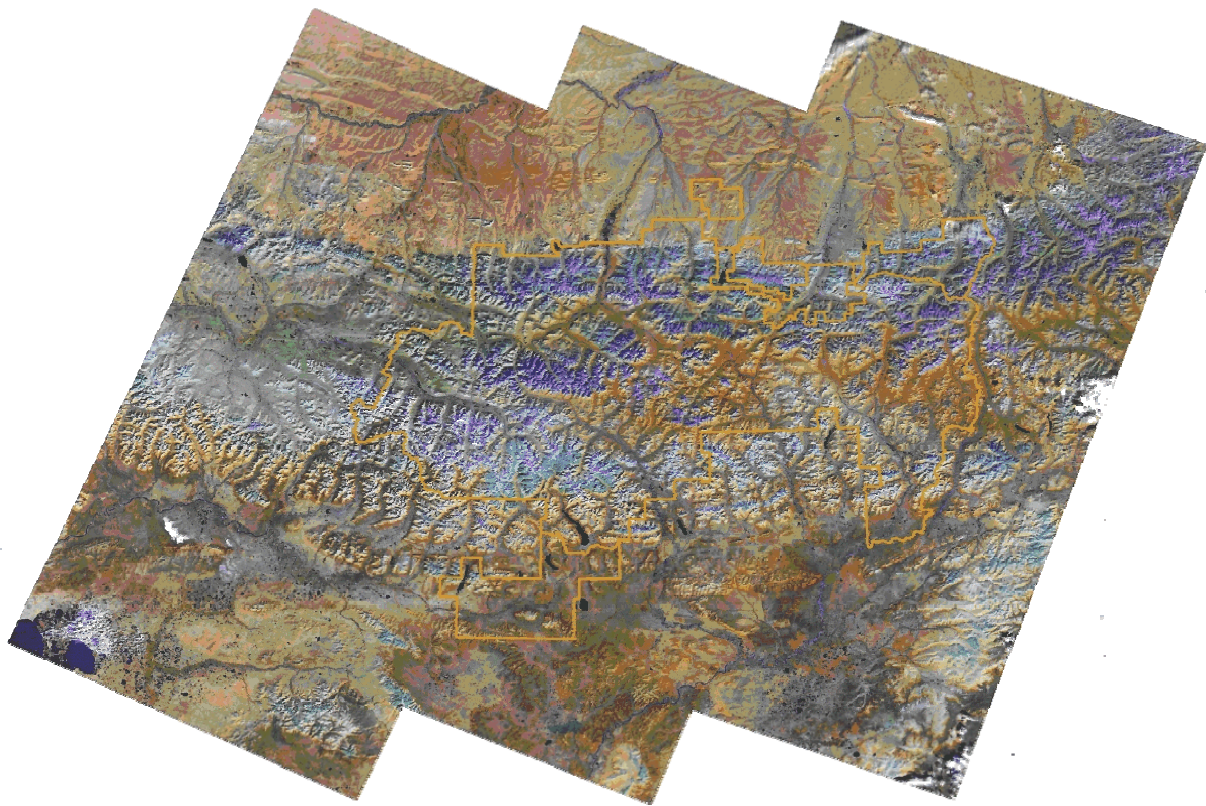




Landsat Derived Map and Landcover Descriptions for Gates of the Arctic National Park and Preserve

Natural Resource Technical Report NPS/GAAR/NRTR—1999/001



ON THE COVER

Thematic Mapper satellite image mosaic for Gates of the Arctic National Park and Preserve.
Mosaic by: EarthSat Corp.

Landsat Derived Map and Landcover Descriptions for Gates of the Arctic National Park and Preserve

Natural Resource Technical Report NPS/GAAR/NRTR—1999/001

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Commercial off-the-shelf (COTS) software was used for most of the image processing and GIS production on this project. ERDAS Imagine 8.3 and ESRI ArcView 3.1 were the principal software tools used in the processing and analysis. Precision image orthorectification processing was performed using Image Processing System (IPS), EarthSat's proprietary image processing software. Hardware platforms were primarily an SGI Indigo workstation, and a high-end (dual processor, 500 Mhz) desktop NT workstation.

ABSTRACT

As part of the Inventory and Monitoring Program of the National Park Service (NPS) in Alaska, the Alaska Support Office (NPS-AKSO) commissioned Earth Satellite Corporation (Rockville, MD), and the Alaska Natural Heritage Program (University of Alaska Anchorage), to produce a landcover map and supporting documents for Gates of the Arctic National Park and Preserve (GAAR). Using Landsat Thematic Mapper multi-spectral imagery as the primary data source, landcover was mapped at intermediate scales (1:63,360 - 1:100,000) with 30 classes following a modified version of the Alaska Vegetation Classification (Viereck et al. 1992) system at levels III and IV. The principal results include a digital thematic landcover map, landcover class descriptions, plant association descriptions, study area description, surficial geology type and process descriptions, and an accuracy assessment of the landcover map.

The primary purpose of this document is to provide information which will allow users to interpret, apply, understand, and utilize the landcover map. This document complements an ArcView geographic database which includes the primary data layers developed and utilized in the mapping project. Also, the final digital landcover map and an associated geographic database are accessible through an interactive map and html-formatted version of this users' guide document distributed on CD media by NPS-AKSO.

The development of the GAAR landcover map involved collection and analysis of extensive field-verified datasets and the analysis and interpretation of remotely sensed imagery (satellite and aerial photography). It also involved the development and application of models using ancillary digital data to distinguish among confused landcover (spectral) classes and an accuracy assessment of the derived landcover map. A supervised digital image processing approach, using the Maximum Likelihood (ML) classifier, was performed on each of the six Landsat TM scenes covering the study area. The base landcover map derived from the ML process was refined through iterative modeling using environmental and spectral data layers such as illumination, slope, Normalized Difference Vegetation Index (NDVI), winter satellite imagery, "clustered" data (250 spectral classes), and individual channels of the Landsat TM data, to produce the 30 landcover class filtered 2 acre mapping unit and unfiltered (pixel) map product. A more general 22 class landcover map was also created through combining several of the less spectrally separable classes. The digital image processing was guided by visual interpretation of the Landsat TM data, review of field data, and spot checking of 1:60,000 high altitude color infrared photography.

The landcover classification system was based primarily on vegetation structure (plant height) and form (tree, shrub or herbaceous), and to lesser extent genera (*Picea*) and species (*Picea mariana*) information. The mapping classification, with modifications, follows The Alaska Vegetation Classification (Viereck et al. 1992) system at levels III and IV. A stratified random approach—based on ecoregions, surficial geology and unsupervised Landsat TM imagery—was used to place

polygons for field sampling. The classification system was field checked during late June and early July 1998 using both fixed-wing and a helicopter to reach sampling polygons. Fly-over and ground data were collected for each polygon and included vegetation structure, plant species, % cover, elevation, as well as other site information. Existing vegetation data were used extensively to support the development of both the classification system and the landcover map.

Ground data were used to define plant associations in order to provide a hierarchical link between the relatively coarse scale landcover classes and the species information. Plant association is the finest level of both the Viereck et al. (1992) and National Vegetation Classification System (Grossman et al. 1998) classifications. It is defined as “a plant community type of definite floristic composition, uniform habitat conditions, and uniform physiognomy” (Flahault and Schroter 1910). A total of 40 plant associations were defined; due to limited field reconnaissance and project scope, plant associations were not defined for the forested or tall shrub landcover classes.

A ‘Literature Review’ section provides a synopsis of present and past landcover-related projects. An ‘Ecoregions and Climate’ section provides the reader with a generalized picture of the topography, climate and vegetation within GAAR. A ‘Surficial Geology’ section, based on Hamilton (1999c), is a reference guide to the major surficial geology units that currently influence vegetation in GAAR. The distribution of landcover types in the GAAR project area is as follows:

- 17.69% area in needleleaf forest or woodland,
- 0.53% in broadleaf forest,
- 0.54% in mixed forest,
- 5.88% in tall shrub,
- 22.10% in low shrub,
- 24.42% in prostrate shrub,
- 6.47% in herbaceous,
- 16.17% sparse or barren,
- 1.15% water,
- 0.36% snow/ice, and
- 4.52% indeterminate (mostly clouds and terrain shadow).

An accuracy assessment of the 30 class landcover map was performed to evaluate the reliability of the employed remote sensing techniques in achieving the mapping project objectives, and to provide users of the map an indication of relative confusion among mapping classes. The result showed an estimated overall accuracy for all the landcover classes to be 83.1%, based on the 5 acre minimum mapping unit (MMU) dataset. The user’s accuracies for general landcover types are as follows: 78.9% for needleleaf forest and woodland, 79.2% for broadleaf forest, 93.0% for mixed forest, 90.1% for tall shrub, 87.0% for low shrub, 78.6% for prostrate shrub, 72.0% for herbaceous, 90.7% for sparse /bare-ground, 99.8% for water, and 99.9% for snow/ice. This document presents more detailed discussions of the methods and results of the GAAR landcover mapping project.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Inventory and Monitoring Program of the National Park Service (NPS) is designed to provide reliable and consistent information for assessing the status and trends in the condition of National Park ecosystems. Vegetation mapping is conducted under the inventory portion of the program in order to provide basic information readily useful for making resource management decisions, and to collect data that can be aggregated on a service-wide level for designing monitoring programs. Landcover maps can also be used to understand habitat and fuels availability, model the occurrence of archaeological sites and sensitive species, for park planning, and to provide baseline information about natural resources in the park. This users' guide document presents detailed discussion of the methods and results of the digital landcover mapping project, conducted in (1997-1999) by the Alaska Support Office of NPS (NPS-AKSO), Earth Satellite Corporation, Rockville, MD, and the Alaska Natural Heritage Program (University of Alaska Anchorage), on Gates of the Arctic National Park and Preserve (GAAR) in Alaska.



Figure 1. Location of GAAR

Figure 1 shows the general location of GAAR, and Figure 2 shows the entire project area which includes 8.2 million acres in GAAR, as well as approximately 30 million acres of adjacent areas of the Northern Interior, North Slope, Anaktuvuk Pass, and pipeline corridor contained within the six primary Landsat Thematic Mapper (TM) scenes. The decision to use Landsat TM for the project was based on the very remote and vast project area, the level of mapping information required by NPS, the spatial and spectral characteristics of the available sensors/data, and the time and budget resources available for the project. The "buffered GAAR area" refers to those areas within a 10-mile buffer of the GAAR boundary. This was the primary area of interest for development of the landcover map and supporting documentation, and includes approximately 13.7 million acres (Figure 2).

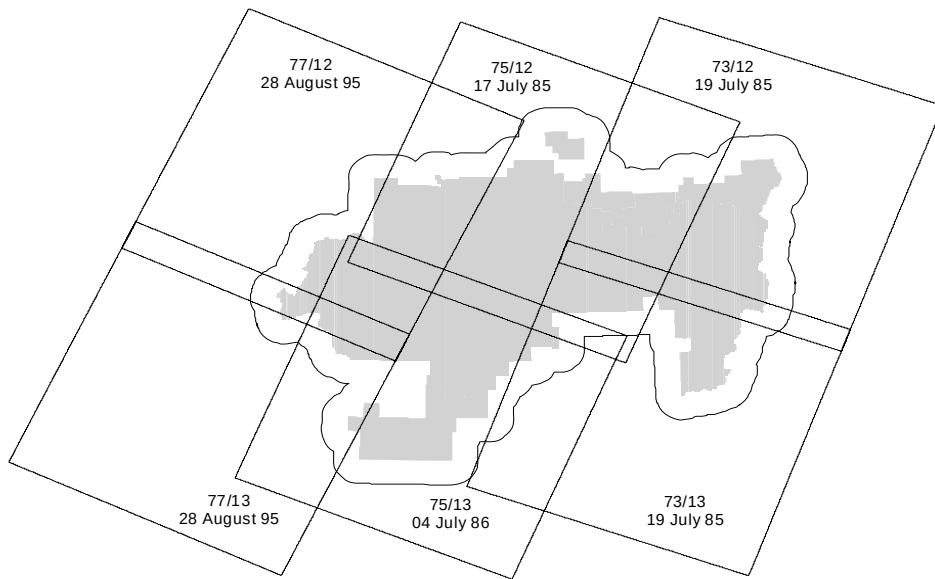


Figure 2. Landsat Thematic Mapper data selected for deriving the landcover map

1.2 SCOPE OF THE PROJECT

The scope and design of the GAAR landcover mapping project was established by a project team consisting of representatives from Earth Satellite Corporation (Rockville, MD), Alaska Natural Heritage Program (Anchorage, AK), Greenehorne and O'Mara (St. Petersburg, FL), Forest Data Inc (Corvallis, OR), the Nature Conservancy (Washington, DC), and resource managers from the NPS-AKSO and GAAR. The project team met in December 1997 to discuss, plan and develop logistics for the GAAR landcover mapping project. Their discussions included the project objectives and goals, user needs and requirements, mapping classes and classification system development, plans and logistics for the 1998 field work, and evaluation of existing datasets and remote sensing data (satellite imagery, air photos,

existing vegetation data, etc.) for developing the landcover map. The team developed a comprehensive Project Design document that details map specifications, methods and procedures used to develop the landcover map, and delivered this document to NPS-AKSO in May 1998.

The landcover for GAAR was mapped at intermediate scales (1:63,360 - 1:100,000) with 30 classes, using a classification based primarily on vegetation structure (plant height) and form (tree, shrub or herbaceous), and to lesser extent genera (*Picea*) and species (*Picea mariana*) information. The mapping classification, with modifications, follows The Alaska Vegetation Classification (Viereck et al., 1992) system at levels III and IV.

The usefulness of the map to land managers is increased dramatically when the landcover classes are linked to finer scale units that reflect plant species and vegetation structure, such as given in plant associations. Plant association, consequently, were also described and are the finest level of both the Viereck et al. (1992) and the National Vegetation Classification System (NVCS; Grossman et al., 1998) classifications—i.e., plant association equals level V of Viereck et al., 1992.

The development of the GAAR landcover map involved collection and analysis of ground truth or field-verified data, analysis and interpretation of remotely sensed imagery (satellite and aerial photography) and accuracy assessment of data derived from these, and the development and application of models using ancillary digital data to distinguish among confused landcover (spectral) classes. The landcover map products are useful for understanding the distribution of the mapped units, broad scale wildlife habitat distribution, and for conducting coarse scale analyses including regional ecological planning. The importance of knowledge of the distribution of the various plant associations to biologists is well established. The results of the GAAR landcover mapping project will help wildlife biologists evaluate forage availability for moose and caribou and to understand the distribution of wetlands, rare habitats and species. The fine scale vegetation structural information provides ornithologists important information for understanding passerine bird habitat distribution.

The primary results of this project were a digital thematic landcover map, landcover class descriptions, plant association descriptions, surficial geology type and process descriptions, and an accuracy assessment of the landcover map. A full list of all products associated with this project is given in Table 1. A version of the digital data as an interactive map and on-line version of this document is available through NPS-AKSO.

The entire database in the table below is available in the GAAR Land Cover Field Data Viewer Project (ArcView 3.1)*. For metadata, follow the links in the table to the appropriate Data Layer (Theme).

Table 1. List of data layers used or produced to derive the GAAR Landcover Map (1997-1999).

Data Layer (Theme)	Data Type	Source
GAAR Landcover (Unfiltered)	Image (GRID)	EarthSat, AKHNP
GAAR Land Cover (2 ac mmu)	Image (GRID)	EarthSat, AKHNP
GAAR Land Cover Legend	Shape File	EarthSat, NPS- AKSO
Landsat TM Mosaic–Bands 4,5,3	Image (Imagine)	EarthSat

* Other related products produced under the GAAR Landcover Mapping Services contract include the ArcView Surficial Geology Project and the environmental and spectral modeling data layers derived for each primary TM scene. These products are available through NPS-AKSO.

1.3 LITERATURE REVIEW

The only vegetation maps that cover all of GAAR were developed on a statewide scale. Viereck and Little (1972) developed a statewide map of vegetation using eight vegetation classes and one ice and snow class. An AVHRR—1-km pixel—map for Alaska was developed by Fleming (1997). The Alaska regional profiles, Arctic region (Selkregg, 1975) also provides general maps and descriptions of the regions people, economics, wildlife, geology and vegetation.

A variety of vegetation classifications—often with associated maps—have been developed that cover all or portions of GAAR. The Alaska Vegetation Classification (Viereck et al. 1992) provides in-depth descriptions of vegetation at multiple scales for Alaska. Few vegetation studies for GAAR had been completed when The Alaska Vegetation Classification was developed and, consequently, it is not fully inclusive of all the map classes that exist in the Park. Several other classifications centered on the Haul Road (Markon 1980, Walker and Webber 1979, Webber et al. 1978). Walker and Webber (1979) and Webber et al. (1978) mapped vegetation adjacent to the Haul Road from the Yukon River to Prudhoe Bay. They interpreted a vegetation classification system they developed using 1:6,000 scale aerial photographs. The vegetation classification uses community physiognomy as the key component, along with community floristics, and was similar to levels III and IV of Viereck et al. (1992). Webber et al. (1978) also investigated weeds and weedy vegetation along the Haul Road, and vegetation response to disturbance. Terrestrial and aquatic habitats were mapped along the proposed Alaskan Natural Gas Pipeline corridor in 1979 (Markon 1980), and paralleled the Trans-Alaska oil pipeline through GAAR. Sixty-nine map classes were used to stereoscopically interpret 1:24000 and 1:36000 true color aerial photographs. The map classes are similar to levels II, III and IV of Viereck et al. (1992).

Several vegetation classifications and maps were specific to single drainages within GAAR (Batten 1974, Densmore 1980, Odasz 1983, 1988, Cooper 1983, 1986a, 1986b,). In the upper Alatna River drainage, the vegetation pattern of white spruce at

treeline was studied by Odasz (1983, 1988). Plant associations (level V of Viereck et al. 1992) along with soil information were described. The results indicate a mosaic of mesotopo graphical-scale plant associations. Vegetation of the John River Valley was described by Batten (1974). Batten defined vegetation classes similar to levels II and III of Viereck et al. (1992), and gives species lists and their relationship to topographic position (i.e., floodplain, sideslope, bedrock). A level V classification was developed for the upper Arrigetch Creek valley above treeline by Cooper (1983, 1986a). Community composition and the structure and pattern of vegetation are described, the plant associations are related to soils, climate, geological substrate, geomorphic process, and a complete list of vascular, lichen and bryophyte species is provided. Cooper also develops hypotheses on the evolution of the present day vegetative cover. The occurrence of white spruce above treeline is also described for the Arrigetch Peaks region by Cooper (1986b). Site characteristics and the vegetation type each tree occurs in are given. General descriptions of vegetation classes similar to levels IV and V of Viereck et al. (1992) for the upper Dietrich River Valley are given by Densmore (1980). Aspect and edaphic factors in relation to elevational gradients are discussed in relation to the vegetation. Particular attention is given to white spruce dynamics at treeline.

Other studies that include vegetation classifications, maps or species occurrences in GAAR include Spetzman (1959), Gustafson (1980), and Shea (1994). General descriptions of ecoregions, plant communities, vegetation succession and species distribution are described for arctic Alaska, including GAAR, by Spetzman (1959). Four ecoregions are described and are similar to those defined by Gallant et al. (1995) and Bailey et al. (1994). Six major plant communities are described and are comparable to level II and III of Viereck et al. (1992). The relationships of *Dryas integrifolia* (entire-leaf mountain-avens) and *D. octopetala* (white mountain-avens) to environmental factors in the Brooks Range were studied by Gustafson (1980). Species composition and soil characteristics of sites sampled are provided. A vegetation map and classification using low altitude color and color infrared aerial photography for monitoring human impacts was developed for the north-central portion of GAAR (Shea 1994).

The various flora of Alaska proved valuable for understanding species distribution in GAAR. These included three vascular plant floras of Alaska (Hulten 1968, Viereck and Little 1972, Welsh 1974). One taxonomic treatment was specific to GAAR, a genus key to the lichens of Alaska (Hasselbach and Neitlich 1998). Other non-vascular treatments for arctic Alaska include Thomson (1984) and Steere (1978). Swanson (1996) also described the distribution of fruticose lichens in the Kobuk Preserve Unit of GAAR.

Surficial geology maps and descriptions are valuable for understanding the distribution of landcover classes and the processes that control them. A series of 1:250,000 scale surficial geology maps have been developed for GAAR by Hamilton (1978a, 1978b, 1979a, 1979b, 1980, 1981, 1984a, and 1984b). Examples of mapped surficial geology units include fan deposits, alluvium undifferentiated, lacustrine

deposits, landslide deposits, sand deposits, drift of fan mountain phase I, and outwash. The mapping comprised ten 1:250,000 quadrangle sheets plus part of one additional sheet, and subsequently has been combined into a single GIS product for GAAR plus a 10-mile peripheral buffer zone. A limited amount of information was lost during the combining of the quadrangle sheets, consequently, individuals desiring more information on specific areas should obtain 1:250,000 scale quadrangles maintained electronically by the U.S. National Park Service or in the published U.S. Geological Survey geologic maps.

Krieg and Reger (1982) describe landscapes along the route of the trans-Alaska pipeline. The landscapes (floodplain, pingo, alluvial fan) are similar to the surficial geology units described by Hamilton (1978a). Descriptions include soils, ice-mass, processes, vegetation and topographic locations. Other physiographic maps and publications describing processes, glaciation and bedrock geology exist for the Brooks Range but were not directly applicable to the study (Detterman et al. 1958, Ferrians 1965, Hamilton and Porter 1975, Sloan et al. 1976, Gedney and Marshall 1981, Hamilton 1982, 1984c, 1986, 1994, 1999a, 1999b, Grantz et al. 1983, Ellis and Calkin 1984, Nilsen and Moore 1984, Moore et al. 1994, Brown et al. 1997, Avé Lallemant et al. 1998).

Two soil maps are available for GAAR (Rieger et al. 1979, Swanson 1995). The statewide soil survey (Rieger et al. 1979) provides coarse level soils information for Alaska but was too coarse to be useful for vegetation mapping purposes. The second map was developed by Swanson (1995) for the Kobuk Preserve Unit of GAAR. The project was an integrated study of landforms, soils, and vegetation for the purpose of helping park managers predict the potential impacts of road development. Its major results include physiographic map unit descriptions (similar to surficial geology units described by Hamilton 1981), soil descriptions and vegetation site type descriptions. The physiographic map unit descriptions describe landforms, geologic materials and the soils of landscape units such as floodplain, terrace, colluvial slope and mountains. Soil descriptions are for types such as cryaquepts, cryofluvents, histosols, orthents and typic cryorthents. The descriptions provide information on drainage class, parent material, slope range, typical pedon, location, and range in characteristics. Vegetation site type descriptions include units such as alpine small stream floodplains, gravelly colluvium, ribbed fens and tussock wetland. The detailed information includes plant species lists and cover values, the setting, map-unit components, soils, and succession.

Two coarse scale ecoregional maps are currently widely used in Alaska: ecoregions of Alaska by Gallant et al. (1995) and ecoregions and subregions of the United States by Bailey et al. (1994). They have been developed for the purposes of implementing ecosystem management, which requires working definitions of ecosystems and supporting inventories of the components that comprise ecosystems. Both ecoregional maps use similar approaches to defining and describing ecoregions. For GAAR, both ecoregional maps are only available at the scale, 1:5,000,000. The units are defined based on similar patterns in potential natural communities, soils,

hydrologic function, landform and topography lithology, climate, and natural processes such as nutrient cycling, productivity, succession, and natural disturbance regimes associated with flooding, wind, or fire. Climate, as modified by topography, is the dominant criterion at the scale mapped for GAAR.

1.4 DESCRIPTION OF PROJECT AREA AND ENVIRONMENT

The Project Area includes approximately 8.2 million acres included in GAAR, as well as approximately 30 million acres of adjacent areas of the Northern Interior, North Slope/Arctic Foothills, Anaktuvuk Pass, and pipeline corridor contained within the six primary Landsat Thematic Mapper (TM) scenes ([Figure 2](#)). The GAAR Landcover Project Area includes a 10-mile buffer around the GAAR boundary and is covered by 6 primary Landsat TM scenes, which encompass the entirety of GAAR plus the adjacent areas. The 10-mile buffered GAAR area was the primary area of interest for development of the landcover map and supporting documentation, and includes approximately 13.7 million acres ([Figure 2](#)). However, several of the resulting image products were extended beyond the Project Area to include the entire extent of the six Landsat TM scenes (for example, the Landsat TM image mosaic). The ‘Ecoregions and Climate Influences on Landcover’ section provides the reader with a general picture of the topography, climate and vegetation within GAAR. The ‘Generalized Surficial Geology Interpretation’ section is provided as a guide to the major surficial geology units that influence vegetation in GAAR. It is not, however, meant to be used as a surficial geology classification.

1.5 ECOREGIONS AND CLIMATE INFLUENCES ON LANDCOVER

GAAR encompasses much of the central Brooks Range, and is approximately 180 miles long by 90 miles wide, and covers 8,202,517 acres. Its elevation ranges from approx. 500 feet to 8,570 feet. To more easily describe the climate and geography of GAAR we present the three ecoregions described by Gallant et al. (1995), the arctic foothills, the Brooks Range, and the interior forested lowlands and uplands ([Figures 3a and 3b](#)).

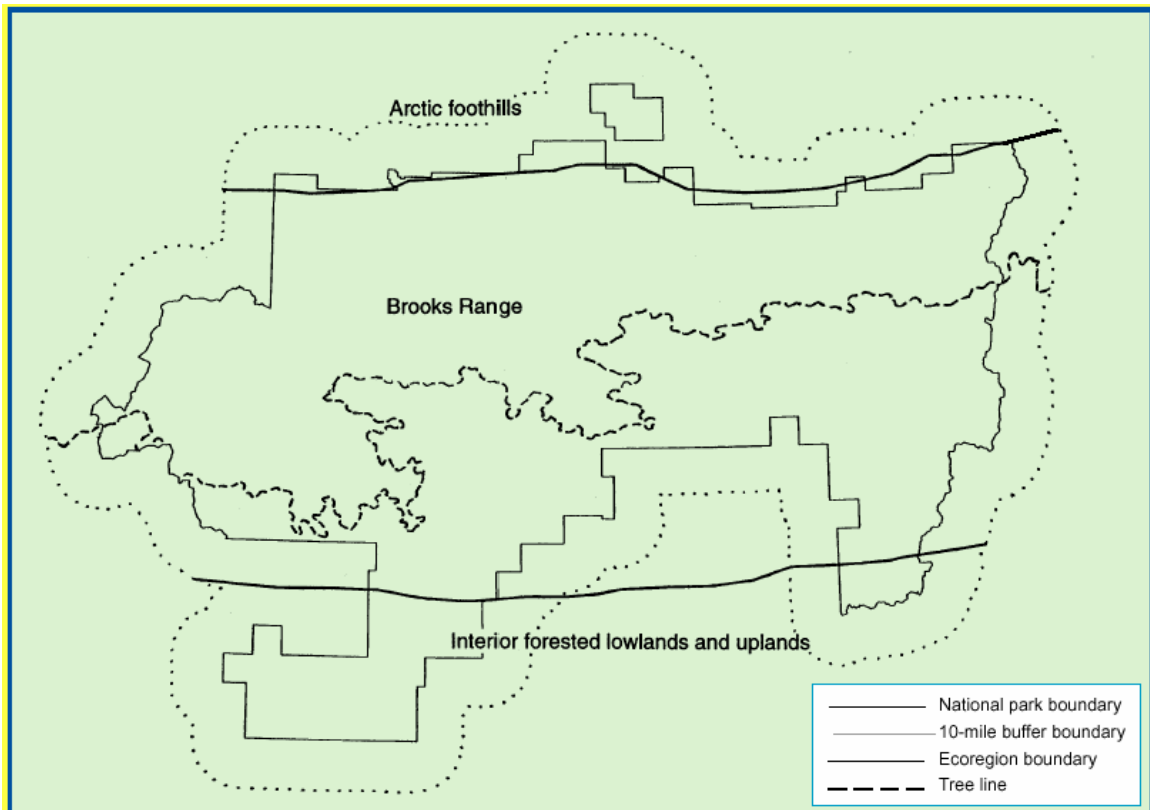


Figure 3a. Ecoregions as defined by Gallant et al. (1995) of GAAR

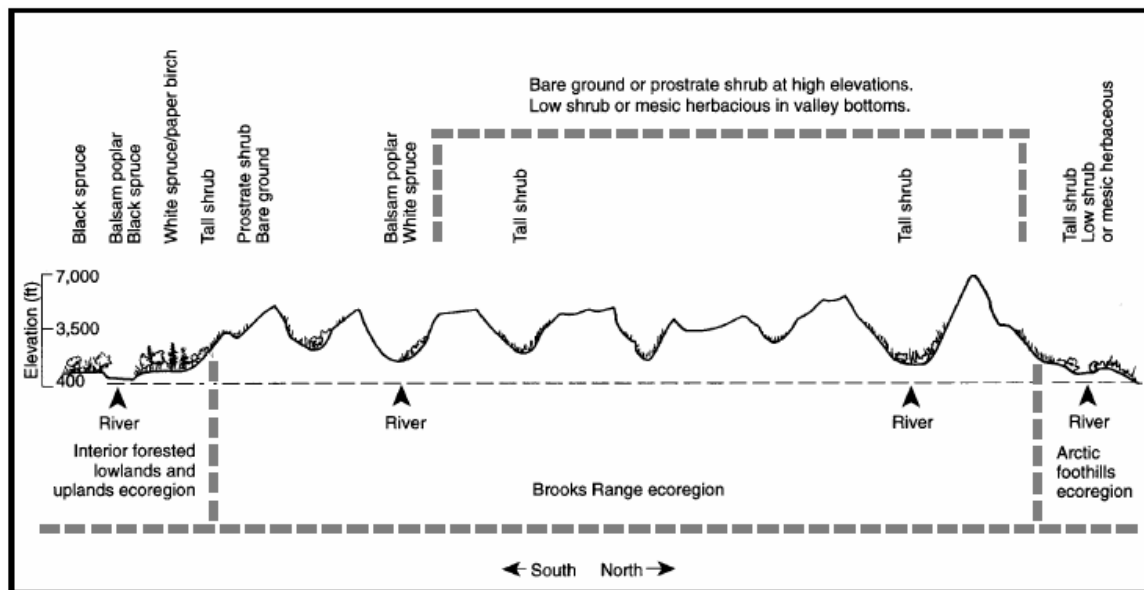


Figure 3b. Longitudinal cross-section of ecoregions, vegetation, and topography of GAAR

Arctic Foothills Ecoregion

The arctic foothills ecoregion is located north of the Brooks Range and consists of treeless rolling hills and plateaus ([Figures 3a and 3b](#)). Elevation ranges to 2,000 feet.

The hills are bedrock outcrops often covered by loess, moraines, ancient outwash and floodplain terraces, and various glacial derived landforms ([Figure 4](#)). The ecoregion is underlain by thick permafrost and many ice-related surface features are present such as ice-cored hills and thermokarst. Tussock tundra dominates the area and few trees are present (Gallant et al. 1995). The arctic foothills ecoregion covers two% of GAAR.



Figure 4. Low relief hills and terraces in the arctic foothills ecoregion

Many of the bedrock outcrops are mesa-like with less than a 500-foot vertical rise. Their crests and upper slopes are a mixture of bare gravel and prostrate shrubs. The mid- and lower-slopes are composed of tussock tundra and narrow water tracks. The water tracks are dominated by open water, diamondleaved willow (*Salix planifolia* subspecies *pulchra*) and sedges (*Carex* species). Surrounding the bedrock outcrops are rolling low relief hills and terraces sloping down to the north flowing rivers that drain the Brooks Range. The hills and terraces are Pleistocene and older glacial till, kettle kame topography, outwash plain terraces, floodplain terraces, and sand deposits including dunes. The surface is predominantly tussock tundra, water tracks, some solifluction on sloping ground, and patterned ground on the more level areas. Polygonal ground was visually evident on level to slightly sloping ground and on relatively dry sideslopes. Frost scars are also a common feature in the tussock tundra.

Brooks Range Ecoregion

The Brooks Range ecoregion consists of steep mountains and wide glaciated valleys

(Figures 3a and 3b). It covers 83% of GAAR and the elevation ranges from approximately 500 feet to 8,570 feet. The mountains “consist of folded and faulted stratified Paleozoic and Mesozoic sedimentary deposits that were uplifted during the Cretaceous period (Gallant 1995)”. Small and scattered glaciers still persist within the headwaters of the higher peaks. Major surficial geology types along an elevational gradient—high to low—change from bedrock, to colluvium, alluvial fans or glacial drift, and then to floodplain or lacustrine deposits (Figure 5).

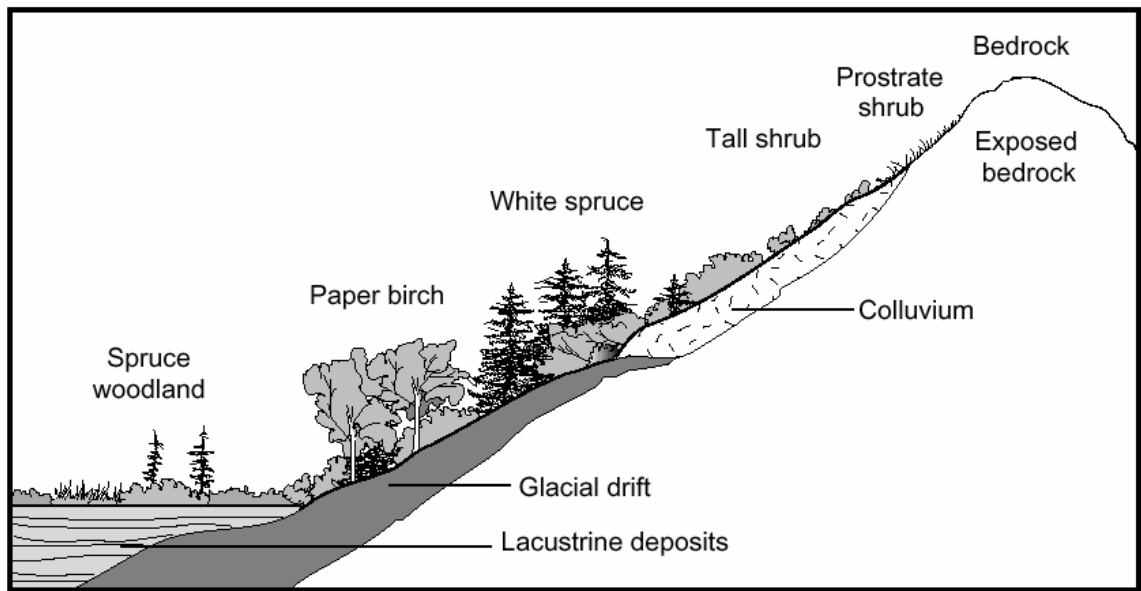


Figure 5. Idealized cross-section of a mountain valley in the South half of the GAAR showing various surficial geology deposits and landcover types.

Bedrock is subjected to intense frost action and nivation that produces erosional landforms—terraces, scarps, and cliffs—and erosional debris. The erosional debris is transported downslope via snow avalanches, rock fall, mass movement, streams, and rock glacier movement to form surficial deposits such as colluvial slopes and alluvial fans. Soil mass movement—solifluction and stream erosion—continue to move the colluvial and alluvial fan deposits downslope. Glacial drift, including moraines and glacial till, deposited during the last glacial retreat dominate the sideslopes and valley floors. Permafrost plays a significant role in valley bottoms and leads to the growth of large masses of ground ice that form tundra polygons, thermokarst and pingos. Frost action also leads to accelerated mechanical soil weathering. Another significant disturbance factor is caused by rivers and streams that constantly erode and deposit sediment, forming floodplains and outwash features.

Landcover is dramatically different between the north and south halves of the Brooks Range ecoregion. In the north half moving downslope, bedrock and talus give way to prostrate shrubs, then low shrubs, tussock tundra, and, along river courses, tall shrubs (Figure 6). Wet herbaceous vegetation occurs on some level valley bottoms. In the south half, moving downslope, bedrock and talus give way to prostrate shrubs, then

low or tall shrubs, and then forests (Figure 7). Talus slopes and avalanche paths are often free of trees and are dominated by alder and willow. On south facing slopes, trees are more common and extend further upslope.



Figure 6. Valley in northern half of GAAR



Figure 7. Valley in South half of GAAR

Interior Forested Lowlands and Uplands Ecoregion

The interior forested lowlands and uplands ecoregion occurs south of the Brooks Range ([Figures 3a and 3b](#)). It represents a patchwork of ecological characteristics including a continental climate, a mantling of undifferentiated alluvium and slope deposits, a predominance of forests dominated by spruce and hardwood species, a very high frequency of lightening fires, and a lack of Pleistocene glaciation (Gallant et al. 1995). Elevation ranges from approximately 500 feet to 3,000 feet, and the ecoregion covers 15% of GAAR.

The uplands are bedrock hills typically covered by loess and glacial drift, and sideslopes of colluvium and solifluction deposits. The valley bottoms are dominated by floodplains, terraces, lacustrine deposits and peat deposits. Where the Brooks Range ecoregion meets the interior forested lowlands and uplands ecoregion, glacial drift is common including glacial till, kettle-kame topography, outwash and moraines. Lakes are common in the valley bottoms due to thermokarst and oxbows along floodplains.



Figure 8. Valley in the interior forested lowlands and uplands ecoregion

Plant diversity increases within the ecoregion as compared with the Brooks Range and arctic foothills ecoregions. Vegetation forms a complex pattern due to the effects of fire, permafrost, soils, and surface water. The hills are better-drained and support large stands of paper birch, white spruce (*Picea glauca*), black spruce (*Picea mariana*) and quaking aspen (*Populus tremuloides*) ([Figure 8](#)). The ridges are often dominated by the prostrate shrubs and lichen. The valley bottoms are, in general, wetter environments than the hills. Open black spruce and white spruce forests dominate, along with peatlands. Areas of dwarf black spruce growing to about 12

feet are also present. Within GAAR this occurs primarily in the lower southeast portion of the park. On floodplains, tall shrubs, balsam poplar, and white spruce are common. Black spruce is generally found on river terraces and flat to rolling uplands because terraces are moderate to poorly drained.

Climate

GAAR has long severe winters and short cool summers. The arctic foothills ecoregion has winter temperatures ranging from -29°C to -20°C (Gallant 1995). Summer temperatures range from 1°C to 15°C , with temperatures occasionally reaching 24°C in some areas. Although freezing can occur any time of the year, July and August are usually frost-free. In the Brooks Range ecoregion, winter temperatures are colder and range from -30°C to -22°C , while summer temperature fluctuates from 3°C to 16°C (based on one weather station at Anaktuvuk Pass). Freezing may occur in any month of the year. South of the Brooks Range, winter temperatures differ from west to east, with a minimum of -18°C to -11°C in the west and -35°C to -22°C in the east. Summer temperatures range from a minimum of 8°C to 11°C to a maximum of 17°C to 22°C . June through mid-September is usually frost free at the lower elevations.

Precipitation is low throughout GAAR. The arctic foothills ecoregion annual precipitation at the base of the Brooks Range is approximately 7.6 inches, and receives 52 to 60 inches of snow. In the Brooks Range at Anaktuvuk Pass, summer precipitation is 11 inches, and winter precipitation averages 64 inches of snow per year. Elevation, aspect, and winds result in a highly variable climate. South of the Brooks Range, average annual precipitation is 10 to 22 inches, and increases with elevation. Convection storms in the summer provide most of the annual precipitation. Of the annual precipitation, 50 to 82 inches of it occurs as snowfall. Snow remains on the landscape for over half of the year on north facing slopes, shadowed areas, and at higher elevations.

Wildfire

Fire occurrence is low in the arctic foothills ecoregion. An average wildfire is 185 ha, with a range of <1 acre to 4,000 acres (Gallant 1995). Fires are common in the Brooks Range ecoregion ranging in size from <1 acres to 273,162 acres according to fire records, with an average size of 4,475 acres. Fires occur frequently in the interior south of the Brooks Range from June to early August. Average fire size is 4,075 acres, with a range of 0.5 acres to 652,000 acres. The high number of fires is related to low precipitation, warm summers, lightening storms, and large number of trees with low lying branches.

Land Use and Settlement

The arctic foothills and Brooks Range are the traditional home to the Nunamiut (Inuit) peoples, and are an important area for subsistence practices including hunting, fishing, and wild plant gathering (Gallant 1995). Caribou, moose, bear, ground squirrel, and ptarmigan are all subsistence resources. Recreational hunting and fishing also occurs throughout the region, and edible greens, roots, and berries are

harvested throughout the summer months. The Kutchin and Koyukon Athabascans also use the Brooks Range for subsistence purposes. South of the Brooks Range, both subsistence and recreational hunting occurs (Gallant 1995). People living in the uplands primarily hunt caribou and moose. People living in the lowlands and riverine areas rely heavily on game and freshwater fish. Small mammals and ptarmigan are hunted by all peoples of the area. Berries, roots, and wild greens are also harvested.

