



Development of a Montana land cover map from Landsat imagery
by Philip William Smith

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Soil Science

Montana State University

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Abstract:

Landsat color composite transparencies were visually interpreted in an effort to produce an accurate low cost land cover map of Montana. Seven categories of land cover were interpreted and the data transferred directly to a mylar overlay registered to a 1:1,000,000 scale base map. Cover categories included in the state map are range, forest, dryland crops, irrigated crops, alpine areas and rock outcrops, water, and urban areas. The map was compiled at an estimated cost of \$0.01/km² and showed 90% agreement with existing county land use maps.

Upon completion, the land cover map was encoded along with the state soils map for conversion to AREAS, South Dakota State University's computerized geographic information system. Output from AREAS includes the hectares of land occupied by each cover type and each cover type's distribution on Montana's soil associations. The results from AREAS show that range occupies 50%, forest 27%, dryland crops 18%, irrigated crops 3%, alpine and rock outcrops 2%, water 0.5%, and urban less than 0.1% of Montana's total land area.

This study demonstrated manual interpretation of Landsat imagery to provide an inexpensive and accurate alternative to conventional surveys for small scale land cover mapping.

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Date May 29, 1981

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FROM LANDSAT IMAGERY

by

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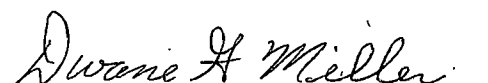
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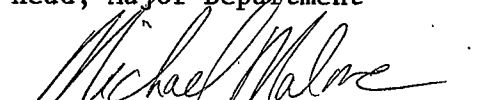
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1. Computer plotted Montana land cover map

ABSTRACT

Landsat color composite transparencies were visually interpreted in an effort to produce an accurate low cost land cover map of Montana. Seven categories of land cover were interpreted and the data transferred directly to a mylar overlay registered to a 1:1,000,000 scale base map. Cover categories included in the state map are range, forest, dryland crops, irrigated crops, alpine areas and rock outcrops, water, and urban areas. The map was compiled at an estimated cost of \$0.01/km² and showed 90% agreement with existing county land use maps.

Upon completion, the land cover map was encoded along with the state soils map for conversion to AREAS, South Dakota State University's computerized geographic information system. Output from AREAS includes the hectares of land occupied by each cover type and each cover type's distribution on Montana's soil associations. The results from AREAS show that range occupies 50%, forest 27%, dryland crops 18%, irrigated crops 3%, alpine and rock outcrops 2%, water 0.5%, and urban less than 0.1% of Montana's total land area.

This study demonstrated manual interpretation of Landsat imagery to provide an inexpensive and accurate alternative to conventional surveys for small scale land cover mapping.

INTRODUCTION

The purpose of this research was to determine the capability and accuracy of manual interpretation of Landsat satellite imagery for inventorying land cover in Montana. Products of this research include a 1:1,000,000 scale state land cover map for Montana and areal tabulations for each land cover category and its distribution on the state's soil associations.

The Need for Land Cover Information and Analysis

Until now, no land cover/use map has been available for Montana. Montana's size and natural resource diversity create a need for a reliable and economical method of land resource inventory. Montana is the fourth largest state in the nation with a total surface area of 235,421 square kilometers (USDI-BLM, 1969). Within this area, the complexity of Montana's geologic, climatic, vegetational and pedologic patterns combine to form a variety of natural ecosystems. Since the demands on these ecosystems are increasing and often conflicting, there is a need for an efficient and cost-effective method of land resource inventory and analysis. The perspective offered by remote sensing from aerial and space platforms provides for the rapid collection of current and detailed land resource data. Particularly valuable is the spatial context of the data, which provides insight into the distribution of resources,

their areal extent, and proximal relationships (Cox, 1977). These assets make land resource inventories compiled from remote sensing data a viable alternative to more conventional surveys.

LITERATURE REVIEW

The recording of remotely sensed data from aerial platforms was underway in the late 1800's and early 1900's. In the following years, two world wars and several international crises stimulated rapid advances in remote sensing methods and technology.

The conservation-oriented programs of the New Deal helped to initiate large aerial mapping programs in the United States. Many of these programs are still conducted by the USDA and other agencies as part of their natural resource surveys.

The manned space program of the 1960's brought space photography into its own and demonstrated the potential for monitoring earth resources from space (Kroeck, 1976).

The Landsat satellite series, operational since 1972, adds another dimension to remote sensing from space. Providing repetitive coverage of the earth's surface, Landsat makes possible the continuous monitoring of the earth's natural resources.

Description of the Landsat Program

The Landsat Program (formerly the Earth Resources Technology Program) was designed as a research and development tool to demonstrate the usefulness of satellite remote sensing in the management of earth resources (Anonymous, 1977). Since the launching of Landsat-1 (formerly ERTS-1) on July 23, 1972, two additional

satellites, Landsats-2 and -3, have been put in orbit. Although Landsat-1 exceeded its planned orbital life, at this writing only Landsats-2 and -3 are still producing data.

Each satellite was launched into a near polar, sun-synchronous orbit at an average altitude of 910 kilometers. The sensor design for all three Landsats is similar except for modifications made on Landsat-3. Landsat's main sensor system is the multispectral scanner (MSS). The MSS collects radiometric data in four discrete spectral bands within the visible and near infrared spectrum (Anonymous, 1977) (Table 1). Upon collection, the data are either transmitted directly to one of the ground receiving stations at Fairbanks, Alaska; Goldstone, California; and Greenbelt, Maryland or stored on tape until the satellite comes in view of a ground station.

Table 1. Landsat MSS characteristics.

Band	Wavelength (um)	Spectral Region
4	0.5 - 0.6	green
5	0.6 - 0.7	red
6	0.7 - 0.8	near IR
7	0.8 - 1.1	near IR

The spacecraft motion produces a continuous strip of data. During image processing at the Ground Data Handling System Facility, this strip of imagery is formed into separate images. These images, called scenes, incorporate a ground coverage area of 185 x 185 kilometers. The lateral ground resolution of the MSS is approximately 80 meters. Each picture element (pixel) covers a ground area of about 0.4 hectares, but the minimum area resolved is usually closer to 2 to 4 hectares (Seevers and Peterson, 1978).

Landsat data are available in either computer compatible tapes (CCTs) containing the digital data of all spectral bands or in a variety of photographic products (Gonzales and Sos, 1974).

Monitoring Land Use from Space Platforms

Starting with photographs from early manned flights, numerous land use studies have been performed using imagery taken from space platforms.

Land Use Surveys from Manned Spacecraft Photography

Manual interpretation of Gemini and Apollo manned spacecraft photography was employed to produce generalized land use maps at scales of 1:250,000 and 1:1,000,000 for portions of the southwestern United States. The broad view provided by the photos was found to

be important in the study of regional relationships of both physical and cultural features (Thrower, 1970).

Skylab photography was interpreted visually in an attempt to map land use in the Fairfax, Virginia area. It was established that the Skylab photography filled the gap between the coarser resolution Landsat MSS data and high altitude U-2 plane photography. The Skylab photography enabled the interpreters to map urban structural detail from orbital altitudes. In comparison, urbanized areas could be delineated on Landsat MSS images but it was difficult to determine the specific activities (commercial, industrial, etc.) present (Lins, 1976).

Automated Analysis of Landsat Data

The format of Landsat products makes possible either manual or automated (computer) interpretation of the MSS data. Automated techniques, involving the analysis of computer compatible tapes have advantages over visual interpretations resulting from the rapid quantitative identification of land resource categories and the immediate generation of summary statistics (Welch, et al., 1979).

Automated analyses of Landsat data have been employed in several studies involving general land use (Dornbach and McKain, 1973; Welch, et al., 1979) and agricultural land use (Richardson, et al.,

1977; Hanuschak, et al., 1979; Bauer, 1978). In the automated analysis of Landsat data, Draeger, et al. (1974) emphasized the importance of human-computer interaction, concluding that the most efficient and cost-effective method for producing "automated" surveys involves the use of manual interpretation at several stages of the process, particularly in the preliminary stratifications.

Manual Analysis of Landsat Data

The analysis of Landsat data by manual interpretation techniques requires less specialized training and less expensive equipment than automated procedures (Heller and Johnson, 1979). In addition, visual interpretation of Landsat imagery permits the rapid construction of regional and local map products (Welch, et al., 1979).

Using a variety of techniques but emphasizing visual interpretation methods, small scale land use maps of the northeastern portion of the Plain of China and the Nun River Basin were produced from Landsat imagery. To help identify crop types, aids including crop calendars, reflectance spectra and the use of images recorded on dates maximizing reflectance differences between crops were applied (Welch, et al., 1979).

Manual interpretation methods were also used to generate a land use map for the state of Iowa from Landsat imagery. The map was

drawn at a scale of 1:250,000 and then printed at 1:500,000 and includes nine categories of land use: Urban residential, urban commercial/industrial, urban open, transportation networks, extractive land, agricultural land, forest, water, and reservoir flood pools. Summer images were used since it was determined that they provided the most complete land use information (Anderson, 1977).

Landsat color composite prints (a single photographic product produced by transmitting blue, green and red light through images of bands 4, 5 and 7 respectively) were interpreted visually and the data mapped directly onto an acetate overlay to produce a land use map of Boone County, Missouri. The interpreters used ancillary data including geologic, hydrologic, topographic, soils, road and previous land use maps in addition to familiarizing themselves with crop calendars, weather data and existing aerial photography. Using this methodology, maps with accuracies between 70 and 90 percent were easily and quickly generated (Elifrits, et al., 1978).

The impending development of Wyoming's fuel reserves requires that a quick and efficient method of land resource inventory be employed to help manage the state's forthcoming growth. The use of photo interpretive techniques for analyzing Landsat imagery were investigated in a preliminary study of Wyoming's Powder River Basin. Landsat data were able to provide much of the needed physiographic

and land use information more quickly and efficiently than conventional inventory methods. Although Landsat imagery did not furnish the detail needed for some land use applications, it was found to be capable of providing a great deal of broad scale land use data on a continuing basis (Breckenridge, et al., 1973).

Cropland inventories comparing 1:125,000 scale color infrared (CIR) high altitude photography and Landsat 1:1,000,000 scale (band 5) black and white imagery were conducted in Kern County, California. Inventories completed using imagery acquired on a single date revealed no significant differences in accuracy between the two imagery sources. In terms of absolute accuracy though, the optimum results were achieved by a multirate analysis of the Landsat imagery. This is significant in that even though the scale had been decreased and the resolution degraded compared to the 1:125,000 photography, the analysis of Landsat data achieved comparable results and in this study slightly higher absolute accuracy (98% vs. 97% accuracy) than the CIR photos. The availability of multirate Landsat scenes and the lower cost of Landsat imagery for an equivalent ground area give Landsat additional advantages over high altitude CIR photography. In any case, surveys completed from either high altitude CIR photos or Landsat imagery can be accomplished at 3% to 5% of the cost and in 95% less time than conventional cropland surveys (Jensen, et al., 1975).

The repetitive coverage of Landsat enables the interpreter to monitor changes in land resources over specific time periods. For California's San Joaquin Valley, photo interpretation of Landsat imagery was used to record land use changes during a one year period. The imagery proved adequate in monitoring and mapping macrolevel land use changes. However, it was determined that to achieve the best mapping accuracy the interpreters should be familiar with the areas's landscape features and their geographic distribution (Estes, et al., 1974).

To estimate irrigated acreage in a section of southwestern Idaho, Landsat false color composites were manually interpreted and the data recorded on a grid corresponding to a commonly used map base. Each map grid cell represented a ground equivalent area of 3.6 x 3.6 kilometers and the imagery was selected to match the time when the bulk of the irrigated crops were at maturity. Imagery covering a three year time span was chosen to determine the extent of irrigated cropland expansion during that period. The data was mapped at 1:1,000,000 and found to have a sampling error of 6-10%, an error rate quite acceptable for this type of survey (Heller and Johnson, 1979).

A similar inventory of irrigated lands was completed for the Klamath River Basin of Oregon. For the inventory it was necessary to use imagery from both mid-summer and late-summer to discriminate

between irrigated and dry farmland. In July all irrigated fields appear red on the imagery as do a few dryland areas. However, by September all dryland crops have matured and appear tan on the imagery while most of the irrigated lands still have a red appearance. By comparing the images from the two dates the irrigated and dryland fields could be definitely separated (Draeger, et al., 1976).

Place (1974) used manual interpretation of Landsat imagery in an attempt to map land use change in the Phoenix, Arizona area. Changes detected included conversion of crop and rangeland to residential development, desert to new cropland, and new reservoir fill-up. Land use change detection from interpretation of high altitude U-2 plane photos was more detailed than the Landsat interpretation but the total area and pattern of change were similar for both interpretations. An attempt to enhance change detection by overlaying images of different dates using different color filters proved ineffective. The primary differences shown by enhancement proved to be different stages of vegetative growth and not land use changes.

