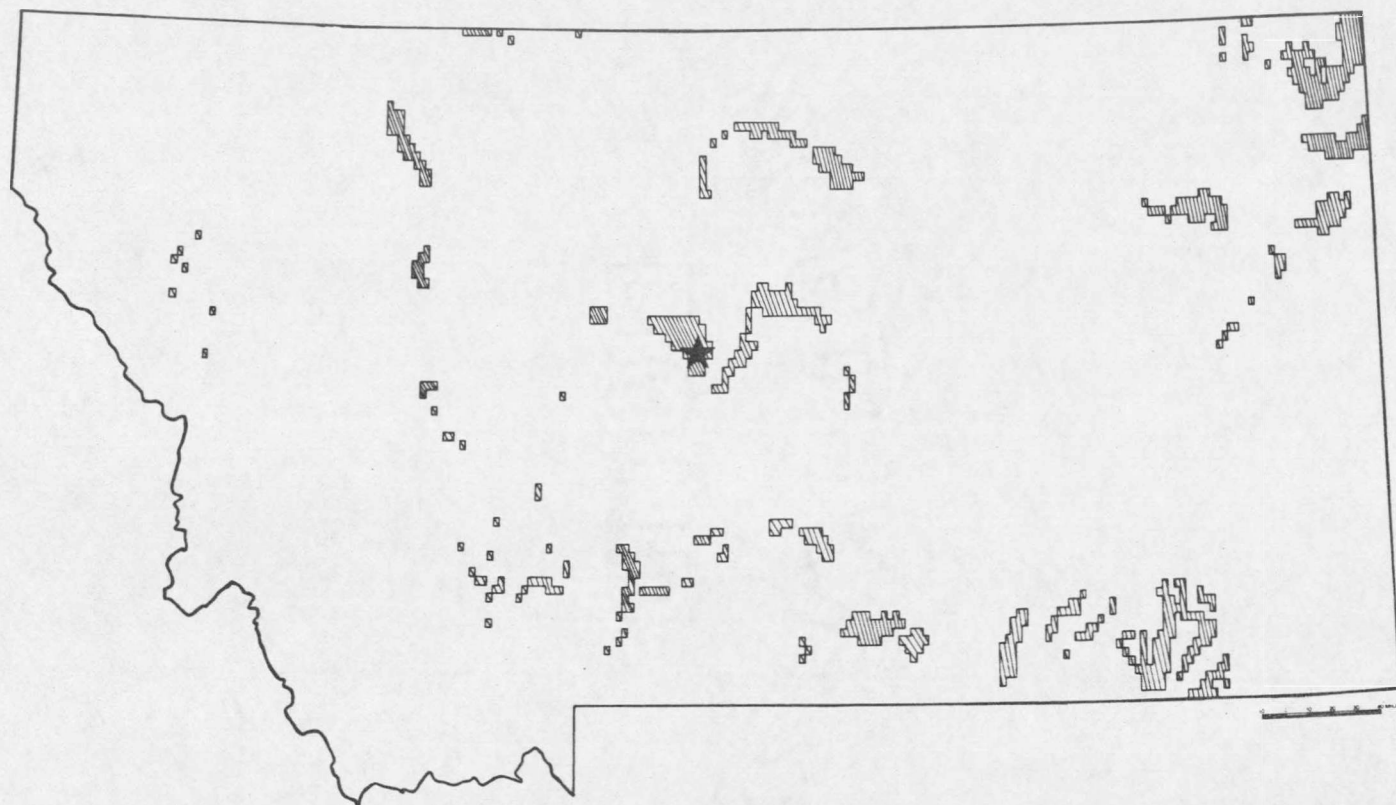


Figure 21. Agricultural environments similar to the Moccasin center.

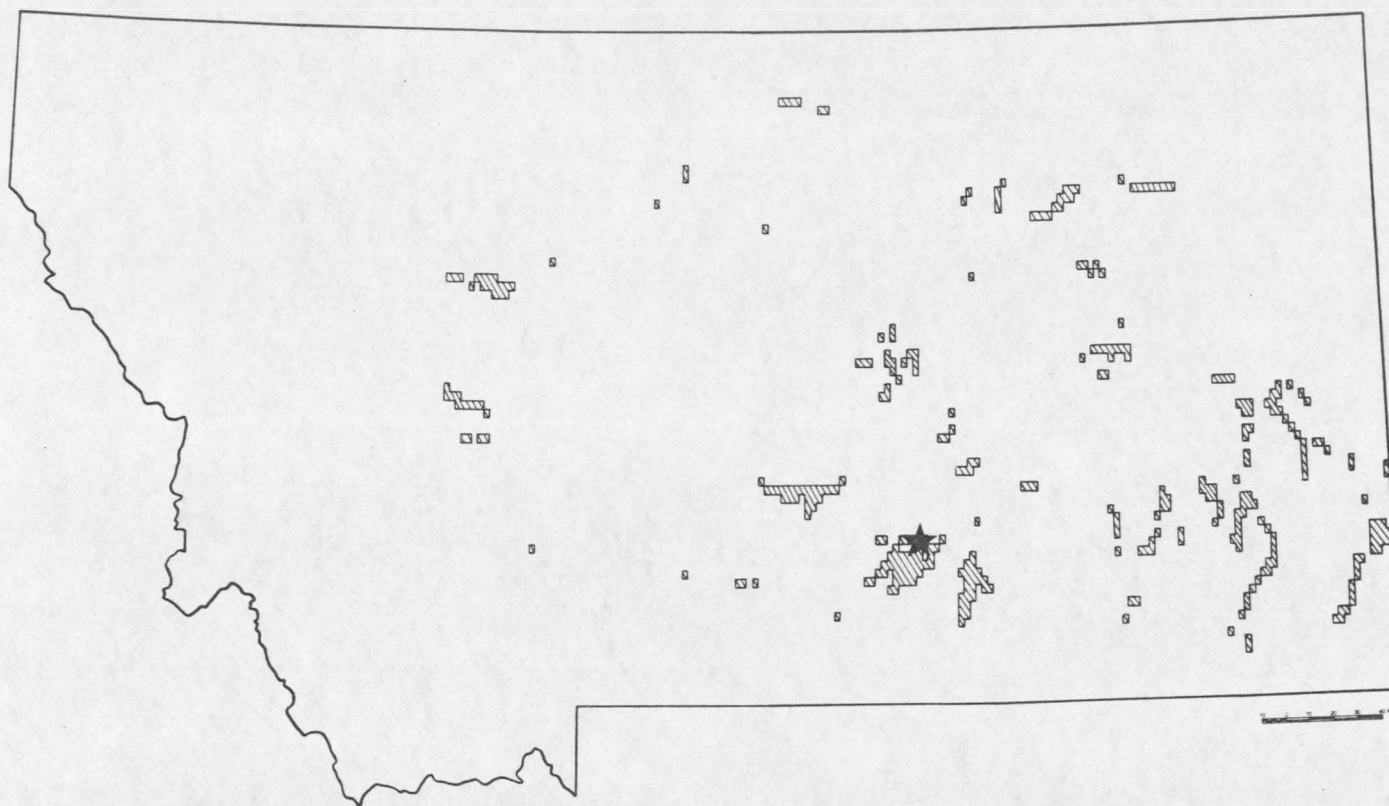


Figure 22. Agricultural environments similar to the Huntley center.

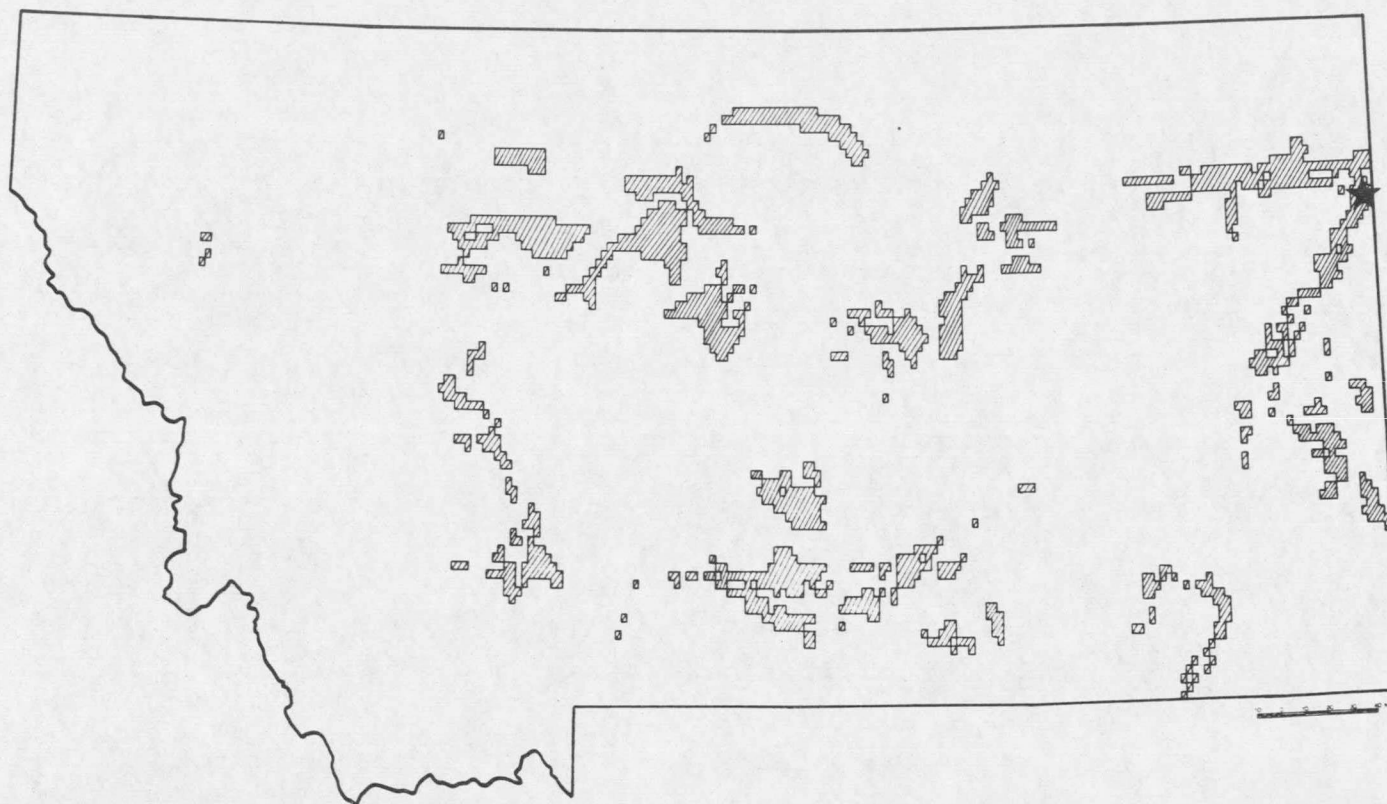


Figure 23. Agricultural environments similar to the Sidney center.

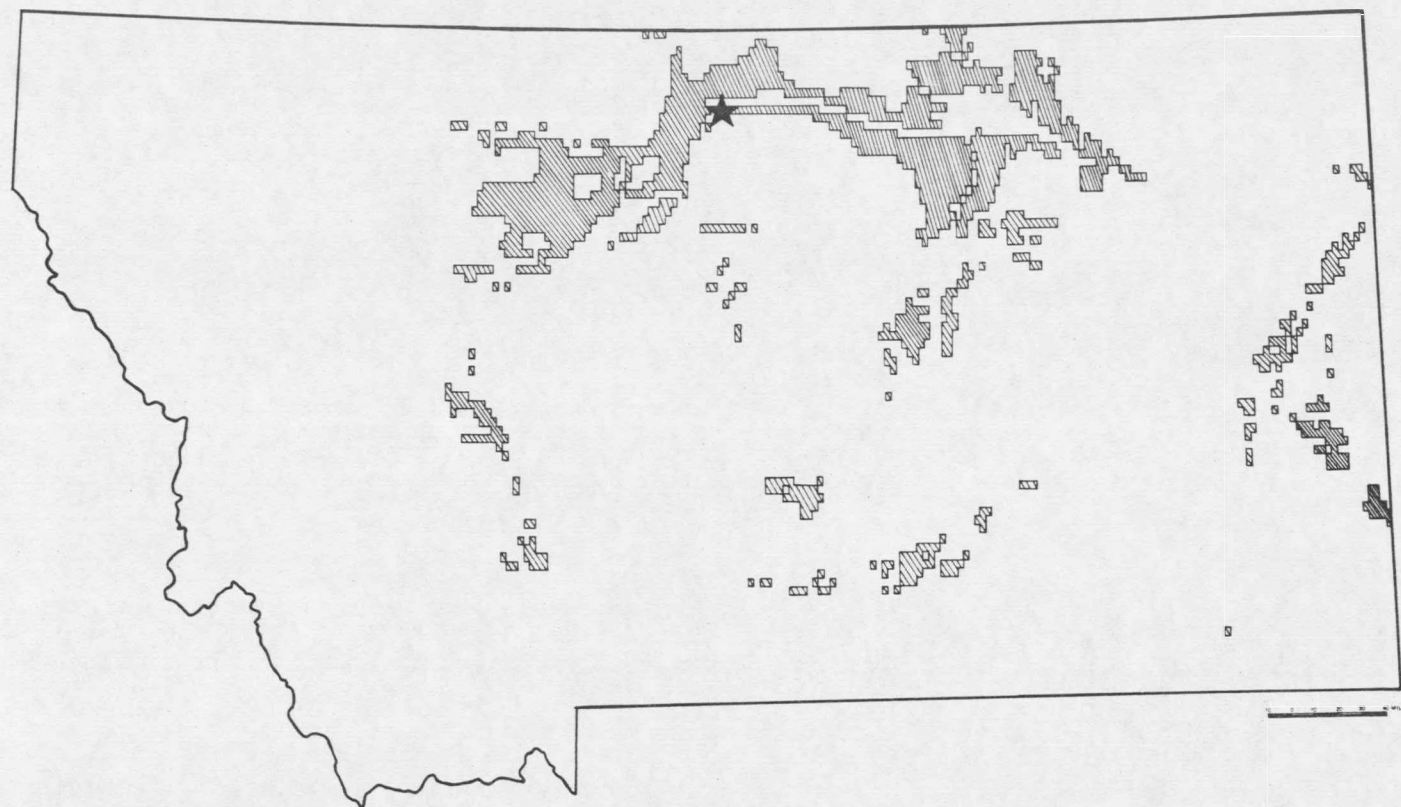


Figure 24. Agricultural environments similar to the Havre center.



Figure 25. Agricultural environments similar to the Creston center.

