Vegetation and Terrain Mapping in Alaska Using Landsat MSS and Digital Terrain Data

Mark Shasby
Technicolor Government Services, Inc., Anchorage, AK 99508
David Carneggie
U. S. Geological Survey, Anchorage, AK 99508

ABSTRACT: During the past 5 years, the U.S. Geological Survey's (USGS) Earth Resources Observation Systems (EROS) Data Center Field Office in Anchorage, Alaska has worked cooperatively with Federal and State resource management agencies to produce land-cover and terrain maps for 245 million acres of Alaska.

The need for current land-cover information in Alaska comes principally from the mandates of the Alaska National Interest Lands Conservation Act (ANILCA), December 1980, which requires major land management agencies to prepare comprehensive management plans.

The land-cover mapping projects integrate digital Landsat data, terrain data, aerial photographs, and field data.

The resultant land-cover and terrain maps and associated data bases are used for resource assessment, management, and planning by many Alaskan agencies including the U.S. Fish and Wildlife Service, U.S. Forest Service, Bureau of Land Management, and Alaska Department of Natural Resources. Applications addressed through use of the digital land-cover and terrain data bases range from comprehensive refuge planning to multiphased sampling procedures designed to inventory vegetation statewide.

The land-cover mapping programs in Alaska demonstrate the operational utility of digital Landsat data and have resulted in a new land-cover mapping program by the USGS National Mapping Division to compile 1:250,000-scale land-cover maps in Alaska using a common statewide land-cover map legend.

INTRODUCTION

The U.S. Geological Survey (USGS) established the Earth Resources Observation System (EROS) Field Office in Anchorage, Alaska in 1980. The original mission of the Field Office was to serve as a technology transfer center for training in the use and analysis of remotely sensed data, principally Landsat multispectral scanner (MSS) satellite data. This mission was carried out by offering structured training courses and cooperative demonstration projects to State and Federal agencies responsible for natural resource assesment and management in Alaska. In addition, the Field Office was equipped with Alaska's first operational image processing system for use in training and cooperative projects. Maintaining this system and making it available to qualified government users for their operational projects was also a part of the original EROS mission.

Over the years, the Field Office has expanded the services it provides to the user community. Today, the Field Office provides image processing services such as land-cover mapping, and integrates this data with other digitial resource data bases to serve the operational programs of Federal, State, and local government agencies in Alaska.

During the past 6 years, the EROS Field Office image processing system has been used on numerous cooperative land-cover mapping projects conducted for and with the U.S. Fish and Wildlife Service (USFWS), the U.S. Forest Service (USFS), the Bureau of Land Management (BLM), and the Alaska Department of Natural Resources (ADNR). These projects have resulted in the development of digital data bases and map products providing land-cover and terrain information for 245 million acres in Alaska. These data bases, derived through the digital analysis of Landsat MSS data and digital elevation model (DEM) data, were developed to meet specific resource planning and management information needs of the participating agencies.

The Alaska National Interest Lands Conservation Act (ANILCA), passed in December 1980, provided the mandate for all major land management agencies in Alaska to prepare comprehensive resource and management plans to assess wildlife habitat, oil and gas exploration and development, wild and scenic rivers, land disposal, timber production, and archeological and cultural resources. In order to meet the short deadlines established by the ANILCA legislation for preparing comprehensive management plans, many resource agencies in Alaska entered

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into cooperative agreements with the Field Office to produce land-cover classifications using Landsat MSS data and a digital analysis approach.

The purpose of this paper is to document the land-cover mapping accomplishments of the Federal and State cooperators who used the EROS image processing system. The collective land-cover mapping effort may be the largest application of digital Landsat MSS data for operational land-cover mapping in the history of the Landsat program. The procedures used to process digital Landsat MSS data and digital terrain data and to develop data bases are presented. Also discussed are the map and data products derived from the mapping program, and a new land-cover mapping program for Alaska endorsed by the USGS National Mapping Division (NMD), called the Interim Land Cover Mapping Program.

BACKGROUND

The earliest uses of Landsat MSS data for mapping vegetation and habitat in Alaska date back to the early 1970's, following the launch of the first Landsat satellite in July 1972. Landsat images were manually interpreted by University of Alaska, Fairbanks, personnel under research contracts with the National Aeronautical and Space Administration (NASA) (Belon and Miller, 1973; Anderson, 1974; Lent and LaPerriere, 1974).