Geographic Information Systems Using Remote Sensing Data Input

The formulation of geographic information systems (GIS) has been a recent development in the management of land resource data.

Such systems commonly contain data on soils, geology, vegetation, transportation, political units and other land related factors (Ford, 1978). Shelton and Estes (1979) discussed the need for the integration of geographic information systems with remotely sensed data. Hill-Rowley and Enslin (1979) noted that the incorporation of remotely sensed land cover information into regional computer grid systems should be a defined objective of regional planning agencies.

New York State's LUNR (Land Use and Natural Resource Inventory) was one of the first systems developed that incorporated remotely sensed data on a large scale. Initiated in 1966 by the Center for Aerial Photographic Studies at Cornell University, LUNR used visual interpretation of conventional black and white aerial photographs to compile a detailed inventory of land use and natural resources in New York. This information is stored on computer discs and products of the system include overlay maps of areal, point, or linear data; printouts listing information about each cell; and computer maps indicating the location of quantitative analyses performed on the data (Ford, 1978; Hardy and Shelton, 1970; Shelton and Tilman, 1978).

Many geographic information systems are now using information derived from the interpretation of Landsat satellite imagery as a source of land resource data. In Minnesota, Landsat imagery has been applied to updating land use data for the Minnesota Land

Management Information System (Sizer, 1974). It was established that high quality Landsat images could yield more detailed land use data than previously existed for Minnesota (Brown, et al., 1973).

The United States Geological Survey has tested the capability of Landsat as a source of environmental data for CARETS (Central Atlantic Regional Ecological Test Site), an experimental regional environmental information system. Like LUNR, CARETS is a geographic information system with overlay capabilities for computer map production. This system has been used in test studies to detect land use changes along the mid-Atlantic coast of the United States with favorable results (Alexander, 1973 and 1974).

CRIES (Comprehensive Resource Inventory and Evaluation System), originated in 1975 by the United States Department of Agriculture and Michigan State University for estimating agricultural growth potential in developing countries, also employs Landsat data as a source of land use information. In the Dominican Republic manual interpretation of Landsat imagery proved to be accurate, practical, and more discriminating than computer classifications for inputs into CRIES. The use of manual techniques for interpreting Landsat imagery is also advantageous in that the technology required for such interpretations is easily transferred to workers in developing areas (Shelton and Tilman, 1978).

Input of remotely sensed data into a GIS allows combination with other spatial resource data to aid in planning and zoning activities. Such an analysis was undertaken near the Black Hills of South Dakota where land use data from visually interpreted high altitude photography were composited with soils information to assist in land use decisions (Cox, 1977).

Landsat data were added to a computer management system for a power plant siting study on the Delmarva (Delaware, Maryland and Virginia) Peninsula. The result was the production of computer drawn composite maps showing areas having acceptable land resource parameters for either nuclear or fossil fuel power plants (Halpern, et al., 1975).

There are several advantages to computer processing of digitized data contained within a geographic information system. Digital data are registered to geographic coordinates and stored in easily accessible form for overlay and monitoring capabilities. In some systems the planimeter task can be done by computer rather than by manual methods and spatial display of the data can be provided at the desired map scale by computer plotter. This eliminates the need for cartographic or photo lab renditions of the data including enlargements and reductions, making a variety of hardcopy products readily available (Cox, 1977).

MATERIALS AND METHODS

Manual interpretation of Landsat false color composite transparencies was used to produce a land cover map for Montana at a scale of 1:1,000,000. The thirty-five images needed for statewide coverage were selected based on percent cloud cover and acquisition during the growing season. The images were purchased from the Aerial Photography Field Office of the USDA-ASCS in Salt Lake City, Utah. A list of the images used is given in Appendix I. It was felt that cloud free imagery obtained during the growing season would be the most useful in identifying land cover. Therefore, only images from the months of May through September with cloud cover of 10 percent or less were chosen. The images used in this study range in date from 1972 to 1976.

To produce the state land cover map each image was registered to rivers, lakes and other identifiable landmarks displayed on a translucent mylar base map at the 1:1,000,000 Albers Equal-Area Projection. The interpretations were done with the aid of a light table and transferred directly to a matte-finish mylar overlay registered to the base map.

Classification of Land Cover

The term land cover is preferred over land use since "use" carries the connotation of a specific activity being present. Such

activity may or may not be detectable on remote sensing imagery. Burley (1961) defined land cover as "the setting in which action takes place, i.e., the vegetation and artificial constructions covering the land surface." Seven categories of land cover were delineated in the production of the state land cover map: Irrigated crops, including irrigated pasture and subirrigated lands; dryland crops; forest; range; water; alpine and rock outcrops; and urban areas having a 1970 census population exceeding 20,000.

Identification of Land Cover Types

A number of factors were considered in identifying land cover categories. These included a landscape feature's color, texture, size, shape and its association with other features. The following sections describe in detail some of the factors considered in the interpretation of land cover types.

Irrigated Crops

Irrigated crops are often located in valley bottoms and along natural drainages in Montana. Since they have a high reflectance in the near infrared, irrigated crops are identified during the growing season on the false color composite imagery by their bright red appearance. To avoid confusion with non-irrigated vegetation, imagery should correspond to dates after which non-irrigated crops

have begun to ripen. On imagery acquired earlier, non-irrigated vegetation may resemble irrigated crops due to the continued presence of adequate soil moisture.

Some irrigated land is readily identified. Such is the case with irrigated crops under center pivot irrigation systems which can be recognized by their distinctive circular shape. However, some land mapped as irrigated crops is associated with riparian and sub-irrigated lands. Since it is difficult to distinguish between irrigated crops and riparian and subirrigated lands, no effort was made to separate them in areas where they were interspersed.

Dryland Crops

As explained in the previous section it is best to use imagery from the latter part of the growing season to avoid confusing dryland with irrigated crops. As dryland crops mature, their appearance on the color composite imagery changes from progressively lighter shades of red, to pink and then to a whitish hue upon crop ripening. In addition to their color, the linear boundaries of many dryland crop fields aid in their identification. Strip-cropped areas can be readily recognized by their contrasting bands of cropped and fallowed land. Areas under fallow at the time of image acquisition were included in the dryland crop classification. On the imagery, fallow areas appear from dark to light grayish blue-green depending

on the tillage techniques employed and the soil surface conditions. Fallowed areas containing stubble appear light brown to gray and may be difficult to distinguish from range cover, particularly where dryland crops and dryland pasture are mixed.

Forest

Areas classified as forest consist of all identifiable coniferous woodland areas. Forest areas, like other concentrations of vigorous vegetation, reflect highly in the near infrared giving them a red appearance on the Landsat imagery. In contrast to the bright red of irrigated crops, forest areas are represented by a darker red on the imagery. Other factors which may aid in the identification of coniferous forests include their granular appearance on the imagery and their irregular boundaries which often follow variations in aspect and topography.

Water

Reservoirs and lakes were classified as water on the land cover map. Clear water absorbs a large percentage of the incident electromagnetic radiation causing it to appear black on the imagery. With increasing turbidity the appearance of water changes from black to light blue. In mountainous areas, water bodies may be hard to identify because of the masking effects of shadows from the rough ter-

rain. Generally, however, water bodies are easily identified and mapped from Landsat imagery.

Urban

Urban areas mapped include only those cities whose populations were greater than 20,000 at the 1970 census. Although visible on the imagery, smaller urban areas were not mapped due to their comparatively insignificant areas and the problems associated with their representation on a map of such small scale.

The appearance of urban areas on Landsat imagery varies from red and flesh-colored tones to white and/or mottled blue patterns. Residential areas appear either flesh-colored or shades of red due to the integration of white tones produced by highly reflective objects such as roofs, sidewalks and streets, and red tones from the high near infrared reflectance of trees, lawns and other vigorous vegetation. Residential areas, especially low density residential areas, may be confused with dryland and irrigated crops in the spring. To avoid confusion it may be beneficial to use imagery taken later in the summer when residential vegetation begins to suffer from lack of moisture, mowing, and other stresses (Anderson, 1977).

Due to the lack of vegetation and presence of highly reflective objects, main business and industrial areas are represented by white

to blueish tones on the imagery. Radiating out of the hub of the central business district is often a network of highways, blueish-gray in appearance, which may also serve as an aid in identifying urban centers.

Alpine and Rock Outcrops

The classification, alpine and rock outcrops, includes all land areas above the treeline and locations having sparse vegetation where rock outcrops predominate. The appearance of alpine areas differs in response to snow cover and vegetation condition. Snow is highly reflective, hence, snow-covered areas are white on the imagery. Snow-free alpine areas also may appear white where little vegetation is present and the area is dominated by light-colored rocks. Alpine areas having sufficient vegetation vary in appearance from pink to red depending on the conditions and quantity of the vegetation present.

The appearance on the imagery of areas dominated by large outcroppings of rock is dependent on the color of the rock. Light colored rock outcrops are highly reflective and are represented by light tones while less reflective rocks appear dark on the imagery.

Range

The range classification includes treeless areas below treeline dominated by grasses and/or shrubs, dryland pasture, and badland.

areas. Range varies considerably in its spectral response depending on soil moisture conditions, vegetation condition, and other vegetation and soil influenced reflection properties. Range appears as shades of gray or gray-brown on the color composite imagery. To avoid confusion with irrigated or dryland crops, range is best depicted on imagery obtained in the latter part of summer. At this time the moisture stressed range vegetation is easily distinguished from the red color of healthy irrigated crops and the uniform pink to white response of ripening dryland crops.

Encoding of the State Land Cover Map

A computerized geographic information system developed by Gary L. Ford is available at Montana State University (Ford, 1978). Upon completion, the state land cover map was digitized and added to this system. This increased the number of maps presently stored in the system to seventeen. These maps include:

1. Soils
2. 1941-70 Average Annual Precipitation
3. 50 Year Peak Precipitation
4. Number of Strong Chinooks per 100 Years
5. Potential Evapotranspiration
6. Average Annual Effects of Erosive Rains
7. Average Length of Frost-Free Season
8. Average Date of First Freeze
9. Average Date of Last Freeze
10. Consumptive Use of Water
11. 1968-72 Average Annual Snowfall
12. Geology
13. Percent of Annual Precipitation Falling from April 1
Thru July 31

14. Percent of Annual Precipitation Falling from May 1
Thru July 31
15. Climax Vegetation
16. Elevation
17. Land Cover

Products of the system include both plotter-drawn maps and alpha-numeric line-printer maps. The system is capable of out-putting data from a single map or performing a joint analysis of several maps (i.e., soils, precipitation, length of growing season, etc.) to produce a composite map locating areas containing a particular set of environmental parameters.

In order to be encoded into the system, a map must first be prepared at a 1:1,000,000 scale with Albers Equal-Area projection. A plotter-drawn mylar grid at the same scale and projection is used to encode the map data. The grid is based on latitude and longitude and has an average cell size covering 21.3 square kilometers. The grid is overlain on the map and the data are coded for each cell by the dominant category present. If no category is dominant then the class at the cell's center is encoded. The data is then recorded and keypunched and the resultant computer drawn map is checked for errors (Ford, 1978).

Areal Tabulation of Land Cover Categories

The encoded state land cover and general soils (USDA-SCS, 1978) maps were sent to the Remote Sensing Institute at South Dakota State

University for conversion to AREAS (Area Resource Analysis Systems) for areal tabulations. AREAS is a computerized geocoded cellular information system. The output received from AREAS included a breakdown of the hectares of each soil mapping unit under a specific land cover (Appendix III). These data were then analyzed for soil-land cover relationships throughout Montana (Appendix IV).

Testing Land Cover Map Accuracy

Source of Ground Truth Data

Due to the prohibitive expense and amount of time required for the collection of ground truth data by field observations, existing land use maps for eighteen Montana counties were used to check the land cover map accuracy. The maps were prepared by the Montana Statewide Cooperative Land Use Mapping Program, coordinated by the Department of Community Affairs, Helena, Montana, and the Yellowstone-Tongue Area Wide Planning Organization, Broadus, Montana. The Department of Community Affairs' maps include: Broadwater, Carbon, Cascade, Deerlodge, Hill, Lewis and Clark, Mineral, Missoula, Park, Pondera, Silver Bow and Teton Counties. Counties embodied by the Yellowstone-Tongue Area Wide Planning Organization maps are: Carter, Custer, Fallon, Powder River, and the northern portion of

Rosebud County. The shaded areas of Figure 1 show where these counties are located in association with the remaining portion of the state.