1.6 GENERALIZED SURFICIAL GEOLOGY INTERPRETATION

Generalized surficial geology was initially delineated through interpretation of a 1:350,000 scale photoprint mosaic of the Landsat TM (bands 4,5,3) data---a 24-bit enhanced false color infrared product which allowed maximum discrimination of vegetation. The surficial geology types to be interpreted were taken from surficial geology maps developed for GAAR by the USDI United States Geological Survey (Hamilton 1978a, 1978b, 1979a, 1979b, 1980, 1981, 1984a, 1984b). For stratification purposes it was not practical to use all the surficial types defined on the surficial geology maps, and, consequently, it was necessary to combine some. These surficial geology types include:

- Bedrock. Bedrock with little or no soil development primarily restricted to upper- and mid-mountain slopes, and ridgetops in the Brooks Range region.
- Bedrock, low elevation, overlain by loess. Bedrock that is typically covered by thin talus, solifluction, loess, or lacustrine deposits. This type is restricted to mountain outliers north and south of the main mountain mass (Brooks Range ecoregion) of GAAR.
- Active floodplain. This surficial geology type consists of floodwater-influenced lands that include floodplains, active terraces, streambeds and outwash plains. It occurs throughout GAAR.
- Mixture of colluvium, fans, rock glacier. This type is a combination of deposits that occur within GAAR's main mountain mass (Brooks Range ecoregion) between the bedrock surficial geology type and the active floodplain type. It includes fan deposits, colluvium (landslides, flows, talus rubble, rock-glaciers, protalus rampart deposits, and solifluction deposits), sand deposits, lateral and terminal moraines, and lacustrine deposits.
- Terraces 10 m above streams. This type occurs in the arctic foothills ecoregion and was delineated because it is spectrally and geomorphically distinct from the surroundings. It consists of Pleistocene age alluvial terraces greater than 10 m vertically above the active floodplain.
- Older glacial moraines, sand, drift, kettle-kame. This type is a combination of deposits that were difficult to separate spectrally within the arctic foothills

ecoregion and the Interior forested lowlands and uplands ecoregion. It includes moraines, sand dunes, loess, lacustrine deposits, drift, some terrace deposits, inactive glacial outwash, and kettle-kame topography.

- Younger glacial moraines, sand, drift. This type is similar to the “Older glacial moraines, sand, drift, kettle-kame” surficial geology type but is spectrally distinct. It also is a combination of deposits that were difficult to separate spectrally within the arctic foothills ecoregion and the Interior forested lowlands and uplands ecoregion. It includes moraines, sand dunes, loess, lacustrine deposits, drift, some terrace deposits, inactive glacial outwash, and kettle-kame topography.
- Thermokarst on areas with relief. This surficial geology type is distinguished from others due to the presence of numerous lakes and ponds in areas with low hills. This type is likely due to a combination of thermokarst and kettle-kame topography. It occurs on a variety of deposits (sand deposits, drift, and floodplain) throughout GAAR.
- Thermokarst on low relief lands. This surficial geology type is distinguished from others due to the presence of numerous lakes and ponds and occurs on level land. These surfaces are likely thermokarst floodplains or outwash. It occurs primarily in the interior forested lowlands and uplands ecoregion.

CHAPTER TWO

METHODS

Flowcharts depicting the various methods employed in this study are found in Figures [9a](#), [9b](#), [9c](#), [9d](#), [9e](#), [9f](#). Further details on these methods are described in the following sections.

Figure 9a. Flowchart for project overview

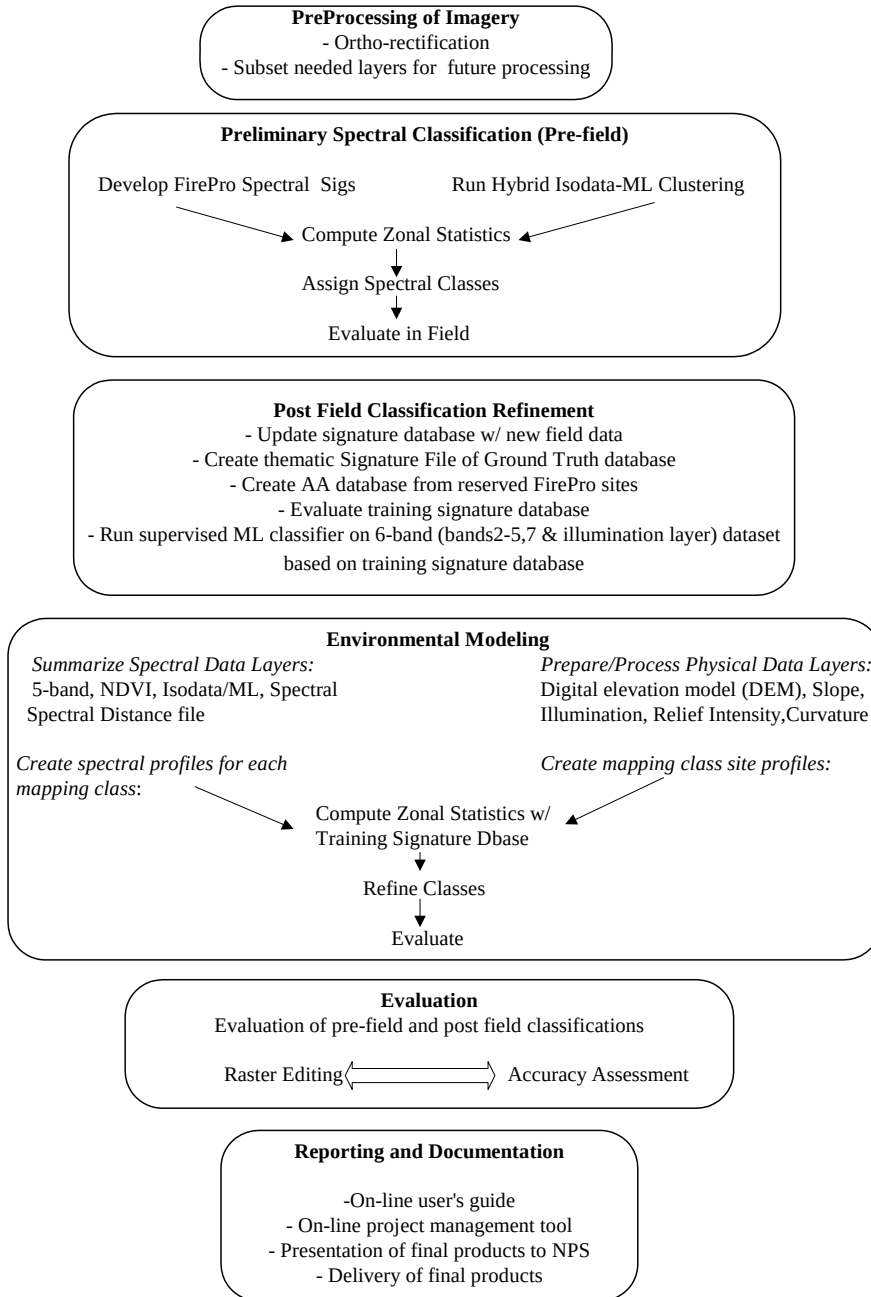


Figure 9b. Flow chart for preprocessing of imagery

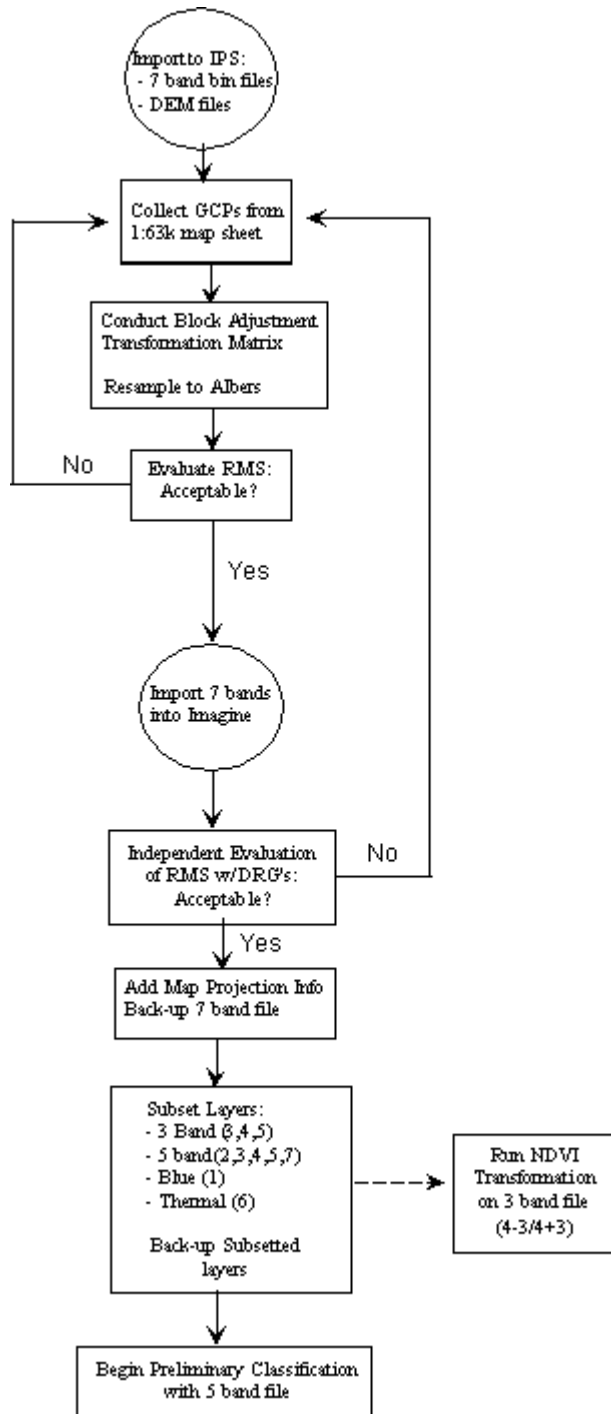


Figure 9c. Flowchart for preliminary spectral classification

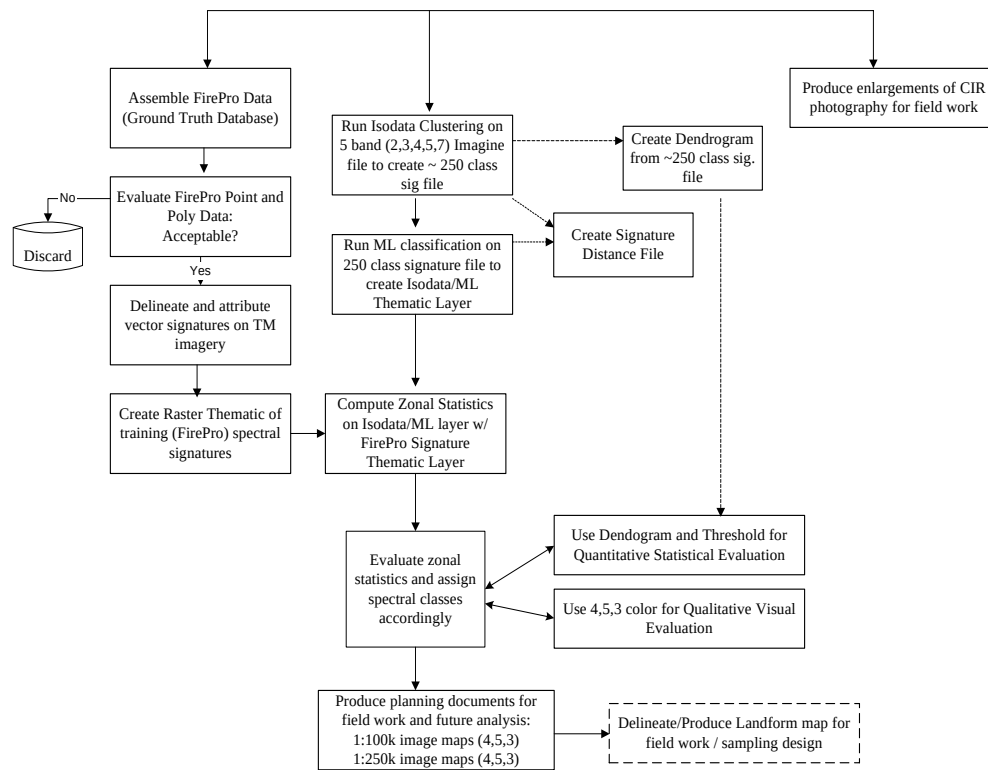


Figure 9d. Flowchart for post-field classification refinement

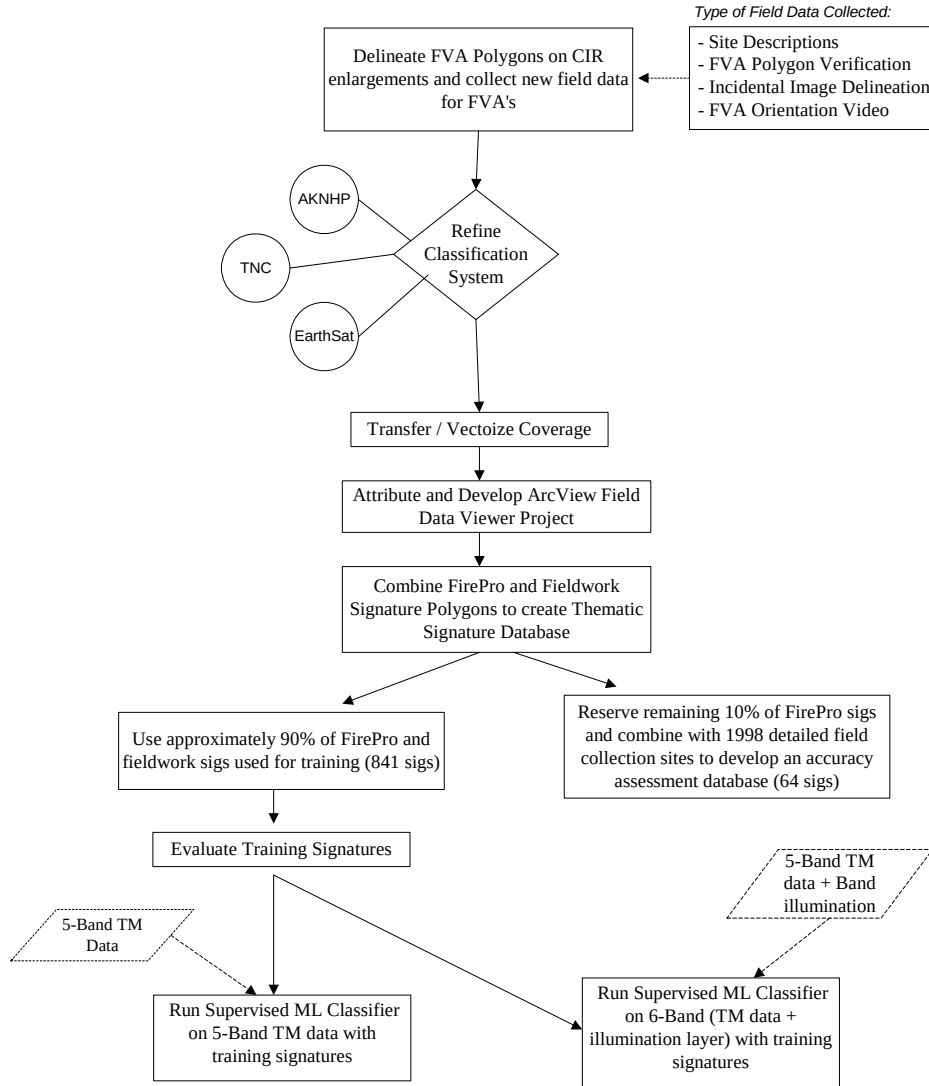


Figure 9e. Flowchart for environmental modeling

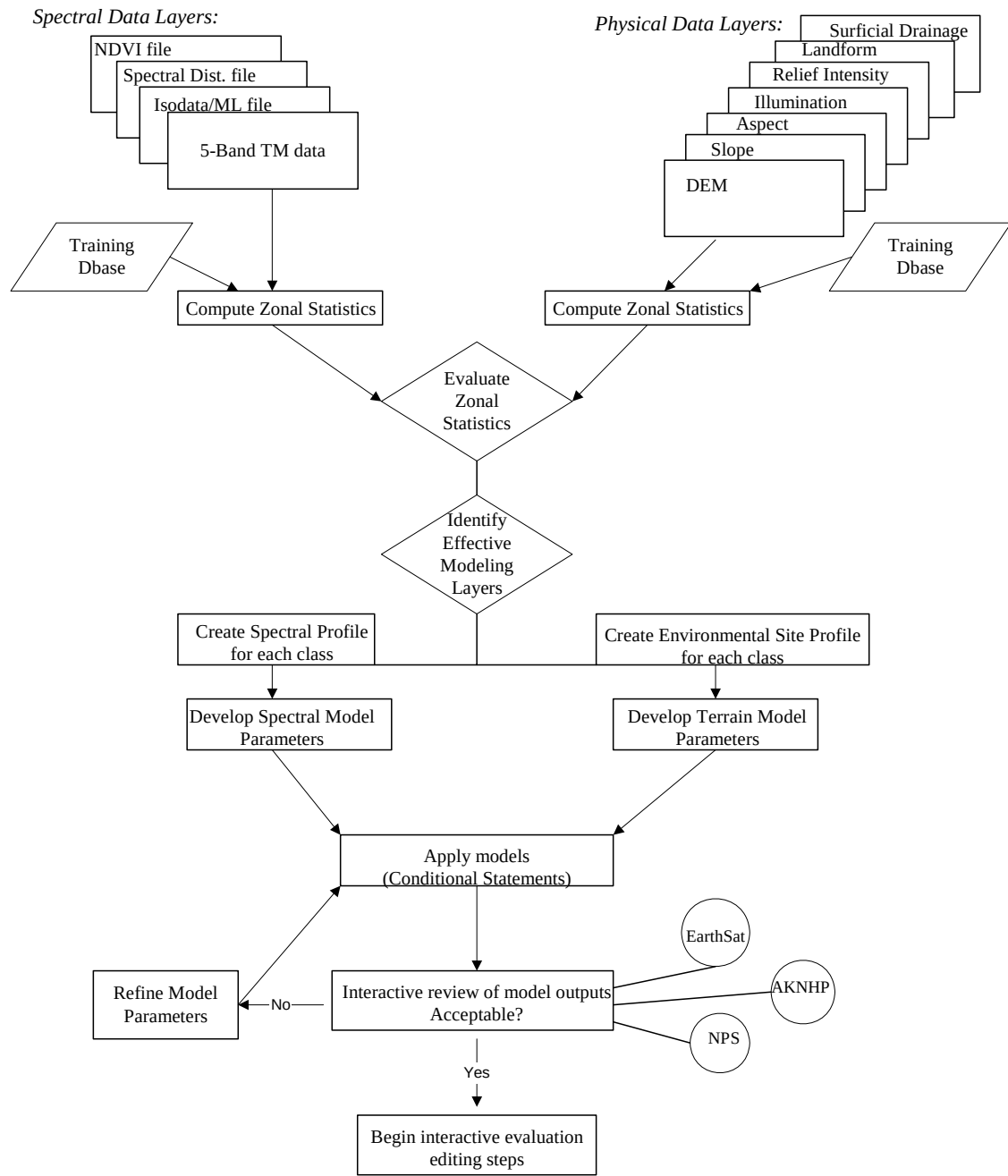
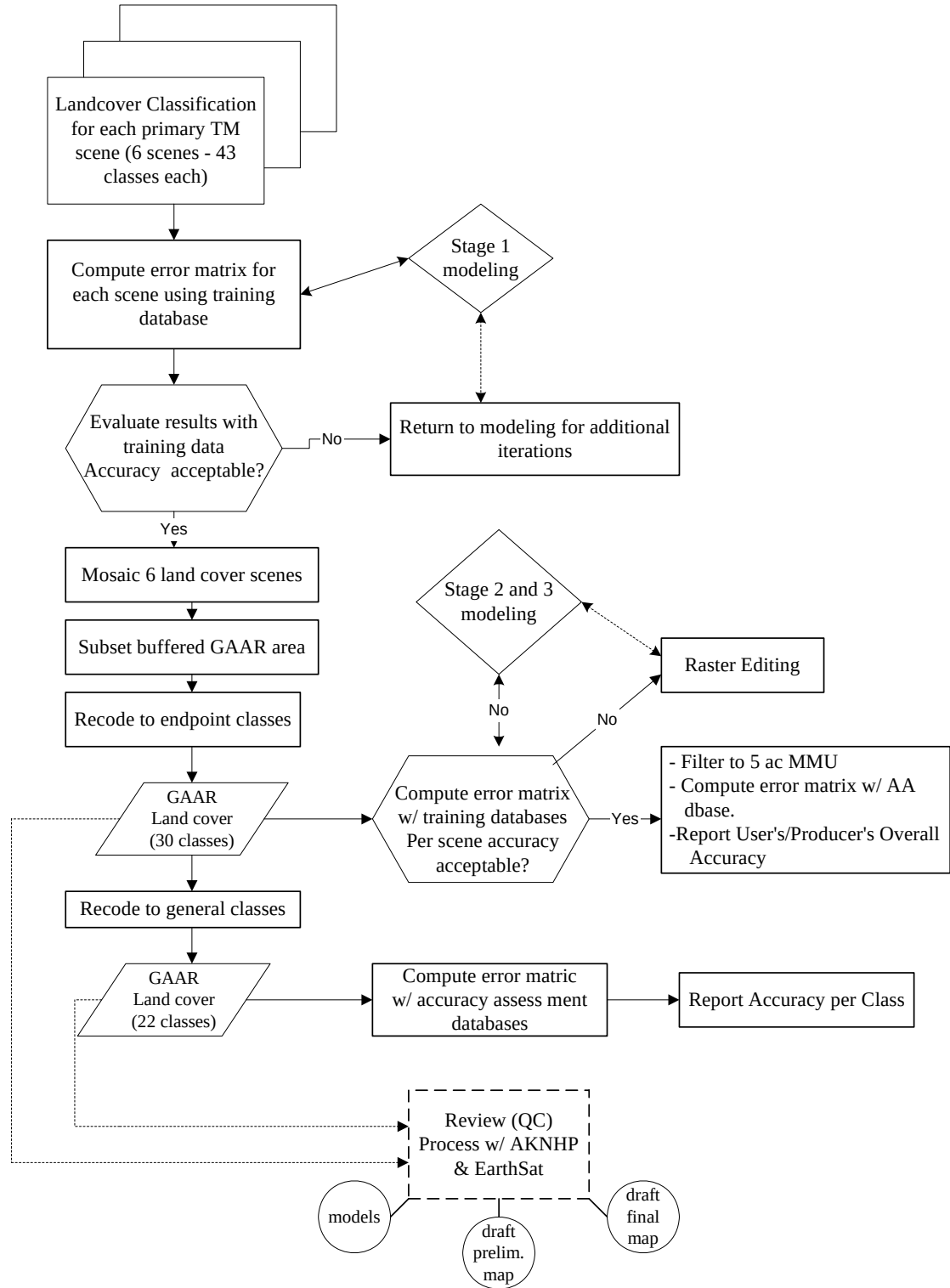


Figure 9f. Flowchart for evaluation of Landcover map



2.1 OVERVIEW OF THE LANDCOVER CLASSIFICATION SYSTEM

A landcover classification system was developed using suggestions from NPS personnel familiar with the Park and data collected during the field season, and followed—with modifications—the Alaska Vegetation Classification (Viereck et al. 1992) system at levels III and IV. A stratified random approach—based on ecoregions, surficial geology and Landsat TM imagery—was used to select polygons for field sampling. Fly-over and ground data were collected for each polygon and included vegetation structure, plant species, percent cover, elevation, as well as other site information.

A combination of spectral image processing, environmental site and spectral modeling and raster editing were required in order to map landcover from Landsat TM data at the required level of geometric accuracy (1:63,360) and classification system detail (30 classes). An initial landcover classification system was developed to train the Landsat TM scenes prior to fieldwork, to increase the accuracy of the field effort, and to classify the spectral signatures during the field season. The landcover classification system was modified after the field season to better represent landcover classes observed in the field ([Table 2](#)), and to determine what could actually be interpreted from the Landsat TM imagery.

Table 2. Landcover classes used in the field to map GAAR					
GAAR landcover classes					
I	II	III		Canopy cover	Height of vegetation / site factor
Forest	Needleleaf			> 15 % tree cover; >75% total tree cover is Needleleaf	All trees
		Closed		60-100	Species unknown
		Closed	Black spruce like	60-100	
			White spruce like		
		Open		30-59	Species unknown
		Open	Black spruce like	30-59	
			White spruce like		
		Woodland		15-29	Species unknown
		Woodland	Black spruce like	15-29	
			White spruce like		
			White spruce-Lichen	>50% lichen	
	Broadleaf			>75% total tree cover is broadleaf	
		Closed	Paper birch-Aspen	60-100	
			Balsam poplar (model)		
		Open	Paper birch-Aspen	30-59	
			Balsam poplar (model)		
	Mixed			25%-75% cover for both broadleaf and needleleaf	
		Closed			Species unknown
		Closed	Black spruce-Broadleaf	60-100	
			White spruce-birch-balsam poplar		
		Open		30-59	Species unknown
		Open	Black spruce-Broadleaf	30-59	
			White spruce-Broadleaf		
Shrub				<15% tree cover, >25% shrub cover	
	Tall shrub	Closed	Alder	75-100	> 1.5 m
			Willow		
			Alder-Willow		
			Birch		
		Open	Alder	25-74	
			Willow		
			Alder-Willow		
	Low shrub	Closed	Willow	75-100	0.33 - 1.5 m
			Dwarf birch-Ericaceous-Willow		
		Open	Willow	25-74	
			Dwarf birch-Ericaceous -Willow		
	Dwarf shrub		Shrub-Sedge (mesic/wet)	25-100	0.1 - 0.33 m; Tussock tundra and peatlands
			Ledum-Dwarf birch (dry)		Upslope
	Prostrate		Dryas-Ericaceous-Willow	25-100	< 0.1 m
			Dryas-Eric-Willow on floodplain		
Herbaceous				<25% tree cover, <25% shrub cover, >25% Herbaceous	
	Gram./forb	Dry		25-100	Dry
		Mesic			Mesic
		Wet			Semiperm. water, emergent veg.
	Aquatic				Permanent water, submerged-floating
	Bryoid	Lichen		Vegetation dominated by mosses or lichens	
Sparsely vegetated				total of 15-25% cover	
Bare-ground				<15% cover	Bedrock and unconsolidated
Water	Silty				
	Clear				
Snow/ice					
Sand dunes					
Mosaic/pattern vegetation					Stringers, peatland, patterned ground
Shadow/Indeterminate		Unknown			Minimal reflectance due to terrain or clouds/shadows

The classification system was developed from three sources, and, in general, followed The Alaska Vegetation Classification (Viereck et al. 1992) system. First, USDI National Park Service (NPS) personnel with experience in GAAR provided a list of possible classes (Table 3). Second, Alaska Vegetation Classification (Viereck et al. 1992) classes were assigned to previously collected Firepro data from GAAR. Third, a list of plant associations and map classes was developed through a literature review of GAAR (Table 4). A total of 30 classes were provided by NPS personnel, 58 classes were derived from the FirePro data (based on 1,000+ points and polygons), and a total of 54 classes were extracted from the 12 published vegetation studies.

Table 3. Preliminary map classes for GAAR from the scoping meeting December 8, 1997

Class			Subclass	
Forest	Needleleaf	Closed	Black spruce	
			White spruce	
		Open	Black spruce	
			White spruce	
		Woodland	Black spruce	
			White spruce	
			Lichen woodland	
		Broadleaf	Closed	
			Open	
	Mixed	Closed	Black spruce-Broadleaf	
			White spruce-Broadleaf	
		Open	Black spruce-Broadleaf	
			White spruce-Broadleaf	
Scrub	Dwarf tree		Black spruce	
	Tall shrub	Closed	Alder	
			Willow	
		Open	Alder	
			Willow	
		Low shrub	Closed	Willow
				Shrub birch-Ericaceous shrub
	Open		Willow	
			Shrub birch-Ericaceous shrub	
	Dwarf shrub		Dryas-Ericaceous	
	Herbaceous	Graminoid/forb	Dry	
			Mesic	
			Wet	
Aquatic				
Mosses				
Lichen				
Water				
Barren				
Sparsely Vegetated				
Snow/ice				

The mapped classes were refined during a scoping meeting attended by NPS personnel and members of the mapping team (Earth Satellite Corporation, Alaska Natural Heritage Program, Forest Data, Inc., Greenhorne & O'Mara, and Ray Kreig & Associates). Several assumptions were made during the refinement of the classes. The group agreed that the mapping classes must be based on landcover characteristics that could be recognized by Landsat imagery, and had to be flexible enough to describe potential new classes derived from Landsat imagery. The mapping classes were derived from the Alaska Vegetation Classification (Viereck et al., 1992) however we did not strictly adhere to this hierarchy. This was primarily because the Alaska

Table 4. Plant associations found in GAAR, arranged by GAAR landcover classes.

GAAR landcover classes			Plant Associations (V)	Location of study	Author
II	III	IV			
Needleleaf forest	Dense-open needleleaf forest	Dense-open white spruce forest	No plant associations defined		
		Open black spruce-like forest	No plant associations defined		
		Open white spruce-like forest	<i>Picea glauca</i> / <i>Alnus crispa</i> / <i>Empetrum nigrum</i> / <i>Vaccinium vitis-idaea</i> / <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Picea glauca</i> / <i>Salix</i> / <i>Dryas integrifolia</i> / <i>Arctostaphylos rubra</i> / <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Picea glauca</i> - <i>Salix lanata</i> - <i>Equisetum arvense</i> - <i>Hylocomium splendens</i>	Upper Alatna River drainage	Odasz 1983
	Woodland	Spruce woodland	<i>Picea glauca</i> - <i>Vaccinium uliginosum</i> - <i>Pyrola asarifolia</i>	Upper Alatna River drainage	Odasz 1983
			<i>Picea glauca</i> / <i>Betula glandulosa</i> / <i>Salix glauca</i> / <i>Vaccinium-Festuca altaica</i> / <i>Cladina</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Picea glauca</i> / <i>Betula glandulosa</i> / <i>Salix glauca</i> / <i>Vaccinium-Empetrum nigrum</i> / <i>Cladina</i> - <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Picea glauca</i> / <i>Betula glandulosa</i> / <i>Vaccinium vitis-idaea</i> / <i>Festuca altaica</i> / <i>Cladina</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Picea glauca</i> / <i>Alnus crispa</i> / <i>Linnaea borealis</i> -mixed herb/ <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980
		Spruce-lichen woodland	<i>Picea glauca</i> / <i>Salix planifolia</i> / <i>Vaccinium-Carex bigelowii</i> / <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Picea glauca</i> / <i>Betula nana</i> - <i>Salix</i> / <i>Vaccinium uliginosum</i> - <i>Carex bigelowii</i> / <i>Cladina</i> - <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Picea glauca</i> / <i>Betula nana</i> - <i>Salix lanata</i> / <i>Carex bigelowii</i> - <i>Eriophorum vaginatum</i> / <i>Sphagnum</i> - <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Picea glauca</i> / <i>Betula nana</i> / <i>Carex saxatilis</i> - <i>Andromeda polifolia</i> / <i>Sphagnum</i>	Upper Dietrich River Valley	Densmore 1980
			No plant associations defined		
	Unclassified needleleaf forest plant associations		<i>Picea glauca</i> - <i>Alnus crispa</i> - <i>Mertensia paniculata</i> - <i>Festuca altaica</i>	Upper Alatna River drainage	Odasz 1983
			<i>Picea glauca</i> - <i>Cassiope tetragona</i> - <i>Lycopodium annotinum</i> - <i>Stereocaulon pasale</i>	Upper Alatna River drainage	Odasz 1983
			<i>Picea glauca</i> - <i>Salix glauca</i> - <i>Dryas integrifolia</i> - <i>Carex saxatilis</i>	Upper Alatna River drainage	Odasz 1983
			<i>Picea glauca</i> - <i>Salix glauca</i> - <i>Shepherdia canadensis</i> - <i>Festuca altaica</i>	Upper Alatna River drainage	Odasz 1983
Broadleaf forest	Closed broadleaf forest	Closed paper birch-aspen forest	No plant associations defined		
		Closed balsam poplar forest	No plant associations defined		
	Open broadleaf forest	Open paper birch-aspen forest	No plant associations defined		
		Open balsam poplar forest	<i>Populus balsamifera</i> / <i>Salix</i> / <i>Vaccinium uliginosum</i> / <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980

			<i>Populus balsamifera</i> / <i>Salix arbusculoides</i> / <i>Shepherdia canadensis</i>	Upper Dietrich River Valley	Densmore 1980
Mixed forest	Closed mixed forest	Closed spruce-broadleaf	No plant associations defined		
	Open mixed forest	Open spruce-broadleaf	No plant associations defined		
Tall shrub	Closed tall shrub		<i>Salix alaxensis</i> /mixed herb	Upper Dietrich River Valley	Densmore 1980
			<i>Petasites frigidus</i> - <i>Salix alaxensis</i>	Alatna River	Cooper 1986
			<i>Arctagrostis latifolia</i> - <i>Salix alaxensis</i>	Alatna River	Cooper 1986
			<i>Betula glandulosa</i> (also listed under shrub birch-ericaceous-willow)	GAAR	Boggs and Garibaldi 1999
			Lichen- <i>Betula glandulosa</i> (also listed under shrub birch-ericaceous-willow)	GAAR	Boggs and Garibaldi 1999
			<i>Betula glandulosa</i> - <i>Alnus crispa</i>	Alatna River	Cooper 1986
			<i>Betula glandulosa</i> / <i>Potentilla fruticosa</i> / <i>Vaccinium</i> spp-	Upper Dietrich River Valley	Densmore 1980
			<i>Festuca altaica</i> / <i>Rhizidium rugosum</i> - <i>Cladina</i>	Alatna River	Cooper 1986
			<i>Betula glandulosa</i> - <i>Cladina stellaris</i>	Alatna River	Cooper 1986
			<i>Alnus crispa</i> / <i>Salix</i> / <i>Carex bigelowii</i> - <i>Boykinia richardsonii</i> / <i>Aulacomnium turgidum</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Juniperus communis</i> - <i>Betula glandulosa</i>	Alatna River	Cooper 1986
	Open tall shrub		<i>Salix alaxensis</i>	GAAR	Boggs and Garibaldi
			<i>Salix lanata</i> ssp. <i>richardsonii</i> / <i>Carex membranacea</i>	GAAR	Boggs and Garibaldi
			<i>Salix lanata</i> ssp. <i>richardsonii</i>	GAAR	Boggs and Garibaldi
			<i>Senecio lugens</i> - <i>Salix alaxensis</i>	Alatna River	Cooper 1986
Low shrub	Closed low shrub	Closed low willow	<i>Salix planifolia</i> spp. <i>pulchra</i> (closed)	GAAR	Boggs and Garibaldi 1999
	Open low shrub	Shrub birch-willow-tundra	<i>Betula glandulosa</i> / <i>Carex aquatilis</i>	GAAR	Boggs and Garibaldi
			<i>Betula glandulosa</i> / <i>Carex bigelowii</i>	GAAR	Boggs and Garibaldi
			<i>Betula glandulosa</i> / <i>Eriophorum russeolum</i>	GAAR	Boggs and Garibaldi
			<i>Vaccinium uliginosum</i> - <i>Ledum palustre</i> / <i>Carex bigelowii</i>	GAAR	Boggs and Garibaldi
			<i>Vaccinium uliginosum</i> - <i>Ledum palustre</i> / <i>Eriophorum</i>	GAAR	Boggs and Garibaldi
			<i>Vaccinium uliginosum</i> - <i>Ledum palustre</i> / <i>Eriophorum</i>	GAAR	Boggs and Garibaldi
			<i>Betula nana</i> - <i>Salix planifolia</i> / <i>Vaccinium</i> - <i>Ledum decumbens</i> - <i>Carex bigelowii</i> / <i>Arctagrostis latifolia</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Salix lanata</i> ssp. <i>richardsonii</i> / <i>Carex bigelowii</i>	GAAR	Boggs and Garibaldi
			<i>Salix planifolia</i> ssp. <i>pulchra</i> / <i>Carex aquatilis</i>	GAAR	Boggs and Garibaldi
			<i>Salix planifolia</i> ssp. <i>pulchra</i> / <i>Eriophorum russeolum</i>	GAAR	Boggs and Garibaldi
			<i>Salix planifolia</i> ssp. <i>pulchra</i> / <i>Carex bigelowii</i>	GAAR	Boggs and Garibaldi
			<i>Carex scirpoidea</i> - <i>Vaccinium uliginosum</i>	Alatna River	Cooper 1986
		Shrub birch-ericaceous-willow	<i>Betula glandulosa</i> (also listed under closed tall shrub)	GAAR	Boggs and Garibaldi
			Lichen- <i>Betula glandulosa</i> (also listed under closed tall shrub)	GAAR	Boggs and Garibaldi
			<i>Vaccinium uliginosum</i> - <i>Ledum palustre</i> / <i>Sphagnum</i>	GAAR	Boggs and Garibaldi
			<i>Vaccinium uliginosum</i> - <i>Ledum palustre</i>	GAAR	Boggs and Garibaldi
			<i>Salix planifolia</i> ssp. <i>pulchra</i> (open)	GAAR	Boggs and Garibaldi
			<i>Equisetum arvense</i> - <i>Salix lanata</i>	Alatna River	Cooper 1986
			<i>Salix planifolia</i> spp. <i>pulchra</i> - <i>Cladina stellaris</i>	Alatna River	Cooper 1986
Prostrate shrub	Prostrate shrub-rock		<i>Dryas octopetala</i> -rock	GAAR	Boggs and Garibaldi 1999
	Prostrate shrub-lichen		<i>Vaccinium uliginosum</i> /fruticose lichen	GAAR	Boggs and Garibaldi 1999
	Prostrate shrub		<i>Dryas octopetala</i> / <i>Carex</i> spp.	GAAR	Boggs and Garibaldi
			<i>Braya humilis</i> ssp. <i>richardsonii</i> - <i>Carex glacialis</i>	Alatna River	Cooper 1986
			<i>Dryas octopetala</i>	GAAR	Boggs and Garibaldi
			<i>Dryas octopetala</i> - <i>Cassiope tetragona</i>	GAAR	Boggs and Garibaldi
			<i>Dryas integrifolia</i>	GAAR	Boggs and Garibaldi
			<i>Salix reticulata</i>	GAAR	Boggs and Garibaldi
	Unclassified prostrate shrub plant		<i>Dryas octopetala</i> - <i>Salix phlebophylla</i> - <i>Festuca altaica</i> / <i>Polytrichum juniperinum</i>	Upper Dietrich River Valley	Densmore 1980
			<i>Empetrum nigrum</i> - <i>Dryas octopetala</i> ssp. <i>alaskensis</i>	Alatna River	Cooper 1986

associations		<i>Dodecatheon frigidum</i> - <i>Dryas octopetala</i> ssp. <i>alaskensis</i>	Alatna River	Cooper 1986
		<i>Boykinia richardsonii</i> - <i>Dryas octopetala</i> ssp. <i>Alaskensis</i>	Alatna River	Cooper 1986
		<i>Cassiope tetragona</i> - <i>Dryas octopetala</i> ssp. <i>alaskensis</i>	Alatna River	Cooper 1986
		<i>Salix reticulata</i> - <i>Dryas octopetala</i> ssp. <i>alaskensis</i>	Alatna River	Cooper 1986
		<i>Dryas octopetala</i> - <i>Vaccinium uliginosum</i> - <i>Cassiope tetragona</i> - <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980
		<i>Dryas octopetala</i> - <i>Vaccinium uliginosum</i> - <i>Rhododendron lapponicum</i> - <i>Rhytidium rugosum</i>	Upper Dietrich River Valley	Densmore 1980
		<i>Dryas octopetala</i> - <i>Arctostaphylos alpina</i> - <i>Trisetum spicatum</i> - <i>Rhytidium rugosum</i> - <i>Cetraria</i>	Upper Dietrich River Valley	Densmore 1980
		<i>Dryas octopetala</i> - <i>Salix rotundifolia</i> - <i>Oxytropis maydelliana</i> - <i>Aulacomnium turgidum</i> - <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980
		<i>Dryas octopetala</i> - <i>Salix phlebophylla</i> - <i>Selaginella sibirica</i> - <i>Polytrichum juniperinum</i>	Upper Dietrich River Valley	Densmore 1980
		<i>Carex scirpodea</i> - <i>Dryas octopetala</i> ssp. <i>octopetala</i>	Alatna River	Cooper 1986
		<i>Carex scirpodea</i> - <i>Carex rupestris</i> (<i>Dryas octopetala</i>)	Alatna River	Cooper 1986
		<i>Vaccinium uliginosum</i> - <i>Salix phlebophylla</i>	Alatna River	Cooper 1986
		<i>Cassiope tetragona</i> - <i>Carex scirpodea</i> - <i>Cladina</i>	Upper Dietrich River Valley	Densmore 1980
		<i>Salix rotundifolia</i> ssp. <i>dodgeana</i> - <i>Kobresia myosuroides</i>	Alatna River	Cooper 1986
		<i>Carex podocarpa</i> - <i>Salix rotundifolia</i>	Alatna River	Cooper 1986
		<i>Saxifraga oppositifolia</i> - <i>Salix rotundifolia</i>	Alatna River	Cooper 1986
		<i>Senecio atropurpureus</i> ssp. <i>tomentosus</i> - <i>Salix rotundifolia</i>	Alatna River	Cooper 1986
		<i>Oxytropis nigrescens</i> - <i>Salix rotundifolia</i> ssp. <i>dodgeana</i>	Alatna River	Cooper 1986
		<i>Salix rotundifolia</i> - <i>Hylocomium splendens</i>	Upper Dietrich River Valley	Densmore 1980
		<i>Betula nana</i> - <i>Vaccinium</i> - <i>Festuca altaica</i>	Upper Dietrich River Valley	Densmore 1980
		<i>Salix phlebophylla</i> - <i>Hierochloa alpina</i> - <i>Antennaria friesiana</i> - <i>Polytrichum juniperinum</i> - <i>cetraria</i>	Upper Dietrich River Valley	Densmore 1980
Herbaceous types	Dry herbaceous	<i>Elymus innovatus</i> - <i>Salix alaxensis</i>	Alatna River	Cooper 1986
		<i>Hedysarum alpinum</i> - <i>Carex franklinii</i>	Alatna River	Cooper 1986
		<i>Hedysarum alpinum</i> - <i>Elymus innovatus</i>	Alatna River	Cooper 1986
		<i>Cetraria tilesii</i> - <i>Carex nardina</i>	Alatna River	Cooper 1986
		<i>Poa glauca</i> - <i>Saxifraga tricuspidata</i>	Alatna River	Cooper 1986
		<i>Calamagrostis purpurea</i> - <i>Artemisia alaskana</i>	Alatna River	Cooper 1986
		<i>Festuca brachyphylla</i> - <i>Potentilla elegans</i>	Alatna River	Cooper 1986
		<i>Saxifraga eschscholtzii</i> - <i>Woodia glabella</i>	Alatna River	Cooper 1986
		<i>Saxifraga punctata</i> - <i>Saxifraga oppositifolia</i>	Alatna River	Cooper 1986
		<i>Minuartia macrocarpa</i> - <i>Luzula arcuata</i> ssp. <i>unalaschensis</i>	Alatna River	Cooper 1986
Mesic herbaceous		<i>Saxifraga serpyllifolia</i> - <i>Potentilla elegans</i>	Alatna River	Cooper 1986
		<i>Calamagrostis canadensis</i>	GAAR	Boggs and Garibaldi
		<i>Carex bigelowii</i>	GAAR	Boggs and Garibaldi
		<i>Carex lugens</i>	GAAR	Boggs and Garibaldi
		<i>Carex membranacea</i>	GAAR	Boggs and Garibaldi
		<i>Eriophorum russeolum</i>	GAAR	Boggs and Garibaldi
		<i>Eriophorum vaginatum</i>	GAAR	Boggs and Garibaldi
		<i>Hylocomium splendens</i> - <i>Festuca altaica</i>	Alatna River	Cooper 1986
		<i>Carex microchaeta</i> - <i>Cladina stellaris</i>	Alatna River	Cooper 1986
		<i>Carex podocarpa</i> - <i>Cladina stellaris</i>	Alatna River	Cooper 1986
Wet herbaceous (Graminoids)		<i>Astragalus aboriginum</i> - <i>Saxifraga oppositifolia</i>	Alatna River	Cooper 1986
		<i>Arctophila fulva</i>	GAAR	Boggs and Garibaldi
		<i>Carex aquatilis</i>	GAAR	Boggs and Garibaldi
		<i>Carex aquatilis</i> - <i>Sphagnum</i>	GAAR	Boggs and Garibaldi
		<i>Carex limosa</i>	GAAR	Boggs and Garibaldi
		<i>Carex rostrata</i>	GAAR	Boggs and Garibaldi
		<i>Carex saxatilis</i>	GAAR	Boggs and Garibaldi
		<i>Eriophorum angustifolium</i>	GAAR	Boggs and Garibaldi
		<i>Paludella squarrosa</i> - <i>Carex aquatilis</i>	Alatna River	Cooper 1986
		<i>Carex krausei</i> - <i>Carex atrofusca</i>	Alatna River	Cooper 1986
		<i>Carex scirpodea</i> - <i>Kobresia simpliciuscula</i> (<i>Dryas octopetala</i>)	Alatna River	Cooper 1986
		<i>Cetraria delisei</i> - <i>Carex membranacea</i>	Alatna River	Cooper 1986
		<i>Pohlia wahlenbergii</i> - <i>Eriophorum scheuchzeri</i>	Alatna River	Cooper 1986
		<i>Wilhelmsia physodes</i> - <i>Arctagrostis latifolia</i>	Alatna River	Cooper 1986
(Forbs)		<i>Equisetum fluviatile</i>	GAAR	Boggs and Garibaldi
Unclassified plant associations		<i>Dicranoweisia crispula</i> - <i>Andreaea rupestris</i>	Alatna River	Cooper 1986
		<i>Drepanocladus tuntrae</i> - <i>Calliergon sarmentosum</i>	Alatna River	Cooper 1986
		<i>Schistidium rivulare</i> - <i>Drepanocladus revolvens</i>	Alatna River	Cooper 1986
		<i>Cetraria hepatica</i> - <i>Pseudephebe minuscula</i>	Alatna River	Cooper 1986
		<i>Umbilicaria caroliniana</i>	Alatna River	Cooper 1986

The Vegetation Classification did not necessarily correspond well to the classes that would be detected by Landsat imagery. In addition, little vegetation information was available from GAAR during development of the Alaska Vegetation Classification. Consequently, classes within the Alaska Vegetation Classification hierarchy did not necessarily correlate well with vegetation classes existing within GAAR.