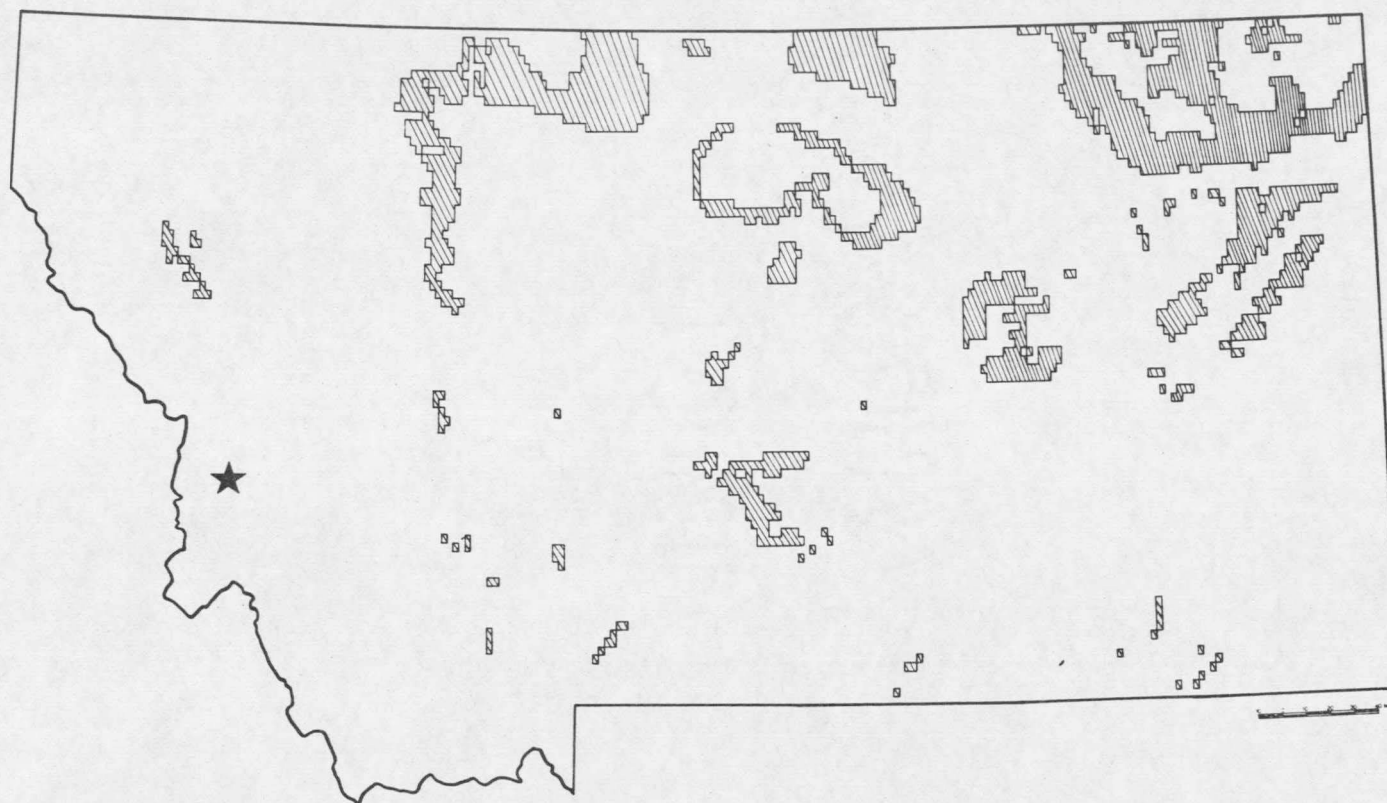


Figure 26. Agricultural environments similar to the Corvallis center.

These maps represent the first tentative effort at identifying areas similar to the research centers. Further work will be required in several areas. First, the environmental parameters of importance at each station must be identified. It seems likely that the same factors will not be important at all stations. Another area for work involves determining the range of parameters to be used in characterizing a site. If the range of characteristics is defined very narrowly for each parameter and if many factors are used, the result will be a map with only a few, very unique cells. This map will not help to extrapolate research results because it is too narrowly defined. It should be broad enough to disclose some distinct groups of cells and yet narrow enough to have meaning.

If work is accomplished in these two major areas it will be possible to define in meaningful terms those lands with characteristics similar to those of the research centers.

Soil Temperature Research

Figure 27 delineates those lands having cryic soil temperatures for north aspects and 45 percent slopes. Munn's (1977) model predicts that for latitudes in Montana north of 45 degrees the cryic-frigid boundary is above 5,000 feet. South of 45 degrees the boundary is above 6,000 feet. Intervals of 1,000 feet were used because that is what is stored in the computer.

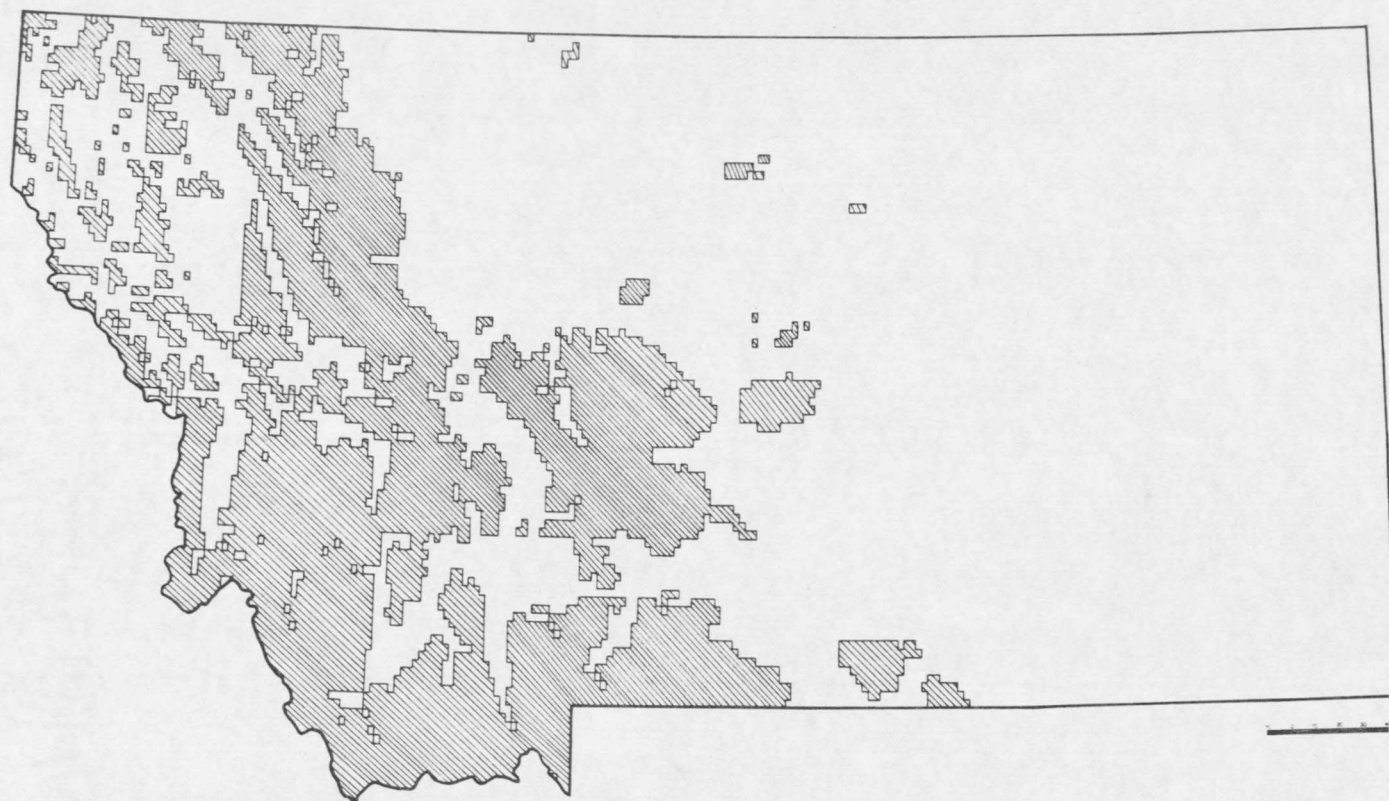


Figure 27. Soils with Cryic temperature regimes.

Similar maps could be prepared for any slope or aspect. These would help mappers locate the boundaries between frigid and cryic temperature regimes which would increase the accuracy of their soil classification.

Growing Season Precipitation Studies

Dr. Caprio planned to use the two new maps produced in this study as a guide in the preparation of new hand-drawn maps of growing season precipitation. The patterns produced in these maps were very complex and could not be photo reduced and still be readable. For this reason, copies of these maps are not included in this thesis.

Delineation of Sodic Claypan Soils

It has been estimated that there are about 17 million acres in the northern Great Plains which have sodic claypan soils (Sandoval and Jacobes 1977). In these soils, a dense layer is found a short distance below the surface which is high in adsorbed or exchangeable sodium. This dense layer prevents moisture from percolating into the deeper layers, as well as restricting plant root growth. Beneath the sodic layer is often found a moderately saline zone which contains gypsum.

Sandoval and Jacobes (1977) recommend deep plowing to improve the condition of these soils. A single plowing to a depth of 24 to 30 inches breaks up the dense layer and mixes the gypsum with the sodic dominated soil. The calcium from the gypsum replaces the sodium on

the exchange sites which results in increased permeability. Improved water movement leaches the sodium and the salts out of the profile. In 2-3 years the productivity of the soil usually increases markedly.

The production of this map, Figure 28, will help to focus attention on the problems associated with these soils. If copies of this map and a discussion of deep plowing were distributed to newspapers and farm journals an increased public awareness of the potential benefits of the practice may result.

Areas Where Summer Fallow May Not Be Recommended

Summer fallowing is a practice which increases the amount of stored soil moisture available at planting time. It is, however, an inefficient practice since only a small percentage of the precipitation which falls during the fallow period is stored in the soil. In some areas, excessive amounts of water have accumulated by summer fallowing and saline seeps have resulted.

Figure 29 shows the locations in the state where summer fallowing may not be recommended for moisture conservation. The two criteria used to identify these lands were (1) greater than 14 inches of average annual precipitation, and (2) soils with low water-holding capacities.

This map was included in a Cooperative Extension Service press release by Dr. Paul Kresge, Extension Soil Scientist. The 1:1,000,000 map from which the smaller version was produced will be drafted into a

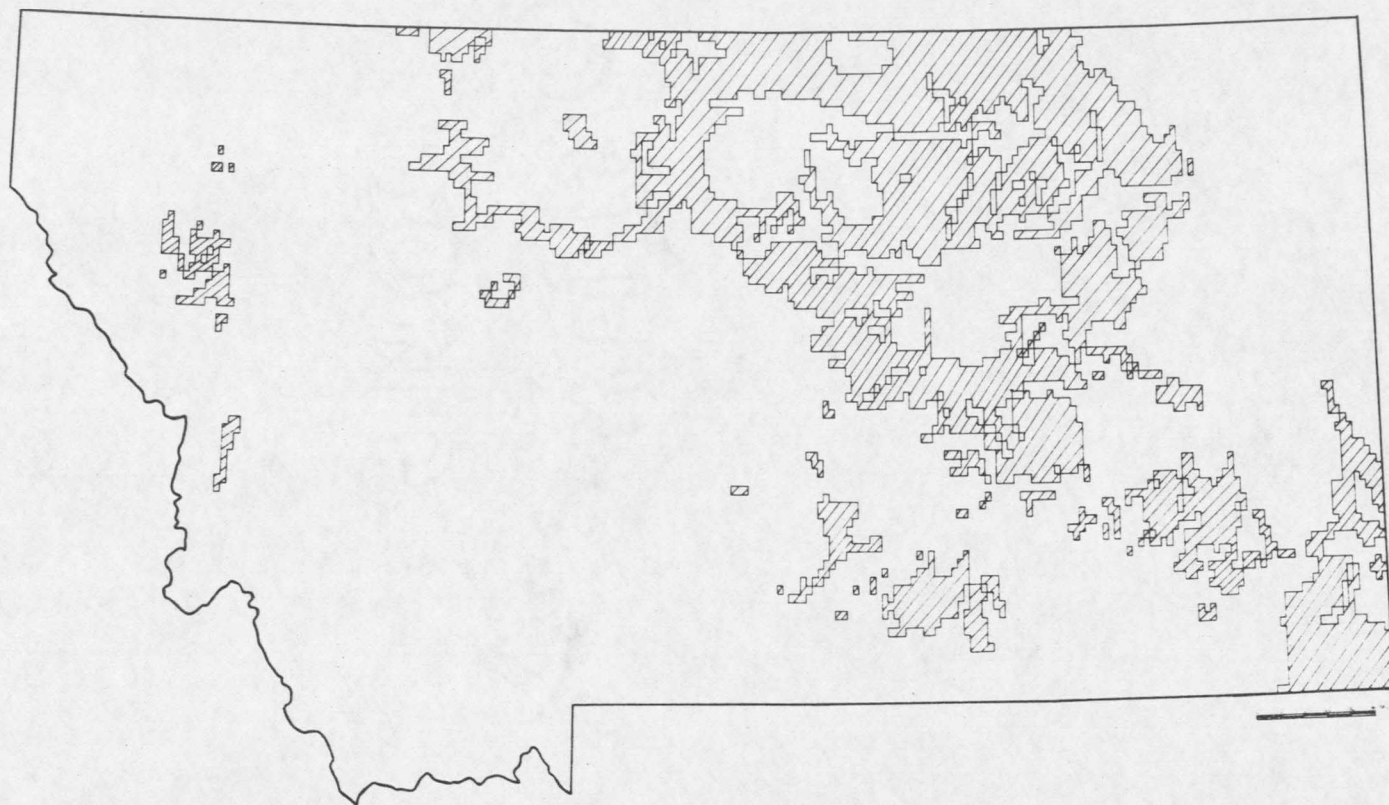
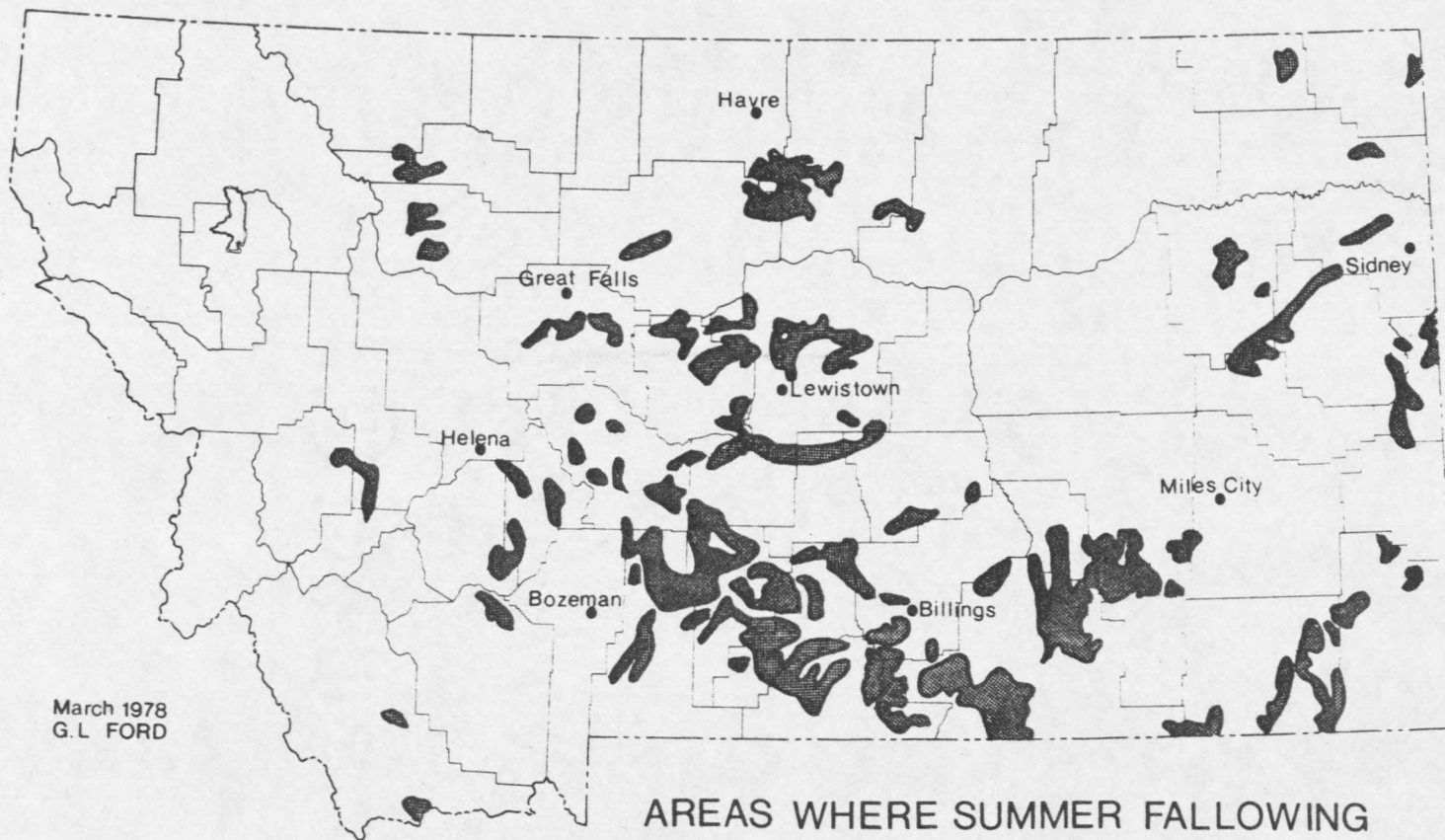


Figure 28. Areas with some soils influenced by sodium.