Selection of Ground Truth Sites

Ground truth sites were chosen by a stratified random sampling of sections located within the described eighteen county area. To select each section, random numbers corresponding to tier and range designations were computer generated to specify township and random numbers between 1 and 36 were generated to determine section. To locate each section on the land cover map, a map of identical scale and projection displaying township locations was overlaid on the land cover map. Each specified section was then located with the aid of 16 lines per inch graph paper. Each cell on the graph paper closely approximates a section at a scale of 1:1,000,000 (1 cell represents 0.99 square miles). The dominant land use within each section was then used to classify each sample site. The resulting classification was then checked for agreement with the classification within the same section on the county land use maps.

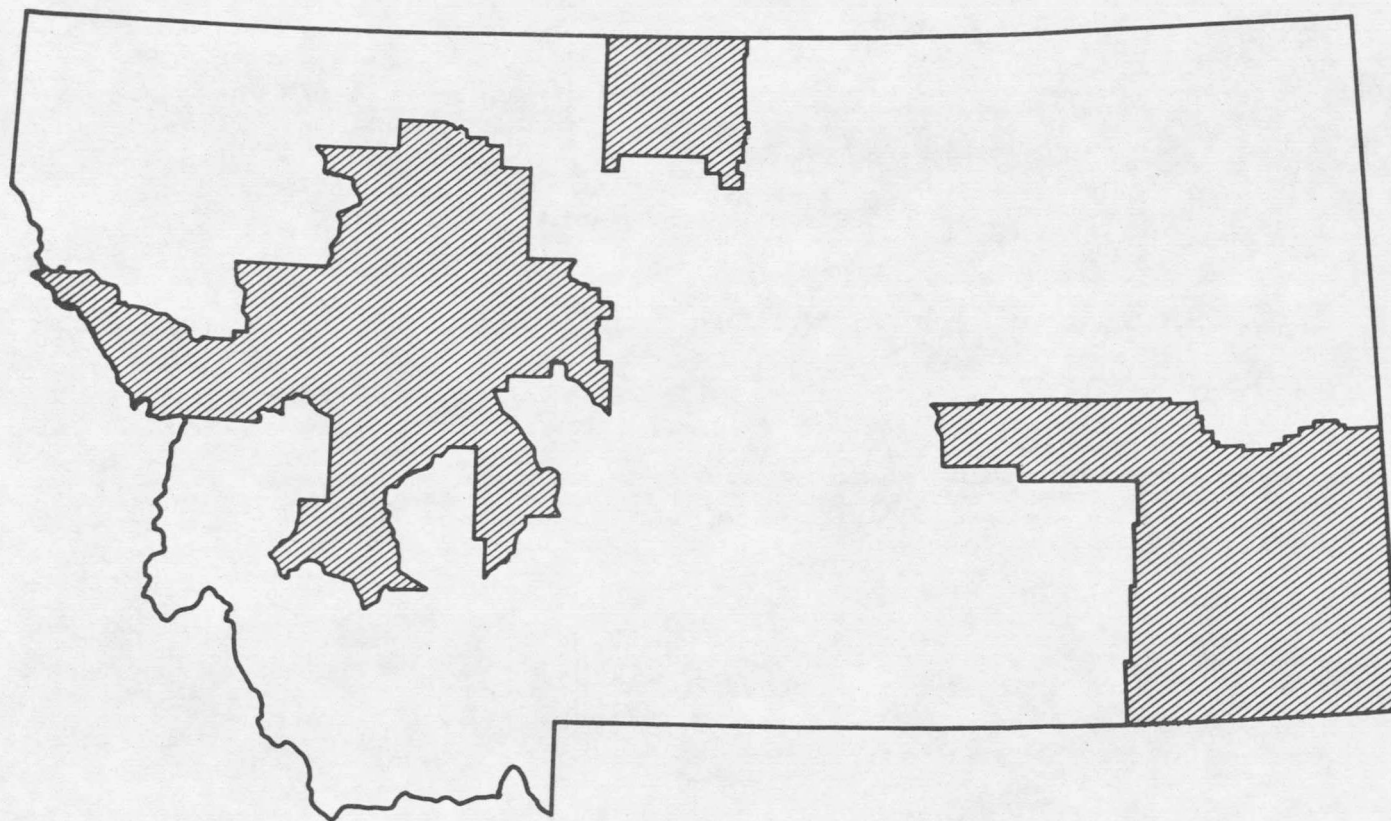


Figure 1. Area covered by county land use maps used as ground truth (shaded regions).

The minimum number of sample sites needed to check each land cover category was determined by the following formula:

$$N = \frac{1.96^2 S^2}{L^2}$$

Where N is the minimum number of samples needed, 1.96 is the t-table value for a confidence interval of .95, S^2 is the estimated variance for a binomial distribution and L corresponds to the acceptable degree of error.

Assuming a map accuracy of at least 80% with a .95 confidence interval yields:

$$N = \frac{(1.96)^2 (0.80)(0.20)}{0.10^2} = 61.5$$

To insure an adequate sample, a running total was kept for each category until 70 checks were performed on each classification. This figure is in excess of the minimum sample size of 50 recommended by Hay (1979) for sampling land use map classification accuracy.

Exceptions to a sampling number of 70 are the water and urban classifications. Due to the difficulty in obtaining seventy random samples on the small relative area occupied by water in Montana, only 25 sample checks on the water classification were performed. It was felt that this number would be adequate, particularly since

surface waters are easily identified on the satellite imagery. In addition, the selection of ground truth sites was not limited to the eighteen county area previously described. Instead, USGS topographic maps were used as ground truth so the sampling area for water could be expanded to include almost all of Montana.

The insignificant area occupied by urban areas in Montana made sampling of these areas impractical. Therefore, no checks were performed on the urban cover classification.

Upon completion of the sampling scheme, the overall classification accuracy for all samples was calculated. In addition, the accuracy for each classification category was determined.

RESULTS AND DISCUSSION

Land Cover Distribution in Montana

Figure 2 is a photo-reduced copy of the 1:1,000,000 Montana land cover map produced from manual interpretation of Landsat imagery. A 1:1,000,000 computer plotted version of the land cover map is presented as a map supplement to this thesis. The computer drawn map does not possess the detail of the original hand-drafted map but it still demonstrates general land cover distribution in Montana.

The results of the AREAS program's tabulations of the areal extent of the seven land cover categories (Table 2) show range to be the dominant cover type in Montana. Range occupies approximately 50% (18,890,000 hectares) of Montana's total land area and is found predominately in the eastern two-thirds of the state and in the intermontane valleys of the west. The largest extents of uninterrupted rangeland occur in east central Montana where soils have developed on soft sandstones, siltstones and claystones. In this area, topography is locally rugged due to differential erosion between beds of softer and harder materials (Veseth and Montagne, 1980). Many of the soil associations having extensive range cover are located on these rough, dissected bedrock plains (Table 3). Significant acreages of rangeland also occur on the glaciated till

Table 2. AREAS tabulations for land cover in Montana

Land cover type	Hectares (thousands)	Acres	Percent of total
Range	18,890	46,642	50
Forest	10,029	24,763	27
Dryland	6,614	16,330	18
Irrigated	1,199	2,960	3
Alpine and Rock Outcrop	734	1,812	2
Water	204	505	0.5
Urban	<u>23</u>	<u>57</u>	<u>< 0.1</u>
Total Area	37,693	93,069	100

Table 3. Soil associations (USDA-SCS, 1978) with significant range cover.

Mapping Unit Symbol	Association Description	Hectares of Range Cover (thousands)	% of Map- ping Unit in Range	Location of Major Range Cover Areas
Th	Entisols-Aridisols: Strongly sloping soils on dissected sedimen- tary bedrock plains and hills	3,305	86	Extensive areas in east central Montana
Vh	Entisols-Aridisols: Predominantly clayey, strongly sloping soils on dissected shale plains	1,896	89	Areas throughout eastern Montana
Sg	Mollisols-Aridisols: Nearly level to hilly soils on glacial till plains	1,173	36	Northern east central Montana
Nh	Entisols-Inceptisols- Mollisols: Strongly sloping soils on sedi- mentary bedrock plains and hills	1,117	66	Southern east central Montana and scattered areas in the northeast
Tp	Aridisols-Entisols: Nearly level to moder- ately steep soils on sedimentary bedrock plains	1,113	78	Scattered areas throughout south- eastern Montana

plains of north central Montana. Elsewhere in the state range is often interspersed with other cover types.

Forest occurs on almost 27% of Montana's total land area. Forest cover is primarily limited to the western mountains and the highly dissected plains and hills of eastern Montana (Table 4). Dominant cover species vary from Pinus ponderosa Dougl. and Juniperus scopulorum Sarg. (ponderosa pine and Rocky Mountain Juniper) in eastern Montana to Thuja plicata Donn. and Larix occidentalis Nutt. (western red cedar and western larch) in the northwest (Ross and Hunter, 1976). Crown covers differed from 15% for areas in eastern Montana to about 100% in the western mountains.

Dryland crops occupy over 6.6 million hectares in the state comprising about 18% of Montana's total land area. Observation of the dryland crop distribution (Figure 2) reveals two extensive areas in Montana; the state's northeast corner and the Triangle area located in north central Montana. These areas correspond to the extent of the last continental ice sheet advance with the dominant dryland cropped areas being located on glacial till plain soils (Table 5). One soil association mapping unit, Sg, (USDA-SCS, 1978) contains over 31% of the state's total dryland area. This unit is extensively cropped in the Triangle area. The Judith Basin contains significant dryland crop cover on soils of

Table 4. Soil associations (USDA-SCS, 1978) with significant forest cover.

Mapping Unit Symbol	Association Description	Hectares of Forest Cover (thousands)	% of Mapping Unit in Forest	Location of Major Forest Cover Areas
Me	Inceptisols-Alfisols: Moderately sloping to very steep soils on mountains	2,810	92	Mountains of western Montana
Mf	Inceptisols: Moderately sloping to very steep soils on mountains	2,044	81	Mountains of northwestern Montana
Mo	Mollisols-Inceptisols-Alfisols: Gently sloping to very steep soils on mountains	1,050	77	Mountains east of the divide
Ma	Inceptisols (Andic): Steep and very steep soils on mountains mantled by volcanic ash	827	94	Northwestern Montana
Lg	Inceptisols-Alfisols: Undulating to rolling soils in valleys and on foothill glacial moraines	788	91	Mountain valleys of northwestern Montana
Th	Entisols-Aridisols: Strongly sloping to steep soils on dissected sedimentary bedrock plains and hills	494	13	Southeastern Montana

Table 5. Soil associations (USDA-SCS, 1978) with significant dryland crop cover.

Mapping Unit Symbol	Association Description	Hectares of Dry- land Cover (thousands)	% of Map- ping Unit in Dryland Crops	Location of Major Dryland Cover Areas
Sg	Mollisols-Aridisols: Nearly level to hilly soils on glacial till plains	2,077	64	Triangle area
Og	Mollisols-Entisols: Undulating to strongly rolling soils on glacial till plains	958	66	Northeastern Montana
Gb	Mollisols: Nearly level to steep soils on fans, benches, and terraces	419	32	Judith Basin
Np	Mollisols-Entisols: Nearly level to strongly sloping soils on sedi- mentary bedrock plains	417	42	Wibaux area
Nh	Entisols-Inceptisols- Mollisols: Strongly sloping to steep soils on sedimentary bedrock plains and terraces	402	25	Northeast Montana and Judith Basin

alluvial fans, benches and terraces, while other areas of extensive dryland crops occur on sedimentary bedrock plains in eastern Montana.

Together range, forest and dryland crops make up approximately 95% of Montana's land cover. The remaining 5% is occupied by irrigated crops (3%); Alpine and rock outcrops (2%); water (0.5%); and Urban (<0.1%).

Irrigated crops are present in the intermontane valleys of western Montana and along major river drainages in the east. The western intermontane valleys have intermittently acted as depositional basins since at least late Eocene. Adjacent to the basins' modern floodplains, pediment surfaces extend up the mountain fronts. These pediments are often covered by alluvial fans, benches or terraces (Fields and Petkewich, 1971). It is on these geomorphic features; floodplains, fans, benches and terraces; that much of Montana's irrigated crops occur. Outside of the intermontane valleys, large irrigated cropland areas are located along major river drainages such as the Milk and Yellowstone Rivers (Table 6).

Alpine and rock outcrops are limited to the higher elevations and ridge crests of the western mountains. Table 7 presents the major soil mapping units having significant areas of alpine cover.

Table 6. Soil associations (USDA-SCS, 1978) with significant irrigated crop cover.