Although the FirePro data and literature review provided more detailed information than the NPS landcover class list, both sources of information were important for confirming the classes developed by NPS personnel, indicating new classes, and providing relative abundance estimates for each class. Several iterations of the list were developed and reviewed before the final classes used for fieldwork were developed. After the field season, the landcover classification was modified following field observations and Landsat imagery interpretation. A landcover class key of final landcover classes is provided in [Appendix 1](#).

2.2 PRE-PROCESSING OF SATELLITE IMAGE DATA

An extensive data search resulted in the selection of 10 scenes that provided complete nearly cloud-free coverage of the project area during the short window of opportunity to capture northern Alaska vegetation at peak (July). The two western scenes acquired on August 28, 1995, were determined to be too late in the summer for optimum vegetation discrimination but were still the best available option. The other four primary scenes were acquired in July of 1985 and 1991 ([Figure 2](#)).

Prior to further processing, the TM imagery had to be orthorectified to create a stable and geometrically accurate base map. Recently completed 1:63,360 USGS Digital Elevation Models (DEM) were obtained and mosaiked to complete a parkwide DEM database. Horizontal controls were selected from 1:63,360 USGS topographic mapsheets for the area. In all, 387 ground control points (GCP's) were selected. A rigorous photogrammetric block adjustment process was performed resulting in an RMS of 49.5 meters. Image-to-image co-registration was within 2 pixels. Qualitative evaluation with other layers such as the limited 1:63,360 derived hydrology vector coverages was also very positive.

2.3 PRE-PROCESSING OF FIREPRO DATABASE

Over the past 15 years NPS AKSO has collected an extensive database in support of fire history and succession studies, landcover mapping and fire fuel modeling. Under the AKSO Landcover Mapping program, the spatial coordinates or locations of the FirePro data points were digitized, and the tabular data were automated for use in landcover mapping projects. The FirePro database represented the best available vegetation or landcover information within GAAR project area. This database, which is comprised of ARC/INFO coverages with approximately 1,350 georeferenced points, 1:60,000 high altitude aerial photos, 35-mm photo slides, and field forms, was

utilized extensively in the GAAR landcover project.

The FirePro data included detailed vegetation composition and information on dominant plant communities in sampled sites, and tree cores and cross sections to aid in determining when the site burned. Since 1987, remote sensing specialists in the AKSO GIS office have delineated polygons of homogeneous signature and representative vegetation types on aerial photos, which the FirePro crews then sampled. The sampled areas were qualitatively selected so as to approximate the full range of spectral and vegetative variation in the park. Summaries of the FirePro database were utilized during development of the classification system for the GAAR landcover project.

In order to directly integrate this database into the automated landcover project, it was necessary to generate a spectral signature for each FirePro plot. To accomplish this, spectral signature coverages were developed based on the review of each FirePro site's species composition, percent cover, aerial photos, site photographs, and field forms by an image analyst or botanist. The FirePro polygon was then redrawn on the Landsat TM image base to capture the spectrally homogenous portion of the polygon, and assigned the appropriate mapping class label. FirePro sites that showed inconsistencies in the database, photos, or field-forms were generally not used as spectral signatures. The FirePro derived signature database went through a number of revisions and refinements before use. In all, about 1100 FirePro sites were evaluated resulting in the development of 608 spectral signatures distributed throughout the 6 Landsat TM scenes covering the GAAR project area ([Figure 10](#)). This translated to a 55% success rate of FirePro sites useable as supervised spectral signatures.

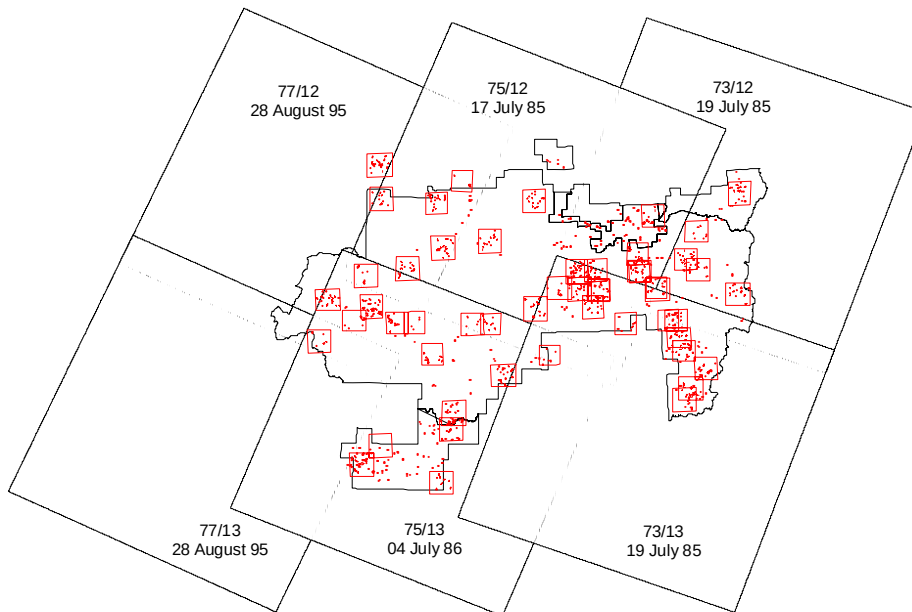


Figure 10. Mosaic design of primary Landsat TM scenes (with FirePro data shown in red)

2.4 DEVELOPMENT OF A PRELIMINARY (PRE-FIELDWORK) LANDCOVER MAP

In preparation for fieldwork, a preliminary landcover map was developed based on the FirePro derived signatures. ISODATA (Iteratively Self-Organizing Data Analysis Technique)---an unsupervised image classification method--- was then performed on each 5-band (bands 2-5 and 7) Landsat TM scene to produce 250 spectral classes. The ISODATA algorithm uses the minimum spectral distance formula to iteratively cluster or classify pixels, refine the criteria for each class, and classify again, so that the spectral distance patterns in the data gradually emerge. The ISODATA algorithms require the user or image analyst to set a number of parameters including the desire number of clusters to produce, the maximum number of iterations, etc. The parameter values used in this analysis were as follows:

Number of Classes = 250
Maximum Iterations = 20
Convergence Threshold = .999
Skip Factor = 5 pixels (in both x and y directions)
Initialization Statistics = 2 Standard Deviation

The 250 spectral classes were then assigned to the field mapping landcover classes (Table 2) based on FirePro-derived signatures. The mapping class for the majority occurring FirePro-derived signature in each spectral cluster was assigned to the cluster. This preliminary 43 class landcover map was taken to the field so that spectrally confused classes could be identified and targeted for refinement of the signatures or the classification system, or both.

2.5 SAMPLING DESIGN AND ‘FIELD VERIFICATION AREA’ SELECTION

Field sampling consisted of selecting 25 areas to record landcover characteristics from both the air and on the ground. These areas were termed field verification areas (FVA’s). Individual FVA’s represented the range in variability of landcover in its specific area, such as across a mountain valley. The FVA’s, in combination, were meant to represent the total range in variability of landcover across GAAR.

The selection of FVA’s within GAAR was based on stratified sampling (Mueller-Dombois and Ellenberg 1974, Steel and Torrie 1960) and involved: 1) a coarse scale stratification of GAAR by ecoregion (Gallant et al. 1995), 2) a fine scale stratification primarily by surficial geology type, aspect and spectral signature, and 3) selectively locating sampling points within these strata. The ecoregions and surficial geology types used in this methods section were similar to but not always the same as the ecoregions and surficial geology types given in the “Project Area and Environment” section. The differences were due to scale rather than observations.

For coarse scale stratification purposes, GAAR was divided into five ecoregions. Four of the ecoregions were based on Gallant et al. (1995), and are arctic foothills, Brooks Range, interior forested lowlands and uplands, and interior highlands (partially given in [Figures 3a and 3b](#)). A fifth ecoregion was defined by the authors. It occurs on the western edge of the park—primarily the Noatak River valley—and is dominated by Pleistocene epoch glaciated valleys overlain by lacustrine deposits. Low elevation hills also occur along with some glacial drift and eolian deposits. These five ecoregions were then delineated on the Landsat mosaic.

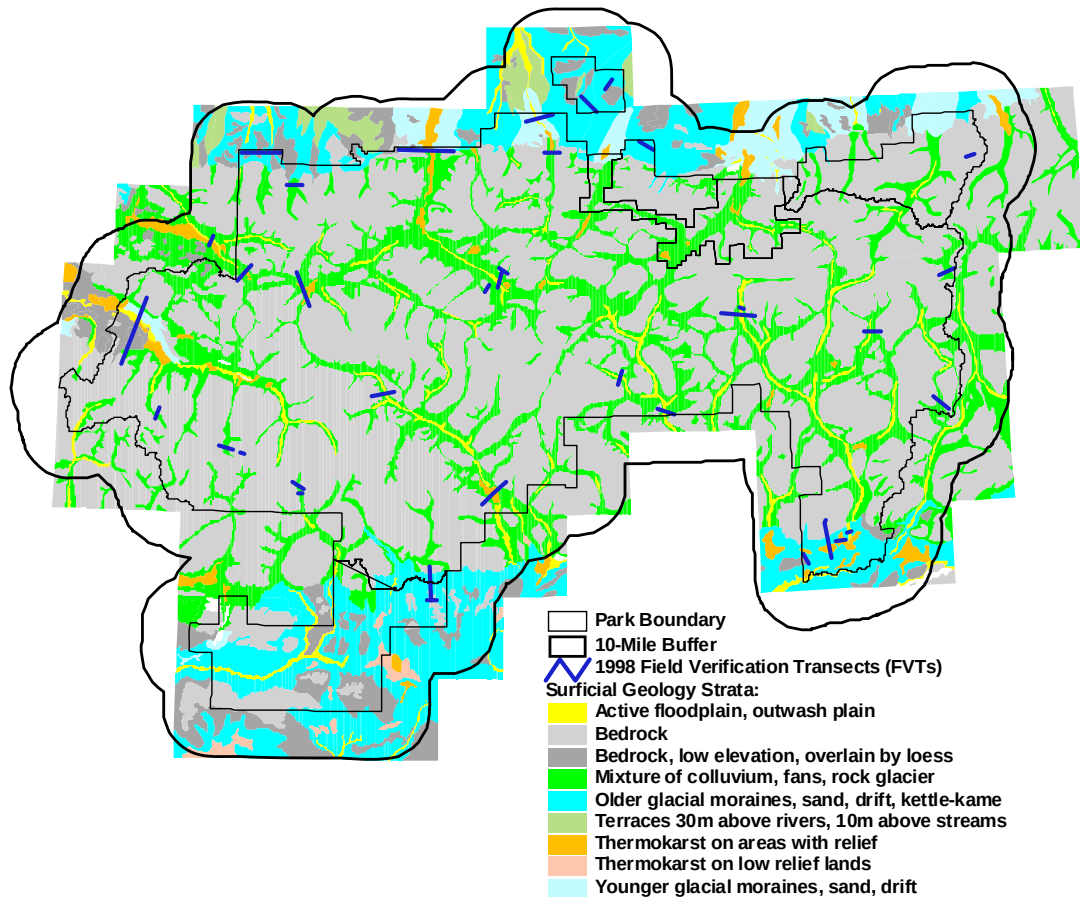


Figure 11. Landscape strata used for the placement of the 1998 Field Verification Transects (FVTs)

Table 5. Number of Field Verification Areas by landsat scene by surficial geology type by ecoregion.

Ecoregion	Surficial geology type	Landsat scene						Total
		77/12	75/12	73/12	77/13	75/13	73/13	
Arctic Foothills	Bedrock, low elevation, overlain by loess	1	4	2	---	---	---	7
	Active floodplain, outwash plain	1	3	1	---	---	---	5
	Terraces 30m rivers, 10m above streams	1	3	1	---	---	---	5
	Older glacial moraines, sand, drift, kettle-kame	1	4	2	---	---	---	7
	Younger glacial moraines, sand, drift	1	1	1	---	---	---	3
	Thermokarst on areas with relief	1	1	1	---	---	---	3
Brooks Range	Bedrock	5	5	9	2	5	2	28
	Active floodplain, outwash plain	1	4	9	0	3	2	19
	Mixture of colluvium, fans, rock glacier	5	5	8	3	6	2	29
	Thermokarst on areas with relief	1	2	2	---	---	---	5
Interior Forest Lowland-Upland	Bedrock, low elevation, overlain by loess	---	---	---	0	2	1	3
	Active floodplain, outwash plain	---	---	---	1	1	1	3
	Older glacial moraines, sand, drift, kettle-kame	---	---	---	1	2	1	4
	Thermokarst on areas with relief	---	---	---	1	1	1	3
	Thermokarst on low relief lands	---	---	---	1	1	---	1
Interior Highlands	Bedrock	---	---	---	1	1	1	3
	Bedrock, low elevation, overlain by loess	---	---	---	1	1	1	3
Lowlands (extra category)	Bedrock, low elevation, overlain by loess	2	---	---	---	---	---	2
	Active floodplain, outwash plain	1	---	---	---	---	---	1
	Older glacial moraines, sand, drift, kettle-kame	1	---	---	---	---	---	1
	Younger glacial moraines, sand, drift	1	---	---	---	---	---	1
	Thermokarst on areas with relief	2	---	---	---	---	---	2

--- means that the particular combination of ecoregion and surficial geology did not occur in the TM scene.

Twenty-five FVA's were placed within GAAR based primarily on the 22 combinations of ecoregion and surficial geology types (Figure 11, Table 5). Additional factors affecting FVA placement were as follows:

- All aspects (north, south, east, and west) on mountain slopes were included (Table 6).
- Both large and small valleys within the Brooks Range ecoregion were sampled.
- Areas with FirePro information were avoided.
- The Kobuk Boot region of GAAR was avoided because extensive past sampling were sufficient to understand the regions landcover distribution. One FVA was sampled in the northern portion.

Table 6. Number of Field Verification Areas found on each aspect per landsat scene by ecoregion by surficial geology type (Aspects are N=North, S=South, E=East, and W=West)

		Landsat scene												Total								
		77/12			75/12			73/12			77/13				75/13			73/13				
		Aspect																				
Ecoregion	Surficial geology type*	N	S	E	W	N	S	E	W	N	S	E	W	N	S	E	W	N	S	E	W	
Arctic Foothills	Bedrock low elevation overlain by loess	0	0	0	1	3	3	2	3	2	2	1	1	---	---	---	---	5	5	3	5	
Brooks Range	Bedrock	3	3	1	2	3	4	2	2	4	4	5	3	0	1	0	1	2	3	2	1	14
Interior Forest Lowland-Upland	Bedrock low elevation overlain by loess	---	---	---	---	---	---	---	---	---	---	---	---	1	0	0	0	---	---	---	---	
Interior Highlands	Bedrock	---	---	---	---	---	---	---	---	1	1	0	0	1	1	0	0	1	1	1	1	3
	Bedrock low elevation overlain by loess	---	---	---	---	---	---	---	---	---	---	---	---	0	0	0	1	1	1	1	1	1
Lowlands (extra category)	Bedrock low elevation overlain by loess	2	1	0	0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2

* Only two surficial geology types (bedrock, and bedrock low elevation overlain by loess) were used when contrasting aspect.

** --- Indicates that the particular combination of ecoregion and surficial geology did not occur in the TM scene.

Alaska Native lands (including selected, hunting camps and private in-holdings) were avoided except those lands north of the Park's boundaries.

- Distinct landcover signatures from the raw Landsat imagery were sampled. In general, these coarse level vegetation changes corresponded to the defined surficial geology types and ecoregions of GAAR.
- Sampling within Landsat scene overlap areas was maximized (14 of the 25 FVA's were in scene overlaps).
- Each Landsat scene was visually weighted by the amount of area each scene encompassed in GAAR to ensure adequate representation of the 22 ecoregion and surficial geology type combinations.
- Two floodplains in the southern portion of GAAR were sampled to capture additional samples of the *dense-open white spruce class*.
- The AVHRR landcover map for Alaska (Fleming 1997) was used to readjust FVA locations.

Within each FVA, one complete or discontinuous transect was laid out on the Landsat mosaic to encompass the FVA's full variation of environmental factors. These environmental variables included ecoregion, surficial geology types, aspect, and distinct Landsat landcover signatures. In the Brooks Range ecoregion each transect spanned an entire valley, from ridgetop to ridgetop. In the remaining four ecoregions, transects that encompassed the environmental variability were often too long to fully sample. Consequently, we formed discontinuous transects with transect segments falling in each distinct environment to be sampled.

Polygons representing all the distinct landcover classes found along each transect were then photo interpreted on 1:12,000 scale enlargements of 1:60,000 AHAP color infrared aerial photography to be used as field maps. Polygons were delineated based on homogeneity and appropriate for the mapping scale (approximately 10 ac). Landcover classes not captured by the transect but found nearby were also delineated and sampled. Approximately 3,200 acres were delineated per FVA. Due to the variable lengths of each transect, polygons may or may not be adjacent to each other. Following the photo delineation work, the landcover classes were tallied. Some readjustment of the FVA's and polygons was made in an attempt to ensure a minimum of five polygons per landcover class would be sampled for each of the six Landsat TM scenes.

2.6 FIELD DATA COLLECTION

The primary goal of the 1998 fieldwork was to collect the number of samples required to create the landcover map product. The intent of this transect-polygon

sampling approach was to both collect samples that could be used to generate spectral training signatures for use in the automated image classification, and also to gain a complete picture of the occurrences of the mapping classes for areas over all slope/aspect/landform positions in the FVA. This transect “snapshot” was essential to establishing realistic parameters in the environmental and spectral models used to refine the landcover map. A secondary goal during field data collection was to obtain more specific site information that could be used to describe plant associations, and to tie this more detailed vegetation information back to the landcover mapping classes. To support these objectives, field data were collected by a three-person crew at three different levels of detail:

FVA ‘fly over’ polygons

The purpose of this level of field data collection was specifically to provide additional training signatures for the automated image processing and modeling required to produce the landcover map. Information was recorded on field forms (Figure 12) and included the data required to select a landcover mapping class call for each sampled polygon. This information included air photo number, polygon code, latitude and longitude, landcover class name and code, date, surveyors, photos, azimuth, audio tape, video tape, slope, aspect, landform, surficial geology, and hydrologic regime. Landcover information included percent of polygon covered by the dominant species, species height, and total percent cover for the following lifeform categories: needleleaf forest, broadleaf forest, shrub (tall, low, dwarf, prostrate), herbaceous, lichen, water, bare soil, and tussocks. Dominant species and percent cover always summed to 100%. Photographs were collected at each site.

Canopy cover was ocularly estimated (Brown 1954) for the dominant species, and defined as percent of the ground in the polygon covered by the gross outline of an individual plant's foliage (canopy), or the outline collectively covered by all individuals of a species or life form within the polygon (Daubenmire 1959). Percent bare ground was also estimated.

When arriving at the FVA transect area, the image analyst and botanist flew a reconnaissance of the transect and landed at one end of the FVA (typically on a high vantage point). From here, the image analyst and the botanist surveyed the potential sample sites and compared them to the polygons already delineated on the 1:12,000 CIR (color infrared) enlargements and to the 1:100,000 Landsat TM image map of the FVA. Polygons were then adjusted on the CIR photo to ensure that they were sufficiently large (~10 acre) and recognizable on both the CIR photo and TM image. Each polygon was sampled by slow fly-by in the helicopter. Approximately 9 polygons were visited at each FVA for a total of 225 samples. Most FVA polygons were sampled using a helicopter, but fixed wing Super Cub ‘slow fly-by’ or float plane ‘drop and pickup’ missions were also flown in several FVA’s where there was limited helicopter access.

Figure 12. Field form used to gather fly-over information per polygon.

1998 GAAR LANDCOVER MAPPING PROJECT; FVA FIELD DATA FORM

Air Photo Number:		Polygon code:		Lat/Long:	
Landcover class name:				Landcover class code:	
Date:		Surveyors:			
Photos: Roll number:		Frame Number:		Azimuth:	
Audio: Tape #	Footage:	Dig photo: ses. #	photo #:	azimuth:	
Video: tape #:	Footage:	Needleleaf			
Slope (0-100 degrees):		Aspect (0-360 degrees):		Closed black spruce	
Landform:		Surficial Geology:		Closed white spruce	
Hydrologic Regime (circle one): Dry - Mesic - Wet - Aquatic				Open black spruce	
				Open white spruce	
Water %:		Bare Soil %:		Woodland black spruce	
% of polygon covered by tussocks:				Woodland white spruce	
				Woodland white spruce-lichen	

Dominant Species:	% Cover	Height (dm)	Dominant Species:	% Cover	Height (dm)	
						Broadleaf
						Closed paper birch-aspen
						Closed balsam poplar
						Open paper birch-aspen
						Open balsam poplar
						Mixed
						Closed black spr-broadleaf
						Closed white spr-birch-popl
						Open black sp-broadleaf
						Open white sp-broadleaf
						Tall Shrub
						Tall closed alder
						Tall closed willow
						Tall closed alder willow
						Tall closed birch
						Tall open alder
						Tall open willow
						Tall open alder-willow

	Total cover:	Height (dm)			
Tree:			Low Shrub	Herbaceous	Other
Needleleaf:			Low closed willow	Graminoid/forb dry	Sparsely vegetated
Broadleaf:			Low closed dwarf birch-eric-wil	Graminoid/forb Mesic	Bare-ground
Shrub:			Low open willow	Graminoid/forb Wet	Water-silt
Tall (>1.5m):			Low open dwarf birch-eric-wil	Aquatic	Water-clear
Low (0.33-1.5m):			Dwarf Shrub	Bryoid lichen	Snow/ice
Dwarf (0.1-0.33m):			Dwarf shrub-sedge (mesic-wet, peat, tussocks)		Sanddunes
Prostrate (<0.1m):			Dwarf ledum-dwarf birch-willow (dry)		Neighborhood
Herbaceous:			Prostrate Shrub		
Lichen:			Prostrate dryas-eric-wil		
			Prostrate dryas-eric-willow floodplain		

Vegetation and environmental Comments:

% inclusions and description (clumped or random distribution)

Site 'on the ground' descriptions

The purpose for this level of data collection was to support classification system refinement, to provide a more thorough understanding of the mapping classes and improved class descriptions, and to provide the required information for linking the landcover map to the plant communities.

One hundred and twelve 'on the ground' site descriptions were gathered during the field season by sampling within FVA polygons used for development of the GAAR map. One ground person was let off at a FVA and visited as many polygons as time allowed. Within a polygon, selection of sample sites was similar to the approach termed "subjective sampling without preconceived bias" as described by Mueller-Dombois and Ellenberg (1974). Site selection was based on homogeneous vegetation. Sample sites (homogeneous landcover units) were not chosen with regard to their position in any classification, extant or envisioned, or by applicability to specific management considerations.

The ground person walked through a polygon and recorded vegetation composition, structure, and site variables. Vegetation description and physical site description forms were used to record information (Figures 13 and 14). Vascular and nonvascular vegetation information within the polygons was collected, and six letter codes were used to abbreviate species names. In most cases a full species list was obtained, however, if time was insufficient, only the dominant species from each structural layer was recorded. The six-letter code for a species combined the first three letters from the genus and specific epithet, and was based on Hulten (1968). Canopy cover was ocularly estimated (Brown 1954) for each species and could sum to greater than 100%. Dominant plant species not identified in the field were collected and identified in the office. Canopy height was estimated for the dominant species.

1998 GAAR LANDCOVER MAPPING PROJECT; SITE DESCRIPTION FORM

Polygon code: _____ Date: _____ Surveyors: _____

Date: _____

[illegible]

Vegetation Comments:

Figure 14. Physical site description form for 'ground' polygon information

1998 GAAR LANDCOVER MAPPING PROJECT; SITE DESCRIPTION FORM

Air Photo Number: _____		Polygon code: _____	
Landcover class name: _____		Landcover class code: _____	
Date: _____		Surveyors: _____	
Photos: Roll number: _____		Frame Number: _____	
Lat: _____	Long: _____	UTM: _____	
Slope (0-100 degrees): _____		Aspect (0-360 degrees): _____	
Landform: _____		Surficial Geology: _____	

Hydrologic Regime

☐ Permanently Flooded	☐ Seasonally/Temp Flooded	☐ Seasonally Flood/Saturate
☐ Semipermanently Flooded	☐ Saturated	☐ Intermittently Flooded

Circle one: Dry Mesic Wet Aquatic

Environmental Comments:

Soil Texture:

_____ dm	_____ sand	_____ sandy loam	_____ loam	_____ clay loam	_____ clay	_____ peat	_____ silt loam	_____ Muck
_____ dm	_____ sand	_____ sandy loam	_____ loam	_____ clay loam	_____ clay	_____ peat	_____ silt loam	_____ Muck
_____ dm	_____ sand	_____ sandy loam	_____ loam	_____ clay loam	_____ clay	_____ peat	_____ silt loam	_____ Muck

Depth to Ice: _____

Unvegetated Surface: _____ % Bare soil _____ % Bedrock _____ % Litter, duff

_____ % Wood (> 1 cm) _____ % Large rocks (cobbles, boulders > 10 cm)

_____ % Small rocks (gravel, 0.2-10 cm) _____ % Sand (0.1-2 mm)

_____ % Other (describe): _____

	Total cover	Height	Seedling
Trees			
Needleleaf	_____	_____	_____
Broadleaf	_____	_____	_____
Shrub:			
Tall (>1.5m):	_____	_____	_____
Low (0.33-1.5m):	_____	_____	_____
Dwarf (0.1-0.33m):	_____	_____	_____
Prostrate (<0.1m):	_____	_____	_____
Graminoid	_____	_____	_____
Forb	_____	_____	_____
Lichen	_____	_____	_____

% of polygon covered by tussocks: _____

Disturbance comments:

Ground cover information was collected for each polygon. The categories are presented in [Table 7](#). The percentages for the ground cover categories typically sum to approximately 100%. The percent surface within the polygon that was covered by woody debris greater than 5 inches in diameter was also recorded.

Table 7. Ground cover categories and definitions (adapted from Jensen et al. 1992)

Category	Description
Bare Soil	<1/16 inch diameter soil particles and ash.
Gravel	1/16 < 3 inches diameter.
Rock	>3 inches diameter.
Litter and Duff	Litter includes leaves, needles, twigs, fecal material, bark, and fruits; duff is the fermentation and humus sections of the organic layer.
Wood	Downed wood fragments > 1/4 inch diameter.
Cryptograms	All bryophytes, club mosses, and lichens.
Basal Vegetation	The soil surface taken up by the live basal or root crown portion of plants.
Water	That portion of the polygon's area that is covered by water at the time of the sampling.

The following site variables were recorded within each polygon: slope, aspect, landform, surficial geology, hydrologic regime (dry, mesic, wet, aquatic), depth of soil peat, A, B and C horizons, depth to permafrost, and depth to water. Other recorded variables included air photo number, polygon code, landcover class name, landcover class code, date, surveyors, photos, latitude and longitude, environmental comments and disturbance comments. A photographic record was taken for each site. The vegetation information recorded for fly-over descriptions was also recorded for each ground description.

Incidental Observations

The third level of detail was very general observations annotated on 1:100,000 and 1:250,000 Landsat TM image maps during transit to and from FVA transect areas. These observations typically include a general vegetation call indicating, for example, "tussock tundra" without providing any indication as to the percentages of herbaceous, low shrub, tussocks, hydrologic regime, etc. They also often represented broad landscapes rather than particular sites. Photographs were often collected for these sites, and in some cases GPS points were recorded. The purpose of these sites was to provide a 'reality check' on the Landsat TM derived landcover map, and to provide additional general information for editing the map. Because of the long distances between FVA's, nearly every major valley in GAAR was well represented by this type of observation. There were 631 incidental observation recorded and entered into the ArcView project database.

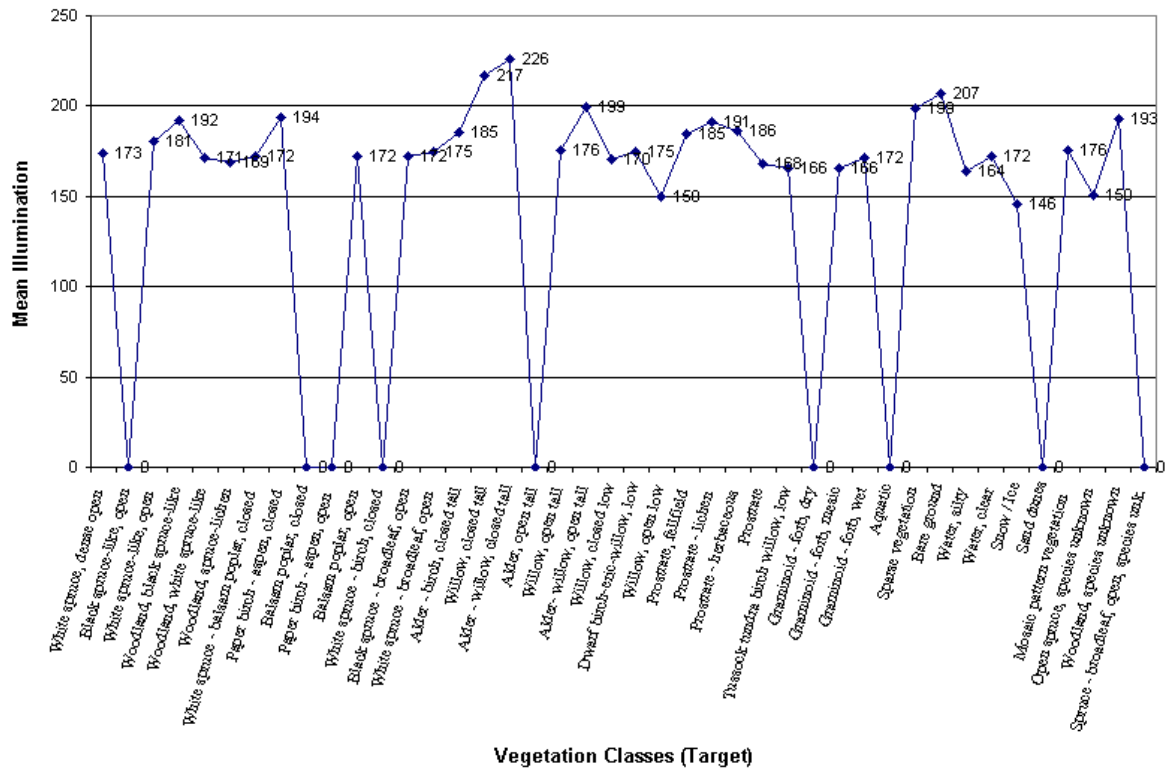
2.7 DEVELOPMENT AND EVALUATION OF SPECTRAL SIGNATURE DATABASE

Field data collected in GAAR in '98 were digitized and attributed. The FVA polygons were utilized to generate over 200 additional spectral signatures. A total of 608 signatures were derived from the FirePro database. Therefore, the total number of signatures defined for GAAR was approximately 850. All of these signatures were evaluated for spectral homogeneity and size (minimum of 9 pixels). They were also interactively evaluated through interpretation of the simulated 4,5,3 (RGB) color associated with each signature. Finally, each signature was rechecked for proper mapping class assignment. The number of training signatures for each mapping class can be found in [Appendix 2](#).

2.8 SUPERVISED MAXIMUM LIKELIHOOD SATELLITE IMAGE CLASSIFICATION

The derived signature files described above were utilized as input into a supervised classification of the TM scenes using the Maximum Likelihood (ML) classifier. ML classification was run on the 5-band (bands 2,3,4,5,7) TM image dataset. The output from the supervised ML classification of Landsat TM scene can be improved by the addition of other data or modeling layers that have the potential to improve the spectral classification. Illumination or shaded relief was found to improve the accuracy of the supervised ML output when included as a layer in the spectral database for separating aspect differences, and upslope versus floodplain. An illumination data layer was integrated with the 5 TM bands to create a 6-band (band 2, 3, 4, 5, 7 and illumination) file, and the ML classifier was run on both the 5-band and 6-band files. The addition of the illumination layer resulted in approximately 5% improvement in the classification of the training data for most of the study area. An example of an illumination profile for the training signatures is provided in [Figure 15](#). However, due to the low stature of the vegetation and fairly low relief in arctic foothill region, the illumination layer of the 6-band TM data created a smoothing effect that reduced quality of the landcover map significantly in this area. Hence, the arctic foothill ecoregion was reprocessed as a 5 band data set (i.e., without an illumination layer).

Figure 15. Example of illumination profile for training signatures (TM image 75/12)



Due to the large number of spectral signatures (over 200/scene), each TM scene was treated as a separate stratum for automated image classification. This situation was ideal for maximizing vegetation discrimination within each individual scene. The exceptions were the Path 77, Row 12 and Row 13 images which were processed as a unit due to the low number of spectral classes available in these two scenes. The training signatures were further evaluated based on a confusion matrix for each Landsat TM scene and training data for that scene. Classes that were below 75% accuracy were targeted for refinement of signatures. Signatures were added and deleted as appropriate from the signature files for each Landsat TM scene, and the supervised ML classifications rerun.

2.9 SPECTRAL AND ENVIRONMENTAL MODELING

2.9.1 Three Stages of the Modeling

The output from the supervised ML classification for each Landsat TM scene was further refined through extensive modeling, using additional data layers that showed great potential for improving the spectral classification. These layers included slope, illumination (shaded relief), Transformed Normalized Difference Vegetation Index (TNDVI), and 4 Landsat TM bands 3, 4 and 5 (especially band 5), and Winter MSS Band 4. Not all classes of the ML classification required refinement or modeling, and

classes requiring modeling were selected based on their low per class accuracy on the training data confusion matrices of each classified TM scene. Three sequential stages of spectral and environmental modeling were implemented.

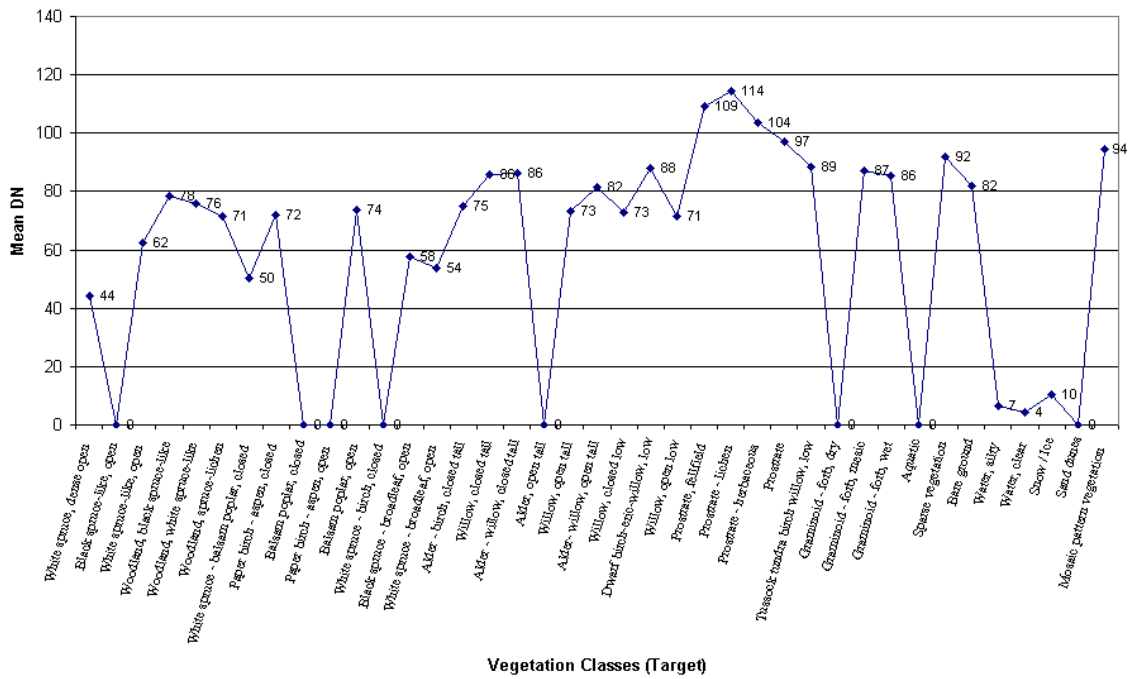
Stage 1. Target mapping class level (43 classes) identified initially confused classes, suggested relevant modeling layers for discrimination between confused classes, established initial classification parameters, and refined the classification system for the entire Project Area.

Stage 2. Endpoint mapping class level (30 classes) further refined techniques for discriminating confused classes within the 10-mile buffered GAAR area.