March 1978
G.L. FORD

Montana Agricultural
Experiment Station

Figure 29.

final form at a later date and made available to researchers and other interested parties.

This map should have helped to keep the summer fallow-recrop question in the minds of the Montana farmers who live in the shaded areas.

Effectiveness of Computer-Drawn Maps

The principal advantage of the computer-drawn map is that thousands of cells can be quickly analyzed and compared. A composite map can be produced by the computer in a fraction of the time that one can be produced manually.

At present, however, there are several problems which need to be resolved to increase the utility and effectiveness of these maps. Most of these can be resolved without difficulty.

If a large amount of enhancing is required of the computer maps to increase their utility, much of the time saved by machine processing will be lost.

Even though special plotter pens were used, the contrast between the lines drawn and the background was not sufficient for photographic processing or viewing of these maps at large meetings. The maps included in this thesis had to be redrafted in ink on tracing paper, line patterns were placed on the cells, and then they were photographically reduced. While the maps are excellent for personal use they

are poor, in their present condition, for formal presentations. The use of darker ink and better plotter paper would help alleviate this problem.

One disadvantage of the computer map has recently been overcome. This is the large size of the 1:1,000,000 maps which makes them unacceptable by newspapers and magazines. It is now possible to alter the scale of these maps and produce a size which most publishers will use. If a shading system is implemented it will be possible to go from plotter to newspaper without any delay and thus increase the timeliness of these maps.

One type of information which is useful but lacking at present is location data, i.e., county lines, cities, water features, etc. The temporary solution to this problem has been to produce a clear, half-tone, mylar overlay of these reference systems to superimpose on the plotter-drawn maps. A more effective mechanism should be found. Since the public often views computer products with some apprehension every effort must be taken to make the maps easy to use.

Computer maps have limitations for overlay presentations. The computer can perform a series of analyses of individual maps and then produce a composite, while manual operations must superimpose each of these in turn to arrive at the final map. However, for group presentations this manual process communicates well with the public, while the final computer map does not convey how it was produced.

It should be possible to improve the quality and effectiveness of the present computer-drawn maps without great expense. For large meetings and other special situations some enhancement may still be required.

CONCLUSIONS

The Montana Computer Graphic System has demonstrated potential as a research aid and a mechanism for rapidly communicating agronomic information to the public.

This system produces a useful product at a low cost and requires little maintenance.

The 1:1,000,000 map scale, latitude-longitude grid system, and change-point encoding method comprised a procedure that could be used by nonspecialists to rapidly encode resource data for computer storage.

The system has analytical capabilities and applications far beyond those demonstrated in this thesis. It could be readily adapted to process dynamic resource data such as soil water status and land use patterns.

RECOMMENDATIONS

The utility and effectiveness of the system can be increased by the use of: (1) plotter pens which draw darker lines and use different colored inks, (2) better quality plotter paper or drafting film, (3) cell shading patterns, (4) geographic references, and (5) easier techniques to access the system.

A technique is needed for transferring the plotter grid onto drafting film without shrinkage or stretching as this will increase encoding efficiency and accuracy and reduce the amount of time required to make corrections.

To ensure the continued use of the system, workers in several disciplines should obtain practical experience in its application.

The users manual should be tested and then distributed to experiment station researchers.

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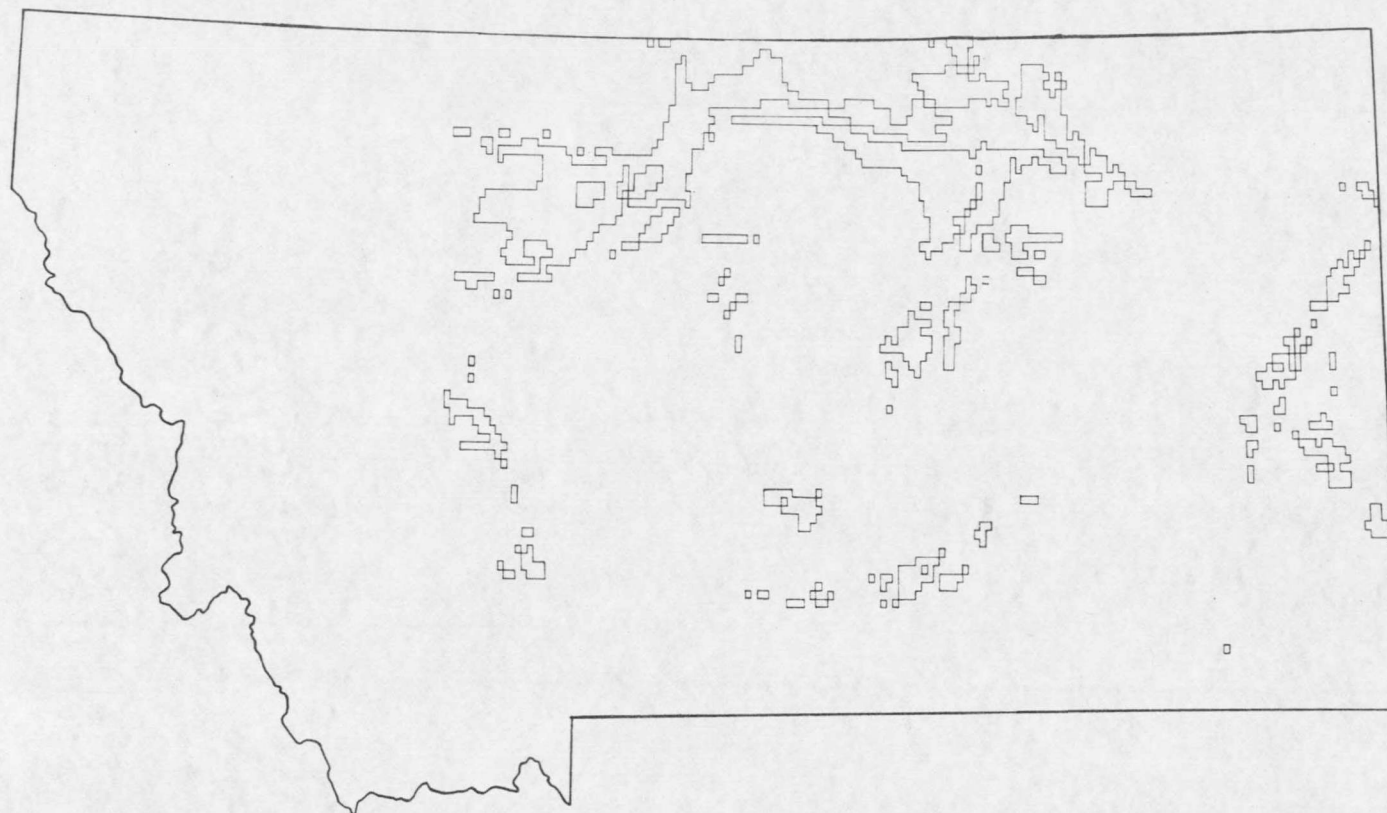
APPENDICES

APPENDIX I
USERS MANUAL FOR THE MONTANA COMPUTER GRAPHIC SYSTEM

The Montana Computer Graphic System (MCGS) was designed as a low-cost, broad-scale research and planning aid. Data contained in the system are usually based on long-term averages and are generalized information.

The system utilizes the computer to produce plotter-drawn maps. Use of the computer permits the researcher to view the geographical distribution of one or more components of the natural landscape such as soils, climate, climax vegetation, geology, or others. The amount of data displayed can vary from statewide coverage of a parameter to a single class depending upon the needs of the user. In addition, it is possible to use the computer to overlay many different factors to obtain a composite map. For example, a researcher may be interested in locating the lands in the state which have a certain type of soil, length of frost-free season, and average annual precipitation. By specifying the range of characteristics of importance for each parameter, a plotter-drawn map can be produced which displays the locations that have these features. Figure 1 is an example of such a map. This use of the system to locate agriculturally or environmentally similar areas is one of the most frequent applications of the MCGS.

Maps are produced at a scale of 1:1,000,000 and the Albers Equal-Area projection. This scale is adequate for obtaining an overview of the state or a major portion of it. Since this system is



Appendix figure 1. Example of plotter-drawn map.

based upon generalized resource information it should not be used for site specific work. An on-site field examination is required for these activities.

The system has its greatest reliability in the eastern two-thirds of the state and in the intermontane valleys of the west. It has less reliability in mountainous areas.

The data are stored and retrieved on a cell basis. For this reason the computer-drawn map consists of rectangles and straight lines rather than the conventional circles and curved lines found on man-made maps. In using the computer maps a good rule to follow is that clusters of cells are more reliable than individual units.

This manual is designed for two different types of users. The first, and probably most common, will be the researcher or planner who wants to use all or a portion of one or more of the existing files. For this type of application this manual contains instructions on how to identify the required parameters and the format to use in submitting this information for computer processing. The other potential user will be the occasional individual who would like to add files to the data bank. Many types of resource information are not presently in the MCGS; thus, a researcher may find it desirable to add new resource data to the system and then combine this information with existing files to obtain an important composite display. For this second type

of user, a detailed description is presented of the entire storage and retrieval process.

Potential users should examine the following list of files to determine if it contains environmental parameters of importance to their work and if the map intervals are sufficiently narrow to be usable. Background information is provided for each map file stored in the computer. The identification numbers for the intervals of each parameter are also listed. These are the values that the computer uses to identify these intervals and thus these identification numbers will be written on the fortran coding sheets.

Title: Average Length of Frost-Free Season Publication Date: 1965

Source: Dr. J. M. Caprio, Agricultural Climatologist, Montana Agricultural Experiment Station, Montana State Univ., Bozeman.

<u>Classes:</u> (in days)	<u>Computer Identifier</u>
10- 30	001
30- 50	002
50- 70	003
70- 90	004
90-100	005
100-110	006
110-115	007
115-120	008
120-125	009
125-130	010
130-135	011
135-140	012

Comments: Reference used was Mont. Agric. Exp. Stn. Folder No. 83.
Data based upon weather records for 1921-50.

Title: Average Date of First Freeze

Publication Date: 1965

Source: Dr. J. M. Caprio, Agricultural Climatologist, Montana Agricultural Experiment Station, Montana State Univ., Bozeman.

Classes: (dates)

Computer Identifier

8/03- 8/08	001
8/08- 8/13	002
8/13- 8/18	003
8/18- 8/23	004
8/23- 8/28	005
8/28- 9/02	006
9/02- 9/07	007
9/07- 9/12	008
9/12- 9/17	009
9/17- 9/22	010
9/22- 9/27	011
9/27-10/02	012

Comments: Reference used was Mont. Agric. Exp. Stn. Folder No. 82.
Data based upon weather records for 1921-50.

Title: Average Date of Last Freeze

Publication Date: 1965

Source: Dr. J. M. Caprio, Agricultural Climatologist, Montana Agricultural Experiment Station, Montana State Univ., Bozeman.

Classes: (dates)

Computer Identifier

5/05-5/10	012
5/10-5/15	011
5/15-5/20	010
5/20-5/25	009
5/25-5/30	008
5/30-6/04	007
6/04-6/09	006
6/09-6/19	005
6/19-6/29	004
6/29-7/09	003
7/09-7/19	002
7/19-7/29	001

Comments: Reference used was Mont. Agri. Exp. Stn. Folder No. 81.
Data based upon weather records for 1921-50.

Title: Preliminary Estimate of Average
Annual Potential Evapotranspiration

Publication Date: 1973

Source: Dr. J. M. Caprio, Agricultural Climatologist, Montana Agricultural Experiment Station, Montana State Univ., Bozeman.

Classes: (in inches)

<u>East of</u> <u>Divide</u>	<u>Computer</u> <u>Identifier</u>	<u>West of</u> <u>Divide</u>	<u>Computer</u> <u>Identifier</u>
11.5-12.5	001	11.5-12.5	001
12.5-13.5	002	12.5-13.5	002
13.5-14.5	003	13.5-14.5	003
14.5-15.5	004	14.5-15.5	004
15.5-18.0	013	15.5-17.0	005
18.0-20.5	014	17.0-19.0	006
20.5-22.0	015	19.0-20.0	007
22.0-23.5	016	20.0-21.0	008
23.5-25.0	017	21.0-22.0	009
25.0-26.5	018	22.0-23.0	010
26.5-29.0	019	23.0-24.0	011
29.0-31.5	020	24.0-25.0	012
31.5-33.0	021		

Comments: Based on the conversion of average date when lilacs begin to bloom to estimated average annual accumulation of solar thermal units $\times 10^{-5}$ (see Mont. Agric. Exp. Stn. Circ. 251 and Bul. 607).

Title: Percent of Average Annual Precipitation Falling from May 1 to July 31 Publication Date:

Source: Dr. J. M. Caprio, Agricultural Climatologist, Montana Agricultural Experiment Station, Montana State Univ., Bozeman.

<u>Classes:</u> (in percent)	<u>Computer Identifier</u>
17.5-20.0	001
20.0-22.5	002
22.5-25.0	003
25.0-27.5	004
27.5-30.0	005
30.0-32.5	006
32.5-35.0	007
35.0-37.5	008
37.5-40.0	009
40.0-42.5	010
42.5-45.0	011
45.0-47.5	012
47.5-50.0	013
50.0-52.5	014
52.5-55.0	015
55.0-57.5	016

Comments: The base period used in computing these percentages was 1941-70. Unpublished data.

Title: Percent of Average Annual Precipitation Falling from April 1 to July 31 Publication Date:

Source: Dr. J. M. Caprio, Agricultural Climatologist, Montana Agricultural Experiment Station, Montana State Univ., Bozeman.

Classes: (in percent) Computer Identifier

20.0-22.5	001
22.5-25.0	002
25.0-27.5	003
27.5-30.0	004
30.0-32.5	005
32.5-35.0	006
35.0-37.5	007
37.5-40.0	008
40.0-42.5	009
42.5-45.0	010
45.0-47.5	011
47.5-50.0	012
50.0-52.5	013
52.5-55.0	014
55.0-57.5	015
57.5-60.0	016
60.0-62.5	017
62.5-65.0	018
60.0-61.75	019
61.75-62.5	020

Comments: The base period used in computing these percentages was 1941-70. Unpublished data.