Mapping Unit Symbol	Association Description	Hectares of Irrigated Cover (thousands)	% of Mapping Unit in Irrigated Crops	Location of Major Irrigated Cover Areas
Ap	Entisols-Aridisols-Mollisols: Nearly level to strongly sloping soils on low terraces, fans, and floodplains	256	15	Milk, Yellowstone Big Horn, and Clark's Fork Rivers
Av	Entisols-Inceptisols-Mollisols: Nearly level to strongly sloping soils on low terraces fans, and floodplains	194	43	Beaverhead, Bitterroot, Deerlodge, Gallatin, Flathead and Townsend Valleys
Ct	Mollisols nearly level to moderately sloping outwash terraces, fans, and benches	98	55	Bitterroot, Flathead Valleys
Kb	Aridisols-Mollisols: Nearly level to moderately steep fans, terraces and benches	88	15	Bitterroot, Flathead Valleys
Dt	Mollisols-Alfisols: Nearly level to strongly sloping soils on lacustrine terraces	52	34	Flathead Valley
Tb	Aridisols and Mollisols: Nearly level to steep sloping soils on fans, benches, and terraces	52	18	Yellowstone River between Billings and Hysham
Pb	Mollisols and Aridisols: Nearly level to steep fans, terraces and benches	48	26	Fairfield Bench
B	Mollisols: Nearly level soils in cold wet basins	48	56	Big Hole and Centennial Valley

Table 7. Soil associations (USDA-SCS, 1978) with significant alpine or rock outcrop cover.

Mapping Unit Symbol	Association Description	Hectares of Alpine and Rock Outcrop Cover (thousands)	% of Mapping Unit in Alpine Rock Outcrops	Location of Major Alpine and Rock Outcrop Cover Acreage
R	Mountain peaks and gently sloping to very steep alpine grasslands	433	56	High mountains of western Montana
Me	Inceptisols-Alfisols: Moderately sloping to very steep soils on mountains	146	5	High mountains of western Montana
Mf	Inceptisols: Moderately sloping to very steep soils on mountains	100	4	Northwestern Montana

Surface water locations are scattered throughout the state while the recorded urban areas correspond to those cities whose populations exceeded 20,000 in the 1970 census. These cities are: Billings, Bozeman, Butte, Great Falls, Helena and Missoula.

Comparison with Existing Montana Land Use Data

Although not directly comparable, the AREAS tabulations of land cover are similar to previously existing information on Montana land use. The USDA, ESCS (Frey, 1974) report on major land use in the United States presents similar acreages (Table 8) for land under crops, range and forest uses.

Table 8. USDA, ESCS land use statistics for Montana (Frey, 1974).

Land Use	Hectares (thousands)	Acres	Percent of total
Cropland	6,489	16,021	17.19
Grassland, Pasture, & Range	20,633	49,465	53.09
Forest	8,059	19,899	21.36
Special uses	1,876	4,633	4.97
Other uses	<u>1,279</u>	<u>3,158</u>	<u>3.39</u>
Total	38,336	93,176	100.00

The lower percentage of forestland listed in the USDA, ESCS report compared to the AREAS figure is partially due to inclusion of some forest cover areas in the special uses category. The special uses classification includes land used for recreational activities which embraces a significant amount of forest cover lands, reducing the forest use area total in the USDA, ESCS figures.

The larger USDA, ESCS figure for land in range may be the result of the inclusion of grazeable woodland areas in this category. This would also contribute to the lower areal figure for forestland compared to the AREAS figures.

The Montana Situation Statement's (Anonymous, 1979a) tabulations (Table 9) for lands under irrigation and forest compare favorably with the AREAS computations. However, the report's figures for surface waters is noticeably larger than that obtained by AREAS. The lower AREAS figure for surface waters is likely due to the method used to encode the original hand-drafted map into the computer mapping system. The large cell size (21.3 km^2) used to encode the mapped land cover data precluded all but the larger water bodies from being encoded. Another method for measuring surface water areas (i.e., planimeter or grid dots) may produce more compatible results.

Table 9. Montana Situation Statement's (Anonymous, 1979a) areal tabulations for water, range, forest and irrigated crops.

Land Use	Hectares (thousands)	Acres	Percent of Montana's total area
Range	21,870	54,000	57
Forest	9,392	23,189	25
Irrigated Crops	1,053	2,600	3
Water	398	982	1

Land Cover Map Classification Accuracy

The percentage agreement between the state land cover map and the county land use maps used as ground truth was determined and is shown in Table 10. The overall agreement for all land cover categories mapped was 90%. This figure, assuming the county land use data are accurate, is well above the 85% minimum accuracy level recommended by Anderson (1976) for land cover surveys using remote sensing data.

It should be emphasized that interpretation errors detected by the ground truth procedure demonstrate only a lack of agreement

Table 10. Map accuracy by land cover type.

Cover Type	Number of Samples	Total Correct Samples	Percent Samples Correct
Irrigated Crops	70	61	87
Dryland Crops	70	62	89
Forest	70	65	93
Range	70	66	94
Alpine and Rock Outcrops	70	58	83
Water	<u>25</u>	<u>25</u>	<u>100</u>
Total	375	337	90

between the land cover map and the county land use maps. It is not known whether an error's source is within the state land cover map or the county land use maps. Therefore, the accuracy figures in this text show only percent agreement between the maps.

Only one individual category, alpine and rock outcrops, fell below the 85% mark. Table 11 shows a tendency to confuse forest with alpine areas, resulting from an inability to always successfully delineate the treeline. This problem was particularly acute in the Absaroka and Beartooth Ranges southeast of Bozeman, one of

the major ground truth areas for the alpine classification. The Landsat image used to interpret this area was dated September 30 when snow was covering the higher elevations. This created a masking effect which made it difficult to discern the treeline causing forest to be mapped incorrectly as alpine cover.

A tendency to confuse range with irrigated crops is also demonstrated in Table 11. Reexamination of the satellite imagery revealed that the majority of these errors were the result of mistaking moist range sites for irrigated crops, especially when the range sites were interspersed with irrigated lands.

Many of the land cover map errors resulting in misidentification of range as dryland crops originated as location errors. Locational errors occurred when dryland crop fields were not positioned at the same coordinates on the land cover map as on the maps used as ground truth. These locational misalignments prevented the verification of some dryland areas, resulting in classification errors. Also contributing to the classification errors between range and dryland crops was the inclusion of small range areas in the dryland mapping unit. When these range inclusions, mapped as dryland crops, were checked against the ground truth they were declared as errors.

Table 11. Sample point distribution by land cover categories.

Interpreted Data	GROUND TRUTH DATA					
	Irrigated Crops	Dryland Crops	Forest	Range	Alpine & Rock Out- crops	Water
Irrigated Crops	61	1	1	7	-	-
Dryland Crops	-	62	-	8	-	-
Forest	-	-	65	5	-	-
Range	1	1	2	66	-	-
Alpine & Rock Outcrops	-	-	12	-	58	-
Water	-	-	-	-	-	25

Only minor problems were encountered in distinguishing dryland from irrigated crops. Initially there was concern over the ability to discriminate between dryland and irrigated crops on satellite imagery from a single date. However, only once during the ground truth process were irrigated and dryland crops confused. This occurred when a small area of dryland crops, incorporated

into an area containing irrigated crops, was mapped as irrigated land. Subsequently, the ground truth procedure exposed this inclusion and it was counted as an interpretation error.

Similar to the dryland-irrigated error described above, the inclusion of small clearings (range cover) in the forest mapping unit resulted in conflicts with the ground truth data. However, this lumping of forest areas was necessary to avoid overcrowding the small scale land cover map with excessive detail.

Range was the most accurately interpreted land cover type. Errors in the range mapping unit were evenly distributed between the major cover types with no significant bias. The high accuracy levels of range and forest cover categories are in part a reflection of the relatively large land area they occupy.

Cost of Land Cover Map Development

Development of the 1:1,000,000 Montana land cover map from manual interpretation of Landsat imagery required 169 man-hours of labor and cost approximately \$0.01/km². Included in this figure are expenditures for imagery acquisition, interpretation, mapping, materials, and ground truth expenses (Table 12).

Table 12. Cost of producing 1:1,000,000 Montana land cover map from manual interpretation of Landsat imagery.

Imagery	35 color composites	\$ 852
Interpretation and mapping*	150 hours	1,050
Materials		20
Maps used for ground truth		4
Ground truthing*	19 hours	<u>133</u>
	Total	\$2,059

*Based on a pay rate of \$7.00/hour.

Comparison with Other Mapping Projects and Methods

The cost incurred in the production of the Montana land cover map compares favorably with similar mapping projects. A preliminary 1:250,000 scale land use map of Iowa was drafted for about \$0.03/km² involving 90 man-hours of Landsat image interpretation (Anderson, 1977). Higher costs, \$0.10/km², were experienced in the construction of a 1:250,000 Landsat derived land use map for Boone County, Missouri. This increase in expenses reflects the entire Landsat image cost being charged to the area covered only by Boone County. Since 5 to 10 counties are usually

represented on a single image, the price per unit area for mapping only Boone County was inflated (Elfrits, et al., 1978).

Direct transfer of data manually interpreted from Landsat imagery was used to produce land cover maps at 1:250,000 and 1:150,000 for New York state. The imagery was enhanced by a diazo process and the maps produced at a cost of \$0.39/km² (Hardy, et al., 1973). Similar diazo enhanced imagery obtained from Cornell University proved to have little additional value over standard color composite imagery for delineating land cover in Montana. Use of the diazo processed imagery was therefore not deemed worth the added expense for visually interpreting land cover in Montana.

The expense of producing the state land cover map from Landsat imagery is a small fraction of the construction cost for a similar map using conventional means. Conventional aerial photo coverage is available for all of Montana at various dates, scales and film types. The National Cartographic Information Center (NCIC) in Reston, Virginia provides an Aerial Photography Summary Record System (APSRS) listing the types of air photo coverage for Montana that may be purchased.

Statewide land cover mapping would require the interpretation of an estimated 4,500; 1:40,000 scale, air photos at a minimum cost of \$9,000 for the photos alone. The use of smaller scale

photos would reduce the photography and interpretation expenses but the cost would still exceed that of a survey employing Landsat imagery as the data source. These findings support the conclusions demonstrated by Mertz (Watkins, 1978) that vegetational land cover maps can be obtained from Landsat data for about 10% of the cost of conventional survey methods. The reduced cost makes Landsat imagery an attractive alternative to conventional survey methods for mapping land cover at small scales over large areas.

CONCLUSIONS

Manual interpretation of Landsat imagery proved an accurate and economical method of mapping land cover statewide in Montana. Its low cost (\$0.01/kilometer²) and accuracy (90%) make Landsat a viable alternative to conventional aerial photo and ground surveys. Landsat imagery is particularly suited for small scale regional mapping projects such as state and county inventories.

Repetitive coverage and low analysis costs make manual interpretation of Landsat imagery practical for updating existing land cover information. Additionally, statewide land cover data interpreted from Landsat imagery was easily entered into the Montana Computer Graphic System for comparison with soil and other environmental information.

Data timeliness and image quality are two problems associated with Landsat imagery. The satellites' passover dates for a specific area are predetermined, thus prohibiting the researchers from defining the dates of acquisition. Further limitations involve image quality and cloudiness. Poor image quality hampers interpretation and cloudiness may render an image entirely useless. Fortunately, the semi-arid climate of Montana provides much cloud-free weather, and cloudiness was not a major problem in this study. However, careful imagery prescreening for date, image

quality and cloudiness is important for any land cover mapping involving Landsat imagery. For Montana, imagery acquired during late July through mid-September proved the most useful for interpretation of the land cover categories mapped in this project.

The Landsat project's future should be of major concern to researchers interested in using Landsat imagery for impending projects. At present, the Landsat series is an experimental project only. Plans to give Landsat operational status by turning part or complete control of the project to commercial interests have not been worked out (Anonymous, 1979b). Landsat's usefulness in natural resource inventories makes it imperative that these problems be resolved soon to insure continuity of Landsat data.

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APPENDICES

APPENDIX I

INDEX OF LANDSAT IMAGERY USED TO PREPARE THE MONTANA

LAND COVER MAP

Table I-1. Index of Landsat imagery used to prepare the Montana land cover map.