Stage 3. Final endpoint mapping class level (30 classes) developed and tested the final models on 10-mile buffered GAAR area. These models were based on assumptions regarding landcover and terrain/landscape/surficial geology relationships, and summary statistics of vegetation distribution by surficial geology-derived landscape categories. Classes requiring modeling were selected based on their low class accuracy on the training data confusion matrices for the target mapping classes (43 classes). The primary goal of the Stage 1 modeling was to identify confused classes in each individual Landsat TM scene area, and determine what ancillary data from the environmental/spectral modeling database would be useful for separating the confused classes. The confusion matrices for the target mapping level (43 classes) were also reviewed in refining the classification system and revising the endpoint mapping classes (30 classes).

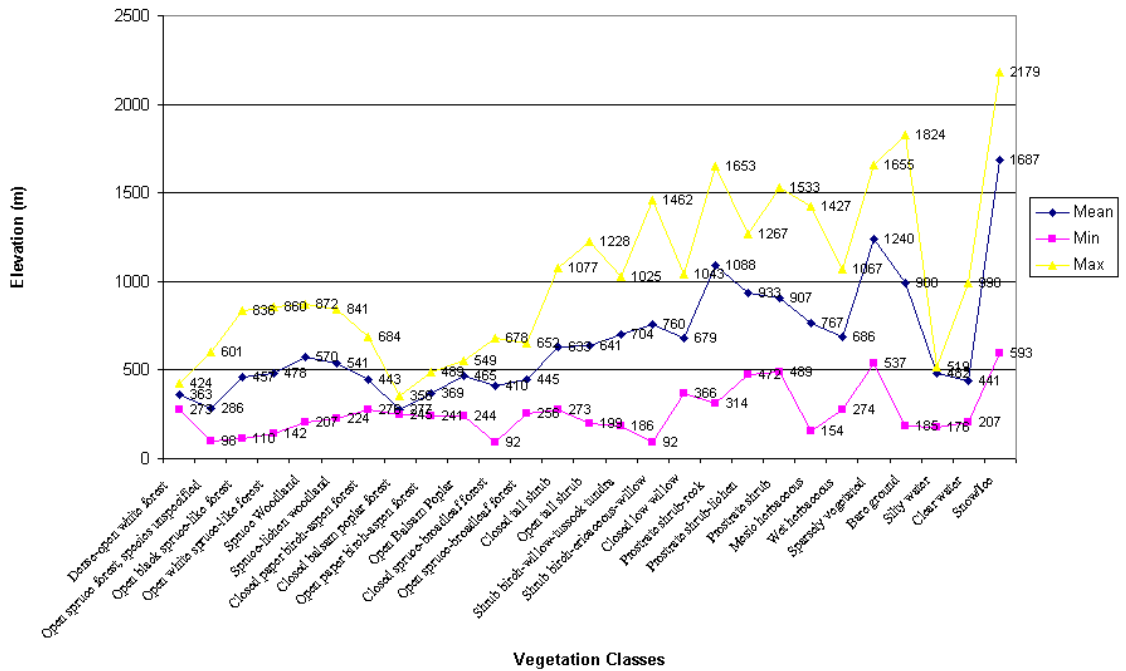
Based on the evaluation of summary statistics for the training signatures with 20 spectral/environmental modeling layers, modeling was focused on 10 of these layers that were determined to provide the highest potential for improving the landcover map. These modeling layers, the ML classification output, and the confusion matrices were reviewed interactively with ANHP in Anchorage in November 1998 to identify problems and class confusion in the ML classification, and to determine which modeling layers and parameters were useful and appropriate for correcting these problems. The key modeling layers identified were slope, illumination (shaded relief), elevation, Transformed Normalized Difference Vegetation Index (TNDVI), Landsat TM (Bands 3,4,5, especially band 5) and Winter MSS (Band 4). An example of a band 5 profile for the training signatures is provided in [Figure 16](#).

Figure 16. Example of Band 5 profile for training signatures (TM image 75/12)

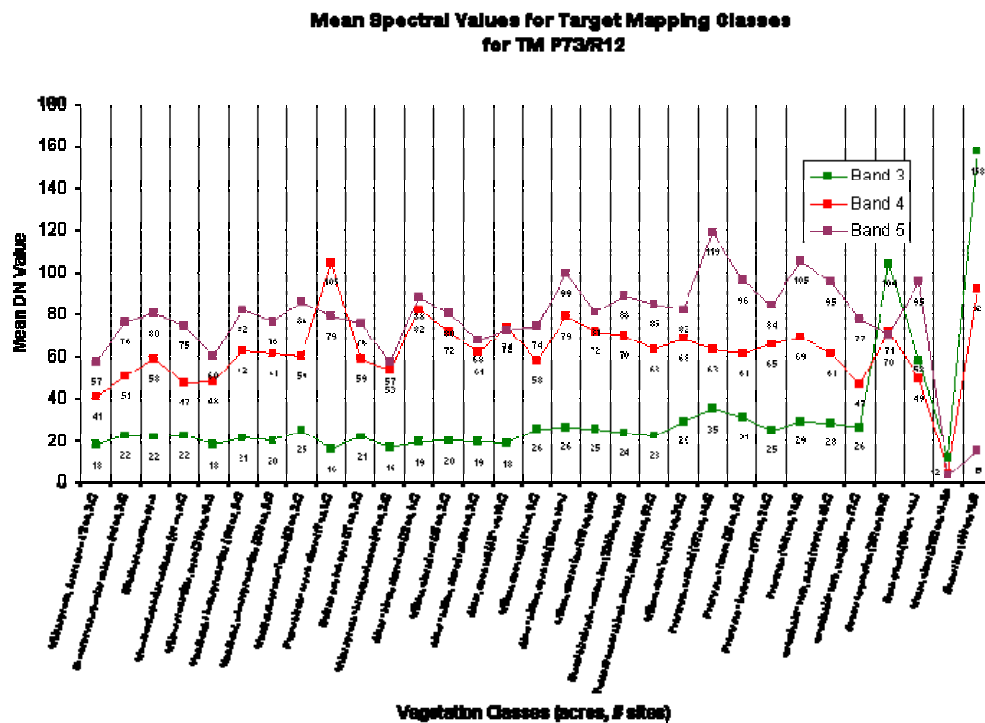


A profile for the entire GAAR area of training signatures and mean elevation values is depicted in Figure 17.

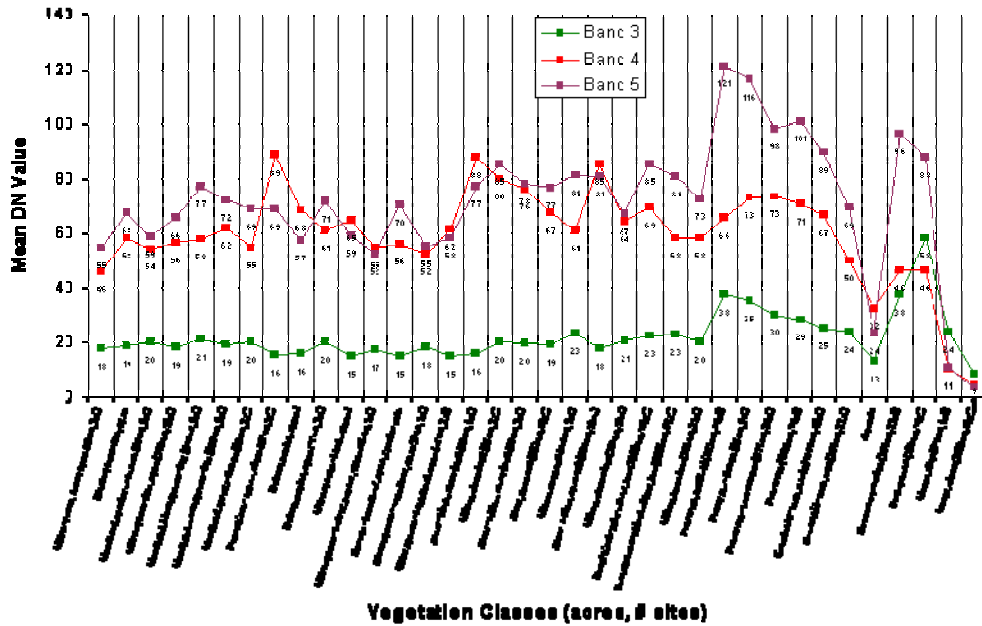
Figure 17. Profile for entire GAAR area for elevation and training signatures



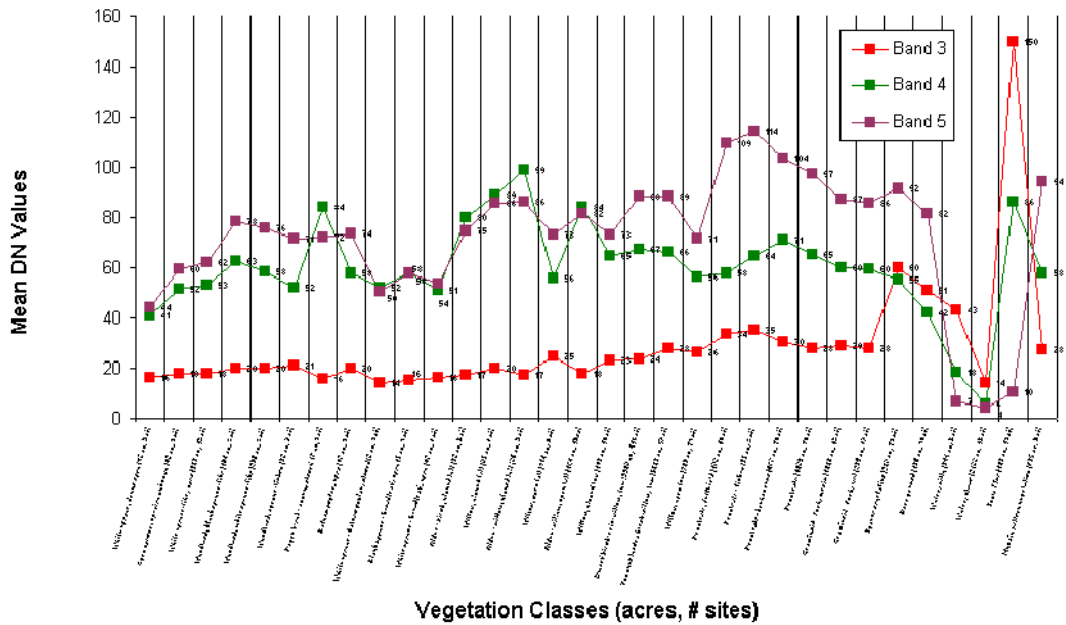
For each of the key modeling layers, a graphic spectral and environmental profile was generated from the summary statistics showing the average value of the modeling layer for each of the 43 target mapping classes. Profiles for Bands 3,4,5 and TNDVI for each primary TM scene are located in [Figures 18a, 18b, 18c, 18d, 18e, 18f](#) and [19a, 19b, 19c, 19d, 19e, 19f](#), respectively. This also was an essential tool for identifying spectrally confused classes based on the separability of the training signatures in these particular Landsat TM data layers (TM bands 4,5,3). Slope profiles for the training signatures were also developed to determine differences in slope characteristics of landcover classes which could be modeled to improve the landcover map ([Figure 20](#)).



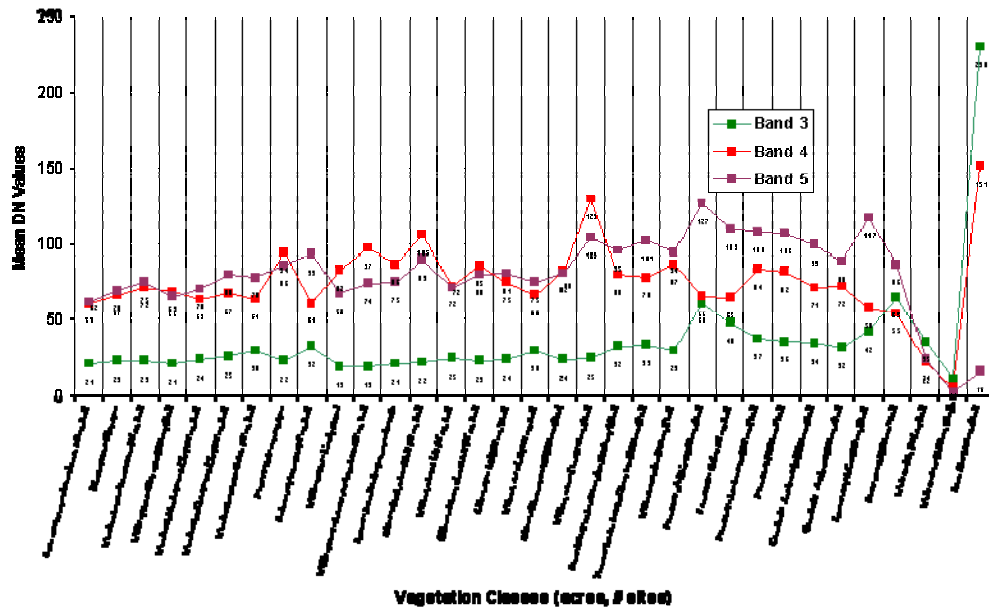
Mean Spectral Profiles for target Mapping Classes
for TM P73/R13



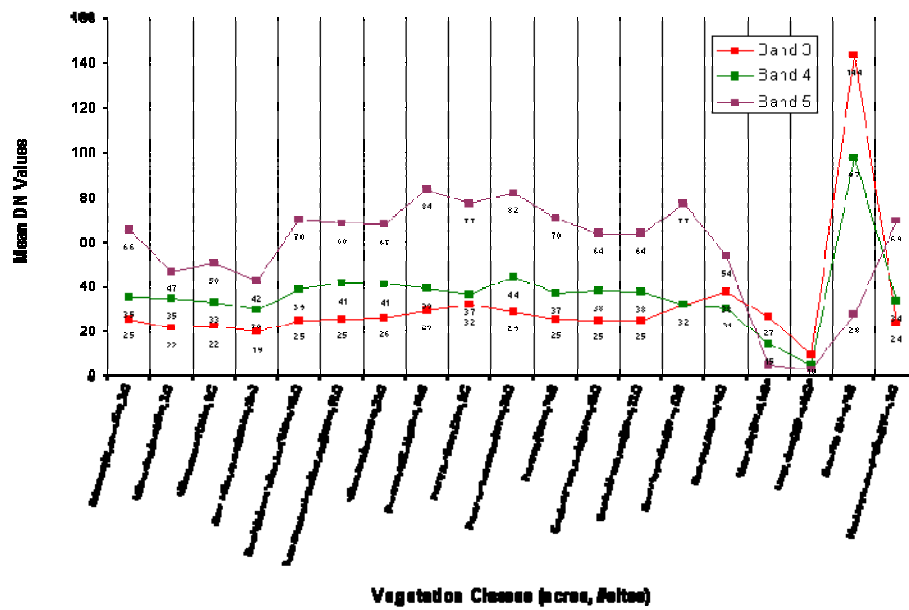
Mean Spectral Profiles for Target Mapping Classes
TM scene P75/R12



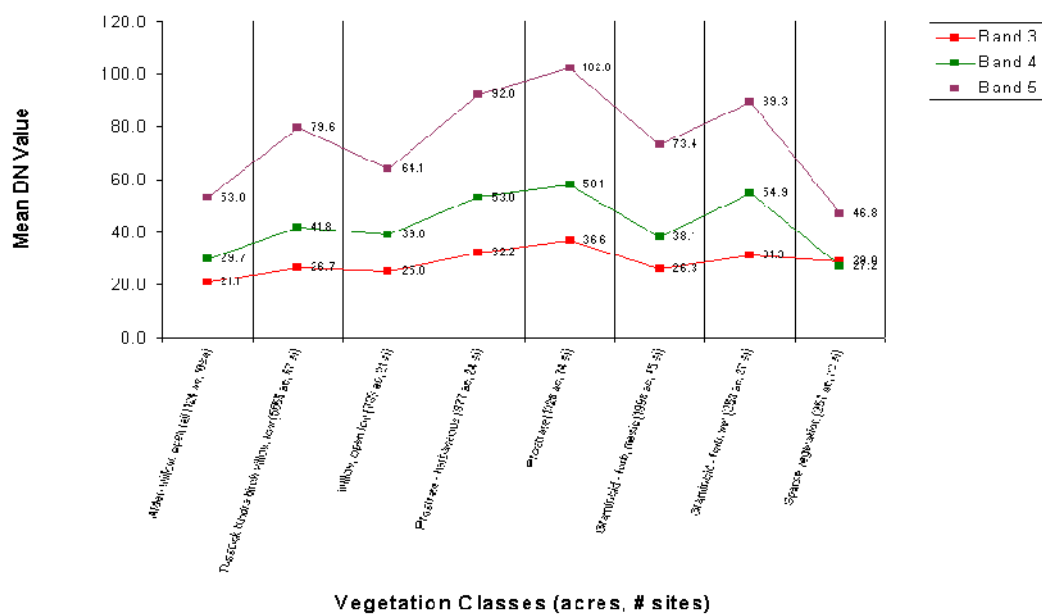
Mean Spectral Profiles for Target Mapping Classes
for TM P76R13



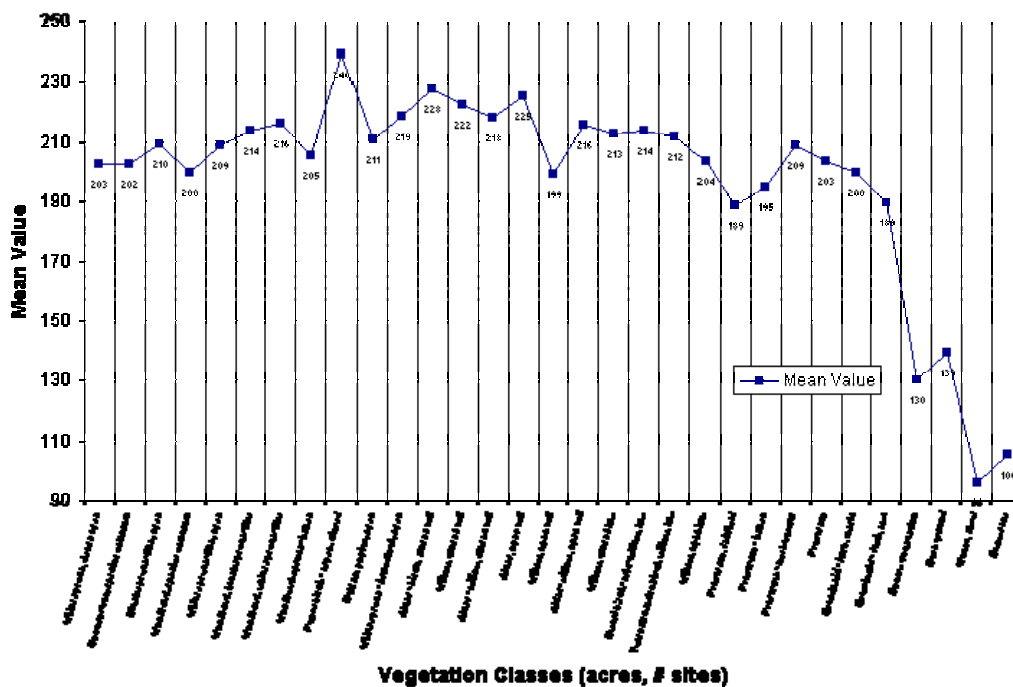
Mean Spectral Profiles for Target Mapping Classes
TM scene P77R12



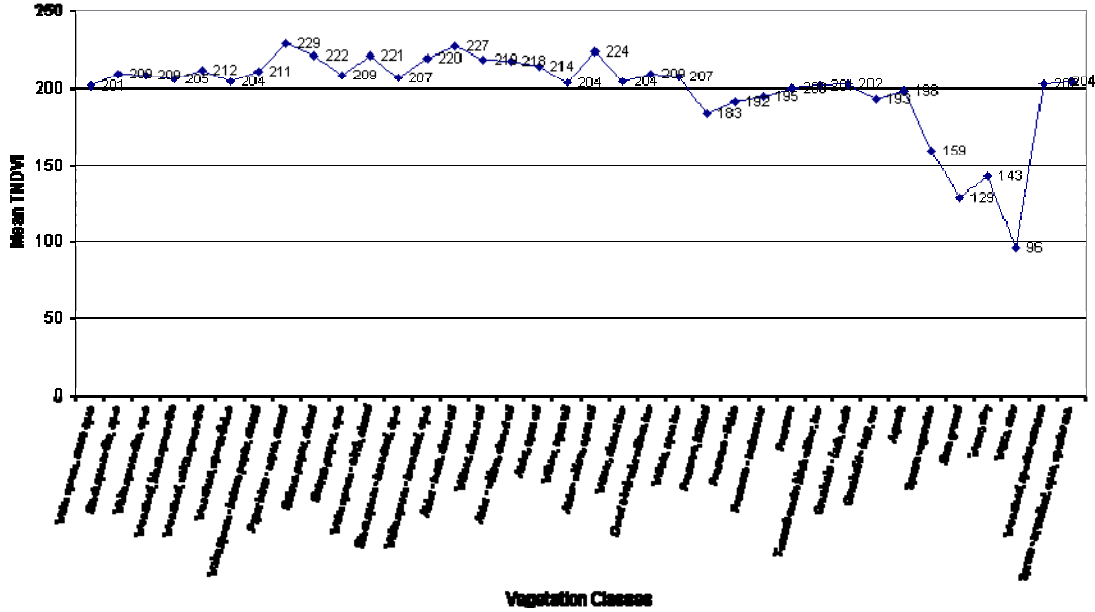
Mean Spectral Values for Target Mapping Classes for TM P77/R13



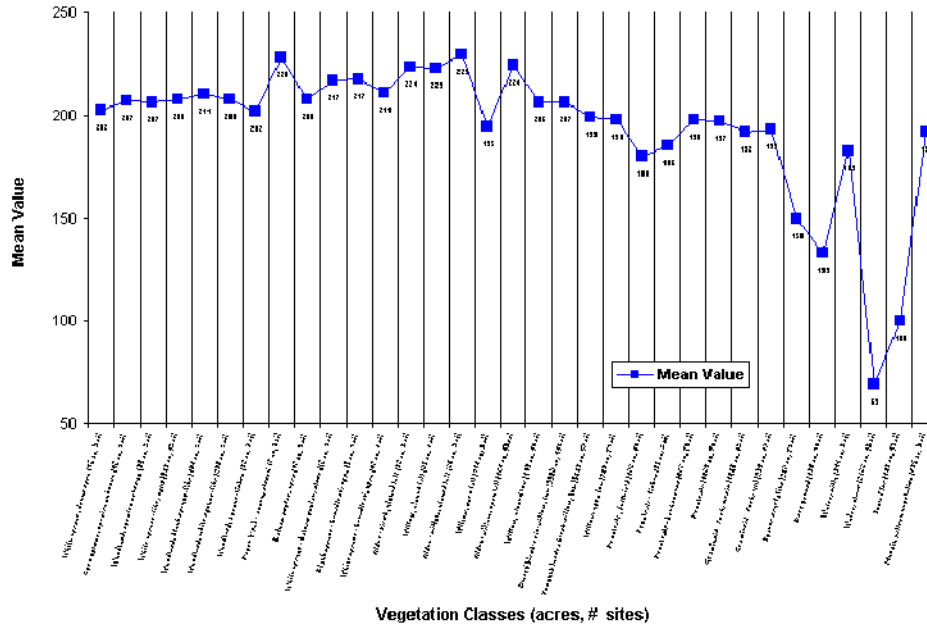
Mean TNDVI Values for TM Image P73/R12



Mean TNDVI Values for TM Image 73/13



Mean TNDVI Values for TM image P75/R12



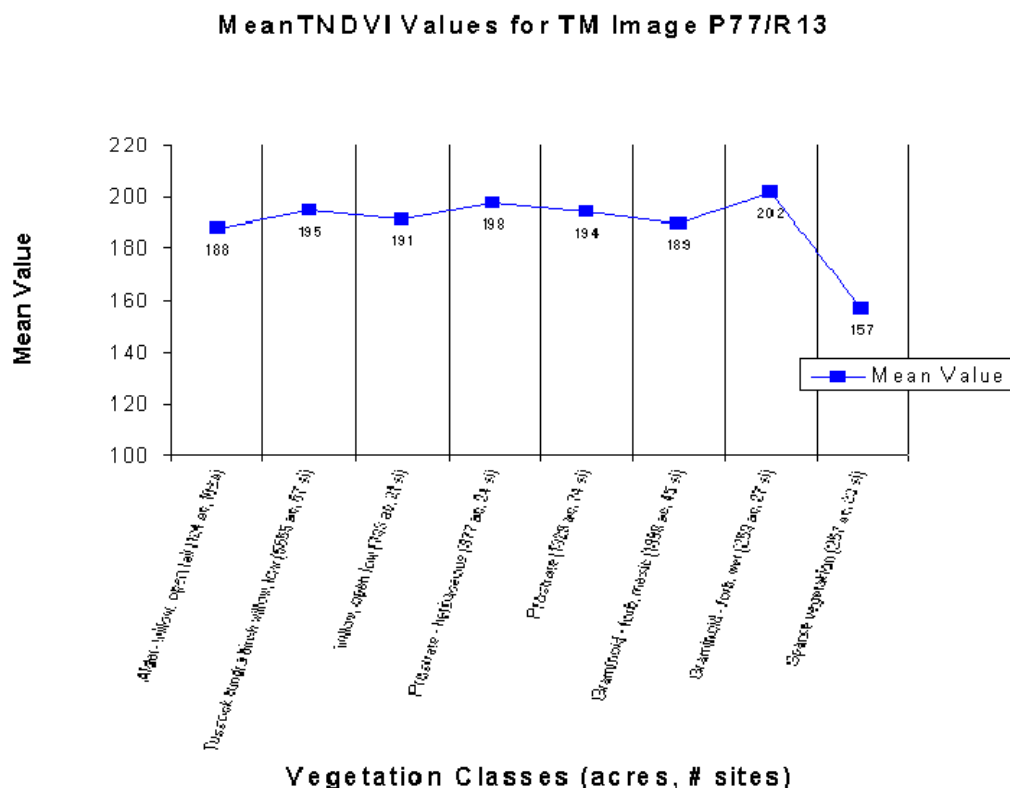
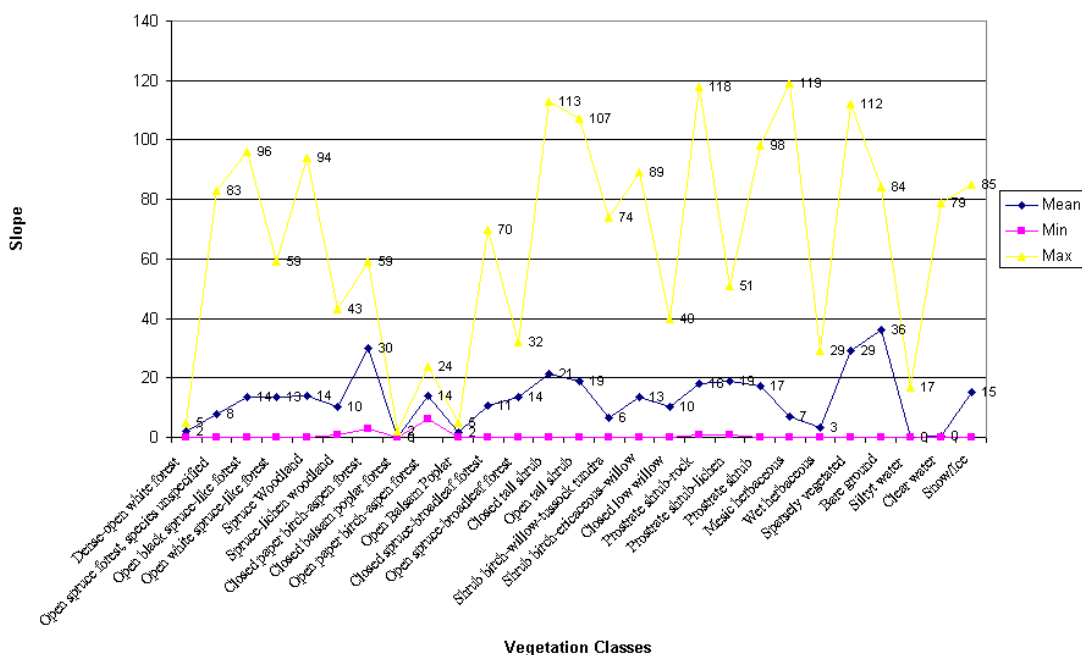


Figure 20. Profile for slope of all training signatures in GAAR



A secondary goal of Stage 1 modeling was to develop the “index” mapping classes in each individual TM strata. Index classes are those mapping classes which are readily identifiable through image interpretation (such as water, bare rock, and terrain and/or

cloud shadow) and provide a realistic frame of reference for future modeling or editing of the more challenging vegetation classes.

Following model development, refinement and testing, the 43 target mapping classes were recoded to the 30 endpoint mapping classes. Stages 2 and 3 focused on improving the discrimination of these endpoint mapping classes using the key model layers identified in Stage 1. All Stage 2 and Stage 3 modeling (as well as all raster editing) was implemented at the 30 endpoint mapping class level.

In Stage 2, models for discriminating confused classes were developed and applied to the ML output for each of the six individual Landsat TM scene areas. Because of the spectral variability between TM scenes, each scene (strata) was modeled separately. However, the model parameters were optimized and applied only to the portion of the TM scene contributing to the 10-mile buffered GAAR area mosaic ([Figure 11](#)). Initial parameters for modeling these classes were established based on review of the graphic spectral/environmental profiles for the key modeling layers. These parameters were refined using an interactive display of the classification viewer-linked to the model layer displayed with candidate parameter values color coded. If this visual evaluation showed promise, the model was executed on a class-by-class basis, and the model output layer was then visually checked through overlay and swiping operations on the ML classification (the pre-model version). An ecological/biophysical justification was required for every model implementation. Following each iteration, the model results were reviewed interactively to ensure accuracy and consistency. If the model output passes this evaluation, it was mosaicked into the thematic landcover database, or further modeled as appropriate. Additional iterations of the ML classification for each scene were conducted as particular signatures contributing to class confusion were refined and/or eliminated. This required review and reiteration of the models (or mosaicking in the earlier model outputs) on the revised ML classification. The decision to rerun the models or utilize the earlier version of the model outputs was based on interactive review of the original model outputs for a particular class overlaid on the revised ML classification. In mid-Feb '99, a draft version of the landcover database (with most modeling steps and edits implemented) was reviewed with the project team botanists and ecologists from AKNHP and NPS in Anchorage. Based on this feedback, several additional modeling and editing steps were identified and implemented to develop the draft landcover map which was then thoroughly reviewed by NPS staff familiar with the project area and mapping project. Based on the NPS's review of the draft landcover database, numerous edits were performed. Edits that could be accomplished through further modeling were incorporated in Stage 3 post-processing modeling. Most of the requested edits required interactive raster editing to implement.

Final Stage 3 modeling involved development and application of terrain and landscape/surficial geology models to further refine the landcover classification through a post-processing step. These models were based on assumptions regarding landcover and terrain/landscape/surficial geology relationships. This involved first developing summary statistics of the draft landcover data with the major surficial

geology types (derived from Hamilton, 1999c), and then developing modeling parameters to exploit any strong terrain/surficial geology/landcover relationships. Due to the scale of the surficial geology data (1:250,000) relative to the Landsat TM data (~1:100,000) and the indirect and varying influence of surficial geology on vegetation, the surficial geology was not determined to be of great value for improving the landcover map through modeling. However, the 1:63,360 derived digital terrain data (slope and illumination) were found useful for modeling several classes based on upslope/floodplain occurrences. Illumination was also useful in representing the partial shadow effect as an additional data layer in the spectral database.

2.9.2 Summary of Key Data Layers Used for Modeling

The TNDVI (Transformed Normalized Difference Vegetation Index) was useful for refining the *prostrate shrub* classes, *sparsely vegetated*, and *bare-ground* classes because of the direct relationship of relative “greenness” to separability of these classes. Spectral reflectance of the TNDVI layer is less affected by terrain shadow, which was particularly important for discriminating these classes in alpine areas of the Brooks Range.

Illumination/aspect was useful for refining upslope versus floodplain and aspect differences. Because of the various illumination conditions dependent on local aspect, slope and neighboring terrain, and the limited direct relationship between illumination and vegetation, this layer was determined to best represent the modeling as a continuous variable (as opposed to discrete aspect categories such as S, SE, SW, etc.). This layer also improved the accuracy of the supervised ML output when included as a layer in the spectral database, particularly in areas that were in partial terrain shadow.

Winter MSS Imagery was useful for separating woodland/open spruce from wetland herbaceous, or wet herbaceous from other classes. It was also useful for distinguishing low shrub classes from woodland/spruce forest. However, this application was limited due to low sun angle and extreme shadow problem in winter imagery.

Band 5 TM was useful for establishing thresholds for mapping classes based on moisture/amount of standing water, for example, refining mesic herbaceous areas with areas of very dark (wet) areas to wet herbaceous. Band 5 was also used extensively with delineation of AOI's to refine water classes.

Slope was useful for discriminating floodplain from upslope and water/shadow separation. The raw slope layer (based primarily on 1:63,360 level DEMs) contained too many contour line relics to be useful for modeling. Several different approaches and scales to eliminating relics were investigated, and it was determined that a 5x5 smoothing (low pass) filter removed most problems while preserving the essential detail for upslope/floodplain modeling.

Several methods were investigated to utilize the illumination layer to improve the landcover classification. The most successful was incorporating the illumination layer into the 5-band TM spectral database utilized in the supervised ML classification process. TNDVI was effective for modeling the *bare-ground*, sparse, and prostrate classes. TM Band 5 was effective in separating these classes and improving characterization of water areas, as well as separating the *wet herbaceous* class from *mesic herbaceous* or *shrub birch-willow-tussock tundra*. Winter MSS data (band 4) were used to improve the woodland and spruce forest separation, reducing confusion between woodland and low shrub (*Shrub birch-ericaceous-willow* and *shrub birch-willow-tussock tundra*) and improving the graminoid-forb wet classes (this reduced commission error with woodland/spruce). However, the low sun angle/large shadow during Winter image acquisition limited the effectiveness of these data to well illuminated areas. Slope was useful in separating floodplain from upslope area, and was therefore used to separate balsam poplar forest (floodplain) from aspen-birch forest (upslope). It was also used to separate black spruce (floodplain) from white spruce (upslope). A latitudinal treeline coverage was also developed and used to ensure no forested areas occurred north of treeline. Most of these problems occurred in terrain shadow areas, or in very wet sites (*wet herbaceous* or *silty/clear water* classes).

2.9.3 Consideration of Ecoregions in Modeling and Editing

As described in Section 1.5, the GAAR project area encompasses three ecoregions:

- 1) Arctic foothills
- 2) Brooks Range
- 3) Interior forested lowlands and uplands

Each region includes climate, landscape, and ecological processes that influence vegetation. Based on previous studies and literature review, field data collected as part of the FirePro program and the 1998 field season, and applying this information in interpreting Landsat TM imagery, we have more precisely delineated each of the regions ([Figure 3a](#)). This delineation was necessary in order to utilize the relatively small scale (1:1,000,000) existing ecoregions information in editing the relatively large scale (~1:100,000) landcover database.

Based on interactive review of the incidental observations coverages from the 1998 field season, the digitized annotations from NPS's 1:250K quadrangle mapsheets, and the mosaiked multispectral TM imagery (displayed as 4,5,3 RGB), a latitudinal treeline coverage was developed for the buffered GAAR area. This coverage was utilized for defining the northern extent of the Interior forested lowlands and uplands region. The arctic foothills region was interpreted from the TM imagery and a preliminary version (2/12/99) of the landcover database. The Brooks Range region was defined as the area north of the northern boundary of the Interior lowland/upland region (treeline) and south of the arctic foothills region. For purposes of

establishing surficial geology/landcover relationships (Section 1.6), the Brooks Range and arctic foothills regions (areas north of latitudinal treeline) were combined as one stratum. The Forested interior lowland/upland region (south of treeline) was determined to have significantly different surficial geology/landcover combinations, and was therefore treated as a second stratum.

In the Brooks Range and interior lowland/upland region regions, the quantity and distribution of spectral signatures and “natural” stratification of the TM scenes corresponding with the regions (Brooks Range – Landsat TM Row 12; Interior - Row 13) resulted in a good characterization of the landcover in these regions based on the multispectral ML classification. However, significant post-processing was required to account for the diversity of mapping classes, and spectral confusion.

In the case of the arctic foothills, it was determined that the similarity in stature and form of the vegetation (relative to the 28.5m TM data) in the region required separate spectral processing and modeling.

In general, north of treeline and south of the arctic foothills, open deciduous forests were recoded to open tall alder-willow, and closed deciduous forest or mixed broadleaf-spruce forest were recoded to tall closed alder-willow. In the arctic foothills ecoregion, these classes were recoded to tall open willow, and tall closed willow respectively. In several areas in the North portion of the project area, these darker signatures initially mapped as open spruce, mixed forest or woodland were actually patterned ground, and were recoded as such. North of treeline, open spruce and woodland spectral classes were recoded to *sparsely vegetated* or terrain *shadow/indeterminate* (primarily this class occurred in drainages as mixed pixels of *bare-ground*, rock partially obscured by shadow).

2.9.4 Modeling to Reduce Spectral Confusion Between Mapping Classes

Models and parameters applied to each individual Landsat TM scene (strata) are detailed in Tables 8a, 8b, 8c, 8d, 8e, 8f. These models and the underlying physiological process permitting separation by one or more modeling layers are summarized in the following paragraphs (listed approximately in order of model iteration from first model to last model applied).

Water / Shadow confusion. In areas of high terrain and extensive terrain shadows, erroneous water often appeared in areas of shadow or partial shadow. A combination of illumination, slope, and the preliminary classification (ISODATA) was used to ensure that overclassified water areas were recoded to shadow based on the principal that mappable water bodies only occur on low slope areas, and not in terrain shadow areas. The illumination and preliminary classification were again used to enhance the shadow class.

Prostrate shrub-rock / Sparsely vegetated / Bare-ground confusion. The “greenness” as indicated by NDVI was used to separate the *prostrate shrub-rock/sparsely*

vegetated/bare-ground rock classes. This layer was particularly useful because of partial penetration of terrain shadow.

Snow/Ice and *Bare-ground* confusion. The preliminary (ISODATA derived) classification was used to develop a snow/ice and bare rock layer. Particular clusters corresponding with snow, ice, and bare rock were selected from the ISODATA classification, and used as a mask for these classes.

Prostrate / Prostrate shrub-rock / Prostrate shrub-lichen confusion. Once the prostrate classes were separated from the *sparsely vegetated* and *bare-ground* classes, further thresholding with NDVI was used to break out the prostrate from the *prostrate-rock* class. The *prostrate shrub-lichen* was more spectrally unique, and generally was well represented in the ML classification output.

Water / Bare-ground confusion. *Water* and *bare-ground* areas were confused, particularly along rivers and lake edges. Landsat TM Band 5 was used extensively during editing to reduce this problem. Slope and illumination were also again used to ensure that lakes were realistically depicted.

Wet herbaceous / Spruce woodland confusion. *Wet herbaceous* was initially overclassified in numerous sites. In the southern and central portions of the project area, woodland (or open spruce forest) were misclassified as *wet herbaceous*. Winter MSS (Band 4 NIR) imagery and the illumination data layer were utilized to discriminate correctly classified wet herbaceous areas from misclassified woodland areas. For integrating Winter MSS data in moderately well illuminated areas, low stature vegetation has brighter reflectance (white response due to homogenous snow pack) than woodland (gray response due to snow/spruce shadow pattern) or open spruce forest (darker gray response due to more spruce shadow dominated snow pattern). The misclassified *wet herbaceous* areas were recoded to woodland. Due to low sun angle in the Winter MSS imagery (and resulting severe terrain shadow particularly in the Brooks Range region), this model was only useful in moderately well illuminated aspects (S and SE).

Spruce woodland / Low shrub confusion. Although incorporation of the illumination layer in the spectral database reduced this type of confusion, areas of fairly low illumination continued to show some spectral confusion between the woodland and low shrub classes. Winter MSS (Band 4 NIR) was useful in correcting woodland areas misclassified as low shrub (*shrub birch-willow-tussock tundra* and *shrub birch-ericaceous-willow*). Again, however, this model could only be used in moderately well illuminated areas. In the central and southern portions of the project area, low shrub in partially shadowed aspects was misclassified as woodland. In these areas, raster editing based on the FirePro and 1998 field data and image annotations was utilized to determine whether the woodland on partially shadowed aspects was legitimate or was actually a low shrub or prostrate class (depending on northern latitude and context). Determining the specific low shrub class was also based on the context of the site (review of the mapping classes of surrounding areas). This

approach was very difficult in the transition areas between the Forested Lowlands/Uplands and Brooks Range ecoregions (in this area, woodland did occur on low to moderate north aspects). Where woodland occurred on the south aspect of an E-W drainage, the north aspect was usually dominated by low shrub (generally *shrub birch-willow-tussock tundra* in floodplain, and *shrub birch-ericaceous-willow* on upslopes. There were too many exceptions to this rule to allow realistic model-based separation of these two low shrub classes). Where low shrub or *open tall shrub* occurred on the south aspects of an E-W drainage, the north aspect was usually dominated by prostrate shrub with low shrub stringers.