The first studies to use digital Landsat MSS data in Alaska followed shortly thereafter. The early publications report the feasibility of using computer-aided analysis techniques to classify vegetation for environmental assessment, range inventory, and wildlife habitat mapping objectives (Belon *et al.*, 1975; George *et al.*, 1976; LaPerriere, 1976). Initially, the digital processing was conducted either on a prototype research image processing system at the University (Fairbanks, Alaska) or by private contractors in the contiguous 48 states.

During the mid-seventies two large vegetation-mapping projects using digital Landsat MSS data were conducted. The first was an Application System Verification and Transfer (ASVT) project, a cooperative study of the BLM, NASA, and USGS (EROS Data Center). The objective was to produce a vegetation map for approximately 2 million acres of BLM land along the Denali Highway and to compare the costs, personnel time, and accuracy of vegetation mapping using digital Landsat data relative to conventional maping techniques (Krebs, 1980).

The second project involved the digital analysis of ten Landsat scenes covering the National Petroleum Reserve of Alaska (NPRA). The project was conducted by the USGS National Mapping Division for a BLM environmental impact statement. This 23-million-acre project was one of the largest digital mapping projects using Landsat data (Morrissey and Ennis, 1981). The results from these two studies contributed greatly to the decision by USGS and BLM to continue processing digital Landsat data for vegetation mapping in Alaska.

In 1980, the USGS opened the EROS Field Office in Anchorage and installed in it Alaska's first operational image processing computer system. The system is called IDIMS*, an acronym for Interactive Digital Image Manipulation System. IDIMS serves two primary functions. First, it supports EROS' technology transfer mission for demonstrating image processing capability, training government users, and image processing on cooperative demonstration projects. Secondly, it is available for operational use by any qualified cooperating government agency.

The first operational users of IDIMS in Alaska were personnel from the BLM and the Geophysical-Institute, University of Alaska, Fairbanks (GIUAF). The BLM used IDIMS to build digital data bases that combined land-cover classifications from the NPRA with digital terrain data. These data bases and associated interpretive maps were used to support environmental impact statements prepared in conjunction with oil and gas leasing (Spencer and Krebs, 1983).

Personnel from GIUAF used IDIMS to classify vegetation using digital Landsat data of the Seward Pennisula. The classifications were used for a range inventory being conducted for the U.S. Department of Agriculture's Soil Conservation Service (SCS) (George *et al.*, 1976; George *et al.*, 1977) and a caribou habitat study for the BLM.

In 1981, EROS personnel entered into a cooperative agreement with the USFWS to produce vegetation and terrain map products for the Togiak and Kenai National Wildlife Refuge (NWR) (Talbot *et al.*, 1985). Simultaneously, ADNR's Division of Geological and Geophysical Surveys (DGGS), EROS, and USFWS were beginning a cooperative project to classify vegetation and terrain for 35 million acres in the Bristol Bay Subregion of southwestern Alaska, which encompassed the Togiak NWR and three additional NWRs (Becharof, Izembek, and Alaska Peninsula) on the Alaska Peninsula (Wibbenmeyer *et al.*, 1982).

When these land-cover mapping projects were completed in 1982-83 and evaluated, the USFWS made a major committment to continue working cooperatively with USGS EROS to produce land-cover and terrain maps for all but two of the remaining refuges. The Refuges include Tetlin (Talbot *et al.*, 1984a; Talbot *et al.*, 1984b), Yukon Flats (Shasby *et al.*, 1983), Kanuti (Talbot *et al.*, 1986), Arctic, Yukon Delta, Koyukuk, Nowitna (Talbot and Markon, 1986), Selawik, and Innoko (Markon and Talbot, 1986). Kodiak and Alaska Maritime NWRs were the only refuges excluded. The land-cover and terrain data for the 14 refuge projects, totaling 80 million acres, were produced at a cost ranging between $0.01 and $0.05 per acre (includes field data collection, images

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processing, and output products). These data are being integrated into USFWS' Geographic Information System (Henderson, 1984).