Title: Average Annual Precipitation, based Publication Date: 1977
on 1941-70 Period

Source: Snow Survey Unit, Soil Conservation Service, U. S. Department
of Agriculture, Bozeman.

<u>Classes:</u> (in inches)	<u>Computer Identifier</u>
0- 6	001
6- 8	002
10- 12	003
12- 14	004
14- 16	005
16- 18	006
18- 20	007
20- 30	008
30- 40	009
40- 50	010
40- 60	011
50- 60	012
60- 80	013
80-100	014
100-120	015
>120	016

Comments: Based upon snow course data, mountain storage precipitation gauge data, and climatological stations. Data collected by Snow Survey Unit of the SCS, National Weather Service, Forest Service, and others.

Title: Average Annual Snowfall, 1958-72

Publication Date: 1975

Source: Snow Survey Unit, Soil Conservation Service, U. S. Department of Agriculture, Bozeman.

Classes: (in inches)

Computer Identifier

0- 25	001
25- 50	002
50-100	003
100-200	004
200-300	005
300-500	006
500-700	007
500-800	008
500-1000	009

Comments: Based on data obtained from federal, state, and private cooperative snow surveys for Montana, coordinated by SCS/USDA and from Climatological Data for Montana published by USCOMM-NOAA.

Title: Average Annual Value of Factor R

Publication Date: 1976

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

Classes:

Computer Identifier

10	001
15	002
20	003
25	004
30	005
50	006
75	007
100	008
125	009
150	010

Comments: Factor R is the designation in the Universal Soil Loss Equation for the effects of average annual erosive rains. Map is based on data obtained from 1958-72 average annual snowfall data, from climatological data, and from isopluvials of 2 year 6 hour precipitation.

Title: 50 Year 24 Hour Peak Precipitation Publication Date: 1973

Source: Snow Survey Unit, Soil Conservation Service, U. S. Department
of Agriculture, Bozeman.

<u>Classes:</u>	<u>Computer Identifier</u>
0.0-2.2	001
2.2-2.4	002
2.4-2.6	003
2.6-2.8	004
2.8-3.0	005
3.0-3.2	006
3.2-3.4	007
3.4-3.6	008
3.6-3.8	009
3.8-4.0	010
4.0-4.2	011
4.2-4.4	012
4.4-4.6	013
4.6-4.8	014
4.8-5.0	015
3.0-3.4	016
3.4-3.8	017
3.8-4.2	018
4.2-4.6	019

Comments: Taken from National Oceanic and Atmospheric Administration
Atlas 2, Vol. 1, 1973.

Title: Elevation

Publication Date: 1970

Source: Snow Survey Unit, Soil Conservation Service, U. S. Department of Agriculture, Bozeman.

Classes: (in feet)

Computer Identifier

above 9,000	001
7,000-9,000	002
6,000-7,000	003
5,000-6,000	004
4,000-5,000	005
3,000-4,000	006
2,000-3,000	007
below 2,000	008

Comments: Data obtained from U. S. Geological Survey topographic maps and compiled into a 1:1,000,000 map.

Title: Number of Strong Chinooks Per 100 Years Publication Date:

Source: Dr. J. M. Caprio, Agricultural Climatologist, Montana Agricultural Experiment Station, Montana State Univ., Bozeman.

Classes:

Computer Identifier

0- 75	001
75-100	002
100-150	003
150-175	004
175-200	005
200-225	006
225-250	007
250-275	008
275-300	009
100-125	010
125-150	011

Comments: Unpublished map.

Title: Consumptive Use of Water

Publication Date: 1973

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

Classes:

Computer Identifier

High	001
Moderately high	002
Moderate	003
Moderately low	004
Low	005
Mountainous	006

Comments: Map published in Irrigation Guide for Montana.

Title: Geology

Publication Date: 1931
(reprinted 1960)

Source: Geologic Map of the United States, U. S. Geological Survey,
Washington, DC.

Classes:

Computer Identifier

Lance Formation	011
Fort Union Formation	010
Montana Group	019
Colorado Group	015
Claggett and Eagle Formations	016
Bearpaw and Judith River Formations	014
Older Tertiary Volcanic Rocks	027
Intrusive Rocks	025
Devonian to Cambrian Rocks	007
Mississippian Rocks	005
Dakota Sandstone and Lower Cretaceous	017
Jurassic Rocks	012
Dakota Sandstone to Morrison Formation	018
Archean Rocks	004
Upper Part of Belt Series	002
Alluvium, Lake Deposits, Beach Sand, Marine Deposits, and Glacial Deposits	023
Older Intrusive Rocks	013
Miocene and Pliocene Continental Deposits	021
Triassic Rocks	026
Pennsylvanian Rocks	006
Younger Volcanic Rocks and Interbedded Continental Deposits	024
Belt Series, undivided and other Algonkian Rocks	001
White River Group	022
Mesa Verde Formation	028

Comments: Original map was at a scale of 1:2,500,000 and was subsequently enlarged to 1:1,000,000. This map is very generalized, particularly for the mountainous portions of the state.

Title: SoilsPublication Date: 1978Source: Montana Agricultural Experiment Station with the cooperation of the Soil Conservation Service and Forest Service, U. S. Department of Agriculture.Classes:Computer
Identifier

INTERMOUNTAIN AND PIEDMONT SECTION

Aridic/Xeric/Ustic-Frigid:Av Entisols, Inceptisols, & Mollisols of nearly level
to sloping terraces, fans, & flood plains

Av1	Fluvaquents-Torriorthents-Calciorthids Villy, Ryell, Rivra	085
Av2	Xerochrepts-Xerifluvents-Haplaquolls Chamokane, Corvallis, ?	047
Av3	Ustochrepts-Ustifluvents-Haplaquolls ? , ? , ?	093
Av4	Argiborolls-Haploborolls-Fluvaquents Beaverton, Gallatin, Villy	029
Av5	Haploborolls-Argiborolls-Camborthids ? , ? , ?	112

Aquic-Cryic:B Mollisols of nearly level cold, wet basins

B	Cryaquolls-Cryoborolls ? , ?	132
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Xeric-Frigid:Ct Mollisols of nearly level to strongly sloping
outwash terraces, fans, & benches

Ct1	Haploxerolls-Xerochrepts-Xeropsamments Victor, Chereete, Kalispell, Blanchard variant, Jocko	004
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<u>Classes:</u>	<u>Computer Identifier</u>
Ct2 Haploxerolls-Natrargids ? , Ravalli	110
<u>D Mollisols & Alfisols of nearly level to sloping lacustrine terraces</u>	
Dt1 Haploxeralfs-Argixerolls Tarkio, ?	041
Dt2 Natrixerolls-Argixerolls Post, Polson, ?	053
<u>E Inceptisols & Entisols of nearly level to strongly sloping outwash terraces & fans with forest cover</u>	
Et Xerochrepts-Xerorthents-Ustochrepts ? , ? , Totelake	038
<u>Fg Mollisols of undulating to rolling glacial moraines</u>	
Fg Haploxerolls-Natrixerolls Quigley-like, Polson	067
<u>Ustic-Frigid:</u>	
<u>Gb Mollisols of nearly level to highly dissected, sloping, & steep benches & terraces</u>	
Gb1 Argiborolls-Haploborolls Bozeman*, Amsterdam* (*presently cryic series)	122
Gb2 Argiborolls-Lithic Haploborolls-Haploborolls Hilger, Castner, Turner/Absarokee, rock outcrop <u>1/</u>	036
Gb3 Argiborolls-Eutroboralfs-Haplaquolls Hanaker, Bignell, Turrah	096
Gb4 Argiborolls Martinsdale, Fairfield, Work/Turner Farnuf	012

1/ Series listed to the right of the slash (/) are minor soils.

<u>Classes:</u>	<u>Computer Identifier</u>
Gb5 Argiborolls-Calciborolls Danvers, Judith, Fairfield/Utica, Windham	010
Gb6 Calciborolls Windham, Utica, Judith, Ipano	051
<u>Gf Mollisols of sloping to steep foothills</u>	
Gf1 Argiborolls-Lithic Argiborolls Martinsdale, Sinnigam, rock outcrop/Doughty, Castner	087
Gf2 Argiborolls-Haploborolls Terrad, Timberg, Big Timber	034
Gf3 Calciborolls-Haploborolls Lap, Armington, rock outcrop/Windham, Reeder	141
Gf4 Haploborolls-Ustorthents Winifred, Wayden	055
Gf5 Haploborolls-Lithic Haploborolls Hedoes, Belain, Castner	049
<u>Gg Mollisols of undulating to rolling piedmont glacial moraines</u>	
Gg1 Argiborolls-Haploborolls ? , ?	092
Gg2 Argiborolls-Haploborolls-Calciborolls Williams, Zahl, ?	042
<u>Ustic-Frigid/Cryic:</u>	
<u>Hf Mollisols & Entisols of sloping to steep foothills</u>	
Hf1 Haploborolls-Argiborolls-Cryoborolls Perma, McDonald, Skaggs	059
Hf2 Haploborolls-Cryoborolls-Paleboralfs Castle, Frica*, Mord, Tigeron/Absarokee, Sinnigam (*proposed series)	073
Hf3 Argiborolls-Haploborolls-Cryoborolls Absarokee, ? , Bridger	106

<u>Classes:</u>	<u>Computer Identifier</u>
Hf4 Ustorthents-Lithic Haploborolls Wayden, Castner/Lambeth, Regent, Lap, Rottulee, rock outcrop	111

Ustic-Cryic:Ib Mollisols of nearly level to highly dissected,
sloping, & steep benches & terraces

Ib1 Cryoborolls Bridger, Passcreek, Rooset	101
Ib2 Cryoborolls-Cryaquolls ? , ?	123
Ib3 Cryoborolls-Cryoborolls, shallow Michelson, Redchief, Fifer, terrace escarp- ments	009

If Mollisols & Inceptisols of sloping to steep
foothills

If1 Cryoborolls-Lithic Cryoborolls Ess, Cheadle, Nielsen	100
If2 Cryoborolls Hanson, Skaggs/Duncom	086
If3 Cryoborolls-Cryochrepts-rock outcrop Leavitt, Orofino, Maxville, Tiban, ?	121
If4 Cryoborolls-Cryochrepts-Ustochrepts Sebud, Whitore, Duncom, Whitecow	050

Ig Mollisols of undulating to rolling piedmont glacial
moraines

Ig Cryoborolls Leavitt, Burnette, Adel, Babb	008
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Aridic-Frigid:Jb Mollisols & Aridisols of nearly level to highly
dissected, sloping, & steep benches & terraces

<u>Classes:</u>	<u>Computer Identifier</u>
Jb Argiborolls-Calciorthids Radersburg, Amesha, Scravo	098
<u>Jf Mollisols, Aridisols, & Entisols of foothills</u>	
Jf Argiborolls-Haplargids-Torriorthents, shallow Nuley, Evana*, Riedel variant	097
<u>Kb Aridisols of nearly level to highly dissected, sloping, & steep benches & terraces</u>	
Kb1 Calciorthids-Torriorthents Crago, Amesha, Scravo	099
Kb2 Calciorthids-Haplargids-Argiborolls Musselshell, Diamondville, Evanston	138
Kb3 Calciorthids-Argiborolls-Camborthids Avalanche, Evanston, Alona variant	144
Kb4 Calciorthids Musselshell, Cargill, Crago, Ashuelot	094
<u>Kt Aridisols of nearly level to dissected, sloping, & steep lacustrine terraces</u>	
Kt Camborthids-Natrargids Lone Pine, Round Butte/Irving	064
<u>Kf Aridisols & Mollisols of sloping to steep foothills</u>	
Kf Calciorthids-Argiborolls Rencot, Tolman	108
<u>Udic-Frigid/Cryic:</u>	
<u>Lt Cryic Inceptisols & Entisols of nearly level outwash terraces with forest cover</u>	
Lt Cryochrepts-Cryorthents ? , ?	145

<u>Classes:</u>	<u>Computer Identifier</u>
<u>Lg Inceptisols & Alfisols of undulating to rolling valley and foothill glacial moraines with forest cover</u>	
Lg1 Cryochrepts-Eutroboralfs-Eutrochrepts ? , ? , ?	003
Lg2 Cryoboralfs-Cryoborolls Loberg, Adel	007
Lg3 Cryochrepts-Cryoboralfs ? , ?	127
<u>Udic-Cryic:</u>	
<u>Ma Inceptisols (Andic) of steep & very steep forested mountains</u>	
Ma Cryochrepts-Cryandepts (mixed lithology with Holloway, Truefissure surficial volcanic ash)	046
<u>Me Inceptisols & Alfisols of steep & very steep forested mountains</u>	
Me1 Cryochrepts-Cryoboralfs-Eutroboralfs (glacial deposits over quartzitic, argillaceous, and dolomitic lithology) Holloway*, Sherlock, Bignell (*glacial phase)	002
Me2 Cryochrepts-Cryoboralfs (argillaceous & quartzitic lithology) Garlet, Mikesell, Worock	125
Me3 Cryochrepts-Cryoboralfs-Cryoborolls (granitic and crystalline lithology) Garlet(?), Loberg or Woodrock, Leavitt	089
Me4 Cryochrepts-Cryoboralfs-Lithic Cryoborolls (mixed lithology) Whitore, Garlet, Nugget or Loberg, Cheadle	048
Me5 Cryochrepts-Cryoboralfs-rock outcrop (granitic and crystalline lithology) Garlet, ? , rock outcrop	135

Classes:Computer
IdentifierUdic/Ustic-Frigid/Cryic:Mf Inceptisols of steep & very steep forested mountains

Mf1	Cryochrepts-Ustochrepts-Eutroboralfs (mixed Holloway, Winkler, Yourame, Bignell lithology)	032
Mf2	Cryochrepts-Ustochrepts-Cryorthents Elkner, Ambramt, Stecum	095
Mf3	Cryochrepts-Ustochrepts-Cryoboralfs (calcareous Whitore, Repp, Trapper lithology)	005
Mf4	Cryochrepts-Ustochrepts-Lithic Cryoborolls (argillaceous and quartzitic lithology) ? , ? , Cheadle	069

Mo Mollisols, Inceptisols, & Alfisols of steep & very
steep mountains with open forest-grass cover

Mo1	Cryoborolls-Cryochrepts-Cryoboralfs (mixed ? , ? , ? lithology)	139
Mo2	Cryoborolls-Cryochrepts-Ustochrepts (calcareous Hughesville, Whitore, Skaggs lithology)	090
Mo3	Cryoborolls-Cryoboralfs-Cryochrepts (mixed Teton, Loberg, Garlet lithology)	079
Mo4	Cryochrepts-Cryoborolls-Haploborolls (mixed Skaggs, ? , ?/Sheege, Tigeron lithology)	015
Mo5	Cryoborolls (mixed lithology) Duncom, Tarrete, Mayflower	142
Mo6	Eutroboralfs-Argiborolls-Lithic Cryoborolls (granitic and crystalline lithology) Loberg variant, Hilger, Cheadle	088

Udic-Cryic:R Mountain peaks & sloping to very steep alpine
grasslands

R	Rock outcrop, talus, Cryoborolls & Cryochrepts (mixed lithology)	006
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Classes:Computer
Identifier

GREAT PLAINS SECTION

Aridic/Ustic-FrigidAp Entisols, Aridisols, Inceptisols, & Mollisols of
nearly level to sloping low terraces, fans, &
flood plains