Wet herbaceous / *Mesic herbaceous* / *Shrub birch-willow-tussock tundra* confusion. *Wet herbaceous* is also misclassified North of treeline. *Wet herbaceous* was extensively overclassified in the ML classification in the Brooks Range and arctic foothills ecoregions. Band 5 TM data was very useful for thresholding very wet sites within the *wet herbaceous* mapping class from less wet sites (*mesic herbaceous*). In the Arctic foothills, many of these resulting *wet herbaceous* areas are closely grouped sub-pixel patterns of water tracks.

In the northern portion of Path 73, Row 13 (hereafter abbreviated as “p73r13”), *wet herbaceous* was confused with *shrub birch-willow-tussock tundra*. This is for the most part North of treeline. Here also, Band 5 was used to threshold actual *wet herbaceous* from those sites that were either *mesic herbaceous* or *shrub birch-willow-tussock tundra*.

On the south side of Noatak River, *wet herbaceous* also appeared to be overclassified and required recode to *mesic herbaceous* utilizing TM Band 5. Also in glaciated valleys of eastern portion of the arctic foothills, patterned ground class was misclassified as *wet herbaceous*, and required raster editing. This is due to heterogeneity of the patterned ground class, and reduced spectral reflectance due to the dominant water component of this class (particularly sub-pixel size low-centered polygons).

Mesic herbaceous / *Shrub birch-willow-tussock tundra* confusion. This confusion occurred North of the treeline boundary (primarily in Row 12 scenes in the arctic foothills and south into those valleys forming the headwaters of the north flowing rivers out of the Brooks Range). This error also occurred in the valleys of the Brooks Range region. Because of the high number of training samples (signatures) of *mesic herbaceous* and low *shrub birch-willow-tussock tundra*, the spectral based classification was relied on as the primary discriminator between these classes. In the arctic foothills, incorporation of the illumination layer in the TM spectral database as part of the ML classification was determined to create additional spectral confusion between the mapping classes. Also, several errors in signatures were noted in this region. All signatures were reviewed and the ML classification reiterated with only the TM spectral database (w/o illumination) for this region (TM scenes p73r12, p75r12, p77r12). This process improved the preservation of linear features (water tracks and small shrub-line streams) as well as the consistency of the landcover

information in this region.

Mesic herbaceous / Prostrate shrub confusion. In the higher elevation valleys, *mesic herbaceous* areas were found adjacent to *prostrate shrub* areas. This confusion was particularly problematic when the herbaceous content of the *prostrate shrub* areas was close to the 25% upper threshold for this mapping class. Because of the large number of training samples (signatures) for each of these two classes, the spectral classification was relied heavily for discriminating these two classes. Other modeling layers were ineffective at separating the two classes, and image interpretation and review of CIR photos was also not effective at reducing the confusion.

Balsam poplar forest / Paper birch-aspen forest and *Mixed spruce-birch-aspen forest / Mixed spruce-balsam poplar forest* confusion. Slope was used to model these classes based on the assumption that balsam poplar occurred only in floodplain (minimal slopes) while aspen-birch occurred only on upslope areas. The “raw” slope data proved to be unusable due to contour line relics from the interpolation process during DEM creation. However, several iterations or tests were performed to determine a suitable filtering method. Applying a 5x5 majority filter to the raw data resulted in a dataset suitable for modeling this level of general site slope characteristics. Erroneous open balsam poplar primarily in upslope areas in the south park buffer (forested lowland and upland interior ecoregion) also required extensive editing based on image interpretation. These areas were generally edited to be open white spruce or woodland classes.

Closed tall shrub/ Open and closed paper birch-aspen forest confusion. Spectral confusion between the *closed tall shrub* class (mainly alder) and the *paper birch-aspen forest* classes was observed in the southern portions of the buffered GAAR area, particularly in the 10-mile buffer area around the park (where ground reference data was very limited). These problems were in relatively small areas and mainly errors of omission for the broadleaf forest classes, but errors of commission for the *closed tall shrub* class. Because limited training signatures were available for the broadleaf forest classes (approximately 4 signatures for each of the four different broadleaf forest types), raster editing based on review of the FirePro and 1998 field data, image annotations, and image interpretation (with CIR spot checking) was relied on for improving these classes. The tall shrub classes were very well represented by training signatures (approximately 70 signatures total for open and *closed tall shrub* classes), and within the park appeared to be accurately depicted. In the forested interior areas to the south of the park (but within the 10-mile buffer), the broadleaf forest or mixed forest was more prevalent, and underrepresented by our FirePro 1998 field data derived signature database.

Rivers and small lakes/ponds. In the spectral based ML classification and initial modeling for each TM scene, the continuity of the water class in a number of primary/secondary rivers required improvement. Also, the distinction between *silty water* and *clear water* classes was inconsistent. Changes in water levels between the multiple dates of scenes also resulted in problems in maintaining continuity of rivers

at TM scene boundaries. Also, small ponds (less than 4 pixels) appeared to be underrepresented.

To correct these problems, an additional modeling step was added during the interactive raster editing process. This involved first creating a *clear water/silty water/shadow* “candidate” layer by establishing thresholds in TM Band 5 through interactive interpretation. This layer was then raster edited simultaneously with the complete landcover database using the TM imagery and selected airphotos as a guide. Areas in the water candidate layer that were visually interpreted as “true” water were maintained as water classes, while shadow areas were eliminated from further consideration as water types. Following completion of raster editing, this “corrected” water layer was mosaicked into the landcover database.

Spruce characterization. The open all spruce forest areas were recoded to either open black spruce forest class or open white spruce forest class based on terrain and aspect site characteristics. Open spruce, unspecified which occurred in the floodplain landscapes was recoded as *open black spruce-like forest* while open spruce, unspecified which occurred on upslope positions was recoded as *open white spruce-like forest*.

This editing step was implemented as the final edit to the 30 class draft landcover database. A combination of modeling with illumination and slope was utilized to make the distinction between floodplain and well illuminated upslope spruce forests. Several potential slope thresholds were investigated, applied, and provided to NPS in hardcopy and digital form for review. Based on this review, a threshold of 10% slope was chosen as the lower limit of the *open white spruce-like forest* class, with *open black spruce-like forest* occurring between 0 and 10% slope. This assumption required modifying the *open black spruce-like forest* class description to include open white spruce forest occurring in the floodplain (often found along river meanders/oxbows).

Due to some errors resulting from the assumptions regarding spruce landscape site characteristics, as well as scale limitations of the digital elevation and derived slope and illuminating information, a version of the digital database was also developed which collapses the two open spruce categories into a single open spruce class (species unspecified). This version of the landcover database is available through NPS-AKSO.

2.10 RASTER EDITING AND FILTERING APPROACH

Raster editing is the process of changing, adding, or deleting raster attributes or data values of thematic and continuous raster data. Raster editing is used in image classification to correct bad or noisy data values, or to recode or reassign pixels to another class. The image analyst can use modeling functions for computing the values to replace noisy pixels or areas in the image data. In the GAAR landcover project,

raster editing was focused on classes that could not be separated effectively through models, but could be positively identified through image interpretation and review of the GAAR Landcover Database (FirePro, 1998 field data, annotations/notes).

During preliminary product development, the landcover map was first reviewed at small scale (1:250,000) to identify obvious problems. More detailed editing was conducted at approx. 1:100,000 throughout the GAAR project area. In most cases, areas requiring edits were analyzed to determine whether problems could be resolved through further modeling. Many edits were completed through this approach (further refinement of and application of models on a local or ecoregion basis). The FirePro database and coverages from the 1998 field season implemented in the Field Data Browser were also used extensively in editing/reviewing the landcover map. CIR aerial photos (1:60,000) were used to spot check questionable areas in the landcover map.

Airphoto interpretation was used to verify and spot check TM image interpretation. Prior to implementing edits, all FVA's were evaluated extensively with airphoto enlargements, image prints, and the Field Data Viewer (FirePro and '98 data). Problem classes were identified for FVA areas, and then other non-FVA areas investigated to look for similar problems. Raster editing at a display scale of 1:100,000 was planned. However, the hard copy review materials were required at 1:63,360 (unfiltered), and therefore much of the editing was completed at 1:63,360 or larger scale. To reduce focusing edits on insignificantly small areas, a 2 acre filtered version of the database was linked to the unfiltered version being edited. This permitted identification of large problem areas (rather than noise) that would appear in the unfiltered database. Priority for raster editing was focused along mosaic scene boundaries, and within the park boundaries (where virtually all ground reference data was located). Substantial editing was also required within the 10-mile park buffer. This editing was difficult due to the lack of field data for areas outside the park (other than incidental observations and image annotations). Further edits were required following modeling to clean-up *bare-ground* and *sparsely vegetated/shadow* areas (particularly in the western portion of the project area covered by p77r12 and p77r13), and also to clean up problems in the cloud obscured north-west portion of the buffered GAAR area (p73r12). Additional edits to other classes in p77r12 and p77r13 were required due to the radiometry/low vegetation response of these late August satellite images. Further edits were completed based on comments from NPS review of the draft landcover classification in July/August 1999. This review focused mainly on the evaluation of hardcopy 1:63,360 products for the entire project area (16 tiles). NPS staff familiar with the park or particular areas reviewed and annotated recommendations on the draft plots. EarthSat reviewed these comments with NPS, and implemented all requested edits (including refinement of existing models).

Following implementation of all NPS requested edits, the unfiltered pixel map was filtered through a three step process to arrive at the 2 acre minimum mapping unit (MMU). First, all single "detached" pixels were identified and recoded to the mapping class of the majority occurring pixels surrounding the detached pixel.

Second, the resulting map was run through a clumping algorithm which grouped connected pixels into millions of individual clusters of like mapping class pixels. Third, an elimination algorithm was then applied to this clumped file so that all groups of less than approximately 2 acres (9 pixels) were automatically recoded to the majority occurring class surrounding the clump. [Note: Although 9 pixels is actually about 1.5 acres, a nine pixel MMU is consistent with a 3 pixel by 3 pixel window, which is simpler to visualize when using the landcover map.] The 5 acre MMU product was created by simply passing the 2 acre MMU through a 5 x 5 (low pass) majority filter.

2.11 QUALITY CONTROL AND EVALUATION

Throughout the project, from fieldwork to final product, the image analyst, botanists, and ecologist team remained consistent. This ensured a high level of consistency in the landcover map. Several face-to-face modeling and evaluation steps resulted in the involvement of the project team in discussions regarding classification system and editing/modeling. Flexibility and customization in terms of mapping classes, scale of hardcopy draft products, and final MMU resulted in a more useable suite of products. A detailed review of the draft product by NPS and substantial feedback resulted in significant edits to the landcover map to produce the final map product.

CHAPTER THREE

RESULTS AND DISCUSSION

3.1 DISTRIBUTION OF LANDCOVER WITHIN GAAR

The distribution of landcover in the GAAR Project Area is as follows (Table 9):

- 17.69% area in needleleaf forestand woodland,
- 0.53% in broadleaf forest,
- 0.54% in mixed forest,
- 5.88% in tall shrub,
- 22.10% in low shrub,
- 24.42% in prostrate shrub,
- 6.47% in herbaceous,
- 16.17% sparsely vegetated or bare-ground,
- 1.15% water,
- 0.36% snow/ice,
- 0.18% mosaic/pattern vegetation, and
- 4.52% indeterminate (mostly clouds and terrain shadow).

Table 9. Landcover composition of buffered GAAR area (based on 2 ac MMU).

Class Value	Class Name	Area (sq mi)	Area (ac)	% of Total
1	Dense-open white spruce forest	9.203	5,889.9	0.04%
2	Open spruce forest, species unspecified	0.000	0.0	0.00%
3	Open black spruce-like forest	1,735.540	1,110,745.5	8.08%
4	Open white spruce-like forest	644.008	412,165.1	3.00%
5	Spruce woodland	1,274.470	815,661.0	5.93%
6	Spruce-lichen woodland	137.379	87,922.7	0.64%
7	Closed paper birch-aspen forest	30.827	19,729.3	0.14%
8	Closed balsam poplar forest	15.831	10,131.7	0.07%
9	Open paper birch-aspen forest	48.843	31,259.3	0.23%
10	Open balsam poplar forest	19.313	12,360.4	0.09%
11	Closed spruce-broadleaf forest	51.637	33,047.7	0.24%
12	Open spruce-broadleaf forest	64.546	41,309.1	0.30%
13	Closed tall shrub	621.666	397,866.4	2.89%
14	Open tall shrub	640.828	410,129.6	2.98%
15	Shrub birch-willow-tussock tundra	1,445.795	925,309.0	6.73%
16	Shrub birch-ericaceous-willow	3,262.668	2,088,107.3	15.19%
17	Closed low willow	38.211	24,455.2	0.18%
18	Prostrate shrub-rock	1,301.092	832,698.8	6.06%
19	Prostrate shrub-lichen	247.415	158,345.7	1.15%
20	Prostrate shrub	3,696.645	2,365,852.6	17.21%
21	Dry herbaceous	0.000	0.0	0.00%
22	Mesic herbaceous	1,333.226	853,264.8	6.21%
23	Wet herbaceous	56.592	36,218.7	0.26%
24	Aquatic herbaceous	0.519	332.0	0.00%
25	Sparsely vegetated	1,565.518	1,001,931.2	7.29%
26	Bare-ground	1,907.814	1,221,000.7	8.88%
27	Silty water	111.731	71,507.9	0.52%
28	Clear water	135.238	86,552.4	0.63%
29	Snow/ice	76.583	49,013.2	0.36%
30	Sand dunes	0.016	10.0	0.00%
31	Mosaic/patterned vegetation	38.174	24,431.3	0.18%
32	Shadow/indeterminate	970.751	621,280.4	4.52%
	Total	21,482.077	13,748,529.1	100.00%
	Class Group	Area (sq mi)	Area (ac)	% of Total
	Needleleaf forest	3,800.600	2,432,384.1	17.69%
	Broadleaf forest	114.814	73,480.7	0.53%
	Mixed forest	116.183	74,356.8	0.54%
	Tall shrub	1,262.494	807,996.1	5.88%
	Low shrub	4,746.674	3,037,871.6	22.10%
	Prostrate shrub	5,245.152	3,356,897.1	24.42%
	Herbaceous	1,390.337	889,815.5	6.47%
	Sparse or barren	3,473.347	2,222,942.0	16.17%
	Water	246.969	158,060.3	1.15%
	Snow/ice	76.583	49,013.2	0.36%
	Mosaic/pattern vegetation	38.174	24,431.3	0.18%
	Shadow/indeterminate	970.751	621,280.4	4.52%
	Total	21,482.077	13,748,529.1	100.00%

3.2 ACCURACY ASSESSMENT

Both qualitative and quantitative evaluations of errors were made at various stages of developing the GAAR landcover map for the purpose of improving or refining the mapping process. Accuracy assessments were performed on the endpoint (30 class) and general (22 class) final GAAR landcover in order to quantitatively determine what proportion of the overall landcover map decision is correct, the probability that individual landcover classes are correctly mapped, which landcover classes are

overestimated or underestimated, and the distribution of errors between mapping classes. Due to the relatively small number of samples in the reserved accuracy assessment database (64 sites total), the authors consider the much larger training database (851 sites) to be a more representative dataset to draw conclusions as to mapping class confusion and reliability. Therefore, this training dataset is used as the source for all accuracy statements in this report. However, the complete confusion matrices, and user's and producer's accuracies for both the accuracy assessment database (reserved from training/processing) and the training database (included in the processing and therefore biased) are included in this document as [Tables 10a, 10b, 11a, and 11b](#).

An estimate of overall accuracy (based on comparison of the 5 acre MMU landcover data with the approximately 850 training areas) for the 30 landcover classes is 83% ([Table 10b](#)). The user's accuracies for general landcover types are as follows: 78.9% for needleleaf forest and woodland, 79.2% for broadleaf forest, 93.0% for mixed forest, 90.1% for tall shrub, 87.0% for low shrub, 78.6% for prostrate shrub, 72.0% for herbaceous, 90.7% for sparse /barren, 99.8% for water, and 99.9% for snow/ice.

Error matrices (also called confusion matrices) and associated statistics have been adopted by the remote sensing community as the standard technique for accuracy assessment (Campbell 1987, Congalton 1991, Jensen, 1996).

An error matrix is a square array of numbers set out in rows and columns that represents the number of information classes or classification categories, used to compare on a category-by-category basis, the relationship between known reference data and the corresponding results of a classification ([Tables 10a, 10b, 11a, and 11b](#)). The columns and rows of an error matrix show the number of sample units assigned to a particular landcover class (classification data) relative to the actual number of sample units that belong to the landcover class (reference data). From an error matrix the *overall accuracy* of the classification of a landcover map can be quantified along with both the *producer's accuracy* (or errors of omission or exclusion) and *user's accuracy* (or errors of commission or inclusion). The overall accuracy is computed as the sum of all the main diagonal cells in the error matrix divided by the total number of sample units used in the error matrix. The overall accuracy shows the proportion of the classification that is correct but it does not indicate how the accuracy is distributed across the individual landcover classes. (Story and Congalton 1986).

The producer's accuracy is the sum of all correctly classified sample units in a landcover class divided by the total number of reference data in that landcover class. The producer's accuracy indicates how well members of a particular landcover are classified, or shows the ease or difficulty with which members of a particular landcover class are correctly identified, classified or mapped by the mapping methodology. On the other hand, the user's accuracy indicates the probability that a particular landcover class (classification data) would represent that landcover class in the reference or ground truth data. The user's accuracy, computed as the sum of all correctly classified sample units in a landcover class divided by the total number of

classification data in that landcover class, is termed a measure of reliability in specific map categories. The error of commission is computed as 100% minus the producer's accuracy and error of omission is 100% minus user's accuracy.

Typically, ground reference data are reserved for accuracy assessment purposes from those data used for supervised training signatures. This procedure was followed in the GAAR landcover project. However, because of the relatively small accuracy assessment database for GAAR (64 polygons), and the limited representation within this database of many of the landcover classes, an additional accuracy assessment was performed using the training signature data. As previously stated, the estimates of accuracy throughout this document are primarily based on a 5 acre minimum mapping unit landcover database with the training data set. However, both sets of confusion matrices are included for additional reference related to accuracy and mapping class confusion ([Tables 10a, 10b, 11a, 11b](#)).

Table10b. Confusion matrix for landcover map x training signature data (6 ac MMU landcover)

Reference / Training Data																																				
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Row Total	User %	Theme	
1	180	0	0	0	107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	207	59.9	1		
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
3	10	0	4270	2725	310	53	0	18	0	10	6	142	75	118	91	53	9	0	0	0	15	0	61	22	0	0	0	0	0	0	0	0	7888	53.5	3	
4	0	0	1150	1911	183	58	1	0	7	0	201	160	22	23	6	102	0	0	0	0	234	0	0	0	0	0	0	0	0	0	0	0	4038	47.3	4	
5	6	0	810	248	4837	35	5	2	0	1	2	4	82	570	63	173	10	0	0	0	762	0	24	28	0	0	0	0	0	0	0	0	8895	51.2	5	
6	0	0	13	3	92	934	0	1	0	0	0	0	0	0	2	3	7	0	0	0	19	0	5	0	0	0	0	0	0	0	0	0	1089	87.4	6	
7	0	0	11	3	4	420	0	0	0	0	0	0	0	0	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	535	78.5	7	
8	2	0	0	0	3	0	144	326	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	475	68.6	8		
9	0	0	51	3	13	0	0	0	90	0	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	214	42.1	9	
10	0	0	3	0	1	0	0	0	0	39	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	62	62.9	10	
11	0	0	0	7	19	0	0	0	0	0	502	12	1	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	572	87.8	11	
12	0	0	16	41	0	0	0	7	0	0	70	167	33	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1735	90.3	12	
13	0	0	22	49	4	0	1	0	0	9	23	9	6162	779	29	132	5	0	1	30	0	5	199	0	0	0	0	0	0	0	0	0	0	7461	92.6	13
14	0	0	61	63	80	0	0	15	113	17	8	282	8657	153	332	0	0	40	0	5	0	0	5	0	0	0	0	0	0	0	0	0	8831	92.8	14	
15	0	0	14	0	187	0	0	0	0	0	0	10	181	17066	2594	11	114	7	816	0	946	134	0	0	0	0	0	0	0	0	0	0	3	22080	77.3	15
16	0	0	219	37	803	80	2	0	7	14	6	0	403	1533	4025	25851	74	20	74	1024	0	670	173	0	3	0	0	0	0	0	0	0	35018	73.8	16	
17	0	0	0	2	0	0	0	0	0	0	0	0	6	0	0	266	24	438	0	0	19	0	0	0	0	0	0	0	0	0	0	0	755	58.0	17	
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	122	0	5926	72	158	0	50	0	0	8	2	0	0	0	0	0	6367	93.2	18	
19	0	0	0	3	23	0	0	0	0	0	3	3	33	23	0	0	0	1117	8	0	7	5	0	0	0	0	0	0	0	0	0	0	1199	93.2	19	
20	0	0	2	21	4	0	0	0	0	2	0	1	50	280	2251	741	11	506	44	10797	0	1394	34	0	3	6	0	0	0	0	0	0	12	16147	66.9	20
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A	N/A	21	
22	0	0	53	0	70	9	0	0	0	0	0	0	20	92	2501	2651	3	115	0	134	0	12508	477	0	12	0	0	0	0	0	0	0	0	18445	87.1	22
23	0	0	0	0	0	0	0	0	0	0	0	0	3	15	0	0	0	0	0	0	0	1577	0	0	0	0	0	0	0	0	0	0	1595	98.9	23	
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0	49	100.0	24
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1536	124	0	0	0	0	0	1808	95.0	25	
26	0	0	0	0	0	0	0	0	0	0	5	1	0	13	99	0	0	0	0	0	6	0	0	0	41	1457	0	0	0	0	0	0	1873	87.1	26	
27	0	0	0	0	2	4	0	0	0	0	5	4	0	0	0	11	0	0	0	0	0	0	0	14	10	4	0	0	0	0	0	0	55	0.0	27	
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37148	100.0	28	
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5690	100.0	29	
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A	N/A	30
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A	N/A	31
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61638	81.63	32	
Col. Total	178	0	6695	5220	6364	1169	573	353	120	194	888	1908	7170	9463	26549	34514	583	6718	1315	14082	0	15881	2649	74	1888	1800	0	37138	5742	0	0	61633	250414	Total Ref.		
Prod. %	89.9	N/A	83.9	36.6	72.4	79.9	73.3	92.4	75.0	20.1	56.5	82.1	65.9	59.8	64.3	74.9	77.8	88.2	84.9	76.7	N/A	78.9	59.5	66.2	91.1	91.1	N/A	100.0	99.1	N/A	N/A	100.0	61633	250414	288232	Correct
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32			83.16	Overall Acc.

Notes:

N/A indicates that there were no accuracy assessment reference data for the particular class. For these mapping classes, estimated accuracy as cited in the report is based on the confusion matrix for the training data. Dry herbaceous was not sampled in '98. Only one sample of this type was found in the FiePro data and it was not suitable for signature delineation (it also represented a very local phenomena of this type on some of the Killik R. sand dune areas). Therefore, this class was not mapped. Open spruce (unspecified) was recorded to open spruce (white or black) classes based on slope and illumination modeling. Therefore, this class was not mapped. Because the silty water class predominantly occurs in rivers with substantial mixed pixel effects along the river banks/sand bars, evaluation of this class is qualitative and discussed in the mapping class description for silty water (Section 3.6).

Table 11a. Confusion matrix for general (22 class) landcover map x accuracy assessment data (5 ac MMU landcover)

3.3 DISCUSSION OF ACCURACY OF LANDCOVER CLASSES

The estimated overall accuracy for the 30 class landcover data at 5 ac MMU when compared to the training database was 83% (or 79% based on comparison with the accuracy assessment database).

The estimated overall accuracy for the 22 class landcover data at 5 acre MMU when compared to the training data was 89% (or 95% based on comparison with the accuracy assessment database).

Classes showing primary confusion are discussed below. Additional details regarding spectral confusion can be found in Section 3.6. Landcover Class Descriptions. All accuracies refer to the 30 class landcover data at a 5 acre mapping unit.

Mapping classes showing a particularly high degree of confusion (less than 65% producer's or user's accuracy) included *open black spruce-like forest*, *open white spruce-like forest*, *spruce woodland*, *open balsam poplar forest*, *closed spruce broadleaf forest*, *open tall shrub*, and *shrub birch-willow-tussock tundra*, and *wet herbaceous*.

The producer's accuracy for the *open black spruce-like* class was 63.9%, with a user's accuracy of 53.5%. The producer's accuracy for the *open white spruce-like* class was 37%, with a user's accuracy of 47%. Most of the errors of commission and omission were due to confusion between the two open white spruce-like classes and to a lesser extent with the woodland classes. The *open black spruce-like forest* sites with tall shrub understory also exhibited some confusion with the mixed spruce-broadleaf forest and the tall shrub and low shrub classes. This is due to the high IR (infrared) response characteristic of the broadleaf tree and shrub species. Because of the substantial spectral confusion between the two open spruce classes, slope and illumination models were utilized based on the assumption that *open white spruce-like forest* occurs on well illuminated upslopes, while *open black spruce-like forest* was assumed to occur on low slopes and floodplains, under average to well illuminated conditions. When considering the *open black spruce-like* and *open white spruce-like forest* classes as a single mapping class, the producer's accuracy increases to 84%, while the user's accuracy also improves to 84%.

The producer's accuracy for the *open balsam poplar forest* class was 20%, with a user's accuracy of 62%. Errors of commission and omission were due to confusion with the *open paper birch-aspen forest* class and the *open tall shrub* class. Slope was used to model these classes based on the assumption that balsam poplar occurred only in floodplain (minimal slopes) while aspen-birch occurred only on upslope areas. Because limited training samples were available for the *closed paper birch-aspen forest* classes (4 signatures), raster editing based on review of the FirePro and '98 field data, image annotations, and image interpretation (with CIR spot checking) was relied on for improving these classes. The Landsat TM 4,5,3 (RGB) signatures for

this class are light orange-red, with increasing red and orange brightness corresponding to the low density of the low shrub understory. When considering all the closed and open broadleaf forest classes as a single broadleaf forest mapping class, the producer's accuracy is 82%, while the user's accuracy is 79%.

The producer's accuracy for the *spruce woodland* class was 72%, with a user's accuracy of 51%. Some of the errors of commission and omission were due to confusion with the *open black* and *open white spruce-like forest* classes. This generally occurred when a *spruce woodland* site included 15-24% lichen, but not enough to be classified as a *spruce-lichen woodland* site (> 25% lichen required). However, of greater concern is the large errors of commission found in the low shrub classes, and in particular, the *shrub birch-ericaceous-willow* class. This confusion generally occurred on partially shadowed aspects that resulted in darker signatures than a well illuminated low shrub class. Although incorporation of the illumination layer in the spectral database reduced this type of confusion, areas of fairly low illumination continued to show some spectral confusion between the woodland and low shrub classes. Where woodland occurred on the south aspect of an E-W drainage, the north aspect was usually dominated by low shrub (generally *shrub birch-willow-tussock tundra* in floodplain, and *shrub birch-ericaceous-willow* on upslopes, but with too many exceptions to this rule to allow realistic model-based separation of these two low shrub classes). Where low shrub or tall shrub occurred on the south aspects of an E-W drainage, the north aspect was usually dominated by prostrate shrub with low shrub stringers. When considering the *spruce woodland* and *spruce-lichen woodland* classes as a single mapping class, the producer's accuracy increases to 75%, while the user's accuracy also improves to 56%.

The producer's accuracy for the *closed spruce-broadleaf forest* class was 57%, with a user's accuracy of 88%. Errors of commission and omission were due primarily to confusion with the *open spruce-broadleaf forest* and the *open white spruce-like forest* classes. The spruce-broadleaf forest classes are by definition spectrally mixed, and are very difficult to separate spectrally from open spruce forests with tall shrub understory. Manual editing based on review of the FirePro and '98 field data, image annotations, and image interpretation (with CIR spot checking) was relied on for improving these classes. Because this class was relatively rare, efforts were made during field work to make extensive image annotations identifying areas of *closed spruce-broadleaf forest*. When considering all the *closed* and *open spruce-broadleaf forest* classes as a single mixed spruce-broadleaf forest mapping class, the producer's accuracy is 77%, while the user's accuracy is 93%.

The producer's accuracy for the *open tall shrub* class was 60%, with a user's accuracy of 83%. Errors of commission and omission were due primarily to confusion with the closed tall shrub and the *shrub birch-ericaceous-willow* and *shrub birch-willow-tussock tundra* classes. The confusion with these low shrub classes was found mainly on partial terrain shadowed areas, where the low shrub classes were in significant abundance as the understory. Incorporation of the illumination (shaded relief) data in the supervised spectral classification reduced this confusion; However,

this class did require substantial editing based on review of the FirePro and '98 field data, image annotations, and image interpretation. When considering both the *closed* and *open tall shrub* classes as a single tall shrub mapping class, the producer's accuracy is 77%, while the user's accuracy is 90%.

The producer's accuracy for the *shrub birch-willow-tussock tundra* class was 64%, with a user's accuracy of 77%. Errors of commission and omission were due primarily to confusion between *shrub birch-willow-tussock tundra* class and to a lesser extent with the prostrate shrub classes (with a relatively large herbaceous component) or the *mesic herbaceous* class (with a relatively large shrub component). Because of the high number of training signatures for *shrub birch-willow-tussock tundra*, *mesic herbaceous* and *shrub birch-ericaceous-willow*, the spectral based classification was relied on as the primary discriminator between these classes. There was also confusion north of treeline with the *wet herbaceous* class. The wettest *shrub birch-willow-tussock tundra* sites were usually spectrally separable from the drier of the *shrub birch-ericaceous-willow* sites (however, these wet tussock tundra sites were usually confused with the *mesic* or *wet herbaceous* classes). Finally, there were some commission errors with the woodland classes. Part of this confusion was often due to partial terrain shadow. Another factor believed to contribute to commission errors in woodland areas were sites with relatively low spruce cover (10-15%) with understory dominated by low shrub. When considering the *shrub birch-willow-tussock tundra*, *shrub birch-ericaceous-willow*, and *closed low willow* classes as a single low shrub mapping class, the producer's accuracy is 82%, while the user's accuracy is 87%.

The producer's accuracy for the *wet herbaceous* class was 60%, with a user's accuracy of 98%. Errors of commission and omission were due primarily to confusion between the *shrub birch-willow-tussock tundra* and *mesic herbaceous* classes, as well as some confusion with the *silty water* class. Based on the Landsat TM 4,5,3 (RGB), signatures for this class typically are darker grey to blue with red tones. Signatures for sites in early or late season (when minimal active vegetation covers the site) often appear even darker due to the spectral absorption characteristics of the seasonally wet site. There was also significant commission errors with the open spruce forest classes. Modeling with winter imagery (Landsat MSS Band 4) resulted in some reduction in these errors. Modeling with TM Band 5 (which is highly sensitive to water/moisture) was effective at separating the *wet herbaceous* sites from the *mesic herbaceous* sites. When considering the *wet herbaceous*, *mesic herbaceous*, and the *aquatic herbaceous* classes as a single herbaceous mapping class, the producer's accuracy is 79%, while the user's accuracy is 72%.

3.4 DISCUSSION OF APPLICATIONS AND LIMITATIONS

To properly interpret and apply the landcover classes developed in the GAAR mapping project, users must bear in mind the characteristics of the data used to derive

the map, as well as the characteristics of the vegetation and other landcover types of interest. It is important to note that the GAAR landcover project had the objectives to 1) map landcover characteristics that could be recognized by Landsat imagery, and 2) delimit mapping classes that are flexible enough to describe potential new classes derived from Landsat imagery. Hence, although the mapping classes were derived from the Alaska Vegetation Classification (Viereck et al. 1992), they did not strictly adhere to this classification hierarchy. In the GAAR project, the landcover classification system was customized so as to take advantage of the characteristics of the Landsat TM data, while balancing the mapping detail needs of the end user. This classification system and the determination of final mapping classes remained open for discussion well into the image processing phases of the project. Review of the Landcover Class Descriptions (Section 3.6) and this section provide additional insight into the characteristics of the mapping class species composition as related to the Landsat TM data.

For the 7-band Landsat TM data with a pixel size of 28.5m, the scale of derived maps should be no larger than 1:63,360. However, at this large of scale very few landcover types can be consistently mapped without generating a great deal of “noise” or scattered pixels. A more appropriate mapping unit for Landsat TM derived landcover products is 5 acre (25 pixels). At this size of mapping unit, many of the small linear features (streams, riparian shrub areas, ridge lines, pipelines) can be lost in the filtering process. In order to preserve more of the spatial detail found in the unfiltered landcover data, the final landcover database was filtered to approx. 2 ac (9 pixels). While this mapping unit resolution provides a good compromise for legibility (not pixilated), 5 ac is still recommended as the appropriate minimum mapping unit for this landcover data. For purposes of estimating class accuracy in this report, the 5 ac landcover data was utilized.

However, both the 2 ac and unfiltered (pixel) landcover data are included in the ArcView 3.1 GAAR Landcover Field DataViewer product ([Table 1](#)). Further environmental and ecological factors important for optimal use of the landcover map are discussed in the following paragraphs by ecoregion.

Arctic Foothills

Within the arctic foothills, low shrub and herbaceous mapping classes dominate the region. Mesic herbaceous in the Brooks Range northern foothills and arctic foothills may include a high sphagnum moss component. This decreases the proportion of exposed water/moist detritus resulting in a higher visible and IR reflectance, and lighter signature. Farther South in the valleys of the Brooks Range, the moss component may be less significant. This results in more exposed water, more vis/IR absorption, and a darker signature.

Low *shrub birch-ericaceous-willow-tussock tundra* sites on the northern foothills of the Brooks Range vary greatly depending on moisture/wetness, degree of patterning interspersed frost boils with prostrate shrubs, and herbaceous and moss content, and temperature/permafrost (macroscale freeze/thaw status). In some mesic herbaceous sites, tussocks covered over 80% of the site, however there was no significant shrub

component (70% herbaceous / 25% moss). These sites appeared ruby red to maroon in the TM imagery (4,5,3 RGB).

Also on the northern foothills, lighter areas (white tones) were indicative of higher prostrate shrub content on sub-pixel frost heaves or local morainal ridge remnants and/or higher lichen content in *shrub birch-willow-tussock tundra* or *mesic herbaceous* mapping classes. These lighter signatures also were indicative of drier sites. The darker maroon tones, primarily found in the *mesic herbaceous* sites are linear sub-pixel wide wetter areas (water tracks). Sites where % shrub was not high enough to be considered in the *shrub birch-willow-tussock tundra* class, or the % tussock was near the lower limit to be considered a tussock site, were considered to be *mesic herbaceous* sites. The wettest of these areas with a significant portion of surface covered by water (greater than 10%), were classified as *wet herbaceous*. Although these sites contained emergent vegetation, the principal difference discernible through analysis of the Landsat TM data in these sites from the *mesic herbaceous* sites was the amount of exposed water (primarily in the form of large or multiple water tracks).

Brooks Range

Within the Brooks Range, terrain shadow presented the greatest challenge to development of the landcover map. The *shadow/indeterminate* mapping class was reserved for only those areas completely obscured by terrain shadow (or clouds/cloud shadow). Fortunately, the dominant vegetation in this region were the prostrate mapping classes which were very well represented by spectral signatures (176 signatures total). With this abundance of samples, the assumption that all reflectance variations of the prostrate mapping classes (including those variations due to illumination conditions) is fairly realistic. As a result, most of the spectral confusion in this region was between the three prostrate shrub classes. Confusion between the prostrate shrub classes and other vegetation mapping classes (such as *shrub birch-willow-tussock tundra*, or *shrub birch-ericaceous-willow tundra*) was minimal. Exceptions were *mesic herbaceous* areas occurring in relatively high elevation alpine areas. These sites were on the drier end of the mesic regime (as opposed to the wetter *mesic herbaceous* found in the floodplain areas). Prostrate shrub sites with a high herbaceous component had a very similar spectral response to this alpine *mesic herbaceous* type (both are fairly bright red) and were therefore confused in the ML classification. Raster editing using FirePro and 1998 field sites was utilized to assist in editing these areas.

The *prostrate shrub-rock* mapping class usually had a reddish-green spectral response, with the green due to the significant contribution of bare rock (and high TM band 5 response in relation to TM band 4). The *prostrate shrub-rock* class was often distinguishable based on less uniform vegetation pattern and context/slope position (generally very steep slopes, and often upslope of prostrate shrub areas). The prostrate shrub class generally had a much higher IR response, with a pink or red signature (depending on ratios of dryas/cassiope, lichen, herbaceous, and rock). Generally, the sites with more green vegetation (and less rock or lichen) exhibited

redder responses, while those sites with less green vegetation and more lichen and rock tended to be lighter red to pink. *Prostrate shrub-lichen* areas (found mainly in transitional zones between Brooks Range/Forested interior transition region) are nearly always found on ridge tops above. This prostrate class is spectrally distinct from other prostrate classes, with a white to whitish-pink signature.

Interior Forested Lowlands/Uplands

The interior forested lowlands/uplands ecoregion encompasses the greatest variety of mapping classes, and was the most difficult area to map because of spectral confusion between many classes. This was complicated by the fact that most of the training data used to develop the ML classification was more representative of the other two ecoregion (arctic foothills and Brooks Range). This was understandable considering that only a small portion of the park itself was included in the interior forested lowlands and uplands ecoregion. This includes the Kobuk “boot” area, and forested valleys running predominantly N-S into the Brooks Range. However, the dominant open spruce forest and spruce woodland classes that make up majority of the area in this region were spectrally distinct, and could be consistently mapped in the automated classification. The *dense open white spruce-like forest* signature appears a dark brown color, while the *open black* and *open white spruce-like forest* appears medium brown/gray, and the *spruce woodland* a lighter gray brown. *Open black* and *open white spruce-like forest* classes could not be separated spectrally; however effort was made to model these based on slope and aspect. Open spruce forest (with tall shrub alder understory) had significant spectral confusion with the open and closed mixed forest classes. Both of these have dark reddish-brown signatures. These types were also often intermixed, or occur within close proximity to each other. The FirePro and '98 field data and image annotations were also used extensively to check these classes. The latitudinal position (northern extent) was an important factor during editing to eliminate the mixed forest possibility (and generally determined that the site was open spruce with tall shrub understory. However, although depending on the site shadow effects these areas were also recoded to closed or open tall shrub).

The broadleaf forest classes were not spectrally separable, and upslope and floodplain models were developed using slope to separate birch aspen (open and closed) from balsam poplar (open and closed) respectively. The closed broadleaf forest classes appeared as bright deep red signatures, with less pronounced bright red color where more open broadleaf forest was prevalent. *Closed tall shrub* also was spectrally confused with these open and closed broadleaf forest classes. The proportionally representative number of training signatures for the tall shrub classes (70 signatures) as compared to the broadleaf forest (20 signatures) helped reduce the amount of error from this confusion. In the south park buffer area, where aspen-birch becomes more prevalent than represented by the training database, additional raster editing was required.

The signature color of the *spruce-lichen woodland* class (whitish-pink to white-gray) varied a great deal depending on the amounts of spruce, size of spruce, proportion of lichen, and amount of low and tall shrub. Because of the relatively few training

samples (11 signatures), additional raster editing was required to improve the accuracy of this class. The areas where more pink tones were visible usually indicated more dwarf birch low shrub. The whiter sites indicated more lichen and usually less shrub and/or spruce. The grayish-white sites indicated a “typical” *spruce-lichen woodland* site balanced with ~20% spruce, and 30% or more lichen. Darker gray tones indicated higher spruce cover, and these sites were often classified as *spruce woodland* or *open black* or *open white spruce-like forest* if the white lichen was not obvious in the image.

Burn areas also presented problems in this region. Burn areas were generally classified as low shrub or tall shrub, and often included spruce woodland patches. However, the significant burn areas since the primary 1985 satellite imagery, and the succession/regrowth of burn areas visible in the 1985 imagery, will most likely not be represented appropriately utilizing these landcover maps. Approximate burn areas were annotated on the image maps when possible during the '98 field season, and these annotations digitized. However, because of the sporadic and incomplete nature of this ancillary data layer, they were used only for reference during raster editing (not modeling). No attempt was made to incorporate these annotations directly in the landcover map for burn areas unless the burn was clearly visible in the circa 1985 imagery base.

3.5 KEY TO LANDCOVER CLASS

A key to the landcover classes used is found in [Appendix 1](#).

3.6 LANDCOVER CLASS DESCRIPTIONS

The names and Viereck codes of the landcover classes in the GAAR project area are listed below. This is followed by full descriptions and accuracy assessment statements for each individual GAAR landcover class. Landcover class descriptions were derived from several sources including literature descriptions, Firepro data, Natural Resources Conservation Service data (Swanson 1996), 1998 FVA fly-over data, and 1998 on the ground site descriptions. For some of the mapping classes, on the ground site descriptions (and literature review) added some plant association information to the landcover class descriptions, in addition to vegetation structure, site moisture level, and soil characteristics.