During this period, BLM personnel had completed digital data bases for NPRA and had commenced land-cover mapping within the Unalakleet River watershed (Meyer and Spencer, 1983). Their mapping effort has subsequently been extended southward into the Anvik-Bonasilla (Osborne *et al.*, 1986), Iditarod-George (Spencer *et al.*, 1986), and Kvichak areas of western Alaska. For each of these areas, vegetation and terrain data have been combined into data bases and manipulated to produce additional interpretive maps, for example, moose habitat, in support of BLM's oil and gas leasing program.

In 1983, USFS personnel from the Forestry Sciences Laboratory in Anchorge embarked on a massive operational land-cover classification project encompassing the entire Tanana River Basin. USFS personnel worked on IDIMS for 2 years to produce vegetation classifications from digital Landsat data for 35 million acres. These data were used in support of their mandate to produce vegetation and timber statistics in Alaska for the National Resource Inventory (Winterberger, 1984). Currently, USFS personnel are working on a second massive land-cover mapping project to obtain vegetation statistics for southeast Alaska, an area of approximately 35 million acres.

Also in 1983, ADNR/DGGS signed an interagency agreement for EROS personnel to produce land-cover and terrain data for four 1:250,000-scale USGS quadrangles, in support of ADNR's Resource Mapping Program in the Copper River Basin. Land-cover maps and associated terrain data were produced for the Valdez, McCarthy, Gulkana, and Nabesna quadrangles, an area of approximately 16 million acres (Loveland, 1984).

Although IDIMS has been used on small demonstration projects with other agencies, for example, the National Park Service, and for other applications, such as minerals targeting and hydrologic applications, the greatest use has been vegetation classification. Table 1 summarizes the major land-cover mapping projects in Alaska which used IDIMS at the EROS Field Office or EROS Data Center. They total approximately 245 million acres or approximately two-thirds of the state.

METHODS

The integrated approach to collecting field data and analyzing Landsat and digital terrain data, used by EROS and all of its cooperators to produce land-cover classifications, is relatively consistent (Fleming, 1985). All use Landsat false-color composite images and high altitude color-infrared aerial photographs to locate representative ground sample sites, use helicopter surveys to collect ground data, and then combine digital Landsat MSS and terrain data in a digital data base approach. The Landsat MSS data are on computer-compatible tapes, and the terrain data (arc-second Digital Elevation Models - DEMs) are derived from digitizing contours from 1:250,000-scale USGS topographic maps. Other source materials used in the mapping process include administrative boundaries, digital hydrography, and stratification data, either physiography interpreted from Landsat scenes, both summer and winter, or aerial photographs. The latter data sources are usually in map or map-like format and must be converted to digital format before entry into the data base. The data base used in the classification process is in grid-cell format, generally 50 metres in size, and registered to maps with a Universal Transverse Mercator projection.

The procedures for preprocessing the Landsat data and making land-cover classifications are similar to those reported by Fleming and Hoffer (1979) and are summarized in Table 2.

Once the preliminary spectral classification results are obtained, they are incorporated into the digital data base, where other data sources are used in the post-classification process to improve classification accuracy. Three common post-classification procedures which are used include (a) physiographic masks, (b) digital terrain data, and (c) winter Landsat scenes. Physiographic strata masks are created by manually delineating the study area into discrete physiographic units. The masks differentiate land-cover classes that appear spectrally similar, but which occur in different physiographic units. For example, water and shadow, or upland and lowland shrubland often appear spectrally similar. They can be separated in the final classification by applying physiographic masks.

Digital terrain data can be used in a similar way to create new strata masks. Here the masks can be classes of a terrain variable, such as an elevation class, or combinations of terrain variables. This approach is used to separate land-cover classes which appear to be spectrally similar but which are differentiable because they occur in different terrain environments. Upland and lowland shrub communities can be separated with an elevation mask.

Finally, masks derived from winter Landsat scenes have been used successfully to separate conifer forest classes from wetland classes. On the winter Landsat scenes conifer forest appears relatively dark, whereas wetland classes are generally uniformly snow covered and appear very bright. A strata mask derived from the winter scenes can improve the separation of these two important land-cover classes. The accuracy of the Landsat classifications is improved significantly with digital strata masks in the post classification process.