Index No.	Area	Date	Identification No.
1	Libby, MT	10/5/72	1074-18082
2	Whitefish, MT	7/14/74	1721-17544
3	Thompson Falls, MT	9/11/73	1415-18022
4	Glacier National Park, MT	7/13/74	1720-17490
5	Flathead Lake, Missoula, MT	7/18/73	1360-17572
6	Bitterroot Valley, MT	7/13/74	1720-17495
7	Cutbank - Shelby, MT	6/11/73	1323-17514
8	Choteau, MT	8/27/72	1035-17513
9	Butte, MT	7/17/73	1359-17521
10	Clark Canyon Reservoir, MT	9/22/74	1791-17415
11	Hill County, MT	9/13/72	1052-17452
12	Great Falls, MT	9/13/72	1052-17454
13	Bozeman, MT	9/13/72	1052-17461
14	West Yellowstone, MT	9/21/74	1790-17361
15	Havre, MT	7/15/73	1357-17395
16	Lewistown, MT	7/15/73	1357-17401
17	Big Timber, MT	7/15/73	1357-17404
18	Gardiner, MT	9/30/72	1069-17405
19	Malta, MT	9/6/73	1410-17332
20	Petroleum County, MT	9/6/73	1410-17334
21	Billings, MT	9/6/73	1410-17341
22	Cooke City, MT	8/1/73	1374-17351
23	Glasgow, MT	9/5/72	1409-17273
24	Ft. Peck, MT	9/5/73	1409-17280
25	Hardin, MT	9/5/73	1409-17282
26	Lodgegrass, MT	9/5/73	1409-17285
27	Scobey, MT	5/3/76	5380-16402
28	Circle, MT	8/17/73	1390-17223
29	Miles City, MT	8/17/73	1390-17230
30	Decker, MT	5/19/73	1300-17243
31	Plentywood, MT	5/2/76	5379-16344
32	Sidney, MT	5/2/76	5379-16351
33	Ekalaka, MT	5/2/76	5379-16353
34	Broadus, MT	6/18/74	1695-17110
35	Thompson Falls, MT - Spokane, WA	10/5/72	1074-18085

APPENDIX II

SOURCES OF REMOTE SENSING IMAGERY

APPENDIX II

SOURCES OF REMOTE SENSING IMAGERY

The purpose of this appendix is to serve as a user guide to selecting and ordering Landsat and other types of remote sensing imagery.

Federal Sources of Remote Sensing Imagery

EROS Data Center

Administered by the Geological Survey of the Department of the Interior, the EROS Data Center (EDC) contains the largest single federal collection of satellite and aircraft imagery. In addition to a large collection of aerial mapping photography; data from the Landsat, Skylab, Apollo and Gemini space programs are available from the EDC. To order or inquire about available imagery or assistance the prospective user is instructed to contact the EDC by phone, letter or personal visit:

User Services Unit
EROS Data Center
Sioux Falls, South Dakota 57198
Phone: 605/594-6511

By submitting to EROS the geographic location of the areas of interest, a user may institute a computer search listing available imagery for that area. The user should also specify the dates and

seasons, acceptable cloud cover, and image format desired.

Geographic computer inquiry forms are available upon request from the EDC.

There are a variety of data types available from EROS.

Landsat images are available in color or black and white transparencies ranging in size from 16 millimeters to 40 x 40 inches and scale from 1:3,369,000 to 1:250,000. The color composite, produced by combining three of Landsat's MSS bands and exposing them through color filters to produce a color image is one popular product. Also available are computer compatible tapes (CCTs) containing the digital information for each Landsat scene. The CCTs are available in nine track tapes having either 800 or 1600 bites/inch.

Imagery from the Skylab, Apollo and Gemini space programs and NASA research aircraft is available in color or black and white prints and transparencies from 16 millimeters to 40 inches on a side. A limited number of CCTs obtained from sensors used in the manned space programs may also be purchased. Conventional aerial mapping photography may be procured in either black and white prints or transparencies.

Prices for standard products obtained from EROS are included with the order forms. Prices are generally comparable with costs of obtaining the same product from other federal sources. Prices

range from around \$3.00 for a 9 x 9 inch black and white print to \$50.00 for a 40 x 40 inch color print and \$200.00 for a CCT of all four Landsat bands. Custom processing to special scales, formats, and rapid delivery orders are available but pricing is increased accordingly. If a Landsat scene desired by a user previously had a color composite produced then a color composite may be purchased at the standard product price. However, if a color composite has not been produced then there is a substantial service charge added to the product cost.

All orders to EROS must be accompanied by check, money order, purchase order or an authorized account identification. A standing account at EROS may be opened with a minimum deposit of \$100.

USDA-ASCS

The ASCS division of the USDA has Landsat and Skylab imagery available in addition to USDA photography for about 80% of the U.S. excluding Alaska. Standard product prices are comparable to those at the EROS Data Center. Air photo coverage is updated approximately every seven years with the majority of the coverage at 1:20,000 (8 1/2 inch lens) and new photography at 1:40,000 (6 inch lens). However, it is possible to request photo products at other specified scales.

To obtain NASA aerial photography, Landsat and Skylab imagery the user is instructed to contact:

Aerial Photography Field Office
ASCS-USDA
2222 West 2300 South
P. O. Box 30010
Salt Lake City, Utah 84125
Phone: 801/524-5856

Orders for USDA aerial photography can be initiated by contacting the local ASCS office or by contacting the Aerial Photography Field Office in Salt Lake City.

To obtain a listing of aerial photography available for a specific state the user should contact the National Cartographic Information Center (NCIC) and request an Aerial Photography Summary Record System booklet for the state of interest. Each booklet is updated twice a year and may be obtained from:

National Cartographic Information Center
507 National Center
Reston, Virginia 22092
Phone: 703/860-6045

Other Sources of Remote Sensing Imagery

Integrated Satellite Information Services Ltd. (ISIS) is a private Canadian enterprise providing quick processing and delivery of Landsat imagery. ISIS has available almost total coverage of the United States and Canada. The firm promotes its ability to produce imagery within 2 hours of receiving the data and provide delivery within 24 to 48 hours of data reception.

A daily microfiche record (ISISFICHE) of all the Landsat images received in Canada may be obtained by subscription. Standard image products from ISIS include either 8 x 10 inch or 70 x 70 millimeter prints or transparencies (Kroeck, 1976):

Integrated Satellite Information Services Ltd.
P. O. Box 1630
Prince Albert, Saskatchewan
Canada S6V 5T2
Phone: 306/764-3602
764-4259

Additional sources of aerial photography include state agencies such as the Department of Highways and the Department of Natural Resources. Often privately owned local aerial photography firms also have their own photo depositories. If they have already flown the area of interest the user can usually arrange to purchase copies of the desired photos.

APPENDIX III

MONTANA SOIL ASSOCIATION AND LAND COVER COMBINATIONS

Table III-1. Montana Soil Association (USDA-SCS, 1978) and Land Cover Combinations

Soil	Land Use	Hectares	Soil	Land Use	Hectares
B	W	2083	JF	R	141671
B	R	31251	JF	I	2083
B	I	47918	JF	F	33334
B	F	4167	JF	D	12500
R	R	4167	KF	W	6250
R	M	433346	KF	R	81252
R	I	2083	KF	F	22917
R	F	337510	KF	D	14595
X	W	10417	KT	R	45835
X	R	472930	KT	I	18751
X	I	2083	KT	D	8334
X	F	183339	LT	R	2083
X	D	16667	LT	F	29168
AW	W	2083	MA	W	4167
AW	R	18751	MA	R	4167
AW	I	2083	MA	M	43751
AW	D	33334	MA	F	827107
ET	R	4167	OH	R	183339
ET	F	58335	OH	D	185422
FG	R	8334	OT	R	25001
FG	I	4167	OT	D	237507
HF	R	2083	SH	R	100003
IG	R	87502	SH	D	2083
IG	F	25001	ST	R	22917
JB	R	100003	ST	I	2083
JB	I	29167	ST	D	120837
JB	F	10417			
JB	D	8334			

Table III-1. (continued)

Soil	Land Use	Hectares	Soil	Land Use	Hectares
AP1	R	179172	AV3	R	25001
AP1	I	75002	AV3	I	20834
AP1	D	27084	AV3	F	29167
AP2	R	479180	AV4	U	2083
AP2	I	100003	AV4	R	64585
AP2	F	18751	AV4	I	35418
AP2	D	27084	AV4	F	4167
			AV4	D	6250
AP3	R	258341	AV5	R	27084
AP3	I	2083	AV5	I	8334
AP3	F	2083	AV5	D	6250
AP3	D	27084			
AP4	R	137504	CT1	R	31251
AP4	I	47918	CT1	M	2083
AP4	D	62502	CT1	I	72919
			CT1	F	37501
AP5	W	2083	CT1	D	2083
AP5	R	27918			
AP5	I	4167	CT2	R	6250
AP5	D	79169	CT2	I	25001
AP6	R	29167	DT1	U	4167
AP6	I	6250	DT1	R	2083
AP6	F	2083	DT1	I	12500
			DT1	F	79169
AP7	R	41668	DT1	D	2683
AP7	I	20834			
AP7	D	41668	DT2	R	10417
			DT2	I	39585
AV1	R	52085	DT2	F	2083
AV1	I	79169			
AV1	F	6250	GB1	R	20834
AV1	D	6250	GB1	I	20834
			GB1	D	60418
AV2	R	8334			
AV2	I	52085			
AV2	F	22917			

Table III-1. (continued)

Soil	Land Use	Hectares	Soil	Land Use	Hectares
GB2	R	227090	GF5	R	175005
GB2	I	29168	GF5	F	2083
GB2	F	20834	GF5	D	2083
GB2	D	27084			
GB3	R	29168	GG1	R	16667
GB3	I	4167	GG1	I	2083
GB3	F	12500	GG1	F	12500
GB4	R	97919	GG2	W	2083
GB4	I	12500	GG2	R	112503
GB4	F	4167	GG2	D	4167
GB4	D	45835			
			HF1	R	218756
GB5	R	306259	HF1	I	18751
GB5	I	50001	HF1	F	79169
GB5	F	4167	HF1	D	6250
GB5	D	277091			
			HF2	R	183339
GB6	W	2083	HF2	I	2083
GB6	R	52085	HF2	F	60418
GB6	I	4166	HF2	D	10417
GB6	D	8334			
			HF3	R	193756
GF1	R	54168	HF3	I	2083
GF1	F	16667	HF3	F	41668
GF1	D	4167	HF3	D	2083
GF2	R	70835	HF4	R	181255
GF2	I	2083	HF4	F	2083
GF2	D	4167	HF4	D	2083
GF3	R	91669	H42	R	4167
GF3	F	10417			
			IB1	R	41668
GF4	R	208339	IB1	I	8334
GF4	D	6250	IB1	F	2083
			IB1	D	2083

Table III-1. (continued)

Soil	Land Use	Hectares	Soil	Land Use	Hectares
IB2	R	129170	LG1	W	8334
IB2	I	43751	LG1	R	43751
IB2	F	25001	LG1	I	10417
IB3	R	77086	LG1	F	662519
IB3	D	4167			
			LG2	R	10417
IF1	R	60418	LG2	F	62503
IF1	F	52085			
IF1	D	6250	LG3	R	2083
			LG3	F	62502
IF2	R	216673			
IF2	F	50001	ME1	W	10417
			ME1	R	18751
IF3	R	485430	ME1	M	56252
IF3	I	4167	ME1	F	997945
IF3	F	125004			
IF3	D	6250	ME2	R	2083
			ME2	M	2083
IF4	R	58335	ME2	I	2083
IF4	I	2083	ME2	F	179172
IF4	F	64585			
			ME3	R	29168
KB1	W	10417	ME3	M	12500
KB1	U	4167	ME3	F	618768
KB1	R	233340			
KB1	I	50001	ME4	R	37501
KB1	F	6250	ME4	N	2083
KB1	D	58335	ME4	M	43751
			ME4	F	862525
KB2	R	118753			
KB2	I	37501	ME5	M	31251
KB2	D	20834	ME5	F	152088
KB3	R	35418	MF1	W	8334
			MF1	R	31251
KB4	R	297925	MF1	N	2083
KB4	F	6250	MF1	M	4167
KB4	D	18750	MF1	M	4167
			MF1	F	1204200

Table III-1. (continued)

Soil	Land Use	Hectares	Soil	Land Use	Hectares
MF2	R	22917	NB2	U	2083
MF2	M	60418	NB2	R	6250
MF2	I	4167	NB2	I	2083
MF2	F	291675	NB2	D	12500
MF3	R	12500	NH1	R	102086
MF3	M	35418	NH1	I	4167
MF3	I	2083	NH1	D	110420
MF3	F	447929	NH2	R	181396
MF4	R	4167	NH2	F	148036
MF4	F	100003	NH2	D	8340
MO1	R	47918	NH3	R	250007
MO1	N	4167	NH3	F	4167
MO1	F	127087	NH3	D	16667
MO2	R	106253	NH4	R	114587
MO2	M	6250	NH4	D	139587
MO2	F	354177	NH5	R	433682
MO3	R	31250	NH5	I	10417
MO3	F	258341	NH5	F	4167
MO4	R	47918	NH5	D	122920
MO4	M	2083	NH6	R	35418
MO4	F	177088	NH6	D	4167
MO5	R	33334	NP1	R	85419
MO5	F	43751	NP1	F	10417
MO6	R	31251	NP1	D	27084
MO6	F	89586	NP2	R	133337
NB1	R	56252	NP2	I	2083
NB1	I	14584	NP2	F	12500
NB1	D	60418	NP2	D	18751
			NP3	R	25020