<u>LANDCOVER CLASS NAMES</u>	<u>CODE</u>
Dense-open white spruce forest	(I.A.1.J)
Open black spruce-like forest	(I.A.2.F)
Open white spruce-like forest	(I.A.2.E.)
Spruce woodland	(I.A.3)
Spruce-lichen woodland	(I.A.3.1.)
Closed paper birch-aspen forest	(I.B.1.F.)
Closed balsam poplar forest	(I.B.1.C.)
Open paper birch-aspen forest	(I.B.2.X.)
Open balsam poplar forest	(I.B.2.C.)
Closed spruce-broadleaf forest	(I.C.1.X.)
Open spruce-broadleaf forest	(I.C.2.Y.)
Closed tall shrub	(II.B.1.)
Open tall shrub	(II.B.2.)
Shrub birch-willow-tussock tundra	(II.C.2.X.)
Shrub birch-ericaceous-willow	(II.C.X.)
Closed low willow	(II.C.2.B.)
Prostrate shrub-rock	(II.D.Y.)
Prostrate shrub-lichen	(II.D.X.C.)
Prostrate shrub	(II.D.X.)
Dry herbaceous	(III.X.1.)
Mesic herbaceous	(III.X.2.)
Wet herbaceous	(III.X.3.)
Aquatic herbaceous	(III.D.X)
Sparsely vegetated	(IV.X)
Bare-ground	(V.X.1.)
Clear water	(V.X.2.)
Silty water	(V.X.3.)
Snow/ice	(V.X.4.)
Mosaic/patterned vegetation	(V.X.5.)
Shadow/indeterminate	(V.X.6.)
Sand dunes	(V.X.7.)

Dense-open white spruce forest landcover class (I.A.1.J)

Classification. Tree canopy cover is between 50 to 65% with greater than 75% of the total tree cover as needleleaf. The growth form and habitat of needleleaf trees is white spruce-like; that is they grow in well drained, sunny areas, with little knarled or stunted growth ([Figure 21](#)).



Figure 21. Patches of dense-open white spruce forest mixed with other types

Class description. The *dense-open white spruce forest* map class occurs on floodplains and valley bottoms. These areas are sunny with well-drained, loamy or sandy soils. White spruce thrives in these areas as long as the ground remains well drained. Sampled sites have little to no slope and most of the disturbance originates from alluvial and fire processes. Elevation ranges up to 1,391 feet ([Appendix 2](#)).

This map class covers 0.04% of GAAR ([Table 9](#)) and is concentrated in the south half of the Brooks Ranges ecoregion ([Figures 3a and 3b](#)), commonly in the Alatna River, John River, Allen River and Koyukuk River valleys. Dense-open stands are relatively small in size, the sampled polygons ranging up to 142 acres in size ([Table 12](#)). The map class is commonly found adjacent to *closed balsam poplar*, *open balsam poplar*, *open black spruce-like*, *open white spruce-like*, and *spruce woodland* map classes. No stands of spruce (either white or black) with greater than 65% total tree cover were sampled within GAAR, as the park may be too far north to support

thicker stands of white spruce.

Table 12. Analysis of number and size of polygons for each landcover class.

Class Name	Total Acres	Number of Polygons	Polygon Statistics in Acres			
			Min	Max	Mean	Std.Dev.
Dense-open white spruce forest	5,889.9	882	1.6	142.1	6.6	9.8
Open spruce forest, species unspecified	0.0	0	0.0	0.0	0.0	0.0
Open black spruce-like forest	1,110,745.5	24382	0.2	227,199.4	45.6	1,619.5
Open white spruce-like forest	412,165.1	19614	0.2	2,871.8	21.1	84.9
Spruce woodland	815,661.0	48540	0.2	19,548.8	16.9	119.8
Spruce-lichen woodland	87,922.7	11825	0.4	747.0	7.4	16.7
Closed paper birch-aspen forest	19,729.3	2582	1.8	397.2	7.6	15.7
Closed balsam poplar forest	10,131.7	1282	1.8	227.4	7.8	13.4
Open paper birch-aspen forest	31,259.3	5031	0.2	337.6	6.2	9.2
Open balsam poplar forest	12,360.4	2391	1.8	71.9	5.2	5.4
Closed spruce-broadleaf forest	33,047.7	4727	0.8	414.5	7.0	11.6
Open spruce-broadleaf forest	41,309.1	5980	0.6	222.4	6.8	11.6
Closed tall shrub	397,866.4	37322	0.2	1,355.2	10.6	29.3
Open tall shrub	410,129.6	44534	0.2	833.8	9.2	22.1
Shrub birch-willow-tussock tundra	925,309.0	53461	0.2	33,136.2	17.3	228.8
Shrub birch-ericaceous-willow	2,088,107.3	92519	0.2	47,603.4	22.5	283.2
Closed low willow	24,455.2	4729	0.2	171.6	5.2	6.4
Prostrate shrub-rock	832,698.8	54467	0.4	8,065.0	15.3	75.1
Prostrate shrub-lichen	158,345.7	20980	0.4	786.8	7.6	16.1
Prostrate shrub	2,365,852.6	84074	0.2	16,354.1	28.1	179.6
Dry herbaceous	0.0	0	0.0	0.0	0.0	0.0
Mesic herbaceous	853,264.8	75110	0.2	33,392.7	11.4	195.1
Wet herbaceous	36,218.7	5291	0.2	667.4	6.8	14.7
Aquatic herbaceous	332.0	87	0.8	21.1	3.8	3.2
Sparsely vegetated	1,001,931.2	63006	0.2	4,862.6	15.9	61.4
Bare-ground	1,221,000.7	37298	0.2	32,040.5	32.7	436.9
Silty water	71,507.9	38923	0.2	2,503.3	1.8	20.3
Clear water	86,552.4	16470	0.2	9,270.0	5.2	98.7
Snow/Ice	49,013.2	4649	1.6	540.7	10.6	27.3
Sand dunes	10.0	3	2.2	4.8	3.4	1.4
Mosaic/patterned vegetation	24,431.3	1097	0.2	2,511.9	22.3	130.3
Shadow/indeterminate	621,280.4	23054	0.4	108,259.1	26.9	724.8

Tree height can reach greater than 50 feet. Alders [such as *Alnus crispa* (American green alder)] and willows are found growing in canopy breaks along with ericaceous shrubs such as *Arctostaphylos rubra* (red-fruit bearberry), *Vaccinium vitis-idaea* (low bush cranberry), and *Vaccinium uliginosum* (bog blueberry). Mosses such as *Hylocomium splendens* (feathermoss), *Rhytidiadelphus triquetrus*, and *Pleurozium schreberi* are common in these stands as well as small amounts of lichen.

Interpretation key. It was not possible to consistently distinguish white spruce from black spruce from a helicopter. We believe that growth form and habitat were the best characteristics from the air to help separate white from black spruce. Consequently, trees that were small (15 to 30 feet tall), with sparse lower branches, knarled or stunted growth and growing on poorly drained soils were considered black spruce. Large (25 to 70 feet tall) narrow sharp pointed trees and found on well drained soils were considered white spruce. The word “like” was added to the end of black spruce and white spruce—i.e., black spruce-like—to indicate we were uncertain of the species determination and mapping was based on habitat and physiognomy. In addition, any *dwarf tree scrub* classes as defined in the Alaska Vegetation Classification were included in one of the *needleleaf forest* classes, because it was not possible to spectrally separate spruce trees based on height.

The *dense-open white spruce* class is not defined in the Alaska Vegetation Classification. It was described, however, in our classification because it encompassed spruce forests with the highest cover values (50 to 65%) that could be spectrally separated from signatures with lower cover values (25 to 49%). No areas were found with greater than 65% white spruce cover. Due to the higher percentage of spruce cover, this mapping class was spectrally distinguishable from the *open white spruce-like forest* and *open black spruce-like forest* classes, and no slope or illumination (aspect) models were required in order to map the *dense-open white spruce forest* class.

Accuracy assessment and mapping issues. The producer's accuracy for the *dense-open white spruce forest* class was 89.9%, with a user's accuracy of 59.9% (Table 10b). All of the errors of commission and omission were due to confusion with the open white or open black spruce classes. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 2 sites within GAAR. The Landsat TM 4,5,3 (RGB) signatures for this class appeared as a dark brownish-grey, going to a lighter brownish grey with decreasing canopy closure. Confusion with the open spruce class therefore occurred at sites where the canopy cover was close to the 50% cut between the open spruce and dense-open spruce classes. Although partial or complete terrain shadow can also produce a dark brownish-grey signature, this confusion was avoided through very effective modeling of the *shadow/indeterminate* mapping class.

Open black spruce-like forest (I.A.2.F)

Classification. Tree canopy cover is between 25 to 49% with greater than 75% of the total tree cover as black spruce-like trees (Figures 22a and b).

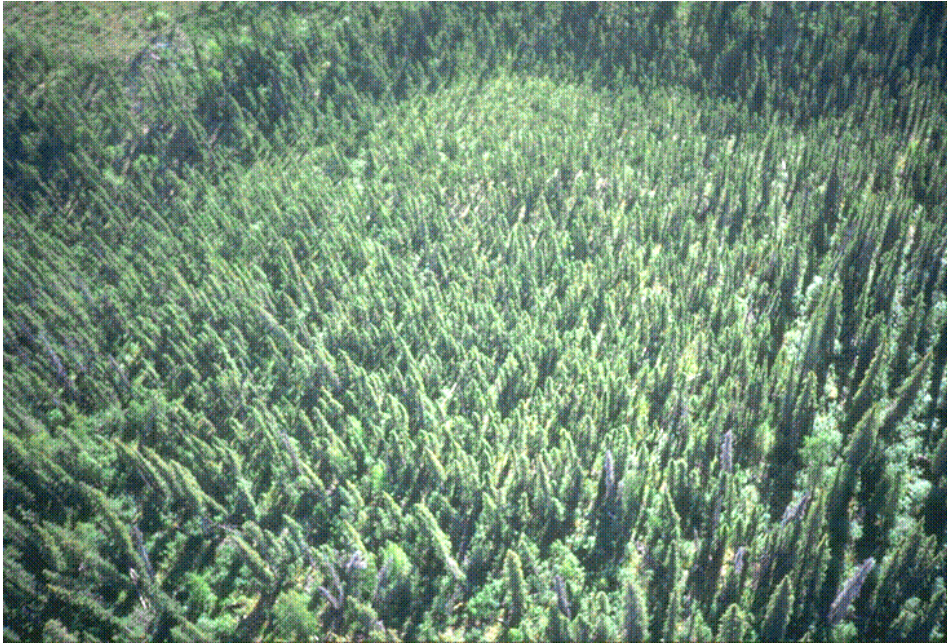


Figure 22a. Open black spruce-like forest (35% black spruce)



Figure 22b. Open black spruce-like forest (35% black spruce)

Class description. Positive identification of spruce species is not possible from a helicopter. Consequently, the *open black spruce-like forest* map class was identified based on growth form. Black spruce are typically small in height (15 to 30 feet), have knarled or stunted growth, have a relatively high number of lower branches, and grow on poorly drained soils.

The map class is concentrated in the south half of the Brooks Range ecoregion and the interior forested lowlands and uplands ecoregion of GAAR (Figures 3a and 3b). It covers 8.1% of the Park (Table 9), and its elevation ranges from 320 feet to over 2,700 feet on sites sampled (Appendix 2). It occurs on sand deposits, lacustrine deposits, glacial till, eolian deposits, colluvium, and alluvial plains. Slopes range from 0° on the floodplains to over 20° on colluvial and glacial drift sideslopes. The soils are mesic to wet often with a thick peat layer. The pH of these sites tends to be slightly acidic, with lower pH (more acidic) values occurring in the flat peatlands. Areas affected by thawing of ground ice produce saturated soils that support black spruce along with peat accumulation.

Open stands of black spruce are often found adjacent to the *spruce woodland*, *closed tall shrub* and *open tall shrub* map classes. The *open black spruce-like forest* map class is relatively contiguous in distribution with an average area of 46 acres and ranging up to 227,000 acres in size (Table 12). However, canopy cover commonly fluctuates between open and woodland.

Tree height can reach 30 feet and averages 15 feet. Associate species found in the map class include *Salix* (willow) species, *Betula glandulosa* (resin birch) or *Betula nana* (dwarf arctic birch), *Vaccinium uliginosum* (bog blueberry), *Ledum palustre* (Labrador tea), and *Potentilla fruticosa* (shrubby cinquefoil). Graminoids such as *Eriophorum russeolum* (russett cottongrass), *Carex aquatilis* (water sedge) and *Carex bigelowii* (Bigelow sedge) are also found, as well as a groundcover of mosses such as *Sphagnum* (peat moss) species and *Pleurozium schreberi*. Lichens growing in these stands include *Cladonia* species, *Nephroma* species, *Cetraria* species, and *Peltigera* species.

Interpretation key. The *open black spruce-like* class corresponds to the similarly named class in the Alaska Vegetation Classification. However, we used a lower tree cover value (25 to 49%) than the Alaska Vegetation Classification (25 to 60%).

Accuracy assessment and mapping issues. The producer's accuracy for the open black spruce-like class was 63.9%, with a user's accuracy of 53.5% (Table 10b). Most of the errors of commission and omission were due to confusion with the *open white spruce-like* forest class and to a lesser extent with the woodland class. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 16 sites within GAAR. The Landsat TM 4,5,3 (RGB) signatures for this class varied a great deal depending upon the understory composition, from a medium brownish-grey for small stature trees or open low shrub understory, to a vivid reddish-brown for those areas with closed tall shrub understory.

These black spruce sites with tall shrub understory also exhibited some confusion with the *mixed spruce-broadleaf forest* and the tall shrub and closed low shrub classes. This was due to the high IR (infrared) response characteristic of the broadleaf tree and shrub species. In particularly wet sites, the signature was often a darker grayish-brown. Because of the substantial spectral confusion between the two open spruce classes, slope and illumination models were utilized based on the assumption that white spruce tends to occur on well illuminated upslopes, while black spruce tends to occur on low slopes and floodplains, under below average to well illuminated conditions. When considering the *open black* and *open white spruce-like forest* classes as a single combined open spruce forest mapping class, the producer's and user's accuracy increases to 84%.

Open white spruce-like forest (I.A.2.E.)

Classification. Tree canopy cover is between 25 to 49% with greater than 75% of the total tree cover as white spruce-like trees ([Figure 23](#)).



Figure 23. Mature open white spruce stands along river (45% spruce)

Class description. The positive identification of spruce species is not possible from a helicopter and, consequently, the *open white spruce-like forest* map class was identified based on growth form. White spruce are assumed to be relatively tall in height (35 to 75 feet average), are narrow and sharp pointed, and display little to no

knarled or stunted growth.

The map class is concentrated in the south half of the Brooks Range ecoregion and in the interior forested lowlands and uplands ecoregion of the park ([Figures 3a and 3b](#)). It covers 3.0% of GAAR, primarily on well drained, sunny areas such as floodplains, but is also found on colluvial and glacial drift sideslopes, and lacustrine deposits ([Table 9](#)). Elevations range from about 460 feet to over 2,800 feet on sites sampled ([Appendix 2](#)). The slope ranges from 0° on the floodplains to over 25° on the colluvial slopes. Soils are mesic to dry. The pH of white spruce sites tend to be higher (neutral) than that of black spruce forests.

This map class commonly occurs adjacent to *closed tall shrub* and *open tall shrub* map classes on the steep sideslopes of narrow valleys, and intermixed with *spruce woodland* found on the thermokarst and peatlands of wide valleys. The *open white spruce-like forest* map class is relatively contiguous in distribution with an average area of 21 acres and ranging up to 2,872 acres in size ([Table 12](#)). However, canopy cover commonly fluctuates between open and woodland.

Plant species found within these areas include *Alnus crispa* (American green alder), *Vaccinium uliginosum* (bog blueberry), *Spiraea beauverdiana* (Alaska spiraea), *Betula papyrifera* (paper birch) in small amounts, *Equisetum* species, *Betula nana* (dwarf arctic birch) or *Betula glandulosa* (resin birch), *Salix* (willow) species, and, if the stand is near a river, small amounts of *Populus balsamifera* (balsam poplar). In canopy breaks where tall shrubs are not present, prostrate shrubs are found. Mosses occur in high quantities, such as *Hylocomium splendens* and *Dicranum* species. Lichens are also found.

Interpretation key. The *open white spruce-like* class corresponds to the similarly named class in the Alaska Vegetation Classification. However, we used a lower tree cover value (25 to 49%) than the Alaska Vegetation Classification (25 to 60%). This class was not spectrally separable from the *open black spruce-like forest* class. Models based on slope and illumination (related to aspect) were used to separate the upslope open spruce forest as the *open white spruce-like forest* class, and the floodplain open spruce forest as the *open black spruce-like forest* class. It should be noted that *open black spruce-like forest* is likely to occur in the floodplain within areas mapped as the *open white spruce-like forest* class.

Accuracy assessment and mapping issues. The producer's accuracy for the *open white spruce-like forest* class was 37%, with a user's accuracy of 47% ([Table 10b](#)). Most of the errors of commission and omission were due to confusion with the *open black spruce-like forest* class and to a lesser extent with the *spruce woodland* class. There was also some confusion with the *dense-open white spruce forest* class. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 27 sites within GAAR. The Landsat TM 4,5,3 (RGB) signatures for this class varied a great deal depending upon the understory composition, from a medium brownish-grey for small stature trees or open low shrub

understory, to a vivid reddish-brown for those areas with tall shrub understory. A tall shrub alder or alder-willow understory was typical of the upslope white spruce-like sites and showed some confusion with the *mixed spruce-broadleaf forest* and the tall shrub and low shrub classes. This was due to the high IR (infrared) response characteristic of the broadleaf tree and shrub species which can easily dominate spectral signature for open spruce classes. Because of the substantial spectral confusion between the two open spruce classes, slope and illumination models were utilized based on the assumption that *open white spruce-like forest* occurs on well illuminated upslopes, while *open black spruce-like forest* was assumed to occur on low slopes and floodplains, under average to well illuminated conditions. When considering the open black and white spruce-like classes as a single mapping class, both the producer's and user's accuracy increase to 84%.

Spruce-lichen woodland (I.A.3.1.)

Classification. Tree canopy cover is between 10 to 35% with greater than 75% of the total tree cover as needleleaf trees. The fruticose lichen cover is greater than 25% (Figures 24a and b).



Figure 24a. Spruce-lichen woodland (10-15% spruce and mat of lichen)



Figure 24b. Spruce-lichen woodland (10-15% spruce and mat of lichen)

Class description. The *spruce-lichen woodland* map class is concentrated within the Brooks Range ecoregion (Figures 3a and 3b). Sampled sites range in elevation from about 700 feet to over 2,700 feet, with most stands occurring below 1,000 feet (Appendix 2). Slope varies from 0° to 35° on sampled sites and the aspect is generally north to northwest. The map class covers 0.64% of GAAR (Table 9), and is typically found on alluvial fans, moraines and stream terraces. They are generally easy to distinguish on aerial photos and on satellite imagery. The soils are mesic.

Stands range up to 747 acres and are often discontinuous and oval in shape (Table 12). Adjacent map classes are often *prostrate shrub-lichen*, *shrub birch-ericaceous-willow* (with a significant lichen component), and most of the forest and woodland landcover classes.

Both white and black spruce occur in the *spruce-lichen woodland* map class, and fruticose lichen cover is often greater than 60%. Trees reach 30 feet in height. Ericaceous shrubs such as *Empetrum nigrum* (crowberry), *Vaccinium vitis-idaea* (low bush cranberry), *Vaccinium uliginosum* (bog blueberry) and *Ledum palustre*

(Labrador tea), as well as *Betula glandulosa* (resin birch) or *Betula nana* (dwarf arctic birch), are common associates. Lichens include *Cladina rangiferina*, *Peltigera* species, and *Stereocaulon* species.

Interpretation key. The *spruce-lichen woodland* class is not described in the Alaska Vegetation Classification. It was included as a distinct class in the GAAR classification because, from an ecological perspective, the class was distinct in structure and composition from other map classes. In addition, it was readily distinguishable spectrally. Again, white spruce could not be distinguished from black spruce for this class.

Accuracy assessment and mapping issues. The producer's accuracy for the *spruce-lichen woodland* class was 80%, with a user's accuracy of 87% (Table 10b). Most of the errors of commission and omission were due to confusion with the *spruce woodland* class. This generally occurred when a *spruce woodland* site included more than 25% lichen, but also a significant component of low shrub (usually *shrub birch-ericaceous-willow*) which results in a much less spectrally distinct signature in the satellite image. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 11 sites within GAAR. The Landsat TM 4,5,3 (RGB) signatures for this class varied depending upon the amount of spruce, lichen, and shrub (usually dwarf birch). The characteristic signature was a whitish-grey which is a combination of the white reflectance of the lichen and the brown-grey reflectance of the spruce. Red tones in the signature represent the open low shrub understory. Although not reported in the accuracy assessments, the *spruce-lichen woodland* class can also be confused with other mapping classes with high lichen cover (>25%) such as the *prostrate shrub-lichen* class, and in some cases the *shrub birch-ericaceous-willow* class. This confusion typically occurred when the spruce cover was near the low threshold for consideration as a woodland (10-15%).

Spruce woodland (I.A.3)

Classification. Tree canopy cover is between 10 and 24% with greater than 75% of the total tree cover as needleleaf trees. The needleleaf species may be either black spruce or white spruce (Figure 25).

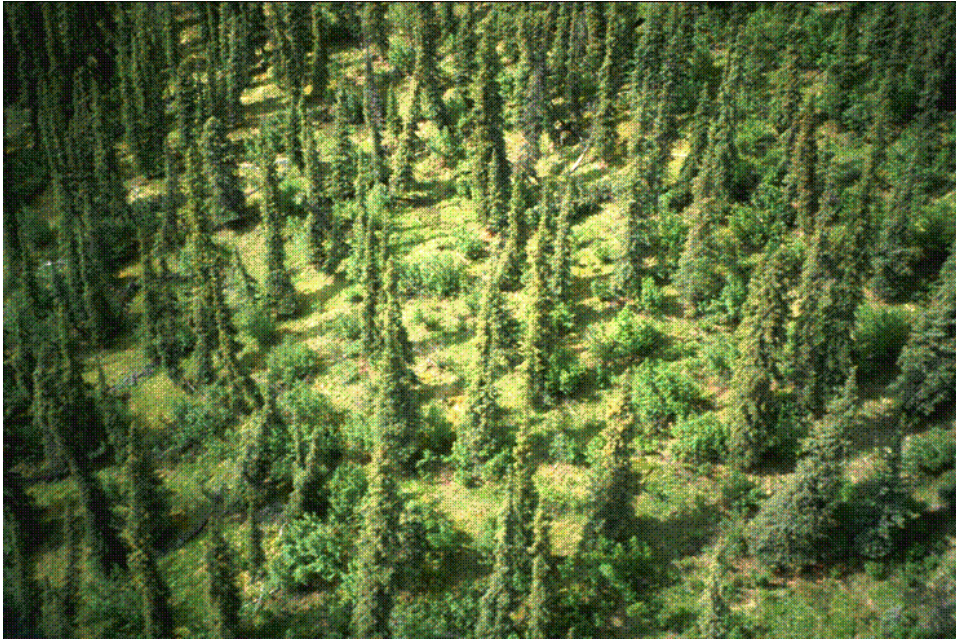


Figure 25. Spruce woodland on side slope (20% white spruce)

Class description. The *spruce woodland* landcover class is concentrated in the southern portion of the Brooks Range ecoregion and in the interior forested lowlands and uplands ecoregion (Figures 3a and 3b), and covers 5.9% of GAAR (Table 9). Elevation ranges up to 2,900 feet (Appendix 2). The map class typically contains either white spruce or black spruce and not a mixture of the two. Occasionally stands are found with both species growing together, although these stands tend to be smaller in size and more limited in distribution. Because black spruce and white spruce occupy distinct sites—they are described separately below—each is analogous to an alliance. The map class is relatively contiguous in distribution with an average size of 17 acres and ranging up to 19,549 acres in size (Table 12).

Black spruce woodland alliance. Black spruce is found on floodplains, terraces, outwash, colluvial deposits, glacial drift on sideslopes, and eolian deposits. The sites are often large and continuous, intermixed with other needleleaf forest map classes. The soils are mesic to wet with poor drainage and may contain a peat layer. The pH is neutral to acidic. Slopes range from 0° on terraces and floodplains to 55° on colluvial and glacial drift sideslopes.

Tree height reaches 30 feet and averages 15 feet. Associated understory species include *Ledum palustre* (Labrador tea), *Vaccinium uliginosum* (bog blueberry), *Vaccinium vitis-idaea* (low bush cranberry), and *Alnus crispa* (American green alder). Prostrate shrubs such as *Arctostaphylos rubra* (red-fruit bearberry) and *Dryas* species are also found in these sites. Mosses include *Sphagnum* (peat moss) species, *Hylocomium splendens* (feather moss), and *Pleurozium schreberi*. Lichens such as *Cladina* species, *Cladonia* species, and *Stereocaulon* species are also common.

White spruce woodland alliance. Sites dominated by white spruce, in contrast, occur in well drained, mesic soils, south facing slopes and sunny areas. They are located in narrow bands on floodplains, on alluvial fans frequently with a high percentage of lichen, and occasionally on colluvial and glacial drift slopes. At treeline, trees are short with a sparse distribution. The tree line does not have an abrupt edge. The slope of these sites range from 0° to 32° in the sites sampled. White spruce sampled sites were generally found at slightly higher elevations than black spruce, occurring between 466 feet to 2,822 feet ([Appendix 2](#)).

These stands occupy areas similar to *open white spruce-like* stands. In fact, the *spruce woodland* and *open white-like spruce* map classes together often form large continuous stands. Both the *open* and *closed tall shrub* map classes commonly grow near white spruce stands along floodplains and on sideslopes.

Tree height averages 15 feet, however they can reach over 40 feet. Both alder and tall willow are found in large canopy gaps of *spruce woodland*, while low growing willows invade smaller openings. The tall shrubs tend to grow in a clumped pattern throughout the stands, however they can reach greater than 55% of the total vegetation cover in some stands.

Species associated with the *spruce woodland* map class include *Alnus* (alder) species, *Salix alaxensis* (feltleaf willow), *Salix monticola* (park willow), *Betula nana* (dwarf arctic birch) or *Betula glandulosa* (resin birch), *Vaccinium uliginosum* (bog blueberry), *Empetrum nigrum* (crowberry), *Rubus* species, *Spiraea beauverdiana* and *Ledum palustre* (Labrador tea). Mosses and lichens are also found in these areas such as *Cladonia* species, *Cetraria cucullata*, *Rhytidiadelphus triquetrus*, *Hylocomium splendens* (feather moss), and *Sphagnum* (peat moss) species in small quantities. Grasses and forbs typically have low cover values in these sites.

Interpretation key. The *black spruce-like woodland* and *white spruce-like woodland* classes used for mapping in the field were collapsed into a single class—*spruce woodland*. We were unable to spectrally separate the two woodland classes. In the descriptions for these two classes, we describe slope and surficial geology characteristics that provide some basis for separation through modeling. However, the relationship was not found to be strong enough to improve mapability of the two individual classes. The *spruce woodland* class is the same as the Alaska Vegetation Classification *spruce woodland* class.

Accuracy assessment and mapping issues. The producer's accuracy for the spruce woodland class was 72%, with a user's accuracy of 51% ([Table 10b](#)). Some of the errors of commission and omission were due to confusion with the *open black* and *white spruce-like forest* classes. This generally occurred when a spruce woodland site included 15-24% lichen, but not enough to be classified as a *spruce-lichen woodland* site (> 25% lichen required). However, of greater concern is the large errors of commission found in the low shrub classes, and in particular, the *shrubs*

birch-ericaceous-willow class. This confusion generally occurred on partially shadowed aspects that resulted in darker signatures than a well illuminated low shrub class. Although incorporation of the illumination layer in the spectral database reduced this type of confusion, areas of fairly low illumination continued to show some spectral confusion between the woodland and low shrub classes. Winter MSS (Band 4 NIR) was useful in correcting woodland areas misclassified as low shrub (*shrub birch-ericaceous-willow-tussock tundra* and *shrub birch-ericaceous-willow*). Again, this model could only be used in moderately well illuminated areas. In the central and southern portions of the project area, low shrub in partially shadowed aspects was misclassified as woodland. In these areas, raster editing based on the FirePro and '98 field data and image annotations was utilized to determine whether the woodland on partially shadowed aspects was legitimate or was actually a low shrub or prostrate class (depending on northern latitude and context). Determination of which low shrub class was also based on the context of the site (review of the mapping classes of the surrounding areas). This approach was very difficult in the transition areas between the forested lowlands/uplands and Brooks Range ecoregions (in this area, woodland did occur on low to moderate north aspects). Where woodland classes occurred on the south aspect of an E-W drainage, the north aspect was usually dominated by low shrub (generally *shrub birch-ericaceous-willow-tussock tundra* in floodplain, and *shrub birch-ericaceous-willow* on upslopes, but there were too many exceptions to this rule to allow realistic model-based separation of these two low shrub classes). Where low shrub or tall shrub occurred on the south aspects of an E-W drainage, the north aspect was usually dominated by prostrate shrubs with low shrub stringers. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 34 sites within GAAR. The Landsat TM 4,5,3 (RGB) signatures for this class varied depending upon the amount of spruce, lichen, and shrub (usually dwarf birch). The characteristic signature was a light to medium reddish-grey. Red tones in the signature usually represent the low shrub scattered tall shrub understory. Darker grey tones in the signatures are usually related to increased spruce cover. When considering the *spruce woodland* and *spruce-lichen woodland* classes as a single mapping class, the producer's accuracy increased to 75%, while the user's accuracy improved to 56%.

Closed paper birch-aspen forest (I.B.1.F.)

Classification. Tree canopy cover is 60 to 100% with *Betula papyrifera* (paper birch) and *Populus tremuloides* (quaking aspen), individually or combined, with greater than 50% of the total tree cover (Figures 26a and b).



Figure 26a. Closed paper birch-aspen forest (85% paper birch)



Figure 26b. Closed paper birch-aspen forest (85% paper birch)

Class description. The *closed paper birch-aspen forest* map class has a limited distribution within GAAR, occurring primarily within the most southern portions of the park, specifically the “Kobuk boot” area and the southern limits of the North Fork River within the park boundaries ([Figure 1](#)). It occupies colluvial and glacial drift sideslopes and floodplains, and covers 0.1% of the GAAR study area. The map class has a patchy distribution with an average size of 7.6 acres and ranging up to 397 acres ([Table 12](#))

Landcover classes found growing adjacent to the *closed paper birch-aspen forest* map class varies with the surficial geology type on which these stands occur. On floodplains and lower sideslopes, needleleaf map classes as well as balsam poplar stands, mix with the map class. On the upper sideslopes, tall shrub map classes occur near *closed paper birch-aspen* stands. Areas with gentle relief as well as relatively steep slopes (greater than 70°) can also support *paper birch-aspen* stands. Elevation varies from about 900 feet on the floodplains and lower sideslopes to over 2,200 feet on mountain slopes ([Appendix 2](#)).

Betula papyrifera (paper birch) and *Populus tremuloides* (quaking aspen) form a mixed overstory in most stands. In canopy openings *Alnus crispa* (American green alder) and *Salix glauca* (grayleaf willow) occur. Additional species include *Vaccinium vitis-idaea* (low bush cranberry), *Rosa acicularis* (prickly rose), *Ledum palustre* (Labrador tea), and *Spiraea beauverdiana* (Alaska spiraea). Mosses, such as *Hylocomium splendens* (feather moss), may be present in high quantities, and fruticose and crustose lichens occur in moderate quantities.

Interpretation key. The *closed paper birch-aspen forest* class is not spectrally separable from the *closed balsam poplar forest*. However, this distinction can be modeled fairly well in GAAR using slope. Balsam poplar was only observed along riparian corridors. So the two classes were distinguished on this basis. Balsam poplar has been noted to occur on uplands in the Kobuk Boot area, but what not distinguishable in the satellite imagery.

Accuracy assessment and mapping issues. The producer’s accuracy for the *closed paper birch-aspen forest* was 73.0%, with a user’s accuracy of 79.0% ([Table 10b](#)). Errors of commission and omission were due to confusion with the *closed balsam poplar forest* class. Slope was used to model these classes based on the assumption that balsam poplar occurred only in floodplain (minimal slopes) while aspen-birch occurred only on upslope areas. There was also some confusion with the *closed tall shrub* due to the similarity in broadleaf forest canopy reflectance. In areas of partial terrain shadow, some confusion also occurred with the *open tall shrub* class. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 5 sites within GAAR. Because limited training samples were available for the *closed paper birch-aspen forest* classes, raster editing based on review of the FirePro and 1998 field data, image annotations, and image

interpretation (with CIR spot checking) was relied on for improving these classes. The Landsat TM 4,5,3 (RGB) signatures for this class were bright red with a smooth texture for lower stature forests, and a slightly courser texture for forest with larger stature trees. The difference in forest stature for the *closed paper birch-aspen forest* class is typically only recognizable in the satellite imagery along the boundaries of stands where an abrupt transition to a lower stature shrub or broadleaf forest type occurs. Transition to stands of open spruce or mixed forest types is recognizable by distinct brown-grey tones intermixed in the forest stand related to the occurrence of spruce species. When considering all the closed and open broadleaf forest classes as a single broadleaf forest mapping class, the producer's accuracy becomes 82%, while the user's accuracy becomes 79%.

Closed balsam poplar forest (I.B.1.C.)

Classification. Tree canopy cover is 60 to 100% and balsam poplar has greater than 50% of the total tree cover ([Figure 27](#)).



Figure 27. Closed Balsam Poplar

Class description. The map class is concentrated in the interior forested lowlands and uplands ecoregion of GAAR ([Figures 3a and 3b](#)), and is restricted to floodplains and, occasionally, on uplands of the Kobuk Boot area. These riparian areas generally support only small stands of balsam poplar with a somewhat patchy distribution,

averaging 8 acres in size ([Table 12](#)). Soils are gravelly or sandy and well drained. Slope is minimal and the elevation ranges up to approximately 1,170 feet ([Appendix 2](#)). These areas are frequently flooded during river high flows. This map class covers 0.07% of the park ([Table 9](#)).

Needleleaf map classes and paper birch-aspen stands may be found growing near balsam poplar forests. Tall shrub map classes, dominated by willow, occupy gravel bars and floodplains and grow adjacent to the balsam poplar stands.

The overstory of the *closed balsam poplar forest* map class is almost exclusively comprised of *Populus balsamifera* (balsam poplar). Trees range up to 50 feet in height. *Picea glauca* (white spruce) and *Betula papyrifera* (paper birch) are occasionally found in the understory. *Alnus crispa* (American green alder), *Alnus tenuifolia* (thinleaf alder), *Salix monticola* (park willow), and *Salix alaxensis* (feltleaf willow) occur in crown cover breaks along with small quantities of *Picea glauca* (white spruce). Additional species include *Equisetum* species, *Galium boreale* (northern bedstraw), *Hedysarum alpinum* (Eskimo potato), *Viburnum edule*, *Rumex arcticus*, *Calamagrostis canadensis* (bluejoint grass), *Agrostis* species, and *Hierochloe alpina* (alpine holy grass). Mosses and lichens are also present in varying amounts including *Dicranum* species, *Drepanocladus* species, and *Rhytidiadelphus triquetrus*.

Interpretation key. The *closed balsam poplar forest* class is not spectrally separable from the *closed paper birch-aspen forest*. However, this distinction can be modeled fairly well using slope. Balsam poplar was only observed along riparian corridors. So the two classes were distinguished on this basis. Balsam poplar has been noted to occur on uplands in the Kobuk Boot area.

Accuracy assessment and mapping issues. The producer's accuracy for the *closed balsam poplar forest* class was 92%, with a user's accuracy of 69% ([Table 10b](#)). Errors of commission and omission were due to confusion with the *closed paper birch-aspen forest* class. Slope was used to model these classes based on the assumption that balsam poplar occurred only in floodplain (minimal slopes) while aspen-birch occurred only on upslope areas. There was also some confusion with the *closed tall shrub* and *open tall shrub* in riparian areas due to the similarity in broadleaf canopy reflectance. In the floodplains, the *open tall shrub* and *closed tall shrub* classes (dominated by willow) occur along more recently formed river meanders/bends, and typically transition into the *closed balsam poplar* and *open balsam poplar forest* classes, and are often found as a significant portion of the forest understory. In areas where the transition from tall shrub to large stature balsam poplar forest is abrupt, the forest stand boundary is sometimes recognizable in the satellite imagery due to shadows caused by differences in forest/shrub canopy heights. In areas of partial terrain shadow, some confusion also occurred with the open tall shrub class. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 4 sites within GAAR. Because limited training samples were available for the *closed balsam poplar forest*

classes, raster editing based on review of the FirePro and 1998 field data, image annotations, and image interpretation (with CIR spot checking) was relied on for improving discrimination of these spectrally confused classes. The Landsat TM 4,5,3 (RGB) signatures for this class were bright to deep red with a smooth texture for lower stature forests, and a slightly courser texture for forest with larger stature trees. Areas with larger canopy trees along major drainages in the southern portion of the GAAR area appeared as a deeper red, partially due to the effects of canopy shadow within the stands. When considering all the closed and open broadleaf forest classes as a single broadleaf forest mapping class, the producer's accuracy improves 82%, and the user's accuracy increases to 79%.

Open paper birch-aspen forest (I.B.2.X.)

Classification. Tree canopy cover is 25 to 59% with paper birch and *Populus tremuloides* (quaking aspen), individually or combined, with greater than 50% of the total tree cover (Figures 28a and b).



Figure 28a. Open paper birch-aspen forest (30-35% paper birch on south aspect sideslope)



Figure 28b. Open paper birch-aspen forest (30-35% paper birch on south aspect sideslope)

Class description. The *open paper birch-aspen forest* map class is concentrated in the interior forested lowlands and uplands ecoregion of GAAR ([Figures 3a and 3b](#)). The map class primarily occurs on colluvial and glacial drift sideslopes, but also occupies floodplains and alluvial deposits, eolian deposits, and glacial outwash. The soils are generally mesic and well drained. These stands can reach over 1,600 feet in elevation ([Appendix 2](#)) and have up to a 70° slope. This map class covers 0.2% of the park ([Table 9](#)).

The *open paper birch-aspen forest* map class occurs in the same areas and adjacent to the *closed paper birch-aspen forest* map class. The open stands are more common than closed stands. Needleleaf forest, balsam poplar and tall shrub map classes are also typically found adjacent to the *open paper birch-aspen forest* map class. Needleleaf forests mix with the map class on gentle to moderate sideslopes, balsam poplar mixes with these stands on floodplains, and tall shrub map classes—dominated by alder and willow—grade into the map class on the upper mountain slopes. The map class has a patchy distribution with an average size of 6.2 acres and ranging up to 338 acres ([Table 12](#)).

Paper birch and *Populus tremuloides* (quaking aspen) form a mixed overstory in most stands. In canopy openings, a wide variety of understory species are present, including *Alnus crispa* (American green alder) and *Salix glauca* (grayleaf willow). Additional species include *Vaccinium vitis-idaea* (low bush cranberry), *Rosa acicularis* (prickly rose), *Ledum palustre* (Labrador tea), and *Spiraea beauverdiana* (Alaska spiraea). Mosses, such as *Hylocomium splendens* (feather moss), may be present in high quantities, and fruticose and crustose lichens grow in moderate quantities. The larger canopy breaks of the map class versus the *closed paper birch-aspen forest* class allows for a higher percentage of the vegetation cover to be tall alder and willow. Other species associated with these stands are quite similar to those found in the *closed paper birch-aspen forests* map class.

Interpretation key. The *open paper birch-aspen forest* class is not described in the Alaska Vegetation Classification. It was not found to be spectrally distinguishable from the *open balsam poplar forest* class. However, it could be modeled fairly well based on slope. *Open paper birch-aspen forest* was only observed in upslope areas, while *open balsam poplar forest* was only observed along riparian corridors (with the rare exception of limited balsam poplar in some upland drainages in the Kobuk Boot/Walker Lake area). The two classes were therefore separated through modeling upslope/floodplain with the slope data layer.

Accuracy assessment and mapping issues. The producer's accuracy for the *open paper birch-aspen forest* class was 75%, with a user's accuracy of 42% ([Table 10b](#)). Errors of commission and omission were due primarily to confusion with the *open balsam poplar forest* class and the *open tall shrub* class. Slope was used to model these classes based on the assumption that balsam poplar occurred only in floodplain (minimal slopes) while aspen-birch occurred only on upslope areas. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 3 sites within GAAR. Because limited training samples were available for the *open paper birch-aspen forest* class, raster editing based on review of the FirePro and 1998 field data, image annotations, and image interpretation (with CIR spot checking) was relied on for improving this class. The Landsat TM 4,5,3 (RGB) signatures for this class are light orange-red, with increasing red and orange brightness corresponding to higher density of tall shrub or low shrub understory. When considering all the closed and open broadleaf forest classes as a single broadleaf forest mapping class, the producer's accuracy becomes 82%, and the user's accuracy increases to 79%.

Open balsam poplar forest (I.B.2.C.)

Classification. Tree canopy cover is 25 to 59% and balsam poplar has greater than 50% of the total tree cover (Figures 29a and b).



Figure 29a. Open balsam poplar forest (40% balsam poplar) with thick alder shrub understory



Figure 29b. Open balsam poplar forest (40% balsam poplar) with thick alder shrub understory

Class description. The map class is concentrated in the interior forested lowlands and uplands ecoregion of GAAR but also occurs in the Brooks Range ecoregion ([Figures 3a and 3b](#)). It covers 0.09% of the park ([Table 9](#)). This map class is similar to the *closed balsam poplar forest* map class. Open stands, however, are more common within GAAR than closed stands. They grow almost exclusively on floodplains and occasionally on uplands in the Kobuk boot area. The soils are typically well-drained with a high sand or gravel content. Slope is minimal with maximum elevations of about 1,800 feet in the sites sampled ([Appendix 2](#)). These areas undergo periodic flooding and support small discontinuous stands of the map class. The map class has a patchy distribution with an average size of 5 acres and ranging up to 72 acres ([Table 12](#)).