LAND-COVER AND TERRAIN PRODUCTS

The primary output products from the classification process are (a) the hard copy maps and (b) the digital computer files of land cover, elevation, slope,

TABLE 1. LAND COVER MAPPING PROJECTS IN ALASKA USING EROS IDIMS SYSTEM

Agency	Project	Acreage	
Bureau of Land Management	Anvik-Bonasila	8 million*	
	Unalakleet	6 million*	
	National Petroleum Reserve, Alaska (NPRA)**	23 million*	
	Iditarod-George	5 million	
	Kvichak	2 million*	
	TOTAL BLM:		44 million
U.S. Forest Service	Tanana River Basin	35 million*	
	S.E. Alaska (in progress)	35 million*	
	TOTAL USFS:		70 million
U. S. Fish and Wildlife Service	Tetlin National Wildlife Refuge (NWR)	1 million	
	Yukon Flats NWR	10 million*	
	Kenai NWR	4 million	
	Togiak NWR	5 million	
	Arctic NWR	20 million	
	Kanuti NWR	2 million	
	Yukon Delta NWR	20 million	
	Koyukuk NWR	8 million	
	Nowitna NWR	3 million	
	Selawik NWR	3 million	
	Innoko NWR	4 million	
	TOTAL USFWS:		80 million
Alaska Dept. of Natural Resources and U. S. Fish and Wildlife Service	Bristol Bay	35 million*	
	TOTAL ADNR/FWS		35 million
Alaska Dept. of Natural Resources	Copper River	16 million	
	TOTAL ADNR:		16 million
TOTAL LAND COVER ACREAGE COMPLETED OR IN PROGRESS:			245 million

*Analysis for these projects performed by agency personnel; analysis for other projects performed by or cooperatively with EROS personnel.
**Original classification performed by NMD, USGS, Menlo Park, Calif.

and aspect data. The map products, either lithographic, paper or photographic, normally are presented at a scale of 1:250,000 for either the entire project area or for the 1:250,000-scale USGS quadrangles.

Digital data products are written to computer-compatible tape and are provided to the cooperating agency for integration into its data base for geoprocessing. The digital files generally are registered to a 50-metre UTM grid for a project area or for 1:250,000-scale quadrangles. In some cases the 50-metre UTM data are resampled and registered to a 200-metre UTM grid for the entire project area. A copy of all digital files is archived and referenced at the EROS Field Office. EROS will access and reformat any digital data to a variety of formats and projections based on the user's requirements. Compatability of data between agencies is insured by adhering to standard data formats.

In addition to the land-cover, elevation, slope, and aspect maps and corresponding digital files, the unregistered and registered Landsat MSS tapes are stored in the EROS digital library. These products are available to the original cooperator and to other cooperating agencies where cost savings can be realized through data sharing, and for the production of derivative products. Data processed on IDIMS and in the EROS digital library are available to the public and private sector.

DERIVATIVE PRODUCTS

Derivative products result from subsequent processing of the data used to satisfy the original land-cover mapping objectives. Examples of subsequent processing range from a regrouping of spectral classes to produce wildlife habitat maps, to the combining of registered MSS data and digital elevation data to produce an enhanced oblique perspective image of a particular landscape. The data base approach facilitates utilization of the data far beyond the production of land-cover and terrain maps. As more data are added to the data base, the number of new products and the potential for new applications grows.

Examples of derivative products from the land-cover classification process include

TABLE 2. LAND-COVER CLASSIFICATION PROCEDURES

Analysis Procedures	Task Examples
Screen and preprocess Landsat data	Fix bad scan lines, perform radiometric destriping, mosaic adjacent scenes
Register Landsat and ancillary data to map base	Select and digitize control points, generate transformation, resample, and register dital data sets.
Identify area(s) to be classified	Digitize study area boundaries and create appropriate digitial masks.
Stratify raw Landsat data	Identify environmentally similar areas, locate training blocks within each type, and develop training statistics.
Field data collection	Delineate homogeneous areas on aerial photos. Visit training blocks in the field and describe vegetation associated with each area.
Perform preliminary classification	Classify training blocks, and produce preliminary classification map.
Final classification	Use post-classification procedures to make final map product. Adjacent scenes are mosaicked and formatted to cover 1° by 3° map quadrangle.

Note: In some areas north of the 68th parallel, the raw Landsat data were not registered to the map base; instead, the classification results were resampled to 50-metre grid cells and registered to a Universal Transverse Mercator map projection.