Table III-1. (continued)

Soil	Land Use	Hectares	Soil	Land Use	Hectares
NP4	R	10417	PH2	W	4167
NP4	D	20834	PH2	R	143754
			PH2	I	12500
NP5	R	154171	PH2	D	100003
NP5	F	8334			
NP5	D	33334	PP1	R	91669
			PP1	D	72919
NP6	R	139587			
NP6	D	316676	PP2	R	181255
			PP2	F	8334
OG1	R	2083	PP2	D	58335
OG1	D	89586			
			SG1	R	154171
OG2	W	2083	SG1	D	983361
OG2	R	233340			
OG2	D	206256	SG2	W	2083
			SG2	R	789606
OG3	R	187505	SG2	I	4167
OG3	I	4167	SG2	F	2083
OG3	D	202089	SG2	D	1045863
OG4	R	75002	SG3	R	229173
OG4	D	460430	SG3	D	47918
PB1	R	14584	TB1	R	70835
PB1	I	2083	TB1	I	10417
PB1	D	16667	TB1	F	4167
			TB1	D	12500
PB2	I	25001			
PB2	D	10417	TB2	R	47918
			TB2	I	2083
PB3	R	41668	TB2	D	22917
PB3	I	20834			
PB3	D	50001	TB3	U	6250
			TB3	R	58335
PH1	R	443763	TB3	I	39584
PH1	F	91669	TB3	F	4167
PH1	D	6250	TB3	D	12500

Table III-1. (continued)

Soil	Land Use	Hectares	Soil	Land Use	Hectares
TH1	R	756272	UG1	R	506264
TH1	D	20833	UG1	I	2083
			UG1	D	108336
TH2	R	477467			
TH2	F	154171	UG2	R	100003
TH2	D	27084	UG2	F	4167
TH3	R	541682	VB1	U	2083
TH3	F	43751	VB1	R	2083
TH3	D	4167	VB1	D	27084
TH4	R	541682	VB2	W	6250
TH4	I	4167	VB2	U	2083
TH4	F	66669	VB2	R	8334
			VB2	D	241674
TH5	R	139696			
TH5	F	229351	VB3	R	50001
TH6	R	848599	VB4	I	2083
TH6	D	6250	VB4	D	20834
TP1	R	68752	VB5	R	102086
TP1	D	52085	VB5	D	31254
TP2	R	266882	VB6	R	4167
TP2	F	8334	VB6	D	8334
TP2	D	8334			
TP3	R	291675	VH1	R	1304203
TP3	D	29168	VH1	F	127087
			VH1	D	75002
TP4	R	152088	VH2	R	58335
TP4	F	39585	VH2	I	2083
TP4	D	8334	VH2	F	2083
			VH2	D	6250
TP5	R	356260			
TP5	F	14584			
TP5	D	129170			

Table III-1. (continued)

Soil	Land Use	Hectares	Soil	Land Use	Hectares
VH3	R	533348	WATER	W	120837
VH3	I	4167	WATER	R	27084
VH3	F	6250	WATER	F	2083
VH3	D	8334	WATER	D	2083

Total = 37,671,904 hectares

Key to Land Use Symbols

R = Range

F = Forest

I = Irrigated Crops

D = Dryland Crops

M = Alpine and Rock Outcrops

U = Urban

W = Water

N = Nonsense

APPENDIX IV

MONTANA SOIL ASSOCIATIONS' DESCRIPTIONS AND
PERCENT LAND COVER

Montana Soil Associations' Descriptions and
Percent Land Cover

The data presented in Table IV-1 were derived from a preliminary draft of a new bulletin entitled Soils of Montana by the National Cooperative Soil Survey in Montana. Being preliminary, these results are subject to change and should not be used without verification.

Table VI-1. Montana soil associations' descriptions and percent land cover.

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover*					Representative Soil Series
						I	D	F	R	A	
Great Plains Section											
Ap1	Torrifluvents	Nearly level to strongly sloping terraces, fans floodplains	alluvium	deep	1,fs1, sil	27	7	-	64	-	Glendive, Harlem, Havre Bowdoin, Hanley
Ap2	Camborthids, Torrifluvents, Torriorthents	Nearly level to strongly sloping terraces, fans floodplains	alluvium, lacustrine sediments	deep	1,sic1, sil	16	4	3	77	-	Glendive, Harlem, Havre, Kaber, Namoc, Busby, Lambeth, Lonna
Ap3	Camborthids, Natrargids, Torrifluvents	Nearly level to strongly sloping terraces, fans floodplains	alluvium	deep	1,sil,s1	1	9	1	89	-	Alona, Busby, Cambeth, Creed, Gerdum, Harlem, Havre, Lonna, Yamac, Absher, Glendive, Hanley
Ap4	Ustochrepts, Ustifluvents, Argiborolls	Nearly level to strongly sloping terraces, fans floodplains	alluvium	deep	sil,l,cl fs1	19	25	-	55	-	Cambert, Cherry, Farland, Farnuf, Havrelon, Lohler, Trembles, Banks, Hoffmanville, Macar, Ridgelawn, Savage
Ap5	Ustifluvents, Haploborolls, Argiborolls	Nearly level to strongly sloping terraces, fans, floodplains	alluvium	deep	1,sil,sic1,	3	59	-	36	-	Farland, Farnuf, Havrelon, Lohler, Shambo, Trembles, Wabek
Ap6	Haploborolls	Nearly level to strongly sloping terraces, fans, floodplains	gravelly alluvium	deep	1,s1,cl	17	-	6	78	-	Lolo, Nesda, Shawa
Ap7	Haploborolls, Argiborolls, Ustifluvents	Level to strongly sloping terraces, fans, floodplains	alluvium, some loess	deep	cl,sil,sic1	20	40	-	40	-	Farnuf, Frazer, Korchea, Savage
Aw	Haplaquepts, Torriorthents, Haplaquolls	Nearly level to gently sloping basins, terraces, floodplains	clay sediments, clayey alluvium	deep	c	4	59	-	33	-	Dimmick, Marvan, McKenzie, Nobe

*I = Irrigated crops, D = Dryland crops, F = Forest, R = Range, A = Alpine and outcrops.

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
Nb1	Argiborolls	Nearly level to steep fans, benches, terraces	alluvium	deep	1,cl,sil	46	11	-	43	-	Farland, Farnuf, Savage, Turner
Nb2	Haploborolls	Nearly level to steep fans, benches, terraces	alluvium, eolian	deep to moder- ately deep	fsl,sil,cl	9	55	-	36	-	Azaar, Lihen, Tally
Nh1	Haploborolls, Calciborolls, Argiborolls	Strongly sloping to steep plains, hills	alluvium, shale, clayey sediments	deep to moder- ately deep	cl,gl,sicl	2	51	-	47	-	Danvers, Lawther, Regent, Utica, Windham, Winifred
Nh2	Ustochrepts, Ustorthents, Haploborolls	Strongly sloping to steep plains, hills	sedimentary mater- ials, alluvium	shallow to deep	1,cl,c,sic	-	2	44	54	-	Barkof, Barvon, Bitton, Cabba, Dast, Lamedeer, Macar, Ringling, Searing, Wayden
Nh3	Ustorthents, Lithic Haplo- borolls, Argiborolls	Strongly sloping to steep plains, hills	sedimentary rock beds, alluvium	shallow to deep	cl,sil,l,sic	-	6	2	92	-	Absarkee, Cabba, Castrer, Lambert, Wayden, Xavier
Nh4	Ustorthents, Ustochrepts	Strongly sloping to steep plains, hills	sedimentary beds, alluvium, glacial till	deep to moder- ately deep	cl,sil,sl,l	-	55	-	45	-	Cambert, Cherry, Dast, Dimyaw, Lambert, Macar, Zahill
Nh5	Ustochrepts, Ustorthents	Strongly sloping to steep plains, hills	sedimentary rock beds, alluvium	deep to shallow	cl,sil,sic, sl	2	22	1	75	-	Cabba, Cambert, Cherry, Dast, Dimyaw, Lambert, Macar
Nh6	Ustorthents, Haploborolls	Strongly sloping to steep plains, hills	alluvium, silt- stone, eolian	deep to shallow	1, cl,sil,sl	-	11	-	89	-	Cabbart, Chama, Dast, Doney, Lambert, Lihen, Shambo, Tinsley, Wayden
Np1	Argiborolls, Ustorthents	Nearly level to strongly sloping plains	sedimentary rock beds, alluvium	shallow to moder- ately deep	cl,l,sil	-	22	8	69	-	Cabba, Doney, Farnuf, Reeder, Wayden

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
Np2	Argiborolls, Lithic Argiborolls	Nearly level to strongly sloping plains	sandstone, shale, siltstone	moder- ately deep to shallow	1,cl	1	11	8	80	-	Absarokee, Amherst, Sinnigam, Borky, Darret
Np3	Ustorthents, Haploborolls, Natriborolls	Nearly level to strongly sloping plains	sedimentary rock beds, alluvium, eolian	moder- ately deep to deep	fs1,l,cl	-	-	-	100	-	Adger, Cabba, Dast, Doney, Rhoades, Tally, Vebar, Badland
Np4	Calciborolls, Haploborolls	Nearly level to strongly sloping plains	alluvium, meta- morphitic rocks, sandstone	deep	gl,l	-	67	-	33	-	Bitton, Castner, Ipano, Twin Creek
Np5	Ustorthents, Argiborolls	Nearly level to strongly sloping plains	sedimentary rock beds, alluvium	moder- ately deep	cl,l,sicl	-	17	4	79	-	Cabba, Doney, Farland, Regent, Wayden
Np6	Haploborolls, Ustochrept, Ustorthents	Nearly level to strongly sloping plains	sedimentary rock beds, alluvium, eolian	deep to shallow	sil,l,cl,sl	-	69	-	31	-	Amor, Cambert, Chama, Cherry, Dast, Lambert, Macar, Shambo, Vebar, Blanchard, Cabba, Dimyaw, Lehr, Tally
Og1	Argiborolls, Haploborolls (loamy)	Undulating to strongly rolling plains	alluvium, eolian, glacial till	deep	1,sl,cl,sil	-	98	-	2	-	Dooley, Farnuf, Parshall, Shambo, Tally, Williams
Og2	Argiborolls, Haploborolls, (clayey)	Undulating to strongly rolling plains	glacial till, alluvium	deep	cl,sicl,l	-	47	-	53	-	Bearpaw, Lawther, Savage, Vida
Og3	Argiborolls, Ustorthents, (thin solum)	Undulating to strongly rolling plains	glacial till	deep	1,cl	1	51	-	48	-	Farnuf, Vida, Williams, Zahill
Og4	Argiborolls, Ustorthents, (thick solum)	Undulating to strongly rolling plains	alluvium, glacial till, lacustrine sediments	deep	sil,l,cl	-	86	-	14	-	Bowbells, Farnuf, Grail, Lambert, Tinsley, Williams

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
Oh	Ustorthents, Argiborolls	Strongly rolling to steep plains	glacial till,	deep	l,cl,sil	-	50	-	50	-	Lambert, Vida, Williams Zahill
Ot	Argiborolls, Haploborolls	Nearly level to strongly sloping terraces	alluvium, glacial till, eolian	deep	sl,l,sil,cl	-	90	-	10	-	Dooley, Farnuf, Manning, Tally, Turner, Wabek
Pb1	Argiborolls, Torriorthents	Nearly level to steep fans, benches, terraces	alluvium	deep	l,sil	6	50	-	44	-	Evanston, Lambeth
Pb2	Calciborolls, Calciorthids	Nearly level to steep fans, terraces, benches	alluvium	deep	gl,sl	71	29	-	-	-	Binna, Crago, Rothiemay
Pb3	Haploborolls, Camborthids, Argiborolls	Nearly level to steep fans, benches, terraces	alluvium, lacustrine sediments, sedimentary rock beds	deep	sicl,l,cl,sic	19	44	-	37	-	#bor, Dutton, Ethridge, Evanston, Kobar, Kremlin
Ph1	Torriorthents (shallow), Argiborolls, Camborthids	Strongly sloping to steep plains, hills	sedimentary rock beds, alluvium, lacustrine sediments	deep to shallow	l,sicl,sil,cl	-	1	17	82	-	Cabbart, Cambeth, Delpoint, Dilts, Ethridge, Evanston, Lisam, Yamac, Yawdim
Ph2	Torriorthents (shallow), Lithic Argiborolls	Strongly sloping to steep plains, hills	sedimentary rock beds, alluvium	shallow to deep	l,sic,cl,sl	5	38	-	55	-	Cabbart, Glendive, Havre, Lisam, Rentsac, Yawdim
Pp1	Argiborolls, Haploborolls, Lithic Argiborolls	Nearly level to strongly sloping plains	sandstone, alluvium, eolian	shallow to deep	cl,l	-	44	-	56	-	Beenom, Boxwell, Chinook, Ernen, Marmarth, Sinnigam, Tanna
Pp2	Argiborolls, Haplargids, Lithic Torriorthents	Nearly level to strongly sloping plains	shale, sandstone	deep to shallow	l,sil,cl	-	24	3	73	-	Bonfri, Brusett, Marmarth, Rentsac, Tanna, Yawdim
Sg1	Argiborolls, Haploborolls	Nearly level to hilly glaciated plains	glacial till, alluvium	deep	l,cl,sl	-	86	-	14	-	Chinook, Joplin, Kevin, Kremlin, Scobey, Telstad