The overstory of the *open balsam poplar forest* map class is almost exclusively comprised of balsam poplar (*Populus balsamifera*). Tree height reaches up to 50 feet. *Alnus crispa* (American green alder), *Alnus tenuifolia* (thinleaf alder), *Salix monticola* (park willow), and *Salix alaxensis* (feltleaf willow) occur in crown cover breaks along with small quantities of *Picea glauca* (white spruce). Forb representation in these stands includes *Equisetum* species, *Galium boreale* (northern bedstraw), *Hedysarum alpinum* (Eskimo potato), *Viburnum edule* (high bush cranberry), and *Rumex arcticus*. Graminoids include *Calamagrostis canadensis* (bluejoint grass), *Agrostis* species, and *Hierochloa alpina* (alpine holy grass). Mosses and lichens are also present in varying amounts, ranging from 3 to 40%. Some of the moss species are *Dicranum* species, *Drepanocladus* species, and *Rhytidiadelphus triquetrus*. In the sampled stands of *open balsam poplar forest*, slightly higher percentages of both mosses and lichens were noted relative to the closed stands.

Interpretation key. The *open balsam poplar forest* class was not spectrally distinguishable from the *open paper birch-aspen forest* class. However, it could be modeled fairly well based on slope. Balsam poplar was only observed along riparian corridors, and the two classes were separated on this basis. Small amounts of balsam poplar have been noted to occur on uplands in the Kobuk Boot area in the vicinity of Walker Lake.

Accuracy assessment and mapping issues. The producer's accuracy for the *open balsam poplar forest* class was 20%, with a user's accuracy of 63% ([Table 10b](#)). Errors of commission and omission were primarily due to confusion with the *open paper birch-aspen forest* class and the *open tall shrub* class. Slope was used to model these classes based on the assumption that balsam poplar occurred only in floodplain (minimal slopes) while aspen-birch occurred only on upslope areas. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 4 sites within GAAR. Because limited training samples were available for the *open balsam poplar forest* classes, raster editing based on review of the FirePro and 1998 field data, image annotations, and image interpretation (with

CIR spot checking) was relied on for improving these classes. The Landsat TM 4,5,3 (RGB) signatures for this class were light orange-red, with increasing red and orange brightness corresponding to higher density of tall or low shrub understory. When considering all the closed and open broadleaf forest classes as a single broadleaf forest mapping class, the producer's accuracy becomes 82%, and the user's accuracy becomes 79%.

Closed spruce-broadleaf forest (I.C.1.X.)

Classification. Tree canopy cover is 60 to 100% with needleleaf and deciduous trees each contributing 25 to 75% of the total tree cover (Figures 30a and b).



Figure 30a. Closed spruce-broadleaf forest (20% white spruce, 40% balsam poplar)

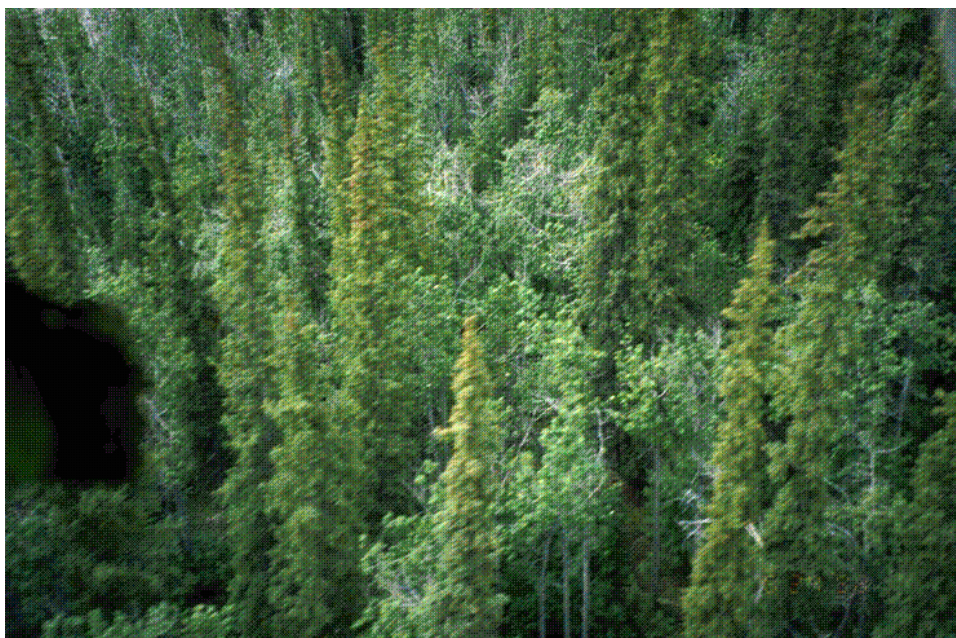


Figure 30b. Closed spruce-broadleaf forest (20% white spruce, 40% balsam poplar)

Class description. This map class is concentrated in the interior forested lowlands and uplands ecoregion ([Figures 3a and 3b](#)), and covers 0.24% of GAAR ([Table 9](#)). These are usually thick stands of trees found on sideslopes and toeslopes. Slopes range from 5° to 50°, and the soils are generally mesic.

White spruce is the most common spruce species, although black spruce occurs, and is mixed with either paper birch, aspen or balsam poplar. Trees within the map class tend to grow in a clumped distribution, therefore open patches in the canopy are frequent and allow for other species to take advantage of the available sunlight. The stand size averages 7 acres and ranges up to 414 acres based on sampled polygons ([Table 12](#)). Low and tall shrubs, such as willow and alder, and herbaceous species grow in the canopy breaks. Mosses generally have low cover values (less than 15%).

Interpretation key. The *closed white spruce-birch* class was not spectrally separable from the *closed white spruce-balsam poplar* class. Some separation of these types based on slope may be possible; however, the significance of this class separation and the degree of error involved in attempting to model it prompted us to group these two classes into the *closed spruce-broadleaf forest* class.

Accuracy assessment and mapping issues. The producer's accuracy for the *closed spruce-broadleaf forest* class was 57%, with a user's accuracy of 88% ([Table 10b](#)). Errors of commission and omission were due primarily to confusion with the *open spruce broadleaf forest* and the *open white spruce-like forest* sites with a significant

tall shrub (predominantly alder) understory. The spruce-broadleaf forest classes were by definition spectrally mixed, and were very difficult to separate spectrally from open spruce forests with close tall shrub understory. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 7 sites within GAAR. Manual editing based on review of the FirePro and 1998 field data, image annotations, and image interpretation (with CIR spot checking) was relied on for improving these classes.

Because this class was relatively rare, efforts were made during field work to make extensive image annotations identifying areas of *closed spruce-broadleaf forest*. The Landsat TM 4,5,3 (RGB) signatures for this class were deep brownish orange-red, with increases in red and orange brightness corresponding to higher broadleaf components, and darker browns/reds corresponding to higher spruce components. When considering all the *closed* and *open spruce-broadleaf forest* classes as a single mixed spruce-broadleaf forest mapping class, the producer's accuracy becomes 77%, while the user's accuracy is 93%.

Open spruce-broadleaf forest (I.C.2.Y.)

Classification. Tree canopy cover is 25 to 59% and needleleaf and deciduous trees each contribute 25 to 75% of the total tree canopy cover (Figures 31a and b).



Figure 31a. Open spruce-broadleaf forest (10% spruce, 15-20% paper birch)



Figure 31b. Open spruce-broadleaf forest (10% spruce, 15-20% paper birch)

Class description. The *open spruce-broadleaf forest* map class is concentrated in the interior forested lowlands and uplands ecoregion of GAAR (Figures 3a and 3b), and covers 0.3% of the park (Table 9). When white spruce is the dominant spruce species, the map class is found on colluvial and glacial drift sideslopes and toeslopes. Slope averaged 13° , and elevation ranges from 840 feet to about 2,410 feet. Soils are generally mesic. On sites where black is dominant, the soils are mesic to wet.

Both black spruce and white spruce occur in the overstory mixed with aspen, paper birch or balsam poplar. The trees tend to grow in a clumped distribution, therefore open patches in the canopy are frequent and allow for other species to take advantage of the available sunlight. Both alder and willow grow in the canopy breaks. The average stand size is 6.8 acres and ranges up to 222 acres (Table 12).

Interpretation key. The *open black spruce-broadleaf* and *open white spruce-broadleaf* classes were not spectrally separable. Because there can be a fair amount of mixing of black spruce and white spruce within the needleleaf components of these mixed spruce-broadleaf stands, modeling based on slope and illumination is not likely to improve the mapability of these classes. These two classes were therefore collapsed into a single *open spruce-broadleaf forest* class.

Accuracy assessment and mapping issues. The producer's accuracy for the *open spruce-broadleaf forest* class was 82%, with a user's accuracy of 90% (Table 10b). Errors of commission and omission were due primarily to confusion with the *closed spruce broadleaf forest* and the *open white* and *open black spruce-like forest* classes.

The spruce-broadleaf forest classes were by definition spectrally mixed, and were very difficult to separate spectrally from open spruce forests with tall shrub understory. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 9 sites within GAAR. Manual editing based on review of the FirePro and 1998 field data, image annotations, and image interpretation (with CIR spot checking) was relied on for improving these classes. Because this class was relatively rare, efforts were made during field work to make extensive image annotations identifying areas of *open spruce-broadleaf forest*. The Landsat TM 4,5,3 (RGB) signatures for this class are deep brownish orange-red, with increases in red and orange brightness corresponding to higher broadleaf components, and darker browns/reds corresponding to higher spruce components. When considering all the *closed* and *open spruce-broadleaf forest* classes as a single mixed spruce-broadleaf forest mapping class, the producer's accuracy is 77%, and the user's accuracy is 93%.

Closed tall shrub (II.B.1.)

Classification. Tall shrub (>3.5 feet tall) cover is 75 to 100%. Tree canopy cover is less than 10% or absent (Figures 32a and b).



Figure 32a. Closed tall alder shrub on steep side slope with scattered white spruce and paper birch



Figure 32b. Closed tall alder shrub on steep side slope with scattered white spruce and paper birch

Class description. This map class is characterized by dense stands of shrubs greater than 3.5 feet tall ranging up to 15 feet and taller. The *closed tall shrub* map class covers 2.9% of GAAR, and occurs in all the ecoregions ([Table 9](#)). Elevation for sampled sites range from about 900 feet up to 3,534 feet ([Appendix 2](#)). It is dominated by nearly pure stands of alder, willow, and resin birch (*Betula glandulosa*), plus mixed alder-willow sites—the four groupings are described below. The average site size is 10.6 acres and ranges up to 1,355 acres ([Table 12](#)).

Alder. Sites dominated by alder within the *closed tall shrub* map class are found on steep colluvial and glacial drift sideslopes averaging 25° and reaching an elevation of over 1,100 feet. It is also found on gentle toeslopes, and on recent floodplain deposits. Alder generally inhabits floodplains of narrow valleys in contrast to tall willow dominated sites that grow in broad valleys. Alder can reach a height of over 10 feet and grows on soils that are generally mesic. Alder is concentrated in the south portion of the Brooks Range ecoregion and the interior forested lowlands and uplands ecoregion ([Figures 3a and 3b](#)).

Alder grows adjacent to needleleaf map classes on the toeslopes and mountain sideslopes. On the upper slopes it grows adjacent to both prostrate and low shrub map classes. Within the *closed tall shrub* map class alder is often found next to tall willow.

Both *Alnus crispa* (American green alder) and *Alnus sinuata* (Sitka alder) are found in these sites. *Alnus crispa* is more common on the floodplains than *Alnus sinuata*. Plants associated with alder dominated sites include *Vaccinium uliginosum* (bog blueberry), *Vaccinium vitis-idaea* (low bush cranberry), *Betula nana* (dwarf arctic birch) or *Betula glandulosa* (resin birch), *Spiraea beauverdiana* (Alaska spiraea), *Salix alaxensis* (feltleaf willow), and other *Salix* (willow) species. Mosses include *Sphagnum* (peat moss) species, *Hylocomium splendens* (feather moss), and *Dicranum* species. Grasses, sedges and lichens also occur.

Resin birch. Resin birch (*Betula glandulosa*) was included within the *closed tall shrub* map class because occasionally it grows upslope in such thick tall stands that it is spectrally similar to alder shrub. These resin birch stands generally reach an elevation higher than that of alder and may be found adjacent to them. Species composition of resin birch dominated stands is similar to the alder dominated sites.

Willow. Nearly pure stands of willow occur within the *closed tall shrub* map class. These willow-dominated sites occur throughout GAAR in all three ecoregions (Figures 3a and 3b). In contrast to the alder dominated sites, they are frequently found in the northern portion of the park. Although they occur on colluvial and glacial till sideslopes, this mapping class is primarily found on the sandy deposits of braided streams, particularly in the northern portion of GAAR. These floodplains have dry, well drained soils. When growing on sideslopes, willow may inhabit fairly steep slopes at high elevation (3,000 feet). Both open and closed stands of willow occur adjacent to needleleaf forests.

Alder-willow. Mixed sites of alder and willow occur within the *closed tall shrub* map class. The sites are often composed of patches of pure willow or pure alder. This type is primarily found on colluvial and glacial drift sideslopes, ranging from gentle to steep (5° to 55°). Mixed alder and willow is commonly found adjacent to needleleaf forests and shrub map classes.

Species associated with willow dominated and mixed alder and willow sites include *Alnus crispa* (American green alder), *Alnus sinuata* (Sitka alder), *Salix alaxensis* (feltleaf willow), *Salix glauca* (grayleaf willow), *Salix lanata* subspecies *richardsonii* (Richardson willow), *Spiraea beauverdiana* (Alaska spiraea), *Potentilla fruticosa* (shrubby cinquefoil), *Empetrum nigrum* (crowberry), *Ribes triste* (red currant), and *Vaccinium uliginosum* (bog blueberry). Both white spruce and black spruce as well as paper birch occur in small quantities, as do moss species.

Plant associations. Two plant associations within this landcover class were defined and described: *Betula glandulosa* (resin birch), and Lichen-*Betula glandulosa*.

However, other undescribed plant associations occur including *Salix alaxensis* (feltleaf willow), *Salix lanata* subspecies *richardsonii* (Richardson willow), *Salix glauca* (grayleaf willow), *Alnus crispa* (American green alder), and *Alnus sinuata* (Sitka alder).

Interpretation key. The *closed tall shrub* class is different than the Alaska Vegetation Classification *closed tall scrub* class. We used >3.5 feet in height as the defining characteristic, whereas the Alaska Vegetation Classification used >4.5 feet. We collected field data using three map classes—*closed alder or birch*, *closed willow* and *closed alder-willow*—but collapsed the classes into the *closed tall shrub* class because they could not be separated spectrally.

Accuracy assessment and mapping issues. The producer's accuracy for the *closed tall shrub* was 86%, with a user's accuracy of 83% (Table 10b). Errors of commission and omission were due primarily to confusion with the *open tall shrub* and the more dense closed canopy *shrub birch-ericaceous-willow* classes. There was also a significant amount of spectral confusion between the *closed tall shrub* class (mainly alder) and the *open* and *closed paper birch-aspen forest* classes in the southern portions of the buffered GAAR area, particularly in the 10-mile buffer area around the park (where ground reference data was very limited). These problems were in relatively small areas and were mainly errors of omission for the broadleaf forest classes (and commission for the tall shrub classes). Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 34 sites within GAAR. Because of the large number and dispersion of tall closed shrub signatures, and also the large number of *shrub birch-ericaceous-willow* signatures, the spectral classification was relied on heavily for separating these two classes. In confused problem areas (usually in valleys and transitions between upslope and floodplain areas) manual edits were implemented based on the review of the FirePro and 1998 field data, image annotations, and image interpretation. Landsat TM 4,5,3 (RGB) signatures for this class were bright orange-red, and very similar to signatures for the broadleaf forest types. When considering both the *closed* and *open tall shrub* classes as a single tall shrub mapping class, the producer's accuracy becomes 77%, while the user's accuracy increases to 93%.

Open tall shrub (II.B.2.)

Classification. Total tall shrub (>3.5 feet tall) cover is 25 to 74% with shrubs at least 3.5 feet in height (Figures 33a and b). Tree canopy cover is less than 10% or absent.



Figure 33a. Open tall shrub (alder) on upslope, with patches of closed tall shrub as well



Figure 33b. Open tall shrub (alder) on upslope, with patches of closed tall shrub as well

Class description. The *open tall shrub* map class covers 3% of GAAR, and occurs in all three ecoregions. This class is similar in distribution and species composition to the *closed tall shrub* map class. It is characterized by open stands of shrubs greater than 3.5 feet tall ranging up to 15 feet. The map class is dominated by nearly pure stands of alder and willow species, plus mixed alder-willow sites—the three groupings are described below. The average site size is 9.2 acres and ranges up to 834 acres ([Table 12](#)).

Alder. Sites dominated by alder within the *open tall shrub* map class are found on steep colluvial and glacial drift sideslopes as well as gentle toeslopes and floodplains. It is frequently found in narrow valleys rather than broad valleys. The slope of sampled sites tended to be slightly higher for open alder sites (40°) versus closed alder sites (25°). Open alder sites were found reaching higher elevations (4,029 feet) on sampled sites than closed alder sites (3,524 feet) ([Appendix 2](#)). Soils are generally mesic. The tall shrubs tend to grow in a clumped distribution, therefore open patches in the canopy are frequent and allow for other species to take advantage of the available sunlight. Alder dominated sites grow adjacent to needleleaf map classes on the toeslopes and mountain sideslopes, and occur next to prostrate shrub and low shrub map classes on the upslope. Sites dominated by tall willow are also commonly found adjacent to alder dominated sites. They are concentrated in the south portion of the Brooks Range, in both the Brooks Range ecoregion and the interior forested lowlands and uplands ecoregion ([Figures 3a and 3b](#)).

Alnus crispa (American green alder) and *Alnus sinuata* (Sitka alder) both occur and reach a height of over 10 feet. *Alnus crispa* is more common on the floodplains than *Alnus sinuata*. Plants associated with alder dominated sites include *Vaccinium uliginosum* (bog blueberry), *Vaccinium vitis-idaea* (low bush cranberry), *Betula nana* (dwarf arctic birch) or *Betula glandulosa* (resin birch), *Ledum palustre* (Labrador tea), *Empetrum nigrum* (crowberry), *Equisetum* (horsetail) species, *Spiraea beauverdiana* (Alaska spiraea), *Dryas* species, *Cassiope tetragona* (four-angled cassiope), *Salix glauca* (grayleaf willow), and other *Salix* (willow) species. Mosses include *Sphagnum* (peat moss) species, *Hylocomium splendens* (feather moss), and *Dicranum* species. Grasses and sedges as well as lichens also occur.

Willow. Sites dominated by willow within the *open tall shrub* map class are more common than closed tall willow sites within GAAR. Both open and closed willow sites are found adjacent to needleleaf forests. Willow is primarily found on the sandy well drained deposits of braided streams, particularly in the northern portion of GAAR. It also occurs on colluvial and glacial till sideslopes. Stands of willow within the map class occur in all the ecoregions of GAAR. *Betula nana* (dwarf arctic birch) or *Betula glandulosa* (resin birch) are commonly associated with sites dominated by willows.

Alder and willow. Mixed stands of alder and willow occur within the *open tall shrub* map class. These sites are primarily found on colluvial and glacial drift sideslopes ranging from 0° to 35° on sampled sites. The mixed alder-willow dominated sites are found adjacent to needleleaf forests and tall shrub map classes. Within these sites, the alder and willow tends to grow in a clumped distribution.

Species associated with the mixed alder-willow dominated sites include *Spiraea beauverdiana* (Alaska spiraea), *Potentilla fruticosa* (shrubby cinquefoil), *Empetrum nigrum* (crowberry), *Equisetum* (horsetail) species, *Alnus crispa* (American green alder) and *Alnus sinuata* (Sitka alder), *Vaccinium uliginosum* (bog blueberry), *Salix alaxensis* (feltleaf willow), *Salix barclayi* (Barclay willow) and other *Salix* (willow) species. *Picea glauca* (white spruce) and *Picea mariana* (black spruce) as well as *Betula papyrifera* (paper birch) occur in small quantities. Mosses are common.

Plant associations. Described plant associations within this landcover class are *Salix alaxensis* (feltleaf willow), *Salix lanata* subspecies *richardsonii*/*Carex membranacea*, and *Salix lanata* subspecies *richardsoni* (Richardson willow). However, other undescribed plant associations occur including *Salix glauca* (grayleaf willow), *Alnus crispa* (American green alder), and *Alnus sinuata* (Sitka alder).

Interpretation key. The *open tall shrub* class is also different than the Alaska Vegetation Classification *open tall scrub* class. We used >3.5 feet in height as the defining characteristic, whereas the Alaska Vegetation Classification used >4.5 feet. We collected field data using three map classes—*open alder*, *open willow* and *open alder-willow*—but collapsed the classes into the *open tall shrub* class because they

could not be separated spectrally.

Accuracy assessment and mapping issues. The producer's accuracy for the *open tall shrub* class was 60%, with a user's accuracy of 83% (Table 10b). Errors of commission and omission were due primarily to confusion with the *closed tall shrub* and the *shrub birch-ericaceous-willow* and *shrub birch-willow-tussock tundra* classes. The confusion with these low shrub classes was found mainly on partial terrain shadowed areas, where the low shrub classes were in significant abundance as the understory. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 45 sites within GAAR.

Incorporation of the illumination (shaded relief) data in the supervised spectral classification reduced this confusion; however, this class did require substantial editing based on review of the FirePro and 1998 field data, image annotations, and image interpretation. Landsat TM 4,5,3 (RGB) signatures for this class were medium to dull orange-red. The dull orange red signature was usually indicative of a more *open tall shrub* with low shrub dominating the understory, and also could be attributed to partial terrain shadow effects. When considering both the *open* and *closed tall shrub* classes as a single tall shrub mapping class, the producer's accuracy becomes 77%, while the user's accuracy increases to 90%.

Shrub birch-willow-tussock tundra (II.C.2.X.)

Classification. Shrub height is between 0.3 to 3.5 feet tall and is greater than 25% of the total vegetation cover (Figures 34a and b). Tussocks cover greater than 25% of the site. Tall shrub (>3.5 feet tall) cover is less than 25%, and tree canopy is less than 10% or absent.



Figure 34a. Shrub birch-willow-tussock tundra

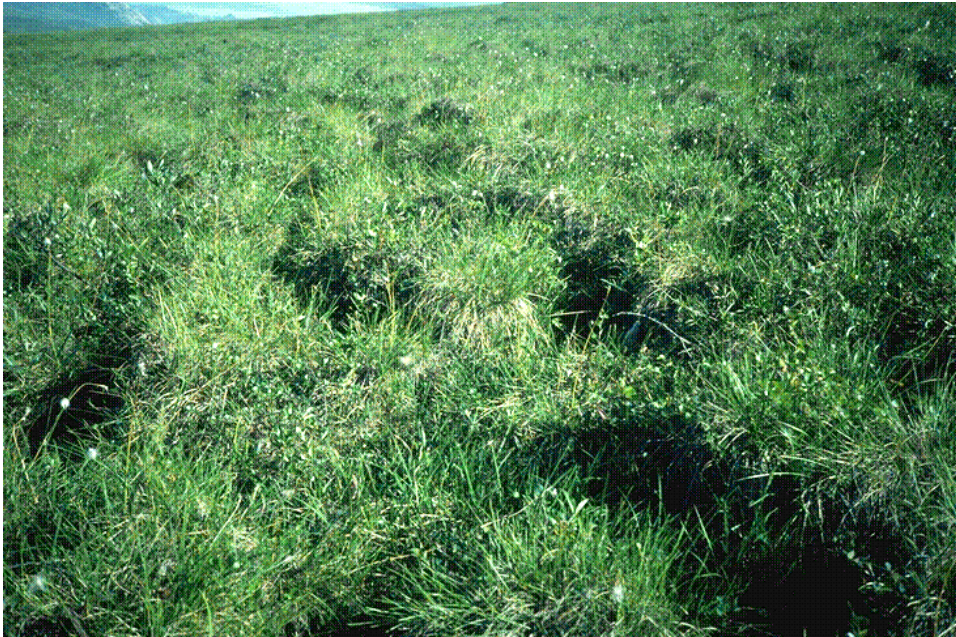


Figure 34b. Shrub birch-willow-tussock tundra

Class description. This mapping class covers 6.7% of GAAR (Table 9) and is extremely common in the arctic foothills ecoregion (Figures 3a and 3b). It is found on a broad range of surficial geology types including floodplains, colluvial sideslopes and glacial drift sideslopes. Slopes on the sites sampled ranged from 0° to 10°, with elevation ranging between 610 and 3,363 feet (Appendix 2). The *shrub birch-willow-tussock tundra* map class is found adjacent to the *shrub birch-ericaceous-willow*, *mesic herbaceous*, and *closed low willow*, and occasionally adjacent to the tall shrub and *wet herbaceous* classes. The average site size is 17 acres and includes huge expanses of tundra ranging up to 33,136 acres (Table 12).

As its name implies, the *shrub birch-willow-tussock tundra* map class contains tussocks—at least 25% of the total cover. Tussocks are sedges comprised of many stems arising from a central crown. They reach 24 inches in height, but are typically only 8 inches tall. Shrub layers associated with tussock tundra may be close to prostrate height or grow as high as 4 feet tall. Shrub birch species (*Betula nana* or *Betula glandulosa*) and willow (*Salix* species) generally decrease in height as you move north.

Species diversity is relatively low within the mapping class. In the overstory, commonly found plants include *Spiraea beauverdiana* (Alaska spiraea), *Betula nana* (dwarf arctic birch) or *Betula glandulosa* (resin birch), *Salix lanata* subspecies

richardsonii (Richardson willow) and *Salix planifolia* subspecies *pulchra* (diamondleaf willow). Ericaceous shrubs are also present including *Vaccinium uliginosum* (bog blueberry), *Ledum palustre* (Labrador tea), and *Arctostaphylos rubra* (red-fruit bearberry). Tussock forming graminoids include *Carex aquatilis* (water sedge), *Carex bigelowii* (Bigelow sedge), *Eriophorum vaginatum* (tussock cottongrass), and *Calamagrostis canadensis* (bluejoint grass). Mosses and lichens found within the map class include *Sphagnum* (peat moss) species, *Hylocomium splendens* (feather moss), and *Cladina* species.

Plant associations. The following plant associations were defined for the *shrub birch-willow-tussock tundra* mapping class: *Betula glandulosa*/*Carex aquatilis*, *Betula glandulosa*/*Carex bigelowii*, *Betula glandulosa*/*Eriophorum russeolum*, *Vaccinium uliginosum*-*Ledum palustre*/*Carex bigelowii*, *Vaccinium uliginosum*-*Ledum palustre*/*Eriophorum vaginatum*, *Vaccinium uliginosum*-*Ledum palustre*/*Eriophorum russeolum*, *Salix lanata* subspecies *richardsonii*/*Carex bigelowii*, *Salix planifolia* subspecies *pulchra*/*Carex aquatilis*, *Salix planifolia* subspecies *pulchra*/*Eriophorum russeolum*, and *Salix planifolia* subspecies *pulchra*/*Carex bigelowii*.

Interpretation key. The overall low shrub category is slightly different than the Alaska Vegetation Classification level II *low scrub* category. We used 0.3 to 3.5 feet in height as the defining characteristic, whereas the Alaska Vegetation Classification used 0.3 to 4.5 feet. The *shrub birch-willow-tussock tundra* map class is not defined in the Alaska Vegetation Classification.

Accuracy assessment and mapping issues. The producer's accuracy for the shrub birch-willow-tussock tundra class was 64%, with a user's accuracy of 77% (Table 10b). Errors of commission and omission were due primarily to confusion of *shrub birch-ericaceous-willow* class and to a lesser extent with the *prostrate shrub* (with a relatively large herbaceous component) or the *mesic herbaceous* (with a relatively large shrub component). Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 52 sites within GAAR. Because of the high number of training signatures for *shrub birch-willow-tussock tundra*, *mesic herbaceous* and low *shrub birch-ericaceous-willow*, the spectral based classification was relied on as the primary discriminator between these classes. Manual editing based on review of the FirePro and 1998 field data, image annotations, and image interpretation was marginally successful and implemented on a limited scale. However, manual edits were limited to to ensure map consistency. There was also confusion north of treeline with the *wet herbaceous* class. The Landsat TM Band 5 was used to threshold actual wet herbaceous from those sites that were either *shrub birch-ericaceous-willow* (or *mesic herbaceous*). The wettest *shrub birch-willow-tussock tundra* sites were usually spectrally separable from the drier of the *shrub birch-ericaceous-willow* sites (however, these wet tussock tundra sites were usually confused with the *mesic* or *wet herbaceous* classes). Finally, there were some commission errors with the woodland classes. Part of this confusion was often due to partial terrain shadow. Another factor believed to contribute to commission errors in woodland areas is relatively low spruce cover (10-15%) with understory dominated by low shrub. Models using winter imagery were used to reduce this error. Landsat TM 4,5,3 (RGB) signatures for this class are quite variable and included a dull orange-red, medium red, and whitish orange. The variation in spectral response was typically due to the variations in site moisture (increased water resulted in a darker/grayer signature), herbaceous component (generally increase red tones in signature) and lichen or moss understory (generally results in whitening/lightening of signatures). Partially senesced herbaceous or willow components of the *shrub birch-willow-tussock tundra* class in the arctic foothills ecoregion also may have contributed to the whitening of sites in this region. When considering the *shrub birch-willow-tussock tundra*, *shrub birch-ericaceous-willow*, and *closed low willow shrub* classes a single low shrub mapping class, the producer's accuracy is 82%, while the user's accuracy is 87%.

Shrub birch-ericaceous-willow (II.C.X.)

Classification. Shrub height is 0.3 to 3.5 feet with greater than 25% of the vegetation cover as low shrub (Figures 35a and b). Less than 25% of the site is covered by

tussocks, less than 2/3 of the total low shrub cover is willow, and less than 75% of the total shrub cover is shrub birch. Tree canopy cover is less than 10% or absent.



Figure 35a. Shrub birch-ericaceous-willow in valley (50% dwarf birch, 25% prostrate shrub)



Figure 35b. Shrub birch-ericaceous-willow in valley (50% dwarf birch, 25% prostrate shrub)

Class description. The *shrub birch-ericaceous-willow* class differs from the *shrub birch-willow-tussock tundra* map class in that it is drier—but still mesic—it has less than 25% tussocks, and it has a different herbaceous species composition. However, the shrub layer is similar. It is found growing on valley bottoms, floodplains, toeslopes, and colluvial and glacial drift sideslopes surfaces with 0° to 45° slope. Elevations for sites sampled range from about 300 to 4,800 feet ([Appendix 2](#)). The sites are generally mesic sites, often with small amounts of standing water present. On these wetter sites, the willow species grow on the dryer portions (mounds), and more hydrophilic vegetation (such as *Carex aquatilis*) concentrates in the troughs. The map class covers 15.2% of GAAR ([Table 9](#)), and is found in all three ecoregions ([Figures 3a and 3b](#)). The average site size is 22.5 acres and includes huge expanses of tundra ranging up to 47,603 acres ([Table 12](#)).

Shrub species commonly found within this mapping class include *Betula nana* (dwarf arctic birch) or *Betula glandulosa* (resin birch), *Vaccinium uliginosum* (bog blueberry), *Ledum palustre* (Labrador tea), *Andromeda polifolia* (bog rosemary), *Vaccinium vitis-idaea*, *Empetrum nigrum* (crowberry), *Salix planifolia* subspecies *pulchra* (diamondleaf willow), and *Loiseleuria procumbens* (alpine azalea). Some sites are dominated by willow, primarily *Salix planifolia* subspecies *pulchra* (diamondleaf willow), *Salix lanata* subspecies *richardsonii* (Richardson willow), *Salix brachycarpa* (barren-ground willow), and *Salix myrtillifolia* (low blueberry willow). Herbaceous species include *Eriophorum* species, *Calamagrostis canadensis* (bluejoint grass), *Carex bigelowii* (Bigelow sedge), and *Carex aquatilis* (water sedge). Lichen and mosses also commonly occur.

Plant associations. Plant associations within the *shrub birch-ericaceous-willow* landcover class are *Betula glandulosa*, *Lichen-Betula glandulosa*, *Vaccinium uliginosum-Ledum palustre/Sphagnum*, *Vaccinium uliginosum-Ledum palustre*, and *Salix planifolia* subspecies *pulchra* (open).

Interpretation key. The overall low shrub category is slightly different than the Alaska Vegetation Classification level II *low scrub* category. We used 0.3 to 3.5 feet in height as the defining characteristic, whereas the Alaska Vegetation Classification used 0.3 to 4.5 feet. The *shrub birch-ericaceous-willow* and *open low willow* classes used for mapping in the field were collapsed into the *shrub birch-ericaceous-willow* class because each class could not be separated spectrally. The *shrub birch-ericaceous-willow* map class is not defined in the Alaska Vegetation Classification.

Accuracy assessment and mapping issues. The producer's accuracy for the *shrub birch-ericaceous-willow* class was 75%, with a user's accuracy of 74% ([Table 10b](#)). Errors of commission and omission were due primarily to confusion with the *shrub birch-willow-tussock tundra* class and to a lesser extent with the *mesic herbaceous* (with a relatively large low shrub component) and the *spruce woodland* class (also with a relatively large low shrub component). Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for

176 sites within GAAR. Because of the high number of training signatures for *shrub birch-ericaceous-willow*, *shrub birch-willow-tussock tundra*, and *mesic herbaceous* classes, the spectral based classification was relied on as the primary discriminator between these classes. Modeling with NDVI was effective at reducing the commission errors with the *prostrate shrub* classes. Manual editing based on review of the FirePro and 1998 field data, image annotations, and image interpretation was marginally successful and implemented on a limited scale. However, manual edits were limited to ensure map consistency. There were also some commission errors with the open spruce and woodland classes. Part of this confusion was due to partial terrain shadow altering the signatures for *shrub birch-ericaceous-willow* for sites sampled in these terrain conditions. Another factor believed to contribute to commission errors in woodland areas is relatively low spruce cover (10-15%) with understory dominated by low shrub. Models using winter imagery were less effective at reducing this error (because the *shrub birch-ericaceous-willow* can realistically occur intermixed with open spruce or woodland mapping areas). Landsat TM 4,5,3 (RGB) signatures for this class were quite variable and include a dull orange-red, medium red, and whitish-orange colors. The variation in response was typically due to the variations in site moisture (generally more water results in a darker/grayer the signatures), herbaceous component (generally more herbaceous vegetation increases red tones in the signatures) and lichen or moss understory (generally more lichen or moss results in whitening/lightening of signatures). Partially senesced herbaceous or willow components of the *shrub birch-ericaceous-willow* class in the Arctic Foothills are also believed to contribute to the “bleaching” of sites in this region. When considering the *shrub birch-willow-tussock tundra*, *shrub birch-ericaceous-willow*, and *closed low willow shrub* classes a single low shrub mapping class, the producer’s accuracy is 82%, while the user’s accuracy is 87%.

Closed low willow (II.C.2.B.)

Classification. Shrub height is 0.3 to 3.5 feet with total low shrub cover between 75 to 100% (Figures 36a and b). Less than 25% of the site is covered by tussocks and greater than 2/3 of the total low shrub cover is willow. Tree canopy cover is less than 10% or absent.



Figure 36a. Closed low willow (75% willow)



Figure 36b. Closed low willow (75% willow)

Class description. This is a common map class located in the northern half of GAAR. It is found on the edge of small streams, and the water tracks of tussock tundra hillsides. Many of the small streams have terrace formation. The streams and water

tracks occur on slopes ranging from 0° to 10°. Elevations for sites sampled range from approximately 1,200 to 3,420 feet ([Appendix 2](#)). Hummocks often form due to the presence of *Eriophorum angustifolium* (tall cottongrass) and *Carex aquatilis* (water sedge). The map class covers 0.18% of GAAR ([Table 9](#)). The average site size is 5.2 acres and ranges up to 172 acres ([Table 12](#)).

Salix planifolia subspecies *pulchra* (diamondleaf willow) is the most frequently found willow in *low closed willow* mapping class. It generally grows 2 feet in height although it can reach 6 feet (Viereck 1972). Species commonly found in the map class include *Calamagrostis canadensis*, *Equisetum* (horsetail) species, *Betula nana* (dwarf arctic birch) or *Betula glandulosa* (resin birch), *Eriophorum* species, and *Petasites frigidus* (frigid coltsfoot). Mosses associated with this class are *Sphagnum* (peat moss) species and *Hylocomium splendens* (feather moss).

Plant associations. Only one plant association is described for the *closed low willow* landcover class, *Salix planifolia* subspecies *pulchra* (closed). Other observed plant associations, but not described, include *Salix planifolia* subspecies *pulchra* (diamondleaf willow) with an understory of *Calamagrostis canadensis* (bluejoint grass) (Kobuk Boot region), and, possibly, low growing *Salix alaxensis* (feltleaf willow) and *Salix lanata* subspecies *richardsonii* (Richardson willow) along floodplains on the northern edge of GAAR.

Interpretation key. The overall low shrub category is slightly different than the Alaska Vegetation Classification level II *low scrub* category. We used 0.3 to 3.5 feet in height as the defining characteristic, whereas the Alaska Vegetation Classification used 0.3 to 4.5 feet. The *closed low willow* class has a corresponding class of the same name in the Alaska Vegetation Classification.

Accuracy assessment and mapping issues. The producer's accuracy for the *closed low willow* class was 78%, with a user's accuracy of 58% ([Table 10b](#)). Nearly all errors of commission and omission were due to confusion between the low shrub classes *shrub birch-willow-tussock tundra* class and *shrub birch-ericaceous-willow*, and to a lesser extent with the *prostrate shrub* (with a relatively large herbaceous component) or the *mesic herbaceous* (with a relatively large shrub component). Modeling with NDVI was effective at reducing the commission errors with the prostrate shrub class. Mapping of this class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 11 sites within GAAR. Manual editing based on review of the FirePro and 1998 field data, image annotations, and image interpretation was effective as the *closed low willow* class was usually identifiable in the field data and imagery at the river/stream confluences and along riparian areas. Landsat TM 4,5,3 (RGB) signatures for this class were typically medium red to magenta. The variation in response was typically due to the variations in site moisture (generally more water results in darkening these signatures) and exposed rock/gravel (generally more exposed sand/gravel bars results in increased white tones and bluish-magenta tones in these signatures). When considering the *shrub birch-willow-tussock tundra*, *shrub birch-ericaceous-willow*, and *closed low*

willow shrub classes a single low shrub mapping class, the producer's accuracy is 82%, while the user's accuracy is 87%.

Prostrate shrub-rock (II.D.Y.)

Classification. Shrub height is less than 0.3 feet with total prostrate shrub cover greater than 25% (Figures 37a and b). Bare-ground comprises 33 to 74% of the total cover. The sites contain less than 25% cover of tussocks. Tree canopy is less than 10% or absent.



Figure 37a. Prostrate shrub-rock in arctic foothills (45% dryas, 40% bare rock)



Figure 37b. Prostrate shrub-rock in arctic foothills (45% dryas, 40% bare rock)

Class description. This is a major type—6.1% of GAAR—located throughout the Park on unstable surfaces such as talus slopes, slopes below bedrock outcrops, frost boils on river terraces, areas of intense frost action in high mountain valley floors, rounded mountain ridges (exposed bedrock) with intense frost action, and sorted patterned ground (Table 9). This map class contains sites with a fellfield appearance (broken rock/rubble mixed with prostrate shrubs), as well as areas on steep sideslopes that contain uneven strips of rubble and prostrate vegetation. Soils are a thin layer of dry to mesic sand, litter, or organic mat interspersed with exposed rock. Rock and bare-ground cover ranges from 33 to 74%, while prostrate shrubs, lichens and forbs comprise the remainder. Slopes range from 0° to 50°. Elevation of sites sampled ranged from 1,030 to 5,423 feet (Appendix 2). The average site size is 15.3 acres and includes large areas ranging up to 8,065 acres (Table 12).

Characteristic vegetation includes *Dryas octopetala* (white mountain avens), *Salix phlebophylla* (skeletonleaf willow), *Salix reticulata* (netleaf willow), *Silene acaulis* (moss campion), *Pedicularis* species, *Diapensia lapponica* (Lapland diapensia), *Loiseleuria procumbens* (alpine azalea), and *Arctostaphylos alpina* (alpine bearberry). Both crustose and fruticose lichens are present, however crustose lichens dominate the lichen flora. Primarily *Cladina* species, *Cetraria* species, and occasionally *Stereocaulon* species are present.

Plant associations. *Dryas octopetala*-rock is the only plant association described for the *prostrate shrub-rock* map class.

Interpretation key. The overall prostrate shrub class is the same as the Alaska Vegetation Classification level II category *dwarf scrub*. Both use 0.3 feet as the defining height characteristic. For the final map, the *fellfield* class used for field work was renamed *prostrate shrub-rock*.

Accuracy assessment and mapping issues. The producer's accuracy for the *prostrate shrub-rock* was 88%, with a user's accuracy of 93% (Table 10b). Nearly all errors of commission and omission were due to confusion between the *prostrate shrub* and *prostrate shrub-lichen*, and the *sparsely vegetated* class. Models utilizing NDVI were effective at reducing confusion with all of these classes. This class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 45 sites in GAAR. Landsat TM 4,5,3 (RGB) signatures for this class typically were greenish red or greenish red speckled with orange or brighter red. When considering the *prostrate shrub-rock*, *prostrate shrub-lichen*, and *prostrate shrub* classes a single prostrate shrub mapping class, the producer's accuracy becomes 84%, while the user's accuracy changes to 79%.