Ap1	Torrifluvents-Salorthids Havre, Harlem, Bowdoin, Lardell/Nobe, McKenzie, Glendive	018
Ap2	Camborthids-Torrifluvents-Torriorthents Yamac, Havre, Harlem, Kobar Glendive	074
Ap3	Camborthids-Natrargids-Torrifluvents Yamac, Gerdum, Havre, Harlem, Glendive	043
Ap4	Ustochrepts-Ustifluvents-Argiborolls Cherry, Havrelon, Lohler, Savage, Farnuf	054
Ap5	Ustifluvents-Haploborolls-Argiborolls Havrelon, Lohler, Farnuf, Savage/Bowdoin, Turner, Nobe	026
Ap6	Haploborolls Lolo, Nesda	131
Ap7	Haploborolls-Argiborolls-Ustifluvents Tally, Savage, Fergus, Straw, Korent	078

Aquic-Frigid:Aw Mollisols & Entisols of nearly level wet basins,
low terraces, & flood plains

Aw	Haplaquepts-Torriorthents-Haplaquolls McKenzie, Nobe, Dimmick	013
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Ustic-Frigid:Nb Mollisols of nearly level to highly dissected,
sloping & steep benches & terraces

Nb1	Argiborolls Farnuf, Turner	066
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Classes:Computer
Identifier

Nb2	Haploborolls Duffy, Lihen, Tally/sand dunes, rock outcrop	076
<u>Np</u>	<u>Mollisols & Entisols of gently to strongly sloping sedimentary bedrock plains</u>	
Np1	Argiborolls-Ustorthents Reeder, Regent, Eltsac, Absarokee/Cabba, Norbert, Gerber, Castner, Amherst, Sinnigam, Borky	077
Np2	Argiborolls-Lithic Argiborolls Absarokee, Sinnigam/Macar, Shane, Rentsac	083
Np3	Argiborolls-Haploborolls-Ustochrepts Farnuf, Vebar, Macar	not encoded
Np4	Calciborolls-Haploborolls Trulon, Lap, Bitton, Straw	082
Np5	Haploborolls-Argiborolls-Ustochrepts Shambo, Labre, Barkof	134
Np6	Haploborolls-Ustochrepts-Ustorthents Chama, Cambert, Cherry, Lamber/Shambo, Farland, Farnuf, Morton, Arnegard	062
Np7	Ustorthents-Argiborolls Doney, Farnuf, Wayden	105
Np8	Ustorthents-Haploborolls-Natriborolls Eltsac, Vebar, Adger/Farnuf	104
Np9	Ustipsamments-Ustorthents Flasher, Dast	130
<u>Nh</u>	<u>Entisols, Mollisols, & Inceptisols of dissected, rolling to steep sedimentary bedrock plains & hills</u>	
Nh1	Haploborolls-Calciborolls-Argiborolls Winifred, Utica, Danvers, Savage/Maginnis, Judith, Roundup, Absarokee, Sinnigam, Windham	081
Nh2	Ustochrepts-Haploborolls-Argiborolls Lamedeer, Barvon, Ringling, Reeder/Doney, Farnuf Lambeth, Cabba	080

<u>Classes:</u>	<u>Computer Identifier</u>
Nh3 Ustorthents-Lithic Haploborolls-Argiborolls Wayden, Castner, Regent/Rentsac, Belfield, Lambeth, Rottulee, rock outcrop	118
Nh4 Ustorthents-Ustochrepts Lambert, Zahill-Cambert	023
Nh5 Ustochrepts-Ustorthents Cambert, Lambert, Dast, Barkof/Tinsley, shale outcrop	057
Nh6 Ustorthents-Haploborolls Tinsley, Lambert, Lihen	063
Nh7 Ustochrepts-Ustorthents-Haploborolls ? , ? , ?	129
<u>Og Mollisols & Entisols of undulating to rolling glacial till plains</u>	
Og1 Argiborolls-Haploborolls Dooley, Parshall/Tally, Zahill	027
Og2 Argiborolls-Haploborolls Bearpaw, Williams, Zahl/Gerber	044
Og3 Argiborolls-Ustorthents Vida, Williams, Zahill	014
Og4 Argiborolls-Ustorthents Williams, Zahill/Bowbells, Farnuf, Grail, Dimmick	024
<u>Oh Entisols & Mollisols of dissected, hilly glacial till plains</u>	
Oh Ustorthents-Argiborolls Zahill, Williams, Tinsley/Dimmick, Farnuf, Grail, Bowbells	025
<u>Ot Mollisols of nearly level to sloping glacial outwash & stream terraces</u>	
Ot Haploborolls-Argiborolls Dooley, Turner, Manning, Parshall, Tally/Wabek	031

<u>Classes:</u>	<u>Computer Identifier</u>
<u>Aridic-Frigid:</u>	
Pb <u>Mollisols & Aridisols of nearly level to highly dissected, sloping, & steep benches & terraces</u>	
Pb1 Argiborolls-Camborthids Brussett, Lonna/Onray, Gilt Edge, Shonkin, Ethridge	137
Pb2 Calciborolls-Calciorthids Rothemay, Binna, Crago, Ashuelot/wet saline land	065
Pb3 Haploborolls-Camborthids-Argiborolls Kremlin, Abor, Dutton/wet saline land, Yawdim, Cabbart	068
Pp <u>Mollisols & Aridisols of gently to strongly sloping sedimentary bedrock plains</u>	
Pp1 Argiborolls-Haploborolls-Lithic Argiborolls Tanna, Roundup, Beenom/Yamac, Yawdim, Delpoint	017
Pp2 Argiborolls-Haplargids-Lithic Torriorthents Evanston, Bonfri, Rentsac/Beenom, Gerber, Lambeth	035
Ph <u>Entisols & Mollisols of dissected, rolling to steep sedimentary bedrock plains & hills</u>	
Ph1 Torriorthents, shallow-Argiborolls-Camborthids Cabbart, Evanston, Delpoint/Dilts, rock outcrop, Yawdim, Kobar, Gerdrum	039
Ph2 Torriorthents, shallow-Lithic Torriorthents-Torrifluvents Cabbart, Rentsac, Havre/rock outcrop, Glendive, Lohler, Yawdim	040
Sg <u>Mollisols & Aridisols of undulating to rolling glacial till plains</u>	
Sg1 Argiborolls-Haploborolls Telstad, Joplin, Chinook, Scobey/Hillon, Thoeny	016
Sg2 Argiborolls-Paleargids-Natrargids Scobey, Phillips-Elloam/Sunburst	011

<u>Classes:</u>	<u>Computer Identifier</u>
Sg3 Argiborolls-Torriorthents-Natrargids Scobey, Sunburst-Elloam/Phillips	020
<u>Sh Entisols & Aridisols of dissected, hilly glacial till plains</u>	
Sh Torriorthents-Natrargids-Torriorthents, shallow Sunburst, Elloam, Lisam	021
<u>St Mollisols of nearly level to sloping glacial outwash & stream terraces</u>	
St Argiborolls-Haploborolls Evanston, Assinniboine, Attewan, Chinook	030
<u>Tb Aridisols of nearly level to highly dissected, sloping, & steep benches & terraces</u>	
Tb1 Haplargids-Haploborolls-Argiborolls Pinelli variant, Kremlin, Chanta, Degrand, Attewan, Yamac	103
Tb2 Natrargids-Hapargids Creed, Pinelli variant, Gerdrum	084
Tb3 Camborthids-Torriorthents Yamac, Marias, Vanda, Busby	102
<u>Tp Aridisols of gently to strongly sloping sedimentary bedrock plains</u>	
Tp1 Camborthids-Haploborolls-Argiborolls Busby, Chinook, Evanston	107
Tp2 Camborthids-Torriorthents, shallow Yamac, Birney, Cabbart (fine-loamy soils)	126
Tp3 Camborthids Cambeth, Lonna, Delpoint	091
Tp4 Camborthids-Torriorthents, shallow Busby, Twilight, Riedel (coarse-loamy), Sunburst	115
Tp5 Haplargids-Camborthids-Natrargids Pinelli variant, Cambeth, Lonna, Creed	052

Classes:Computer
IdentifierTh Entisols & Aridisols of dissected, rolling to steep
sedimentary bedrock plains & hills

Th1	Torriorthents-Camborthids Lambeth, Cambeth, Yawdim, Delpoint	072
Th2	Torriorthents, shallow-Camborthids-Torriorthents Cabbart, Birney, Yamac, Armells	117
Th3	Torriorthents, shallow-Torriorthents-Camborthids Cabbart, Reidel, Yawdim, Yamac/Twilight, Busby	058
Th4	Torriorthents-Torriorthents, shallow-Camborthids Lambeth, Cabbart, Delpoint	114
Th5	Torriorthents-Lithic Torriorthents-Camborthids Yawdim, Rentsac, Busby	136
Th6	Torriorthents-Natrargids Yawdim, Delphill, Creed, Cabbart/shale outcrop	061
Th7	Haplargids-Torriorthents-Camborthids Pinelli variant, Delphill, Yawdim, Kobar	120
Th8	Torriorthents-Lithic Torriorthents-Camborthids Yawdim, Lambeth, Rentsac, Yamac/rock outcrop	113

Ug Aridisols of undulating to rolling glacial till plains

Ug1	Paleargids-Natrargids-Argiborolls Phillips-Elloam, Kevin/Scobey, Sunburst, Nobe	019
Ug2	Natrargids-Camborthids-Torriorthents Elloam, Bascovy, Dilts	060

Aridic/Ustic-Frigid:Vb Aridisols, Mollisols, & Entisols of clayey, nearly
level to sloping terraces, fans, benches, &
lacustrine basins

Vb1	Argiborolls-Eutroboralfs Dutton, Gerber, Pylon, Linnet, Shaak	070
Vb2	Camborthids-Torriorthents-Argiborolls Kobar, Marias, Pendroy, Attewan/Ethridge, Kevin, Scobey, Floweree	037

<u>Classes:</u>	<u>Computer Identifier</u>
Vb3 Camborthids-Natrargids Bickerdyke, Gerdrum	140
Vb4 Natrargids-Torriorthents Absher, Nobe/Lonna	075
Vb5 Torriorthents-Natrargids-Torrifluvents Vaeda, Vanda, Absher, Havre/Harlem, Nobe, McKenzie	033
Vb6 Salorthids-Haplaquepts Lardell, McKenzie	128
<u>Vh Entisols & Aridisols of clayey, moderately sloping to dissected, rolling & steep shale plains</u>	
Vh1 Torriorthents, shallow-Camborthids-Natrargids Lisam, Dilts, Bascovy, Abor, Absher/rock outcrop	022
Vh2 Ustorthents-Ustorthents, shallow-Haploborolls Eltsac, Wayden, Winifred, Cabba, shale outcrop	071
<u>X Badlands & Entisols of highly dissected, steep, river breaks</u>	
X Badlands-Torriorthents, shallow-Torrifluvents Rock outcrop, Lambeth, Lisam, Yawdim, Harlem/ Dilts, Havre	056
<u>WAT Water</u>	
WAT Lakes or Reservoirs	045

Comments: ? indicates unidentified soil series. Soil map was compiled from county soil association maps, published soil surveys, 1:250,000 topographic maps, and the following generalized soil maps: (a) Headwater RC&D, Soil Conservation Service, 1:500,000 map scale; (b) Clark Fork of the Columbia River Basin, Soil Conservation Service and Forest Service, 1:500,000 map scale, April 1974; and (c) Soils of Eastern Montana by J. M. Ashley and C. A. Mogen in Impacts of Induced Rainfall on the Great Plains of Montana, Section 7, Surface Hydrology, Mont. Agric. Exp. Stn. Bul. Map at 1:1,000,000.

Title: Climax VegetationPublication Date: 1976Source: R. L. Ross and H. E. Hunter, Soil Conservation Service, U. S. Department of Agriculture, Bozeman.Classes:Computer
Identifier

EASTERN GLACIATED PLAINS:

- | | | |
|---|---|-----|
| 1 | Silty Range Site, 10-14" Precipitation Zone (P. Z.)

(Includes thin breaks too small or irregular to delineate)
Needleandthread, western and thickspike wheatgrass, green needlegrass,
little bluestem, prairie junegrass, porcupinegrass, blue grama, native
legumes, silver sagebrush, western snowberry, winterfat | 001 |
| 2 | Silty-Clayey Range Site Complex, 10-14" P. Z.

Silty: Same as Site No. 1

Clayey: Same as Site No. 3 | 002 |
| 3 | Clayey and Shallow Clay Range Site Association, 10-14" P. Z.

Western and thickspike wheatgrass, green needlegrass, little bluestem,
prairie junegrass, plains reedgrass, biscuitroot, milkvetches, American
vetch, silver sagebrush, winterfat | 003 |
| 4 | Dense Clay-Clayey-Saline Upland Range Site Complex, 10-14" P. Z.

Dense Clay: Western and thickspike wheatgrass, green needlegrass,
prairie junegrass, big sagebrush, Nuttall saltbush, greasewood

Clayey: Same as Site No. 3

Saline Upland: Alkali sacaton, western and thickspike wheatgrass,
greasewood, Nuttall saltbush, inland saltgrass, bottlebrush squirreltail,
Sandberg bluegrass | 004 |
| 5 | Saline Lowland Range Site, 10-14" P. Z.

Western and thickspike wheatgrass, alkali sacaton, alkali cordgrass,
slender wheatgrass, Nuttall alkaligrass, inland saltgrass, Canada
wildrye, sedge, greasewood, Nuttall saltbush | 005 |
| 6 | Sands and Sandy Range Site Association, 10-14" P. Z.

Sands: Prairie sandreed, needleandthread, Indian ricegrass, little
bluestem, sand bluestem, sun sedge, native legumes, skunkbush sumac

Sandy: Needleandthread, prairie sandreed, threadleaf sedge, little
bluestem, sideoats grama, western and thickspike wheatgrass, native
legumes, blue grama, skunkbush sumac, rose | 006 |

WESTERN GLACIATED PLAINS:

- | | | |
|---|---|-----|
| 7 | Silty Range Site, 10-14" P. Z.

Needleandthread, western and thickspike wheatgrass, green needlegrass,
bluebunch wheatgrass, basin wildrye, prairie junegrass, native legumes,
silver sagebrush, blue grama | 007 |
| 8 | Silty-Clayey Range Site Complex, 10-14" P. Z.