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
Sg2	Argiborolls, Torriorthents, Natrargids	Nearly level to hilly glaciated plains	glacial till	deep	1,cl	<1	57	<1	43	-	Elloam, Kevin, Phillips, Scobey, Sunburst, Telstad, Thoeny
Sg3	Argiborolls, Torriorthents, Natrargids	Nearly level to hilly glaciated plains	glacial till	deep	1,cl,c	-	17	-	83	-	Elloam, Hillon, Kevin, Scobey, Sunburst, Telstad, Thoeny
Sh	Torriorthents, Natrargids, Torriorthents (shallow)	Strongly sloping to steep glaciated plains	glacial till, sedimentary rock beds	deep to c,l shallow		-	2	-	98	-	Cabbart, Elloam, Lisam, Sunburst
St	Argiborolls, Haploborolls	Nearly level to moder- ately steep outwash and stream terraces	alluvium, eolian, lacustrine sedi- ments	deep	1,sil,cl, sl	1	83	-	16	-	Assinniboine, Attewan, Chinook, Ethridge, Evanston, Flowerree, Kremlin
Tb1	Haplargids, Haploborolls, Argiborolls	Nearly level to steep fans, terraces, benches	alluvium, lacus- trine sediments, eolian	deep	1,sil,cl	11	13	4	72	-	Attewan, Ethridge, Evanston, Flowerree, Fort Collins, Keiser, Kremlin
Tb2	Natrargids, Haplargids	Nearly level to steeply sloping fans, terraces, benches	alluvium	deep	1,cl,sl,sil	3	31	-	66	-	Absher, Creed, Fort Collins, Gerdum, Keiser
Tb3	Camborthids	Nearly level to steeply sloping fans, terraces, benches	alluvium, lacus- trine, sediments	deep	1,sic,sil	35	10	3	51	-	Kobar, Lonna, Yamac
Th1	Torriorthents, Camborthids	Strongly sloping to steep plains, hills	sedimentary rock beds, alluvium shale	deep	1,cl,sil	-	3	-	97	-	Bascovy, Cambeth, Delpoint, Lambeth, Yamac
Th2	Torriorthents (shallow) Camborthids, Torriorthents	Strongly sloping to steep plains, hills	sedimentary rock beds, alluvium, lacustrine sedi- ments	deep	1,sl,sic, sil	-	4	23	73	-	Birney, Cabbart, Cambeth, Delpoint, Kirby, Kobar, Lambeth, Riedel, Twilight, Yamac, Yawdim

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
Th3	Torriorthents (shallow), Torriorthents, Camborthids	Strongly sloping to steep plains, hills	sedimentary rock beds, alluvium, glacial till	deep	1,sil,sl,cl	-	1	7	92	-	Busby, Cabbart, Cambeth, Delpoint, Lambeth, Lonna, Riedel, Scroggin, Sun- burst, Yamac, Yawdim
Th4	Torriorthents, Torriorth- ents (shallow), Camborthids	Strongly sloping to steep plains, hills	sedimentary bed- rock, alluvium	deep to shallow	1,sil,sl,cl	1	-	11	88	-	Bainville, Busby, Cabbart, Delpoint, Lambeth, Yamac, Yawdim
Th5	Torriorthents, Lithic Torriorthents, Camborthids	Strongly sloping to steep plains, hills	sandstone, silt- stone, shale, alluvium	deep to moder- ately deep	1,sil,cl	-	-	62	38	-	Bainville, Delpoint, Lambeth, Renstac, Yamac
Th6	Torriorthents, Natrargids	Strongly sloping to steep plains, hills	alluvium, sedi- mentary bedrock	deep	1,sil,cl,c	-	1	-	99	-	Absher, Archin, Benz, Creed, Gerdrum, Lambeth, Lisam, Marvan, Yawdim
Tp1	Camborthids, Haploborolls, Argiborolls	Nearly level to moderately steep plains	alluvium, sedi- mentary bedrock	deep to moder- ately deep	1,sil,sl,cl	-	43	-	51	-	Boxwell, Busby, Cambett, Chanta, Chinook, Delpoint, Evanston, Kremlin, Lonna, Marmarth
Tp2	Camborthids, Torrior- thents (shallow)	Nearly level to moderately steep plains	sedimentary bed- rock, alluvium	deep	1,sl,sicl,cl	-	3	3	94	-	Birney, Busby, Cabbart, Delpoint, Twilight, Yamac
Tp3	Camborthids	Nearly level to moderately steep plains	alluvium, sedi- mentary bedrocks	deep	1,sil,sl,cl	-	9	-	91	-	Busby, Cambeth, Delpoint, Lonna, Yamac
Tp4	Camborthids, Torrior- thents	Nearly level to moderately steep plains	sedimentary bed- rock, alluvium	deep to moder- ately deep	sl,l,cl,sic	-	4	20	76	-	Armells, Busby, Delpoint, Kobar, Riedel, Twilight, Yomac
Tp5	Haplorgids, Camborthids, Natrargids	Nearly level to moderately steep plains	alluvium, sedi- mentary bedrock	deep	1,sil,cl	-	26	3	71	-	Absher, Bonfri, Cambeth, Delpoint, Gerdrum, Lonna Yamac

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
Ug1	Paleargids, Natrargids, Argiborolls	Undulating to strongly rolling plains	glacial till	deep	l,cl,sl	1	18	-	82	-	Creed, Elloam, Kevin, Phillips, Scobey, Thoeny
Ug2	Natrargids, Camborthids, Torriorthents	Undulating to strongly rolling plains	glacial till, sedi- mentary bedrock	deep	c,cl,l,sic	-	-	4	96	-	Bascovy, Creed, Dilts, Elloam, Sunburst, Thoeny
Vb1	Argiborolls	Nearly level to strongly rolling terraces, fans, benches, basins	glacial till, lacus- trine sediments, alluvium	deep	cl,sicl	-	87	-	13	-	Gerber, Linnet, Scobey
Vb2	Camborthids, Torriorthents, Argiborolls	Nearly level to strongly rolling terraces, fans, benches, basins	Lacustrine sedi- ments, alluvium, glacial till	deep	sicl,l,cl,c	-	94	-	4	-	Ethridge, Gerber, Hillon, Kobar, Linnet, Marias, Pondray, Scobey
Vb3	Camborthids, Natrargids	Nearly level to strongly rolling terraces, fans, benches, basins	Alluvium	deep	c,l,sl,sil	-	-	-	100	-	Bickerdyke, Gerdum
Vb4	Natrargids, Torriorthents	Nearly level to strongly sloping terraces, fans, benches, basins	alluvium, glacial till, shale	deep	l,cl,c,sic	9	91	-	-	-	Absher, Nobe, Vanda
Vb5	Torriorthents, Natrargids, Torrifluvents	Nearly level to strongly sloping terraces, fans, benches, basins	alluvium, lacus- trine sediments, sedimentary bedrock	deep	l,c,sic,sil cl	-	23	-	77	-	Absher, Gerdum, Harlem, Havre, Marias, Marian, Thebo, Vaeda, Vanda
Vb6	Haplaquepts	Nearly level to strongly sloping terraces, fans, benches, basins	calcareous clay sediments	deep	c	-	67	-	33	-	McKenzie
Vh1	Torriorthents (shallow), Camborthids, Natrargids	Strongly sloping to steep plains	shale, alluvium	shallow to deep	sic,c,l,sl	-	5	8	87	-	Abor, Archin, Bascovy, Creed, Bilts, Gerdum, Kobar, Lisam, Neldore, Yawdin

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
Vh2	Ustorthents, Ustorthents (shallow), Haploborolls	Strongly sloping to steep plains	shale, alluvium, clayey sediment beds	deep to shallow	cl,sic,c,l	3	9	3	85	-	Benz, Dimyaw, Ellsac, Lawther, Marias, Norbert, Shambo, Vanda, Wayden, Winifred
Vh3	Torriorthents (shallow) Torriorthents	Strongly sloping to steep plains	claystone, shale, clayey, alluvium	shallow to deep	c,sic	1	1	1	97	-	Dilts, Lisam, Marvan, Thebo
X	Badlands, Torriorthents	Steep to very steep river breaks	claystone, shale, alluvium	shallow to mod- erately deep	c,sic,sl	1	2	37	69	-	Alona, Cabbart, Dilts, Lisam, Riedel, Thebo
<u>Intermountain and Piedmont Section</u>											
Av1	Fluvaquents, Torriorth- ents, Calciorthis	Nearly level to strongly sloping fans, terraces, floodplains	stratified alluvium (calcareous)	shallow to deep	1	55	4	4	36	-	Amesha, Mussel, Musselshell, Scavo, Villy
Av2	Xerochrepts, Xerofluvents, Haplaquolls	Nearly level to strongly sloping terraces, fans, footslopes	?	?		63	-	28	10	-	?
Av3	Ustochrepts, Ustofluvents, Haplaquolls	Nearly level to strongly sloping terraces, fans, footslopes	siltstone, alluvium	moder- ately deep	cl,l	28	-	39	33	-	Chereete, Hagstadt, Kiwanis, Larry, Totelake
Av4	Argiborolls, Haploborolls, Fluvaquents	Nearly level to gently sloping fans, terraces, footslopes	loamy, alluvium	moder- ately deep to deep	gl,l,sicl	31	6	4	59	-	Beaverton, Farnuf, Grantsdale, Villy
Av5	Haploborolls, Argiborolls, Camborthis	Nearly level to strongly sloping outwash plains	loamy alluvium	moder- ately deep to deep	gl,l	20	15	-	65	-	Attewan, Beaverell, Bercoil, Grantsdale, Straw

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
B	Cryaquolls, Cryoborolls	Nearly level, cold, wet basins	alluvium	deep	cl	56	-	5	37	-	Furniss, Gallatin, Gapo Leavitt
Ct1	Haploxerolls, Xerochrepts Xeropsamments	Nearly level to moderately sloping on outwash terraces fans, benches	?	deep	?	50	1	26	21	1	?
Ct2	Haploxerolls, Natrargids	Nearly level to moderately sloping outwash terraces, fans, benches	?	deep	?	80	-	-	20	-	?
Dt1	Haploxerolls, Argixerolls	Nearly level to strongly sloping lacustrine terraces	lacustrine sediments	deep	?	13	2	79	6	-	?
Dt2	Natrixerolls, Argixerolls	Nearly level to strongly sloping lacustrine terraces	lacustrine sediments	deep	?	76	-	4	20	-	?
Et	Xerochrepts, Xerorthents, Ustochrepts	Nearly level to strongly sloping outwash terraces, fans	?	deep	?	-	-	93	7	-	?
Fg	Haploxerolls, Natrixerolls	Undulating to strongly rolling soils on glacial moraines	glacial moraine	deep	?	33	-	-	67	-	?
Gb1	Argiborolls, Haploborolls	Nearly level to steep fans, benches, terraces	loess	deep	s11	20	59	-	20	-	Amsterdam, Bozeman
Gb2	Argiborolls, Lithic Haploborolls, Haploborolls	Nearly level to steep slopes on fans, benches, terraces	alluvium, sandstone quartzite, argillite	shallow to deep	cl	10	9	7	74	-	Castner, Grantsdale, Hilger, Perma, Sweetgrass, Turner
Gb3	Argiborolls, Eutroborolls, Haplaquolls	Nearly level to strongly sloping uplands, fans and terraces	alluvium, loess glacial till, siltstone	moder- ately deep to deep	cl	9	-	27	64	-	Cohen, Crow, Danvers, Ekah, Lainy, Lubrecht, Martins- dale, Savage