- *Lake Inventory Data Bases*. The development of a lake inventory data base was jointly conducted by the National Mapping and Water Resources Divisions of the USGA using existing digital land-cover classifications of the north slope of Alaska. Water classes, primarily lakes, are extracted from the land-cover classifications. Computer algorithms assign a unique identification number to each lake, determine its surface area, and compute the latitude and longitude of its center. This information is stored in a tabular data base file. Each lake can be referenced by its identification number. Plotter output at 1:250,000-or 1:63,360-scale shows the lake's centroid and unique index number and can be overlayed on topographic map sheets. The data base provides space in the tabular file for additional lake attribute information such as lake depth, water quality, and water temperature.
- *Image Maps*. Registered Landsat MSS data provide the basic data set for land-cover classification. These data also can be mosaicked to produce a radiometrically and geometrically corrected image for a 1:250,000-scale quadrangle or for a special project area such as the Denali National Park. Cartographic information such as administrative boundries, township and range grid, latitude-longitude reference data, and place names can be added to the registered Landsat image to produce a final image map. The NMD has produced 24 black-and-white Landsat image maps for the 1:250,000-scale quadrangles located north of the 68th parallel in Alaska. In addition, Landsat false-color composite image maps at a scale of 1:250,000 of the Denali National Park (formerly called McKinley National Park) and several quadrangles within Arctic NWR are in publication.
- *Wildland Fire Fuels Mapping*. A fire fuels map can be produced from land-cover classifications by regrouping land-cover types according to their fire behavior characteristics, thereby defining a new set of fire fuel classes. Fire-fuels data together with digital terrain data are incorporated into the BLM's fire behavior prediction system for use in fire management and planning activities.
- *Land Cover Statistics*. Although land-cover map data are generally the preferred output product, statistics summarizing the acreages of land-cover types or the estimated amount of timber producing land in the state are also valid derivative products. Once a land-cover mapping project has been completed, a user can request land-cover acreages. The acreage statistics can be summarized by project area, quadrangle, township, or by management units.

INTERIM LAND-COVER MAPPING PROGRAM

The National Mapping Division, USGS, is responsible for producing and maintaining base maps and related thematic maps for the Nation. The Division conducts a variety of national topographic mapping programs and a national land-use and land-cover mapping program. The latter is a Congressionally mandated program conducted primarily in the 48 contiguous states and Hawaii. The land-use and land-cover data are produced in graphic and digital format at a scale of 1:250,000.

Conventional land-use/land-cover mapping in Alaska by the National Mapping Division has been limited to the Valdez 1:250,000-scale quadrangle. This is due to (a) the limited availability of source material (a problem which has been eliminated by the high altitude photography program active in Alaska since 1978), (b) the diversity of requirements for land-cover maps by different agencies, (c) agency commitments to their own resource mapping programs, and (d) the problems of applying the nationwide land-use/land-cover classification system (Anderson *et al.*, 1976) to Alaska's wildland environment. Moreover, a conventional approach, employing manual interpretation of aerial photographs to produce land-cover/land-use maps for Alaska, would require decades to complete.

As an alternative, NMD implemented an *interim* land-cover mapping program for Alaska (Shasby *et al.*, 1985). This new program acknowledges the land-cover classification work already completed by EROS and its cooperators. The interim land-cover mapping program has three main objectives: (a) to reformat existing land-cover classifications to a common statewide map legend, (b) to classify land cover for the remaining areas of the state, and (c) to produce paper maps, statistics, and computer-compatible tapes (CCTs) containing the land-cover data for the 153 1:250,000-scale quadrangles in the State.

To meet these objectives, a three-phase approach is being implemented. Phase I consists of identifying the existing land-cover classifications that can be reformatted to the map legend of the interim mapping program. A research effort is underway to identify and evaluate the steps needed to convert the existing land-cover classifications from their agency-specific mapping legends to the interim map legend, and to produce a standardized paper map product. Land-cover classifications from six 1:250,000-scale quadrangles have been selected for conversion to the new map legend.

A key element of the research effort has been the development of a statewide land-cover map legend acceptable to all agencies. A statewide legend for Alaska is necessary to insure consistency in form, resolution, and content throughout the State. Federal and State personnel experienced in the use of Landsat data for mapping vegetation and land cover developed a classification legend for the interim program that was satisfactory to the National Mapping Division's Land-Cover Mapping Program and useful to the participating government agencies. The map legend produced contains 16 land-use/land-cover classes. It is presented in Table 3. Currently it represents a combination of the Anderson *et al.* (1976) Level II map legend, and the Viereck and Dyrness (1980) vegetation classification system. The latter is the most widely used system for describing vegetation communities in Alaska. A thorough interagency evaluation of the six interim land-cover maps and the statewide land-cover map legend will be required before the NMD proceeds with Phase I.