Silty: Same as Site No. 7

Clayey: Same as Site No. 9 | 008 |

Classes:Computer
Identifier

9	Clayey and Shallow Clay Range Site Association, 10-14" P. Z. Green needlegrass, western and thickspike wheatgrass, bluebunch wheatgrass, needleandthread, prairie junegrass, plains reedgrass, milkvetches, scarlet globemallow, winterfat, prairie sandreed	009
10	Dense Clay-Clayey-Saline Upland Range Site Complex, 10-14" P. Z. Dense Clay: Western and thickspike wheatgrass, green needlegrass, basin wildrye, prairie junegrass, Nuttall saltbush, greasewood Clayey: Same as Site No. 9 Saline Upland: Alkali sacaton, western and thickspike wheatgrass, greasewood, basin wildrye, Nuttall saltbush, inland saltgrass, bottlebrush squirreltail, Sandberg bluegrass	010
11	Saline Lowland Range Site, 10-14" P. Z. Alkali sacaton, western and thickspike wheatgrass, Nuttall alkaligrass, alkali cordgrass, slender wheatgrass, inland saltgrass, sedge, greasewood, Nuttall saltbush	011
12	Sands and Sandy Range Site Association, 10-14" P. Z. Sands: Prairie sandreed, needleandthread, Indian ricegrass, threadleaf sedge, native legumes, yucca, skunkbush sumac Sandy: Needleandthread, prairie sandreed, threadleaf sedge, bluebunch wheatgrass, western and thickspike wheatgrass, native legumes, skunkbush sumac, blue grama	012
13	Subirrigated and Wetland Range Site Association Tall reedgrasses, tufted hairgrass, slender and bearded wheatgrass, northern mannagrass, prairie cordgrass, tall sedges, basin wildrye, Canada wildrye, willows, cottonwood, boxelder	013
EASTERN SEDIMENTARY PLAINS:		
14	Silty Range Site, 10-14" P. Z. (Includes thin breaks too small or irregular to delineate) Western and thickspike wheatgrass, little bluestem, needleandthread, green needlegrass, bluebunch wheatgrass, big bluestem, prairie junegrass, threadleaf sedge, native legumes, silver sagebrush, skunkbush sumac, winterfat, blue grama, western snowberry	014
15	Silty Range Site, 15-19" P. Z. Western and thickspike wheatgrass, green needlegrass, little bluestem, big bluestem, bluebunch wheatgrass, Idaho fescue, sideoats grama, native legumes, needleandthread, prairie junegrass, silver sagebrush	015
16	Silty-Clayey Range Site Complex, 10-14" P. Z. (Includes thin breaks too small or irregular to delineate) Silty: Same as Site No. 14 Clayey: Same as Site No. 18	016
17	Silty-Clayey Range Site Complex, 15-19" P. Z. Silty: Same as Site No. 15 Clayey: Same as Site No. 19	017

Classes:Computer
Identifier

- | | | |
|----|--|-----|
| 18 | Clayey and Shallow Clay Range Site Association, 10-14" P. Z.
Western and thickspike wheatgrass, green needlegrass, little bluestem, bluebunch wheatgrass, prairie junegrass, native legumes, big sagebrush, Nuttall saltbush, winterfat | 018 |
| 19 | Clayey and Shallow Clay Range Site Association, 15-19" P. Z.
Green needlegrass, western and thickspike wheatgrass, bluebunch wheatgrass, basin wildrye, big bluestem, little bluestem, Idaho fescue, prairie junegrass, prairie sandreed, native legumes, big sagebrush, Nuttall saltbush, winterfat | 019 |
| 20 | Dense Clay-Clayey-Saline Upland Range Site Complex, 10-14" P. Z.
Dense Clay: Western and thickspike wheatgrass, green needlegrass, basin wildrye, big sagebrush, Nuttall saltbush, greasewood, prairie junegrass
Clayey: Same as Site No. 18
Saline Upland: Alkali sacaton, western and thickspike wheatgrass, greasewood, basin wildrye, Nuttall saltbush, inland saltgrass, bottlebrush squirreltail, Sandberg bluegrass | 020 |
| 21 | Sands and Sandy Range Site Association, 10-14" P. Z.
Sands: Prairie sandreed, needleandthread, sand bluestem, Indian ricegrass, little bluestem, sun sedge, native legumes, skunkbush sumac, yucca
Sandy: Needleandthread, prairie sandreed, threadleaf sedge, little bluestem, sideoats grama, big bluestem, native legumes, blue grama, skunkbush sumac, rose | 021 |
| 22 | Riverbreaks, 10-14" P. Z.
Ponderosa pine, Rocky Mountain juniper, western and thickspike wheatgrass, bluebunch wheatgrass, green needlegrass, prairie sandreed, little bluestem, greasewood, big sagebrush, needleandthread, Nuttall saltbush, basin wildrye, native legumes, shadscale saltbush, creeping juniper | 022 |
| 23 | Badlands, 10-14" P. Z.
Western and thickspike wheatgrass, green needlegrass, little bluestem, bluebunch wheatgrass, prairie sandreed, alkali sacaton, prairie junegrass, Nuttall saltbush, big sagebrush, American vetch, plains muhly, sideoats grama, greasewood, juniper | 023 |
| 24 | Forest-Grassland Complex, 12-14" P. Z., on Very Shallow to Deep Soils with a Frigid Temperature Regime and Light Brown, Loamy Surfaces on Rolling to Hilly Terrain
Forest: (50%) Ponderosa pine, Rocky Mountain juniper, little bluestem, bluebunch wheatgrass, sideoats grama, skunkbush sumac, western wheatgrass, native legumes
Grassland: (50%) Little bluestem, needleandthread, western wheatgrass, green needlegrass, bluebunch wheatgrass, prairie sandreed, big bluestem, native legumes, skunkbush sumac, yucca, prairie junegrass, blue grama | 024 |
| 25 | Forest-Grassland Complex, 15-19" P. Z., on Very Shallow to Deep Soils with a Frigid Temperature Regime and Light Brown, Loamy Surfaces on Undulating to Hilly Terrain
Forest: (60%) Ponderosa pine, bluebunch wheatgrass, Idaho fescue, little bluestem, sideoats grama, snowberry, native legumes, arrowleaf balsamroot, green needlegrass, common chokecherry, saskatoon serviceberry
Grassland: (40%) Big bluestem, bluebunch wheatgrass, western wheatgrass, green needlegrass, needleandthread, prairie junegrass, basin wildrye, lupine, snowberry, saskatoon serviceberry, common chokecherry | 025 |

Classes:Computer
Identifier

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|-----------------------------|--|-----|
| 26 | <p>Ponderosa Pine Forests on Moderately Deep to Deep Soils with a Frigid Temperature Regime and Light Brown to Brown Surfaces on Undulating to Steep Terrain, 15-19" P. Z.</p> <p>Typical overstory composition is: Ponderosa pine 100%</p> | 026 |
| WESTERN SEDIMENTARY PLAINS: | | |
| 27 | <p>Silty Range Site, 10-14" P. Z.</p> <p>Bluebunch wheatgrass, western and thickspike wheatgrass, needleandthread, green needlegrass, basin wildrye, threadleaf sedge, prairie junegrass, native legumes, big and silver sagebrush, skunkbush sumac, common choke-cherry, blue grama</p> | 027 |
| 28 | <p>Silty Range Site, 15-19" P. Z.</p> <p>Bluebunch wheatgrass, western and thickspike wheatgrass, Idaho fescue, green needlegrass, basin wildrye, needleandthread, native legumes, big sagebrush, sticky geranium, prairiesmoke</p> | 028 |
| 29 | <p>Silty-Clayey Range Site Complex, 10-14" P. Z.</p> <p>Silty: Same as Site No. 27</p> <p>Clayey: Same as Site No. 31</p> | 029 |
| 30 | <p>Silty-Clayey Range Site Complex, 15-19" P. Z.</p> <p>Silty: Same as Site No. 28</p> <p>Clayey: Same as Site No. 32</p> | 030 |
| 31 | <p>Clayey and Shallow Clay Range Site Association, 10-14" P. Z.</p> <p>Western and thickspike wheatgrass, bluebunch wheatgrass, green needlegrass, big sagebrush, prairie junegrass, plains reedgrass, prairie sandreed, milkvetches</p> | 031 |
| 32 | <p>Clayey and Shallow Clay Range Site Association, 15-19" P. Z.</p> <p>Bluebunch wheatgrass, Columbia and green needlegrass, Idaho fescue, basin wildrye, big sagebrush, western and thickspike wheatgrass, prairie junegrass, prairie sandreed, lupine, other native legumes, sticky geranium, prairiesmoke</p> | 032 |
| 33 | <p>Dense Clay-Clayey-Saline Upland Range Site Complex, 5-9" P. Z.</p> <p>Dense Clay: Western and thickspike wheatgrass, inland saltgrass, Nuttall saltbush, big sagebrush, black sagebrush, bud sagebrush, shadscale saltbush, greasewood, Sandberg bluegrass, prairie junegrass</p> <p>Clayey: Western and thickspike wheatgrass, bluebunch wheatgrass, prairie junegrass, plains reedgrass, big sagebrush, bud sagebrush, milkvetches, winterfat, blue grama</p> <p>Saline Upland: Alkali sacaton, western and thickspike wheatgrass, greasewood, Nuttall saltbush, shadscale saltbush, fourwing saltbush, inland saltgrass, big sagebrush, bottlebrush squirreltail, Sandberg bluegrass</p> | 033 |
| 34 | <p>Dense Clay-Clayey-Saline Upland Range Site Complex, 10-14" P. Z.</p> <p>Dense Clay: Western and thickspike wheatgrass, green needlegrass, inland saltgrass, big sagebrush, Nuttall saltbush, greasewood, prairie junegrass, Sandberg bluegrass</p> <p>Clayey: Same as Site No. 31</p> <p>Saline Upland: Alkali sacaton, western and thickspike wheatgrass, greasewood, Nuttall saltbush, basin wildrye, inland saltgrass, big sagebrush, bottlebrush squirreltail</p> | 034 |

Classes:Computer
Identifier

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|-------------------------|--|-----|
| 35 | Riverbreaks, 10-14" P. Z.

Ponderosa pine, Rocky Mountain juniper, Douglas-fir (north slopes), bluebunch wheatgrass, western and thickspike wheatgrass, green needlegrass, prairie sandreed, basin wildrye, needleandthread, greasewood, big sagebrush, creeping juniper, native legumes, prairie junegrass | 035 |
| 36 | Forest-Grassland Complex, 12-14" P. Z., on Very Shallow to Deep Soils with Frigid Temperature Regimes and Light Brown, Loamy Surfaces on Rolling to Steep Terrain

Forest: (50%) Ponderosa pine, Rocky Mountain juniper, bluebunch wheatgrass, western wheatgrass, skunkbush sumac, snowberry, needleandthread

Grassland: (50%) Bluebunch wheatgrass, needleandthread, western and thickspike wheatgrass, green needlegrass, big sagebrush, prairie sandreed, native legumes, prairie junegrass | 036 |
| FOOTHILLS AND MOUNTAINS | | |
| 37 | Silty Range Site, 10-14" P. Z.

Bluebunch wheatgrass, rough fescue*, needleandthread, prairie junegrass, western and thickspike wheatgrass, green needlegrass, basin wildrye, threadleaf sedge, native legumes, big sagebrush, winterfat, Idaho fescue

*Codominant with bluebunch wheatgrass west of the Continental Divide but insignificant on east side at this P. Z. | 037 |
| 38 | Silty Range Site, 15-19" P. Z.

Rough fescue, Idaho fescue, bluebunch wheatgrass, Columbia needlegrass, basin wildrye, spike fescue, parry danthonia, slender wheatgrass, lupine, sticky geranium, arrowleaf balsamroot, prairiesmoke, big sagebrush, tall larkspur, prairie junegrass, timber danthonia, big bluegrass | 038 |
| 39 | Silty Range Site, 20-24" P. Z.

Rough fescue, Columbia needlegrass, Richardson needlegrass, mountain brome, bearded wheatgrass, slender wheatgrass, basin wildrye, Idaho fescue, lupine, sticky geranium, prairiesmoke, tall larkspur, big sagebrush, spike fescue, spike trisetum, purple oniongrass, nodding brome, quaking aspen, American bistort | 039 |
| 40 | Silty-Clayey Range Site Complex, 10-14" P. Z.

Silty: Same as Site No. 37

Clayey: Same as Site No. 42 | 040 |
| 41 | Silty-Clayey Range Site Complex, 15-19" P. Z.

Silty: Same as Site No. 38

Clayey: Same as Site No. 43 | 041 |
| 42 | Clayey and Shallow Clay Range Site Association, 10-14" P. Z.

Bluebunch wheatgrass, western wheatgrass, green needlegrass, basin wildrye, prairie junegrass, plains reedgrass, big sagebrush, milkvetches, American vetch, biscuitroot | 042 |
| 43 | Clayey and Shallow Clay Range Site Association, 15-19" P. Z.

Rough fescue (except south central Montana), bluebunch wheatgrass, Columbia needlegrass, western and thickspike wheatgrass, Idaho fescue, basin wildrye, lupine, sticky geranium, arrowleaf balsamroot, big sagebrush, prairiesmoke, prairie junegrass, deathcamas | 043 |

Classes:Computer
Identifier

44	Saline Lowland Range Site, 10-14" P. Z. Basin wildrye, alkali sacaton, Nuttall alkaligrass, alkali cordgrass, slender wheatgrass, western wheatgrass, inland saltgrass, greasewood, silver buffaloberry	044
45	Sand\$ and Sandy Range Site Association, 10-14" P. Z. Sands: Prairie sandreed, needleandthread, Indian ricegrass, bluebunch wheatgrass, threadleaf sedge, native legumes, skunkbush sumac, yucca Sandy: Needleandthread, bluebunch wheatgrass, native legumes, thread-leaf sedge, big sagebrush, prairie junegrass, skunkbush sumac	045
46	Limy-Shallow-Very Shallow Range Site Complex, 10-14" P. Z. Limy: Bluebunch wheatgrass, prairie junegrass, needleandthread, thread-leaf sedge, western and thickspike wheatgrass, Sandberg bluegrass, native legumes, winterfat Shallow: Bluebunch wheatgrass, rough fescue, needleandthread, big sagebrush, prairie junegrass, western wheatgrass, Sandberg bluegrass, gray horsebrush, phlox, native legumes Very Shallow: Bluebunch wheatgrass, prairie junegrass, western wheatgrass, threadleaf sedge, phlox, needleandthread, Sandberg bluegrass, native legumes - mountain mahogany, limber pine, antelope bitterbrush, big sagebrush, and Rocky Mountain juniper in cracks and crevices of bedrock	046
47	Subirrigated and Wetland Range Site Association Tall reedgrasses, tufted hairgrass, American mannagrass, tall sedges, slender wheatgrass, bearded wheatgrass, basin wildrye, willows; shrubby cinquefoil, prairie cordgrass, elephanthead pedicularis, monkeyflower, native clovers, Indianpaintbrush, common blue-eyedgrass	047
48	Alpine Grassland on Deep to Moderately Deep, Well Drained to Poorly Drained Soils with Cryic Temperature Regimes and Dark Brown and Very Dark Brown Surfaces on Sloping to Steep Windswept Mountain Tops Above Timberline, 40-70" P. Z. Tufted hairgrass, sedge, sheep fescue, alpine bluegrass, alpine timothy, native legumes, wolf willow, red mountainheath, white dryad, alpine bluebell, bluejoint, purple reedgrass, moss silene, yellow avens, tufted phlox, eriogonum, American bistort, shrubby cinquefoil	048
49	Forest-Grassland Complex, 15-19" P. Z., on Shallow to Moderately Deep Soils with a Frigid Temperature Regime and Brown to Dark Brown Surfaces under Grassland and Brown to Gray Surfaces under Forest on Sloping to Steep Terrain Forest: (60%) Douglas-fir, common snowberry, white spiraea, Oregongrape, heartleaf arnica, Columbia needlegrass, Idaho fescue, bearded wheatgrass, kinnikinnick Grassland: (40%) Bluebunch wheatgrass, Idaho fescue, Columbia needlegrass, basin wildrye, spike fescue, lupine, arrowleaf balsamroot	049
50	Rocky Mountain Juniper and Limber Pine on Shallow Soils with a Frigid Temperature Regime and Dark Grayish Brown Surfaces Developed from Lime-stone or Calcareous Sandstone Residuum on Moderately Steep to Very Steep Mountain Slopes - Rock Outcrop 40-70%, 10-14" P. Z. Typical overstory composition is: Rocky Mountain juniper 60% Limber pine 40%	050
51	Douglas-fir and Ponderosa Pine Climax Forests on Deep Soils with Cryic or Frigid Temperature Regimes and Light Brownish Gray, Brown, or Grayish Brown Surfaces on Hilly to Steep Mountain Slopes, 16-22" P. Z. Typical overstory composition is: Douglas-fir 60% Ponderosa pine 40%	051