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
Gb4	Argiborolls	Nearly level to strongly sloping fans, terraces	loamy alluvium	moderately deep to deep	1,cl,gl	8	29	3	61	-	Beaverton, Fairfield, Farnuf, Judith, Martinsdale, Windham
Gb5	Argiborolls, Calciborolls	Nearly level to strongly sloping fans, terraces	loamy alluvium (calcareous)	shallow cl, l to deep		8	43	1	48	-	Danvers, Fairfield, Farnuf, Judith, Martinsdale, Windham
Gb6	Calciborolls	Nearly level to strongly sloping terraces	limestone alluvium	shallow l, gl to deep		6	13	-	78	-	Judith, Utica, Windham
Gf1	Argiborolls, Lithic Argiborolls	Moderately sloping to steep slopes on foothills	shale, sandstone	shallow l, cl to moderately deep		-	6	22	72	-	Alder, Darret, Doughty, Sinnigam
Gf2	Argiborolls, Haploborolls	Moderately sloping to steep slopes on foothills	shale, sandstone, silt stone, alluvium	shallow cl, l to deep		3	5	-	92	-	Big Timber, Darret, Fergus, Litimber, Terrad, Timberg
Gf3	Calciborolls, Haploborolls	Nearly level to strongly sloping uplands, fans, terraces	alluvium, limestone	shallow sic, l to moderately deep		-	-	10	90	-	Armington, Lap, Perista, Windham
Gf4	Haploborolls, Ustorthents	Undulating to steep sloping uplands	shale	shallow l to deep		-	3	-	97	-	Abac, Arnegard, Cabba, Eltsac, Norbert, Perista, Perma, Roundup
Gf5	Haploborolls, Lithic Haploborolls	Gently sloping to steep foothills	igneous rock, sandstone	shallow l to deep		-	2	2	98	-	Belain, Castner, Hedoes

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	Land Cover					Representative Soil Series
						I	D	F	R	A	
Gg1	Argiborolls, Haploborolls	Undulating to steep pied- mont glacial moraines	alluvium sediments	deep	1	7	-	40	53	-	Chinook, Coben, Ekah, Grantsdale, Martinsdale
Gg2	Argiborolls, Haploborolls, Calciborolls	Undulating to steep pied- mont glacial moraines	alluvium, glacial till	deep	1	-	4	-	95	-	Farnuf, Judith, Martins- dale, Perma, Vida, Williams, Windham, Zahl
Hf1	Haploborolls, Argiborolls, Cryoborolls	Moderately sloping to steep foothills	loamy alluvium	deep	1, sil	6	2	25	68	-	Adel, Boxwell, Bridger, Coben, Danvers, Ekah, Grantsdale, Martinsdale, Philipsburg, Quigley, Savage
Hf2	Haploborolls, Cryoborolls, Paleborolls	Moderately sloping to steep foothills	alluvium	moder- ately deep	1, gl	1	4	24	72	-	Bitton, Castle, Castner, Hanson, Teton, Tigeron
Hf3	Argiborolls, Haploborolls, Cryoborolls	Moderately sloping to steep foothills	alluvium	deep	1	1	1	17	81	-	Absarokee, Bridger, Hilger, Perma, Work
Hf4	Ustorthents, Lithic Haplo- borolls, Cryoborolls	Moderately sloping to steep foothills	shale, alluvium	shallow 1, c to moder- ately deep		-	1	1	98	-	Bridger, Cobba, Castner, Eltsac
Ib1	Cryoborolls	Nearly level to steeply sloping fans, benches, terraces	alluvium, sandstone	moder- ately deep	1	15	4	4	77	-	Bridger, Passcreek, Rooset
Ib2	Cryoborolls, Cryaquolls	Nearly level to steeply sloping fans, terraces, benches	alluvium, sedimen- tary rock, igneous rock	deep	1	22	-	13	65	-	Adel, Bridger, Gapo, Philipsburg
Ib3	Cryoborolls	Nearly level to steeply sloping fans, terraces, benches	alluvium, glacial till, sedimentary rock	moder- ately deep	1	-	5	-	95	-	Fifer, Michelson, Redchief

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
If1	Cryoborolls, Lithic, Cryoborolls	Moderately sloping to steep foothills	alluvium, igneous rock, sandstone	deep to shallow	1	-	5	44	51	-	Bridger, Cheadle, Ess
If2	Cryoborolls	Moderately sloping to steep foothills,	Sandstone, granite, alluvium	moder- ately deep	1	-	-	19	81	-	Cheadle, Hanson, Orofino, Skaggs, Teton
If3	Cryoborolls, Cryochrepts	Moderately sloping to steep foothills	metamorphic rock, igneous rock, alluvium	deep	1	1	1	20	78	-	Adel, Bridger, Gorlet, Philipsburg
If4	Cryoborolls, Cryochrepts, Ustochrepts	Moderately sloping to steep foothills	alluvium, colluvium, glacial till, sedi- mentary rock	deep	1,sl	2	-	52	47	-	Duncom, Garlet, Leavitt, Sebad, Whitecow, Whitore, Winkler
Ig	Cryoborolls	Undulating to steeply sloping piedmont moraines		deep	1	-	-	22	78	-	Adel, Babb, Hanson
Jb	Argiborolls, Calciorthids	Nearly level to strongly sloping fans, terraces benches	alluvium, eolian, stratified sedi- ments	deep	1	20	6	7	68	-	Amesha, Brocko, Coben, Crago, Ekah, Evanston, Martinsdale, Musselshell, Radersburg, Sappington
Jf	Argiborolls, Haplargids, Torriorthents	Moderately sloping to steep soils on foothills	alluvium, sandstone igneous rock	shallow to deep	1,sl,cl	1	7	18	75	-	Attewan, Evanston, Nippt, Nuley, Riedel
Kb1	Calciorthids, Torriorthents	Nearly level to moderately steep fans, terraces, benches	alluvium	deep	1	14	16	2	66	-	Amesha, Crago, Mussel, Musselshell
Kb2	Calciorthids, Haplargids, Agiborolls	Nearly level to moderately steep fans, terraces, benches	?	moder- ately deep to deep	1	21	12	-	67	-	Musselshell, Nippt, Nuley
Kb3	Calciorthids, Argiborolls, Camborthids	Nearly level to moderately steep fans, terraces, benches	Metamorphic rock, igneous rock, alluvium	deep	1,sl	-	-	-	100	-	Attewan, Colono, Musseshell, Nuley, Shurley

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	X Land Cover					Representative Soil Series
						I	D	F	R	A	
Kb4	Calciorthids	Nearly level to moderately steep terraces, fans, benches	calcareous loamy alluvium	moderately deep to deep	gl	-	6	2	92	-	Crago, Williams
Kf	Calciorthids, Argiborolls	Moderately sloping to steeply sloping foothills	alluvium	deep	1	-	12	18	64	-	Amesha, Crago, Evanston, Musselshell, Nuley
Kt	Camborthids, Natriargids	Nearly level to moderately steep lacustrine terraces	lacustrine sediments, alluvium	moderately deep	sic,sicl	26	11	-	63	-	Lonepine, Ronan, Round Butte
Lg1	Cryochrepts, Eutroboralfs, Eutrochrepts	Undulating to rolling foothills of valleys and glacial moraines	clayey alluvium, clayey colluvium	deep	?	1	-	92	6	-	Crow, Haugen, Inez, Lubrecht, Trapps, Whitore, Winfall
Lg2	Cryoboralfs, Cryoborolls	Undulating to rolling foothills of valleys, glacial moraines	glacial till, alluvium, colluvium	moderately deep to deep	l,gl,cl	-	-	86	14	-	Eabb, Hanson, Loberg
Lg3	Cryochrepts, Cryoboralfs	Undulating to rolling foothills of valleys, glacial moraines	colluvium	deep	g to stl	-	-	97	3	-	Garlet, Worock
Lt	Cryochrepts, Cryorthents	Nearly level outwash terraces		deep	?	-	-	93	7	-	No reference series
Ma	Cryochrepts, Cryandepts	Steep to very steeply sloping mountain slopes	loess, ash cap over argillitic residuum	deep	sil,l	-	-	94	1	5	Buckhouse, Coerock, Felan, Holloway, Truefissure
Me1	Cryochrepts, Cryoboralfs,	Moderately sloping to very steep mountain slopes	Limestone, colluvium various rock	deep	gl,sil,sl,l	-	-	92	2	5	Crow, Cambler, Holloway, Loberg, Lubrecht, Trapps, Tropal, Whitore, Winfall, Worock
Me2	Cryochrepts, Cryoboralfs	Moderately sloping to very steep mountain slopes	colluvium, metamorphic rock, sandstone	deep	gl,cl,stsl	1	-	97	1	1	Garlet, Holloway, Loberg, Tenrag, Worock

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Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
Me3	Cryochrepts, Cryoboralfs, Cryoborolls	Moderately sloping to very steep mountain slopes	sedimentary rock, igneous rock, colluvium, glacial till	deep	1,s1,vgl	-	-	94	4	2	Adel, Elkner, Garlet, Sebud, Worock
Me4	Cryochrepts, Cryoboralfs, Lithic Cryoborolls	Moderately sloping to very steep mountain slopes	colluvium, igneous rock, sedimentary rock	shallow to deep	1,s1,cl	-	-	91	4	5	Cheadle, Duncom, Gambler, Garlet, Loberg, Whitore, Worock
Me5	Cryochrepts, Rock Outcrop	Moderately sloping to very steep mountain slopes	colluvium, alluvium	deep	s1l, chan- nery 1	-	-	83	-	17	Garlet, Whitore
Mf1	Cryochrepts, Ustochrepts, Eutroboralfs	Moderately sloping to very steep mountain slopes	colluvium, alluvium, calcareous rock material	deep	gl,s1l,s+s1	1	-	96	2	.5	Crow, Garlet, Holloway, Macmeal, Repp, Trapps, Whitore, Winkler
Mf2	Cryochrepts, Ustochrepts, Cryorthents	Moderately sloping to very steep mountain slopes	granite	shallow to deep	s1,l,s1l	1	-	77	6	16	Ambrant, Elkern, Stecum
Mf3	Cryochrepts, Ustochrepts, Cryoboralfs	Moderately sloping to steep mountain slopes	sedimentary rock, glacial till	deep	gl,s1l,1	1	-	90	3	7	Teton, Mollman, Repp, Trapper, Whitore
Mf4	Cryochrepts, Ustochrepts, Lithic Cryoborolls	Moderately sloping to steep mountain slopes	mixtures of sedi- mentary, igneous, metamorphic rock	shallow to deep	gl,sts1	-	-	96	4	-	Cheadle, Garlet, Winkler
Mo1	Cryoborolls, Cryochrepts, Cryoboralfs	Gently sloping to very steep mountain slopes	?	deep	?	-	-	71	27	-	No reference pedons
Mo2	Cryoborolls, Cryochrepts, Ustochrepts	Gently sloping to very steep mountain slopes	alluvium, colluvium, sedimentary rock	moder- ately deep to deep	1,gl,s1l	-	-	76	23	1	Hanson, Skaggs, Whitecow, Whitore

Table IV-1. (continued)

Map Symbol	Great Groups	Landform	Parent Material	Soil Depth	Surface Texture	% Land Cover					Representative Soil Series
						I	D	F	R	A	
Mo3	Cryoborolls, Cryoboralfs, Cryochrepts	Gently sloping to very steep mountain slopes	colluvium, alluvium, deep igneous rock residuum		l,gl,sil,gs1	-	-	89	11	-	Bridger, Cowood, Ess, Garlet, Loberg, Teton, Worock
Mo4	Cryochrepts, Cryoborolls, Haploborolls	Gently sloping to very steep mountain slopes	alluvium, igneous rock, sedimentary rock	shallow to deep	gl,l	-	-	78	21	1	Belain, Bridger, Castner, Cheadle, Cowood, Hanson, Libeg, Perma, Tropal
Mo5	Cryoborolls	Gently sloping to very steep mountain slopes	shale, limestone	shallow to deep	sil,c	-	-	57	43	-	Duncom, Mayflower, Tarrete
Mo6	Eutroboralfs, Agriborolls, Lithic Cryoborolls	Gently sloping to very steep mountain slopes	alluvium, igneous rock	deep	sil,l,cl	-	-	74	26	-	Cheadle, Farnuf, Hilger, Micmeal, Yourame
R	Rock outcrop, Tallus, Cryoborolls, Cryochrepts	Mountain peaks, gently sloping to very steep alpine grasslands	alluvium, colluvium, glacial till, various rock types	shallow to deep	l,sil,sl,gs1	1	-	43	1	56	Blackleed, Cheadle, Cowood, Garlet, Raynesford, Sebud, Tropal, Whitore

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