Phase II calls for direct intervention into ongoing cooperative land-cover mapping projects. As land-cover classifications are generated to meet agency requirements, EROS personnel will work with the classifications to reformat them to the statewide land-cover map legend.

Phase III involves implementing a strategy to complete the land-cover classifications for the remaining areas of the State. Such a plan includes (a) entering into interagency agreements with cooperating Federal and State agencies to continue producing classifications that meet their specific mapping objectives, and (b) embarking on an internal National Mapping Division land-cover classification program to complete classifications for the remaining unclassified areas of the State.

Land-cover maps (NMD series-L) at 1:250,000 scale and corresponding digital tapes will be available to the public and disseminated by the Division's National Cartographic Information Centers (NCIC). Digital data from the interim program will be stored at the EROS Field Office in Anchorage.

SUMMARY

The vegetation and terrain mapping program carried out by NMD's EROS Field Office and its cooperating agencies has resulted in the production of land-cover and terrain map products and digital data bases for approximately 245 million acres in Alaska. These cooperative programs address vegetation and wildlife management and assessment issues for about two-thirds of Alaska's vast land area. Whereas the initial land-cover and terrain data were produced to meet the requirements of specific resource agencies, they also have provided a wide variety of secondary and derivatrive products useful for other applications to other agencies.

The Interim Land-Cover Mapping Program, for example, will utilize these existing data bases to develop a consistent and continuous 1:250,000-scale land-cover map series for the entire state.

The EROS Field Office and its cooperators have demonstrated how a specialized center of technology can provide a service to the user community in the form of training, technology transfer, and operational support for vegetation mapping and resource assessment. By developing digital data bases with and for Alaska's major land management agencies and storing all of the derivative products in accessible archives, the Field Office serves as a central facility for storing, managing, manipulating, and redistributing this information to Alaska's Federal, State, and local users.

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TABLE 3. PROPOSED INTERIM LAND COVER CLASSIFICATION SYSTEM FOR ALASKA (LEVEL I AND LEVEL II) COMPARED WITH VIERECK ET AL. (1980) LEVEL III.

Level I	Level II	Level III Categories
1. Forest (forest canopy cover of one-third or more)	A. Needleleaf forest (over two-thirds of tree cover contributed by needleleaf species)	Closed needleleaf forest Open needleleaf forest
	B. Broadleaf forest (over two-thirds of tree cover contributed by broadleaf species)	Closed broadleaf forest Open broadleaf forest
	C. Mixed forest (broadleaf or needleleaf species contribute one-third to two-thirds of the tree cover)	Closed mixed forest Open mixed forest
II. Shrub (forest canopy cover of less than one-third and shrub canopy cover of one-third or more	A. Shrublands	Closed tall shrub scrub Closed low shrub scrub Open low shrub scrub Needleleaf woodland Broadleaf woodland
	B. Dwarf shrublands and related communities (rarely exceeding 50 cm in height)	Closed low shrub scrub Open low shrub scrub Closed dwarf shrub scrub Open dwarf shrub scrub Needleleaf woodland
III. Herbaceous (vegetation with 5% or more of vascular and non-vascular [mosses and lichens] cover and less than one-third cover of woody plants	A. Dry or moist	Dry graminoid herbaceous Mesic graminoid herbaceous Dry forb herbaceous Mesic forb herbaceous Needleleaf woodland Broadleaf woodland
	B. Wet	Wet graminoid herbaceous Wet forb herbaceous
	C. Very wet-aquatic	Aquatic herbaceous
	D. Mosses	Mosses Needleleaf woodland Broadleaf woodland
	E. Lichens	Lichens Needleleaf woodland Broadleaf woodland
IV. Agriculture V. Urban VI. Barren VII. Water VIII. Ice and snow	A. Sparse vegetation B. Non-vegetated (rock, soil)	The Viereck et al. classification system is strictly for vegetation and does not apply to land use or non-vegetated lands.

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