Classes:Computer
Identifier

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|----|---|-----|
| 52 | Subalpine Fir, Douglas-fir, and Ponderosa Pine Climax Forests on Deep Soils with Cryic or Frigid Temperature Regimes and Grayish Brown, Light Brownish Gray, or Light Yellowish Brown Surfaces on Moderately Steep to Very Steep Mountain Slopes East of the Continental Divide, 16-35" P. Z. | 052 |
| | Typical overstory composition is: Subalpine fir 50%
Douglas-fir 35%
Ponderosa pine 10%
Engelmann spruce 5% | |
| 53 | Subalpine Fir and Douglas-fir Climax Forests on Deep Soils with Cryic Temperature Regimes and Pale Brown or Light Brownish Gray Surfaces on Moderately Steep to Very Steep Mountain Slopes, 20-45" P. Z. | 053 |
| | Typical overstory composition is: Subalpine fir 65%
Douglas-fir 25%
Engelmann spruce 10% | |
| 54 | Spruce and Douglas-fir Climax Forests on Deep Soils with Cryic or Frigid Temperature Regimes and Brown or Grayish Brown Surfaces and Calcareous Subsoils on Strongly Sloping to Very Steep Mountain Slopes, 20-45" P. Z. | 054 |
| | Typical overstory composition is: Spruce 50%
Douglas-fir 40%
Subalpine fir 10% | |
| 55 | Subalpine Fir, Douglas-fir, and Ponderosa Pine Climax Forests on Deep Soils with Cryic or Frigid Temperature Regimes and Grayish Brown, Light Brownish Gray, or Light Yellowish Brown Surfaces on Moderately Steep to Very Steep Mountain Slopes West of the Continental Divide, 16-70" P. Z. | 055 |
| | Typical overstory composition is: Subalpine pine 50%
Douglas-fir 35%
Ponderosa pine 10%
Engelmann spruce 5% | |
| 56 | Douglas-fir Climax Forests on Deep Soils with a Frigid Temperature Regime and Light Gray Surfaces and Calcareous Subsoils on Gently Rolling to Hilly Mountain Foot Slopes and Strongly Sloping to Steep Mountain Slopes, 16-30" P. Z. | 056 |
| | Typical overstory composition is: Douglas-fir 90%
Grand fir 10% | |
| 57 | Subalpine Fir, Douglas-fir, and Grand Fir Climax Forests on Deep Soils with Cryic or Frigid Temperature Regimes and Light Gray or Pale Brown Surfaces on Steep to Very Steep Mountain Slopes, 30-70" P. Z. | 057 |
| | Typical overstory composition is: Subalpine fir 55%
Douglas-fir 35%
Grand fir 10% | |
| 58 | Western Redcedar and Western Hemlock Climax Forests on Deep Soils with Frigid Temperature Regimes and Brown to Pale Brown or Light Gray Surfaces on Gently Sloping to Gently Rolling Valley Floors, 20-35" P. Z. | 058 |
| | Typical overstory composition is: Western redcedar 70%
Western hemlock 15%
Grand fir 15% | |
| 59 | Grand Fir and Douglas-fir Climax Forests on Deep Soils with Frigid Temperature Regimes and Pale Brown or Light Gray Surfaces on Steep to Very Steep Mountain Slopes, 25-60" P. Z. | 059 |
| | Typical overstory composition is: Grand fir 45%
Douglas-fir 45%
Western redcedar 10%
& western hemlock | |

Classes:Computer
Identifier

- | | | |
|----|---|-----|
| 60 | Subalpine Fir Climax Forests on Deep Soils with Cryic Temperature Regimes and Brown or Strong Brown Surfaces on Steep to Very Steep Mountain Slopes, 60-100" P. Z. | 060 |
| | Typical overstory composition is: Subalpine fir 70%
Mountain hemlock 20%
Douglas-fir 10% | |
| 61 | Hardwood Climax Forests on Alluvial Floodplains Along Major Rivers and Growing on Shallow to Deep, Well Drained to Poorly Drained Soils with Frigid Temperature Regimes | 061 |
| | Typical overstory composition is: | |
| | East of Continental Divide: Cottonwood 80%
Other hardwoods 20% | |
| | West of Continental Divide: Cottonwood 80%
Conifers 20% | |
| 62 | Rockland and Mixed High Elevation Vegetation Consisting of Forests, Krummholz, and Alpine Areas Growing on Shallow to Deep, Very Gravelly or Very Cobbly, and Stony Soils with Cryic Temperature Regimes, 40-110" P. Z. | 062 |
| | Typical composition is: Rockland 70%
Vegetation 30% | |

Comments : Publication Climax Vegetation of Montana. Map is based upon soils and climate. Soils data taken from soil association maps. Soils are grouped by geographic area and annual precipitation zones.

The following sections describe the storage and retrieval process used in the Montana Computer Graphic System. Individuals who need to use existing files rather than add new ones should proceed to the section on the retrieval of the information.

Computer Storage of Resource Data

Before the data can be processed (encoded) for storage in the computer it should be on a map at 1:1,000,000 scale (1 inch = 16 miles) and Albers equal-area projection. Resource data sites will normally be located on a larger scale map which is then reduced to this scale. The 1:250,000 USGS topographic map series is the largest scale which covers all of Montana. Some larger scale maps are available for some, but not all, areas of the state. An index of these maps is available in room 728 Johnson Hall, Montana State University.

All maps which are to be stored in the computer must be at a common scale and projection so they can be overlayed or superimposed for a composite display of several parameters. If a 1:1,000,000 base map is required, one may be found in room 728 Johnson Hall. A Map-O-Graph projector for enlarging or reducing maps is also located there.

It is recommended that the lines used to separate map intervals be labeled frequently and clearly to facilitate the determination of those values during the encoding process. At this time the resource map will be covered with a grid which will obscure some of the detail.

The use of colored pencils to identify each class facilitates this process.

When the map is ready to encode, the user should contact the Agricultural Experiment Station Statistical Services Section and request that a plotter-drawn grid be produced. This grid is used to divide the resource data into many discrete unit cells. The data are stored and retrieved based upon these cells.

The computer map is plotted on opaque paper which is not suitable for encoding since it must be possible to look through the grid to the resource map below. This necessitates taking the plotter grid to a shop, such as Selby's in Bozeman, which has the capability of copying this grid on to static-free drafting film which has a base thickness of .003 inch and matte on one side. This material is transparent, stable, and durable and is ideal for use as an encoding grid.

The grid has some rows and columns numbered on the edge of the map. It is recommended that additional units within the grid be labeled. The easier it is to determine a location within the grid the faster the encoding will be.

The grid should be placed on top of the resource map and secured with masking tape. Fortran coding sheets should be obtained and the name of the resource map being encoded should be written at the top of the sheets. The use of a light table may be beneficial depending upon the complexity of the map to be encoded.

Two people should be used to encode the resource data, one to read from the grid while the other records these values onto the fortran coding sheets. The encoding process always starts at the upper left hand (northwest) corner of the state (column 247). The data should be recorded on the sheets in the following format:

<u>Column</u>	<u>Description</u>
1- 3	Row number
4	Blank
5- 7	Column number
8	Blank
9-15	Resource code
16	Blank
17-19	Column number
20	Blank
21-27	Resource code
28	Blank
29-31	Column number
32	Blank
33-39	Resource code
40	Blank
41-43	Column number
44	Blank
45-51	Resource code
52	Blank
53-55	Column number
56	Blank
57-63	Resource code
64	Blank
65-67	Column number
68	Blank
69-75	Resource code
76-80	Blank

Row and column data are always a 3-digit number, being right justified with zeros being placed in unoccupied card columns on the left (Figure 2).

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^a NUMBER OF STUDENTS MAY EXCEED 100.

The resource codes are left justified in a 7-column field. Zeros are not placed in the unoccupied remainder of the field to the right of the resource value. Either alpha (letter) or numeric (number) symbols may be used for resource codes. Before encoding begins, a legend should be prepared showing the intervals used in the map and the symbols which will be recorded to represent each class. Since many values must be read and recorded to encode a map it is important that this symbol be as short and distinct as possible.

A change point system is used to process the data for computer storage. This means that a row of cells is examined until one is identified which has a different value than the previous interval. The two methods used to assign values to a cell are first, dominant unit and second, centrally located value. A cell is examined and a value assigned based upon the map interval which occupies the majority of the cell. Where no interval is clearly dominant the centrally located unit is recorded. This process continues from left to right (column 247 to column 7) for much of the map. When the last value change is recorded for a row, the first cell to the right of the right edge of the map (006 for much of the map) is recorded but a resource cell is not assigned. This is recognized by the computer as being the format for the end of the row.

After all rows of a map have been encoded, the fortran sheets must be checked for the following:

1. Since the coding began at the left side of the map (where the columns have the highest number) and proceeded to the right (where the column numbers decrease) it is necessary to verify that the columns recorded were in descending order.
2. The change point method means that adjacent values recorded should not be the same. Checking keeps this type of error from getting into the computer.
3. The last value recorded for each row must be a column number without an accompanying resource code. Failure to catch this type of error results in a plotter map with an uneven boundary.
4. The irregular shape of the western boundary of the state presents encoding problems since there are some rows of cells which include a portion in Montana followed by an out-of-state area followed by in-state data. The accuracy of this encoding must also be verified.

When all coding sheets have been checked they are ready to be keypunched and verified. A description of the data should be attached to the fortran forms. This should include the title of the map, its source, the intervals used, and the symbols used to represent each and any other information. There are three rows of 24 large characters

allotted for the title and five 80-column rows established for the credits. Experiment station researchers should take the fortran forms to the Statistical Services Office in the Computer Center for processing.

After the plotter-drawn map is produced it must be checked for accuracy. Verification of the correctness of the map entails superimposing the plotter map on the original hand-drawn map and checking each cell. Registry symbols ($\oplus$) should be placed on both maps before overlaying them. The use of these marks permits the user to put the corrected map in the exact position where the corrections were made.

Each row must be examined carefully and all cells verified. There are three types of data corrections that may need to be made (Figure 3). These are to correct individual cells, to correct portions of a line that must all be changed to a single value, and to correct an entire line. The format to be used for each of these is as follows:

- A. To correct individual cells the data cards must have the following format:

<u>Column</u>	<u>Description</u>
1- 3	Row number
4	Blank
5- 7	Column number
8	Blank
9-10	Correct resource code
11-80	Blank

- B. To correct portions of a line (from column __ to column __) the data cards must have the following format:

<u>Column</u>	<u>Description</u>
1- 3	Row number
4	Blank
5- 7	1st column number where correction should begin
8	Blank
9-11	Last column number where correction should begin
12	Blank
13-14	Correct resource code for the sequence of cells
15-80	Blank

C. To correct an entire line:

Use procedure outlined for the original encoding.

Usually once the registration symbols are used the corrected map will have only a negligible number of invalid cells. Although a totally correct map is the goal, the great number of cells involved precludes this without the expenditure of an excessive amount of time. Certainly the plains areas which are of greatest importance to the Montana Agricultural Experiment Station can be corrected to a high degree of accuracy without large time requirements. It is usually the mountainous areas which have less reliability.

This completes the computer storage portion of the procedure. The next section describes the format used to retrieve data from the system.

Retrieval of Computer Stored Resource Data

The Montana Computer Graphic System has the potential for helping researchers and planners with a wide variety of problems. The complexity and large number of possible applications make it impractical to

enumerate all the possible encoding formats which might be used to retrieve stored data. For this reason, this discussion will be limited to the most common application, the composite analysis of several maps. For other types of application the Statistical Services Section of the Montana Agricultural Experiment Station should be contacted.

For composite analysis the user should examine the list of files and select the intervals of the maps which are of importance. A list of the maps to be utilized should be made and each one assigned a sequential number, i.e., 01, 02, 03, etc. The computer identification number for each interval of each parameter to be used in the composite analysis should also be recorded.

In selecting classes of several files for composite analysis, the number of possible combinations may be large. For example, six soil units, two precipitation intervals, and two frost-free season periods would have 24 possible combinations. Each of these must be identified and recorded on fortran coding sheets (Figure 4). The encoding format groups one class from each parameter into a combination.

If the plotter is to show only the cells which meet one set of specifications, i.e., 10-12 inches of precipitation, 100-110 days frost-free season, Argiborolls, etc., 001 will always go in card columns 1-3 of the first card for each of the possible combinations. These columns will be blank in the other cards of the particular combination. The general format to be used on the fortran coding

IBM

FORTRAN Coding Form

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PROGRAM	SAMPLE OF COMPOSITE ANALYSIS OF 3 FILES										DATE	REVISION	ORIGIN	PAGE	OF
PROGRAMMER															

		FORTRAN STATEMENT																CONTINUATION			
LINE	CONT.	STATEMENT																			
001	1	029																			
	2	006																			
	3	005																			
001	1	112																			
	2	006																			
	3	005																			
001	1	122																			
	2	006																			
	3	005																			
001	1	036																			
	2	006																			
	3	005																			
001	1	096																			
	2	006																			
	3	005																			
001	1	012																			
	2	006																			
	3	005																			
001	1	087																			
	2	006																			
	3	005																			
001	1	034																			
	2	006																			
	3	005																			

Appendix figure 4. Encoding format for composite analysis.

sheets is:

<u>Columns</u>	<u>Description</u>
1- 3	Numeric value for composite (001 if the cells to be shown meet one set of specifications, 002 if two sets are used, etc.). Only required on first card of a set.
4	Blank
5- 6	Map Number (01, 02, 03, etc.).
7	Blank
8-11	Computer identifier for an interval or class of a map.

Thus each line of the fortran coding sheets, and each card which results, identifies a map and an interval of each of these. The cards from each map and interval used are grouped to reflect a possible combination.

To illustrate this methodology, if three files are used for a composite analysis, the computer might be told to look at map 1 and locate the cells which have value 29, then examine map 2 for values 14, 15, or 16 and map 3 for values 3 or 4. Each cell which has one of these six possible combinations will have a 001 assigned to it and a map will be drawn showing the location of these cells.

It is also possible to have a single plotter-drawn map produced which uses several different criteria and displays the cells which meet these with different symbols.

When the coding sheets are submitted for processing, the title and any other information that will go on the plotter produced map should

be included. If the map is to be used for a presentation to a large group some color enhancement will be necessary.

APPENDIX II

INSTRUCTIONS FOR PREPARATION OF THE ALBERS EQUAL-AREA PROJECTION

An equal-area projection based upon two standard parallels was proposed by H. C. Albers of Gotha in 1805. This projection combines a small-scale error with equality of area. It has concentric parallels and meridians that radiate from the center of the parallels. Two standard parallels are chosen so that about two-thirds of the map is encompassed by them and their radii are calculated so as to make the projection equal-area (Rasiz 1948). This computation is involved and the mathematical formulas required are not easy to locate.

Since much time and effort were required to determine how to make this projection, the procedure is included here for others. The following information is based upon correspondence with Mr. Doyle Smith, U. S. Geological Survey, Reston, Virginia.

Mathematical Model

A. Definitions:

- ρ The latitude of a point whose projection coordinates are desired.
- μ The longitude of a point whose projection coordinates are desired.
- E_c The eccentricity of the earth.
- ρ_0 The latitude of the center of the map.
- Δ_μ The longitude referenced to the central meridian. $\Delta_\mu = \mu - \mu_0$

ρ_{sp1} The lower (southerly) standard parallel for projection having two standard parallels or the standard parallel for projection having one standard parallel.

ρ_{sp2} The upper (northerly) standard parallel for projection having two standard parallels.

ℓ The constant of the cone for conic projections.

k The constant of integration for conic projections.

a Radius of the earth in nautical miles.

B Minor axis of Spheroid (meters).

- B. The following are the transformation constants for the Albers Equal-Area Projection. These must be computed before you can determine the location of specific points.

$$\ell = \frac{\frac{a^2 \cos^2 \rho_{sp1}}{(1 - Ec^2 \sin^2 \rho_{sp1})} - \frac{a^2 \cos^2 \rho_{sp2}}{(1 - Ec^2 \sin^2 \rho_{sp2})}}{2 \cdot \frac{C^2}{C^2} (\sin B_2 - \sin B_1)}$$

where $\sin B_1$, $\sin B_2$, and C^2 equal the following:

$$\sin B_1 = \sin \rho_{sp1} \left[\frac{1.0 + \frac{2}{3} Ec^2 \sin^2 \rho_{sp1} + \frac{3}{5} Ec^4 \sin^4 \rho_{sp1} + \frac{4}{7} Ec^6 \sin^6 \rho_{sp1}}{1.0 + \frac{2}{3} Ec^2 + \frac{3}{5} Ec^4 + \frac{4}{7} Ec^6} \right]$$

$$\sin B_2 = \sin \rho_{sp2} \left[\frac{1.0 + \frac{2}{3} Ec^2 \sin^2 \rho_{sp2} + \frac{3}{5} Ec^4 \sin^4 \rho_{sp2} + \frac{4}{7} Ec^6 \sin^6 \rho_{sp2}}{1.0 + \frac{2}{3} Ec^2 + \frac{3}{5} Ec^4 + \frac{4}{7} Ec^6} \right]$$

$\sin B_1$ and $\sin B_2$ are based upon the two standard parallels used

$$C^2 = a^2 (1.0 - Ec^2) \left[\frac{.5}{(1 - Ec^2)} + \left(\frac{.25}{Ec} \log \left(\frac{1 + Ec}{1 - Ec} \right) \right) \right]$$

$$k = \frac{a \cos \rho_{sp1}}{\ell (1 - Ec^2 \sin^2 \rho_{sp1})^{\frac{1}{2}}}$$

$$\sin B_o = \sin \rho_o \left[\frac{1.0 + \frac{2}{3}Ec^2 \sin^2 \rho_o + \frac{3}{5}Ec^4 \sin^4 \rho_o + \frac{4}{7}Ec^6 \sin^6 \rho_o}{1.0 + \frac{2}{3}Ec^2 + \frac{3}{5}Ec^4 + \frac{4}{7}Ec^6} \right]$$

$\sin B_o$ is based upon the parallel midway between the two standard parallels used for the projection.

$$r_o = \left[k^2 + \frac{2c^2}{\ell} (\sin B_1 - \sin B_o) \right]^{\frac{1}{2}}$$

- C. The following equations are used for the transformation from latitude and longitude to x,y (map coordinates) given ℓ , k , and r_o .

$$\sin B = \sin \rho \left[\frac{1.0 + \frac{2}{3}Ec^2 \sin^2 \rho + \frac{3}{5}Ec^4 \sin^4 \rho + \frac{4}{7}Ec^6 \sin^6 \rho}{1.0 + \frac{2}{3}Ec^2 + \frac{3}{5}Ec^4 + \frac{4}{7}Ec^6} \right]$$

$\sin B$ is based upon the actual coordinates you are trying to locate

$$r_m = \left[k^2 + \frac{2c^2}{\ell} (\sin B_1 - \sin B) \right]^{\frac{1}{2}}$$

$$x = r_m \sin (\ell \cdot \Delta\mu)$$

$$y = r_o - r_m \cos (\Delta\mu\ell)$$

x and y are the actual map coordinates.

- D. In solving these equations the following values should be used:

$Ec = 0.082271854$ (the eccentricity of the earth)

$a = 3435.8016$ nautical miles (radius of the earth)

$\rho_{sp1} = 29^{\circ}30'N$ (the lower, southerly, standard parallel)

$\rho_{sp2} = 45^{\circ}30'N$ (the higher, northerly, standard parallel)

$\rho_o = 37^{\circ}30'N$ (latitude of the center of map)

Objective: To convert x and y in nautical miles and show cartesian reference.

E. Solution.

Preliminary (required to compute location of any coordinates):

$$\begin{aligned}
 \text{Series:} &= 1 + \frac{2}{3}Ec^2 + \frac{3}{5}Ec^4 + \frac{4}{7}Ec^6 \\
 &= 1 + \frac{2}{3}(.0822)^2 + \frac{3}{5}(.0822)^4 + \frac{4}{7}(.0822)^6 \\
 &= 1 + \frac{2}{3}(.00676) + \frac{3}{5}(.000046) + \sim 0 \\
 &= \underline{1.00453}
 \end{aligned}$$

$$\sin B_1 = \sin \rho_{ps1} \left[\frac{1 + \frac{2}{3}Ec^2 \sin^2 \rho_{ps1} + \frac{3}{5}Ec^4 \sin^4 \rho_{ps1} + \frac{4}{7}Ec^6 \sin^6 \rho_{ps1}}{1 + \frac{2}{3}Ec^2 + \frac{3}{5}Ec^4 + \frac{4}{7}Ec^6} \right]$$

$$\sin B_1 = \sin 29^\circ 30'$$

$$\left[\frac{1 + \frac{2}{3}(.0822)^2 \sin^2 29^\circ 30' + \frac{3}{5}(.0822)^4 \sin^4 29^\circ 30' + \frac{4}{7}(.0822)^6 \sin^6 29^\circ 30'}{1.00453} \right]$$

$$\sin B_1 = \sin 29^\circ 30' \left[\frac{1 + .001 + \sim 0 + \sim 0}{1.00453} \right]$$

$$= (\sin 29^\circ 30')(.9966)$$

$$\sin B_1 = \underline{.4907}$$

$$\sin B_2 = \sin \rho_{sp2} \left[\frac{1 + \frac{2}{3}Ec^2 \sin^2 \rho_{sp2} + \frac{3}{5}Ec^4 \sin^4 \rho_{sp2} + \frac{4}{7}Ec^6 \sin^6 \rho_{sp2}}{1 + \frac{2}{3}Ec^2 + \frac{3}{5}Ec^4 + \frac{4}{7}Ec^6} \right]$$

$$\sin B_2 = \sin 45^\circ 30'$$

$$\left[\frac{1 + \frac{2}{3}(.0822)^2 \sin^2 45^\circ 30' + \frac{3}{5}(.0822)^4 \sin^4 45^\circ 30' + \frac{4}{7}(.0822)^6 \sin^6 45^\circ 30'}{1.00453} \right]$$

$$\sin B_2 = \sin 45^\circ 30' \left[\frac{1 + .0023 + \sim 0 + \sim 0}{1.00453} \right]$$

$$\sin B_2 = (.7132)(.9978)$$

$$\sin B_2 = \underline{.7117}$$

$$C^2 = a^2(1 - E_c^2) \left[\frac{.5}{(1 - E_c^2)} + \left(\frac{.25}{E_c} \ln \left(\frac{1 + E_c}{1 - E_c} \right) \right) \right]$$

$$= (3435.8)^2 (1 - .0822^2) \left[\frac{.5}{(1 - .0822^2)} + \left(\frac{.25}{.0822} \ln \frac{1 + .0822}{1 - .0822} \right) \right]$$

$$= (11804722)(.9932)[.5034 + .5011]$$

$$C^2 = \underline{11777210}$$

$$\ell = \frac{a^2 \cos^2 \rho_{ps1}}{(1 - E_c^2 \sin^2 \rho_{sp1})} - \frac{a^2 \cos^2 \rho_{sp2}}{(1 - E_c^2 \sin^2 \rho_{sp2})}$$

$$2C^2(\sin B_2 - \sin B_1)$$

$$\ell = \frac{(3435.8)^2 \cos^2 29^\circ 30'}{1 - .0822^2 \sin^2 29^\circ 30'} - \frac{(3435.8)^2 \cos^2 45^\circ 30'}{1 - .0822^2 \sin^2 45^\circ 30'}$$

$$(2)(11792159)(.7117 - .4907)$$

$$\ell = \frac{\frac{8942301.4}{.9984} - \frac{5799350.4}{.9965}}{5212134.3}$$

$$\ell = \underline{.6018}$$

$$\begin{aligned}
 k &= \frac{a \cos \rho_{sp1}}{\ell (1 - Ec^2 \sin^2 \rho_{sp1})^{\frac{1}{2}}} \\
 &= \frac{3435.8 \cos 29^\circ 30'}{.6018 (1 - .0822^2 \sin^2 29^\circ 30')^{\frac{1}{2}}} \\
 &= \frac{2990.37}{.6018 (.9984)^{\frac{1}{2}}}
 \end{aligned}$$

$$k = \underline{4973.03}$$

$$\begin{aligned}
 \sin B_o &= \sin \rho_o \left[\frac{1 + \frac{2}{3} Ec^2 \sin^2 \rho_o + \frac{3}{5} Ec^4 \sin^4 \rho_o + \frac{4}{7} Ec^6 \sin^6 \rho_o}{1 + \frac{2}{3} Ec^2 + \frac{3}{5} Ec^4 + \frac{4}{7} Ec^6} \right] \\
 &= \sin 37^\circ 30' \left[\frac{1 + \frac{2}{3} (.0822)^2 (\sin 37^\circ 30')^2}{1.00453} \right] \\
 &= (.069) (.9971)
 \end{aligned}$$

$$\sin B_o = \underline{.607}$$

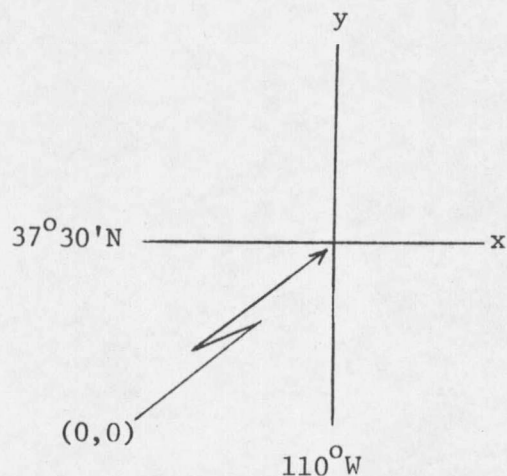
$$\begin{aligned}
 r_o &= \left[k^2 + \frac{2c^2}{\ell} (\sin B_1 - \sin B_o) \right]^{\frac{1}{2}} \\
 r_o &= \left[(4973.0)^2 + \frac{2(11777210)}{.6027} (.4907 - .607) \right]^{\frac{1}{2}} \\
 r_o &= \underline{4492.83}
 \end{aligned}$$

To determine the location of a specific set of coordinates:

Example: 45° North 104° West

$$\rho = 45^\circ$$

$\Delta\mu = 6^\circ$ since 104° West is 6 degrees east from the origin of the map which is located at $37^\circ 30'N$, $110^\circ W$.



$$\sin B = \sin \rho \left[\frac{1 + \frac{2}{3}Ec^2 \sin^2 \rho + \frac{3}{5}Ec^4 \sin^4 \rho + \frac{4}{7}Ec^6 \sin^6 \rho}{1 + \frac{2}{3}Ec^2 + \frac{3}{5}Ec^4 + \frac{4}{7}Ec^6} \right]$$

$$\sin B = \sin 45^\circ \left[\frac{1 + \frac{2}{3}(.0822)^2 \sin^2 45^\circ + \sim 0 + \sim 0}{1.00453} \right]$$

$$\sin B = .7055$$

$$r_m = \left[k^2 + \frac{2c^2}{\ell} (\sin B_1 - \sin B) \right]^{\frac{1}{2}}$$

$$r_m = \left[(4973.0)^2 + \frac{2(11777210)}{.6018} (4907 - .7055) \right]$$

$$r_m = 4040.2$$

$$x = r_m \sin (\ell \cdot \Delta\mu)$$

$$x = 4040.2 \sin (.0618 \times 6^\circ)$$

$$x = 254.44 \text{ nautical miles}$$

$$y = r_o - r_m \cos (\ell \cdot \Delta\mu)$$

$$y = 4492.83 - 4040.2 \cos (\ell \Delta\mu)$$

$$y = 460.6 \text{ nautical miles}$$

These x and y values represent the distance on a 1:1 scale map from 37.5°N and 110°W to the point selected (in this case 45°N and 104°W).

To convert to measurements which the plotter can use to draw the map, the following equations are used:

$$x \text{ inches} = \frac{x \text{ nautical miles} + 275}{13.706}$$

$$y \text{ inches} = \frac{y \text{ nautical miles} - 337.5}{13.706}$$

(13.706 nautical miles/inch on the map)

These measures are calculated from a point close to the bottom of the plotter paper. The plotter starts at the lower left and plots from there.

APPENDIX III
CLIMATIC DATA SUMMARY FOR CORVALLIS RESEARCH CENTER

Frost-Free Season

Year	Last freeze	First freeze	Length of freeze-free season (days)
1966	June 5	Sept 30	117
1967	May 26	Oct 4	131
1968	June 14	Oct 2	110
1969	May 21	Sept 4	106
1970	May 14	Sept 10	119
1971	June 15	Sept. 14	91
1972	May 26	Sept 7	104
1973	June 19	Sept 17	90
1974	June 2	Sept 2	92
1975	May 26	Sept 19	116
1976	May 29	Sept 8	102
1977	May 30	Sept 9	100

Average length of frost-free season at Corvallis Research Center (1966-77) is 106.5 days.

Precipitation

Month	1977	1976	1975	1974	1973	1972	1971	1970	1969	1968	1967	1966
Jan	.41	.25	1.27	1.44	.35	1.04	.96	1.51	2.32	.28	1.31	.90
Feb	.13	.65	.98	.16	.20	1.65	.37	.16	.35	.54	.37	.27
Mar	.62	.34	.59	1.03	.81	.91	.58	.70	.07	.22	.89	.45
Apr	.29	1.19	2.03	.20	.41	1.35	1.91	.36	.46	.45	1.90	.11
May	2.19	1.26	2.10	1.21	.68	1.01	1.39	1.41	2.70	.98	1.13	.32
June	1.11	1.14	1.18	.98	1.91	.93	1.12	2.22	2.96	1.24	2.18	2.19
July	1.55	1.11	1.28	.91	.15	.82	.01	1.89	.24	.25	.38	.27
Aug	1.20	1.50	2.22	1.93	.50	.32	1.23	.04	.03	1.43	.25	.99
Sept	1.04	1.05	.30	.35	1.67	1.36	.62	1.34	.81	1.88	.68	.89
Oct	.68	.21	3.43	.33	1.47	.43	.17	.09	.69	.76	2.41	.72
Nov	1.16	.38	.54	.34	2.12	.42	.87	.45	.11	1.02	.54	.24
Dec	N/A	Trace	.65	.20	.96	.92	.13	.43	.72	.53	1.08	.24
Total	9.08	16.57	9.08	11.23	11.16	9.36	10.60	11.46	9.58	13.12	7.59	

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Average annual precipitation at Corvallis Research Center (1966-77) was 10.8 inches.

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