Prostrate shrub-lichen (II.D.X.C.)

Classification. Shrub height is less than 0.3 feet with total prostrate shrub cover greater than 25% (Figures 38a and b). Less than 33% of the total cover is bare-

ground and greater than or equal to 25% of total cover is fruticose lichen. These sites contain less than 25% tussocks. Tree cover is less than 10% or absent.

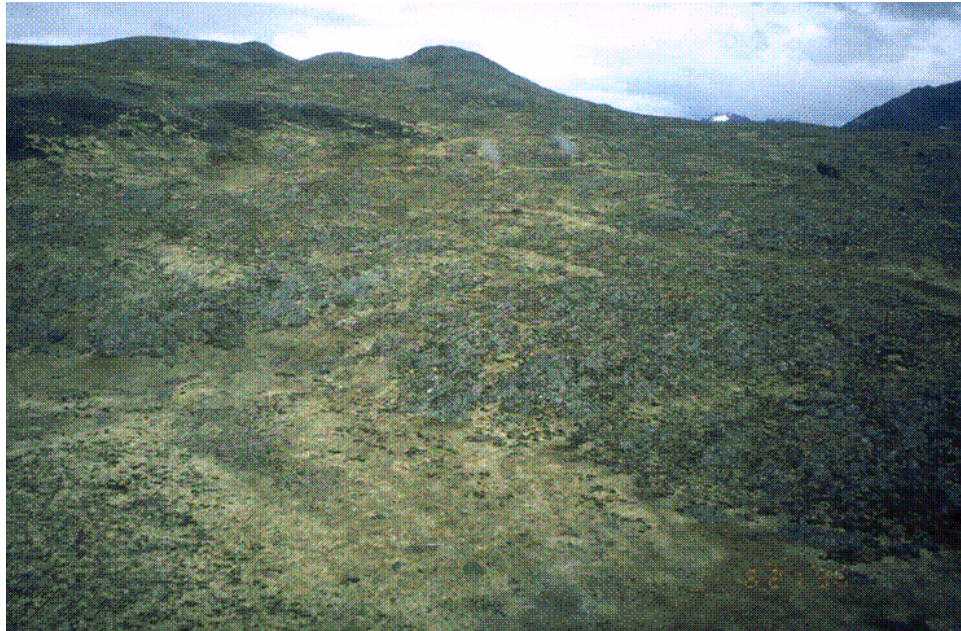


Figure 38a. Prostrate shrub-lichen (30% prostrate shrub, 25% bare rock, 30% lichen)

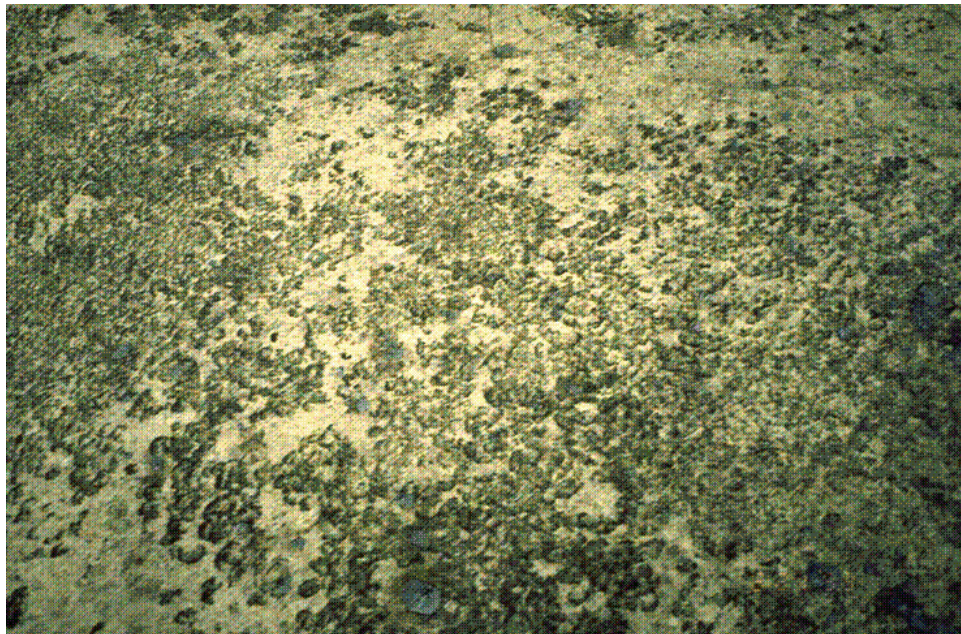


Figure 38b. Prostrate shrub-lichen (30% prostrate shrub, 25% bare rock, 30% lichen)

Class description. The high lichen cover (up to 65% of the total cover) differentiates

this class from other prostrate shrub types. This is a minor type covering 1.2% of GAAR located throughout the Park on relatively stable surfaces including mountain valleys, mountain slopes, rounded mountain ridges (exposed bedrock) and alluvial fans ([Table 9](#)). Slopes range from 0° to 25°. Elevations of sites sampled ranged from about 1,550 to 4,160 feet ([Appendix 2](#)). The soils are a thin duff layer over dry to mesic silt, sand and cobble. Soils are typically dry to slightly mesic. The average site size is 7.6 acres—based on sampled polygons—and ranges up to 787 acres ([Table 12](#)).

Vascular plant cover includes prostrate height shrubs such as *Vaccinium uliginosum* (bog blueberry), *Vaccinium vitis-idaea* (low bush cranberry), *Dryas octopetala* (white mountain avens), *Ledum palustre* (Labrador tea), *Loiseleuria procumbens* (alpine azalea), and *Arctostaphylos rubra* (red-fruit bearberry). *Betula nana* (dwarf arctic birch) or *Betula glandulosa* (resin birch) may also be present and generally grows to a height of 6 to 8 inches. Fruticose lichen genera are *Cladonia*, *Cetraria*, and *Alectoria*.

Plant associations. The *prostrate shrub-lichen* class is comprised of one plant association, *Vaccinium uliginosum*/fruticose lichen.

Interpretation key. The overall prostrate shrub class is the same as the Alaska Vegetation Classification level II category *dwarf scrub*. Both use 0.3 feet as the defining height characteristic. For the final map, the *prostrate-lichen* class used for field mapping was renamed *prostrate shrub-lichen*. This class is comparable to the Alaska Vegetation Classification level IV class *dryas-lichen tundra*.

Accuracy assessment and mapping issues. The producer's accuracy for the *prostrate shrub-lichen* class was 85%, with a user's accuracy of 93% ([Table 10b](#)). Nearly all errors of commission and omission were due to confusion between the *prostrate shrub* class. This class also showed significant confusion with the *sparsely vegetated* class and the *bare-ground* class. This class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 11 sites in GAAR. Models utilizing NDVI were effective at reducing confusion among the confused prostrate shrub classes and *sparsely vegetated* and *bare-ground* classes. Landsat TM 4,5,3 (RGB) signatures for this class typically were white with light reddish orange tones, and was generally fairly unique. However, prostrate shrub sites with relatively high lichen content (20-25%), and relatively low prostrate shrub content (approximately 25-40%) are likely to be misclassified as *prostrate shrub-lichen*. When considering the prostrate shrub-rock, prostrate shrub-lichen, and prostrate shrub classes as a single prostrate shrub mapping class, the producer's accuracy is 84%, while the user's accuracy is 79%.

Prostrate shrub (II.D.X.)

Classification. Shrub height is less than 0.3 feet with total prostrate shrub cover greater than 25% ([Figures 39a and b](#)). Less than 33% of the total cover is bare-

ground, less than 25% of the total cover is fruticose lichen, and less than 25% tussocks. Tree canopy is less than 10% or absent.



Figure 39a. Prostrate shrub (55% prostrate shrub, 25% herbaceous, 10% bare rock, 5% water, 5% moss)



Figure 39b. Prostrate shrub (50%prostrate shrub, 15% herbaceous, 15% lichen, and 5% bare rock)

Class description. *Prostrate shrub* is the predominant shrub type found within alpine

areas of GAAR. It is concentrated within the Brooks Range ecoregion (Figures 3a and 3b), and covers 17.2% of GAAR (Table 9). The map class is found on unstable to stable surfaces such as mountain slopes, high mountain valley floors, rounded mountain ridges (exposed bedrock), the riverside edge of river terraces, and on sorted patterned ground. Slopes range from 0° to 55°, and the elevation typically exceeds 1,600 feet (Appendix 2). The soils are a thin layer of dry to mesic sand, litter or organic mat interspersed with exposed rock. This class often grades into the *sparse vegetation* landcover class and, on more stable sites and downslope, the *prostrate-lichen*, *closed low willow*, *open tall shrub*, and *closed tall shrub* landcover classes. Site size is large averaging 28 acres and ranging up to 16,354 acres (Table 12).

The *prostrate shrub* map class is comprised of vegetation that generally reaches a height of 4 inches or less. The dominant shrub is *Dryas octopetala* (white mountain avens). Other strong associates are *Dryas integrifolia* (entire-leaf mountain-avens), *Salix reticulata* (netleaf willow), *Salix arctica* (arctic willow), *Salix phlebophylla* (skeletonleaf willow), *Cassiope tetragona* (four-angled cassiope), *Vaccinium uliginosum* (bog blueberry), *Arctostaphylos rubra* (red-fruit bearberry), and *Arctostaphylos alpina* (alpine bearberry). Herbaceous vegetation often has high cover values and includes *Carex bigelowii* (Bigelow sedge), *Silene acaulis* (moss campion), *Minuartia* species, *Pedicularis* species, *Boykinia richardsonii*, and *Anemone narcissiflora* (narcissus-flowered anemone). Multiple species of fruticose lichens also occur.

Plant associations. The described plant associations within the *prostrate* landcover class are *Dryas octopetala*/*Carex* species, *Dryas octopetala*, *Dryas octopetala*-*Cassiope tetragona*, *Dryas integrifolia*, and *Salix reticulata*.

Interpretation key. The overall prostrate shrub class is the same as the Alaska Vegetation Classification level II category *dwarf scrub*. Both use 0.3 feet as the defining height characteristic. Two classes, prostrate-herbaceous and prostrate, were used for field mapping, and were collapsed into one class—*prostrate shrub*—after the field season because they could not be separated spectrally.

Accuracy assessment and mapping issues. The producer's accuracy for the *prostrate shrub* class was 77%, with a user's accuracy of 67% (Table 10b). Errors of commission and omission were due to confusion among the *prostrate shrub-rock* and *prostrate shrub-lichen* classes. This class also shows significant confusion *mesic herbaceous*. This class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 127 sites in GAAR. Because of the large number of training samples (signatures) for all of the prostrate classes as well as the *mesic herbaceous* class, the spectral classification was relied on heavily for class discrimination. Models utilizing NDVI were effective at reducing confusion among the confused prostrate shrub classes, and between the *prostrate shrub* and *sparsely vegetated* or *bare-ground* classes. In the higher elevation valleys, *mesic herbaceous* areas were found adjacent to prostrate shrub areas. This confusion was particularly problematic when the herbaceous content of the *prostrate shrub* areas were close to

the 25% upper threshold for the *prostrate shrub* mapping class. Manual editing was for the most part ineffective due to the difficulty of determining shrub/herbaceous components from image interpretation. Based on the Landsat TM 4,5,3 (RGB) signatures for this class typically are orange-red, but may vary considerably. When considering the *prostrate shrub-rock*, *prostrate shrub-lichen*, and *prostrate shrub* classes as a single prostrate shrub mapping class, the producer's accuracy is 84%, while the user's accuracy is 79%.

Dry herbaceous (III.X.1.)

Classification. The dominant vegetation is growing on well drained, dry sites (Figures 40a and b). Herbaceous cover is greater than 25%, tree canopy is less than 10% or absent, and shrub cover is less than 25%.



Figure 40a. Dry herbaceous (clumps of graminoid grasses) on lateral sand dunes along the Killik River

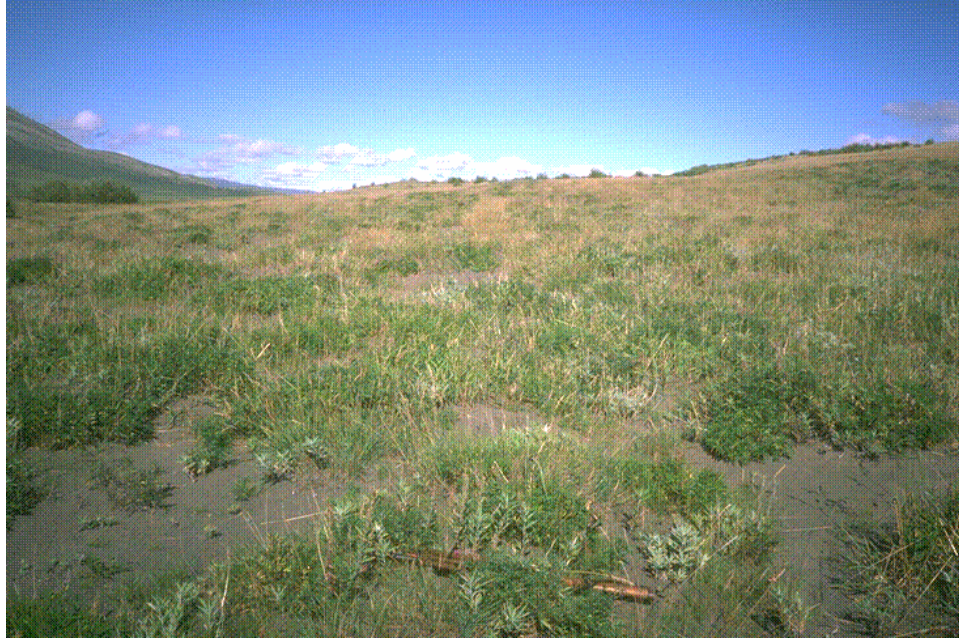


Figure 40b. Dry herbaceous (clumps of grasses) on lateral sand dunes along the Killik River

Class description. The *dry herbaceous* map class is found on well-drained sites with no standing water. It is extremely limited within GAAR found primarily on sand dunes along the Killik River in the north central region of the park. The map class covers <0.01% of GAAR.

Plant associations. No plant associations were described for this class.

Interpretation key. Within the general herbaceous category, graminoids and forbs were combined and the environmental modifiers (dry, mesic, wet and aquatic) were maintained as per the Alaska Vegetation Classification. The GAAR class *dry herbaceous* equals the combined Alaska Vegetation Classification classes dry graminoid herbaceous and dry forb herbaceous.

Accuracy assessment and mapping issues. This class was not found in sufficient quantities to map. It was only observed intermixed with *mesic herbaceous* and low shrub classes on partially stabilized sand dunes along the Killik River north of the Brooks Range.

Mesic herbaceous (III.X.2.)

Classification. The sites are moist and tussocks may dominate ([Figures 41](#)). Permanent standing water is not present. Herbaceous cover is greater than 25%, tree canopy is less than 10% or absent, and shrub cover is less than 25%.



Figure 41. Mesic herbaceous (70% herbaceous, 25% moss, 5% dwarf shrub, 80% tussocks)

Class description. The *mesic herbaceous* map class most primarily occurs in the north half of GAAR on rolling hills, valley bottoms, terraces, and floodplains. It covers 6.2% of the Park ([Table 9](#)), and is a diverse grouping of plant associations that range from *Calamagrostis canadensis* (bluejoint grass) to *Eriophorum russeolum* (russett cottongrass). Upland herbaceous meadows as well as tussock tundra are included in this class. The majority of *mesic herbaceous* sites contain some tussocks.

Standing water may be present in small amounts and is frequently a result of seasonal precipitation fluctuations. These small pools of water are most commonly found within the tussock types. The elevation ranges from 505 to 4,682 feet, and the slope ranges from 0° to 20° ([Appendix 2](#)). The average site size is 11.4 acres—based on sampled polygons—and it often cover huge areas ranging up to 33,393 acres ([Table 12](#)).

The dominant graminoid species include *Carex membranacea* (fragile sedge), *Carex lugens*, *Carex bigelowii* (Bigelow sedge), *Calamagrostis canadensis* (bluejoint grass), *Eriophorum russeolum* (russett cottongrass), and *Eriophorum vaginatum* (tussock cottongrass). *Ledum palustre* (Labrador tea), *Vaccinium uliginosum* (bog blueberry), and *Dryas octopetala* (white mountain avens) are common. Other species include *Salix reticulata* (netleaf willow), *Pedicularis* species, and *Polygonum bistorta* (pink plume). Mosses are also commonly found in tussock dominated sites and include *Sphagnum* (peat moss) species and *Hylocomium splendens* (feather moss).

Plant associations. The following plant associations were defined: *Calamagrostis*

canadensis, *Carex bigelowii*, *Carex lugens*, *Carex membranacea*, *Eriophorum russeolum*, and *Eriophorum vaginatum*.

Interpretation key. Within the general herbaceous category, graminoids and forbs were combined and the environmental modifiers (dry, mesic, wet and aquatic) were maintained as per the Alaska Vegetation Classification. The GAAR class *mesic herbaceous* equals the combined Alaska Vegetation Classification classes mesic graminoid herbaceous and mesic forb herbaceous.

Accuracy assessment and mapping issues. The producer's accuracy for the mesic herbaceous class was 79%, with a user's accuracy of 67% ([Table 10b](#)). Errors of commission and omission were due primarily to confusion between the *shrub birch-willow-tussock tundra* and *shrub birch-ericaceous-willow*, as well as some confusion with the *wet herbaceous* classes. This class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 85 sites in GAAR. Because of the large number of training samples (signatures) for the *mesic herbaceous* class, as well as the *shrub birch-willow-tussock tundra* and *shrub birch-ericaceous-willow*, the spectral classification was relied on heavily for class discrimination. However, reducing confusion between these classes was problematic because many of the *shrub birch-willow-tussock tundra* and *shrub birch-ericaceous-willow* sites had a large herbaceous component. Conversely, many of the *mesic herbaceous* sites have a relatively high shrub component (15-25%). To maintain consistency, manual editing was limited to those areas that could be definitively corroborated in the FirePro, 1998 field data, or image annotations as classes *mesic herbaceous*, *shrub birch-willow-tussock tundra*, and *shrub birch-ericaceous-willow*. Based on the Landsat TM 4,5,3 (RGB) signatures for this class typically were orange-red, but can vary considerably. Signatures for sites in early or late season (when minimal active biomass covers the site) often appeared darker due to the spectral absorption characteristics of the seasonally wet site. Confusion with the *prostrate shrub* class was reduced through the implementation of modeling with NDVI. When considering the *mesic herbaceous*, *wet herbaceous* classes, and the *aquatic herbaceous* mapping classes as a single herbaceous mapping class, the producer's accuracy is 79%, while the user's accuracy is 72%.

Wet herbaceous (III.X.3.)

Classification. The dominant vegetation is emergent—not submerged or floating—and semi-permanent or standing water is present ([Figures 42](#)). Herbaceous cover is greater than 25%, tree canopy is less than 10% or absent, and shrub cover is less than 25%.



Figure 42. Wet Herbaceous area on edge of lake

Class description. The *wet herbaceous* map class occurs on sites that have semi-permanent or standing water and hydrophilic vegetation. It occurs on low centered polygons, saturated river terraces, the edge of ponds, lakes, sloughs, on dune slacks, the edge of small streams, and in water tracks. Water tracks generally occur adjacent to tussock tundra (*mesic herbaceous* map class), but contain more standing water and different sedge species. *Wet herbaceous* plant associations that occur on the edges of thaw lakes and ponds are typically dominated by *Arctophila fulva* mixed with *Hippuris vulgaris* (mare's tail), or *Carex aquatilis* (water sedge). Relative to the other herbaceous map classes, *wet herbaceous* is generally small in size and patchy in distribution. It covers 0.26% of GAAR (Table 9). Elevations for sampled sites ranged from about 900 to 3,500 feet (Appendix 2) and typically occurred on low slope areas.

Frequently found species include *Carex aquatilis* (water sedge), *Arctophila fulva*, *Equisetum fluviatile*, *Menyanthes trifoliata* (buckbean), and *Eriophorum angustifolium* (tall cottongrass). *Hippuris vulgaris* (mare's tail), *Sphagnum* (peat moss) species, and *Potentilla palustris* (marsh fivefinger) may also occur.

Plant associations. The following plant associations were defined for the *wet herbaceous* mapping class: *Arctophila fulva*, *Carex aquatilis*, *Carex aquatilis/Sphagnum*, *Carex limosa*, *Carex rostrata*, *Carex saxatilis*, *Eriophorum angustifolium*, and *Equisetum fluviatile*.

Interpretation key. Within the general herbaceous category, graminoids and forbs were combined and the environmental modifiers (dry, mesic, wet and aquatic) were maintained as per the Alaska Vegetation Classification. The GAAR class *wet herbaceous* equals the combined Alaska Vegetation Classification classes wet graminoid herbaceous and wet forb herbaceous.

Accuracy assessment and mapping issues. The producer's accuracy for the *wet herbaceous* class was 60%, with a user's accuracy of 98% (Table 10b). Errors of commission and omission were due primarily to confusion between the *shrub birch-willow-tussock tundra* and *mesic herbaceous* classes, as well as some confusion with the *silty water* and *mosaic/patterned vegetation* classes. This class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 37 sites in GAAR. Based on the Landsat TM 4,5,3 (RGB), signatures for this class typically are darker grey to blue with red tones. Signatures for sites in early or later season (when minimal active vegetation covers the site) often appear even darker due to the spectral absorption characteristics of the seasonally wet site. There were also significant commission errors with the open spruce forest classes. Modeling with winter imagery (Landsat MSS Band 4) resulted in some reduction in these errors. Modeling with TM Band 5 (which is highly sensitive to water/moisture) was effective at separating the *wet herbaceous* sites. When considering the *mesic herbaceous*, *wet herbaceous* classes, and the *aquatic herbaceous* mapping classes as a single herbaceous mapping class, the producer's accuracy is 79%, while the user's accuracy is 72%.

Aquatic herbaceous (III.D.X)

Classification. Vegetation is submerged, floating, or growing in permanent water. Herbaceous cover is greater than 25%, tree canopy is less than 10% or absent, and shrub cover is less than 25%.

Class description. This class includes aquatic communities in fresh water dominated by pondlilies (*Nuphar* species), *Sparganium* species, aquatic buttercups (*Ranunculus* species), water milfoil (*Myriophyllum spicatum*) and pondweed (*Potamogeton* species).

Interpretation key. Within the general herbaceous category, graminoids and forbs were combined and the environmental modifiers (dry, mesic, wet and aquatic) were maintained as per the Alaska Vegetation Classification. The *aquatic herbaceous* map class is comparable to the Viereck et al (1992) class of the same name.

Accuracy assessment and mapping issues. Although not indicated in the confusion matrices, this class was typically confused with the *silty water* class and occasionally with the *wet herbaceous* class. This site was based on a very small sample, and was therefore inappropriate for evaluating accuracy. To supplement the spectral classification, manual editing based on review of the FirePro and 1998 field data,

image annotations, and image interpretation. However, identification of lakes where this class occurred was still difficult other than where found in large, dense populations. Based on the Landsat TM 4,5,3 (RGB) signatures for this class typically are very dark maroon or blackish-red, but can vary considerably. When considering the *mesic herbaceous*, *wet herbaceous* classes, and the *aquatic herbaceous* mapping classes as a single herbaceous mapping class, the producer's accuracy is 79%, while the user's accuracy is 72% ([Table 10b](#)).

Sparsely vegetated (IV.X)

Classification. Total vegetation cover is 15 to 25% ([Figures 43a and b](#)).

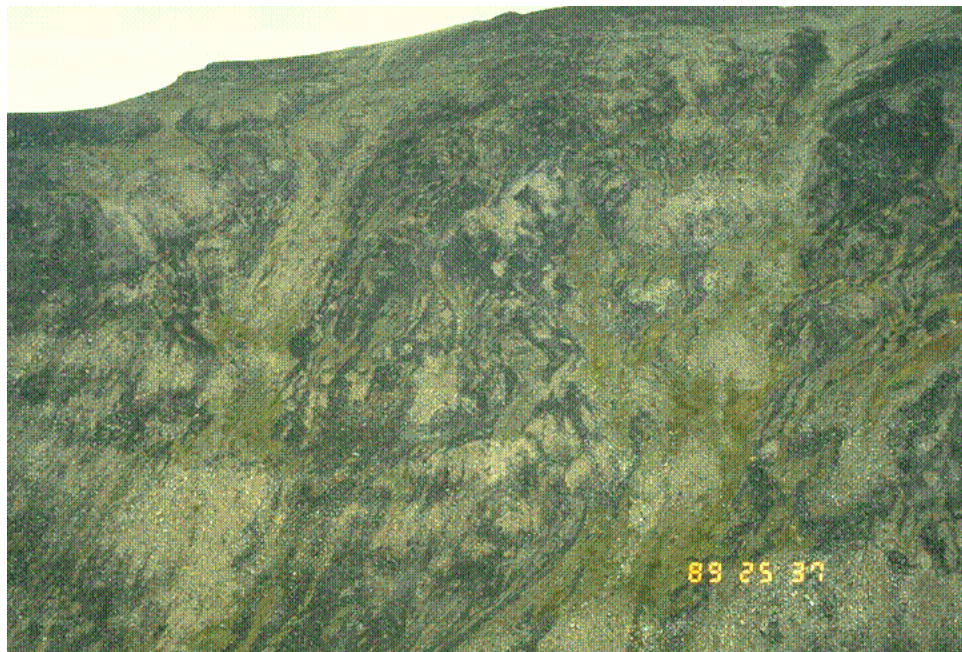


Figure 43a. Sparsely vegetated steep rock and talus slope (~15% dryas/moss)



Figure 43b. Sparsely vegetated steep rock and talus slope (~15% dryas/moss)

Class description. The *sparsely vegetated* map class most often occurs at the upper elevational limit of plant growth in the mountains, between 1,762 and 5,430 feet ([Appendix 2](#)). Below the elevational limit of plant growth, it commonly occurs on talus slopes, areas of intense frost action in high mountain valley floors, fellfield, and rounded mountain ridges (exposed bedrock) with intense frost action. It occurs occasionally on slopes below bedrock outcrops, frost boils on river terraces, and on sorted patterned ground. Included in the *sparsely vegetated* landcover class is high elevation sites below bare ground. Frequently, the vegetation is clumped, rather than a uniform distribution on bare-ground. The soils are a thin layer of dry to mesic sand, litter or organic mat interspersed with exposed rock. Slopes range from 0° to 50°. The map class covers 7.3 of GAAR, and the average site size is 16 acres based on sampled polygons ([Table 9 and 11](#)).

The map class is characterized by prostrate shrubs, and 75 to 85% cover of sand, silt and rocks. The dominant species are *Dryas octopetala* (white mountain avens), *Salix reticulata* (netleaf willow), *Salix arctica* (arctic willow), *Salix phlebophylla* (skeletonleaf willow), *Cassiope tetragona* (four-angled cassiope), *Vaccinium uliginosum* (bog blueberry), *Arctostaphylos rubra* (red-fruit bearberry), *Arctostaphylos alpina* (alpine bearberry), *Carex bigelowii* (Bigelow sedge), *Silene acaulis* (moss campion), and *Pedicularis* species. Moss and fruticose lichens occur, and rocks may be covered with crustose lichen. This map class typically grades into the *bare-ground* landcover class and, on more stable sites, prostrate shrub landcover classes.

Accuracy assessment and mapping issues. The producer's accuracy for the sparsely

vegetated class was 91%, with a user's accuracy of 85% (Table 10b). Errors of omission and commission for this class were primarily due to confusion with the *bare-ground* and *prostrate shrub-rock* class. NDVI was used to separate the *prostrate rock/sparingly vegetated/bare-ground* classes. This layer was particularly useful because of partial penetration of terrain shadow, where much of the *sparingly vegetated* areas are found. This class was based primarily on the quantitative spectral characteristics (training signatures statistics) for 22 sites in GAAR. Based on the Landsat TM 4,5,3 (RGB) signatures for this class typically appeared white, green, or blue with very light pink tone.

Bare-ground (V.X.1.)

Classification. Bare-ground represents areas with less than 15% vegetation cover (Figure 44).



Figure 44. Bedrock interspersed with a sparse covering of prostrate shrub

Class description. The *bare-ground* map class is one of the most common map class in GAAR covering 8.9% of the Park (Table 9), and is concentrated in the Brooks Range ecoregion (Figures 3a and 3b). The average site size is 33 acres—based on sampled polygons—although it typically occurs as huge expanses up to 32,040 acres (Table 12). It occurs in the mountains above the elevational limit of plant growth (average 3,241 feet; Appendix 2). Below the elevational limit of plant growth, it

occurs on talus slopes, floodplains and outwash plains, and areas of intense frost action in high mountain valley floors. Slopes range from 0^0 to 90^0 . This type typically grades into the *sparsely vegetated* landcover class and, on more stable sites, prostrate shrub landcover classes.

Accuracy assessment and mapping issues. The producer's accuracy for the *bare-ground* class was 91%, with a user's accuracy of 87% (Table 10b). This class was primarily confused with the *sparsely vegetated* mapping class, and was also misclassified occasionally in areas of the terrain shadow (*shadow/indeterminate* class). Models utilizing NDVI, slope, and illumination were applied to correct these problems. Based on the Landsat TM 4,5,3 (RGB) signatures for this class typically appeared white, green, or blue based on color of *bare-ground* (or crustose lichen cover for rock).

Clear water (V.X.2.)

Clear water indicates water with little to no sediment or glacial silt (Figure 45). It includes lakes with productive communities of fish and aquatic vegetation. They do not freeze completely in the winter and are generally greater than one meter in depth. Large, slow moving, deep rivers were also mapped as clear water. This type covers 0.6% of GAAR (Table 9).

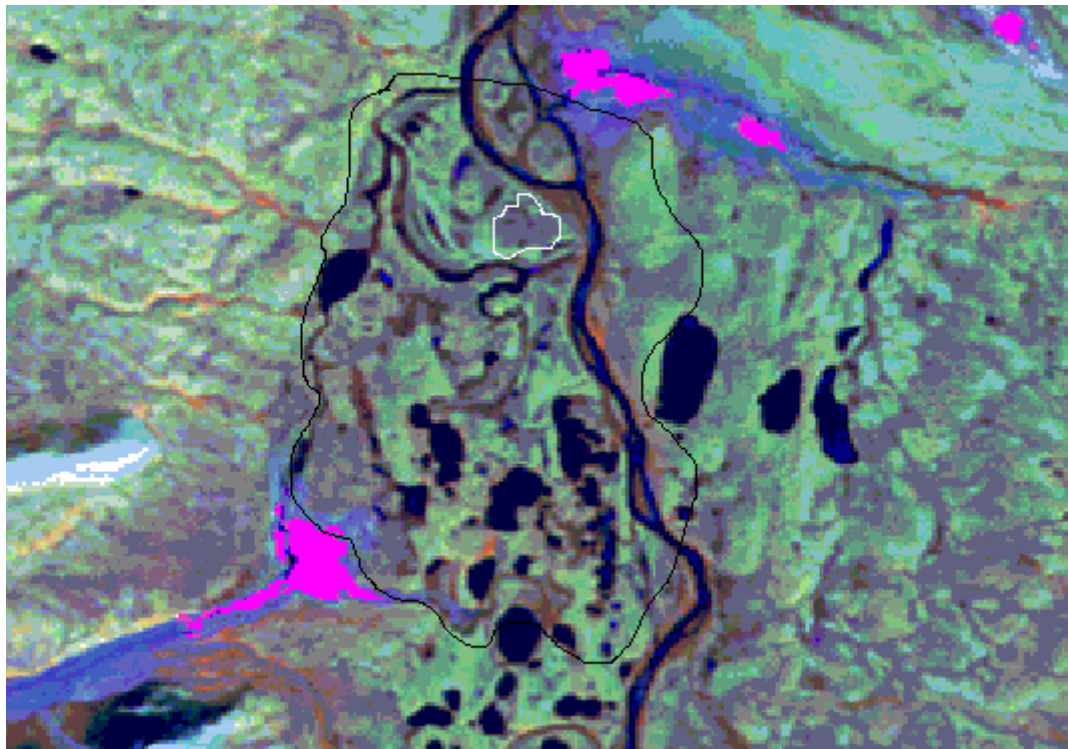


Figure 45. Landsat image that has silty water (blue color), clear water (black and dark blue) and an area mapped as mosaic/patterned vegetation outlined by the polygon

Lakes mapped as clear water include Walker Lake, Chandler Lake, and Nutuvukti Lake. Rivers mapped as clear water include the Noatak, Alatna, and John Rivers.

Accuracy assessment and mapping issues. The producer's accuracy for the *clear water* class was 99%, with a user's accuracy of 100% (Table 10b). This class was typically confused with the silty water class. It was also confused with the shadow/indeterminate class. In areas of high terrain and extensive terrain shadows, erroneous water often appears in areas of shadow or partial shadow. A combination of illumination, slope, and the preliminary classification (ISODATA) was used to ensure that overclassified water areas were recoded to shadow based on the principal that mappable water bodies only occur on low slope areas, and not in typically high slope terrain shadow areas. In the spectral based ML classification and initial modeling for each TM scene, the continuity of the water class in a number of primary/secondary rivers required improvement. Also, the distinction between *silty* and *clear water* classes was inconsistent. Changes in water levels between the multiple dates of scenes also resulted in problems in maintaining continuity of rivers at TM scene boundaries. Also, small ponds (less than 4 pixels) appeared to be underrepresented. To correct these problems, an additional modeling step was added during the interactive raster editing process. This involved first creating a *clear water/silty water/shadow* "candidate" layer by establishing thresholds in TM Band 5 through interactive interpretation. This layer was then raster edited simultaneously with the complete landcover database using the TM imagery and selected airphotos as a guide. Areas in the water candidate layer that were visually interpreted as "true" water were maintained as water classes, while shadow areas were eliminated from further consideration as water types. Following completion of raster editing, this "corrected" water layer was mosaicked into the landcover database. Based on the Landsat TM 4,5,3 (RGB), signatures for this class typically appeared as grey to black.

Silty water (V.X.3.)

Silty water referred to water containing moderate to high levels of glacial silt or areas not deep enough to support aquatic species diversity (Figure 45). Shallow lakes, less than one meter in depth, and most small rivers were mapped as silty water. Many lakes within the mapping area are products of thermokarst, the thawing of permafrost which produces shallow depressions in the landscape. Many of these small lakes were mapped as silty water. Smaller rivers tend to have high turbidity with many suspended particles. This type covers 0.5% of GAAR (Table 9).

Accuracy assessment and mapping issues. The accuracy for the *silty water* class could not be effectively estimated due to the small size and narrow linear shape of these areas (generally swift moving rivers). Errors in this class are primarily due to confusion with the *clear water* class. In addition, lake areas mapped as *silty water* were typically either very shallow (1 meter or less) or in some cases may represent

aquatic or *wet herbaceous* classes. Therefore, the *silty water* class often is found along the banks of lakes, and along fast flowing riverbanks. Based on the Landsat TM 4,5,3 (RGB) signatures for this class typically appeared light grey to dark grey/black.

Snow/ice (V.X.4.)

This class referred to areas covered with ice or late lying snow. The expansive mountain range within the study area formed a wide central band, covering much of the park and contains large areas of both the *bare-ground* and *snow/ice* mapping classes. North facing slopes typically have more snow and ice present than south facing slopes. The mean elevation for the occurrence of the *snow/ice* class is 5,536 feet ([Appendix 2](#)). It covers 0.4% of GAAR and is concentrated in the Brooks Range ecoregion ([Figures 3a and 3b](#)).

Accuracy assessment and mapping issues. The producer's accuracy for the *snow/ice* class was 99%, with a user's accuracy of 100% ([Table 10b](#)). The preliminary (ISODATA derived) classification was used to develop a *snow/ice* layer. Particular clusters corresponding with snow and ice were selected from the ISODATA classification, and used in the final landcover database. Based on the Landsat TM 4,5,3 (RGB) signatures for this class typically appear as bright magenta to purple.

Mosaic/Pattern Vegetation (V.X.5.)

This class includes patterned ground that could not be reliably mapped due to the highly variable, sub-pixel patterns of vegetation, water, or bare ground ([Figure 45](#)). Sorted polygons and ice wedge polygons dominate the type. The class covers 0.2% of GAAR ([Table 9](#)), however, the actual cover of polygonal ground in GAAR is much higher and is a common component of other classes.

Sorted polygons range up to 30 feet in diameter and occur on glacial drift on rounded foothills and mountain slopes on the north edge of GAAR. Vegetation ranges from absent on the rims with prostrate shrubs in the center, to shrubs on the edge with no vegetation in the polygon center.

Ice wedge polygons are typically connected in a polygonal pattern that is similar to the pattern produced by mud cracks. Their diameter ranges from 20 to 100 feet. These polygons are a common feature on level ground of glacial drift, lacustrine and floodplain surficial geology deposits of the arctic foothills and the interior forested lowlands and uplands ecoregions. They also occur in the larger mountain valley bottoms of the Brooks Range ecoregion on glacial drift and lacustrine deposits.

Vegetation of ice wedge polygons is dependent on surface elevation and soil moisture. Low-center polygons have centers often with standing water and support

emergent or tussock vegetation. Low shrubs often dominate their edges. High-center polygons have centers dominated by prostrate shrubs and their edges by low shrubs.

A more exhaustive description of all types of patterned ground is given in the section “Patterned Ground.”

Interpretation key. These areas were primarily identified through image annotations and 1998 field data, and review of CIR photography.

Accuracy assessment and mapping issues. Because of the sub-pixel (less than 28.5m) nature of this mapping class, it was largely delineated through manual editing. These areas were primarily identified through image annotations and 1998 field data, and review of CIR photography. All suitable training areas were therefore incorporated as manual edits.

Shadow/Indeterminate (V.X.6.)

This mapping class included areas of severe terrain shadow where landcover could not be reliably identified. It also included cloud or cloud shadowed areas primarily in the Northeast corner of GAAR. It covers 4.5% of the Park ([Table 9](#)).

Accuracy assessment and mapping issues. The producer’s accuracy for the shadow/indeterminate class was 100%, with a user’s accuracy of 99% ([Table 10b](#)). This class was effectively modeled using illumination, slope, and the preliminary (pre-field) landcover database. Based on the Landsat TM 4,5,3 (RGB), signatures for this class typically appeared as black.

Sand Dunes (V.X.7.)

This class occurred very rarely (total of 173 acres) in GAAR, primarily along the Killik River north of the Brooks Range ([Figure 46](#)). However, large deposits were common in the Kobuk Valley region southwest of the GAAR project area (in particular, the Kobuk Dunes). Vegetation included alder and moist to dry grass/forb sites on the dunes, and ponds and wet herbaceous plant associations in the slacks (depressions). Blowouts, with exposed sand, were also common.



Figure 46 Partially stabilized sand dunes along the Killik River

Accuracy assessment and mapping issues. This class was extremely rare and was only observed intermixed with dry herbaceous, mesic herbaceous and low shrub classes on partially stabilized sand dunes along the Killik River north of the Brooks Range. Manual edits were implemented to include this very limited area.

3.7 PLANT ASSOCIATION DESCRIPTIONS

The plant associations found in the GAAR project area are listed below, and described in full. This part of the document is intended to help users to understand the distribution of species and community structure across the GAAR landscape and to provide a link between the mapped landcover classes and species information. Plant associations were classified by qualitatively grouping similar sites based primarily on the dominant and subdominant species. Species composition, species cover, and vegetation height were also considerations. A description based on vegetation and physical site variables was then written for each plant association. Forested and woodland plant associations and most tall shrub plant associations are not described because too few ground samples were collected in these landcover classes to provide an accurate description.

Salix alaxensis

Salix lanata subspecies *richardsonii*

Salix lanata subspecies *richardsonii*/Carex *membranacea*

Betula glandulosa/Carex *bigelowii*

Betula glandulosa/Carex *aquatilis*

Betula glandulosa/Eriophorum *russeolum*

Vaccinium uliginosum-*Ledum palustre*/Carex *bigelowii*

Vaccinium uliginosum-*Ledum palustre*/Eriophorum *russeolum*

Vaccinium uliginosum-*Ledum palustre*/Eriophorum *vaginatum*

Salix lanata subspecies *richardsonii* /Carex *bigelowii*

Salix planifolia subspecies *pulchra*/Carex *bigelowii*

Salix planifolia subspecies *pulchra*/Eriophorum *russeolum*

Salix planifolia subspecies *pulchra*/Carex *aquatilis*

Vaccinium uliginosum-*Ledum palustre*/Sphagnum

Vaccinium uliginosum-*Ledum palustre*

Betula glandulosa

Lichen-*Betula glandulosa*

Salix planifolia subspecies *pulchra* (open)

Salix planifolia subspecies *pulchra* (closed)

Dryas octopetala-rock

Vaccinium uliginosum/fruticose lichen

Dryas octopetala/Carex species

Dryas octopetala-*Cassiope tetragona*

Dryas octopetala

Dryas integrifolia

Salix reticulata

Calamagrostis canadensis

Carex *bigelowii*

Carex *lugens*

Carex *membranacea*

Eriophorum *russeolum*

Eriophorum vaginatum

Arctophila fulva

Carex aquatilis

Carex aquatilis/Sphagnum

Carex limosa

Carex rostrata

Carex saxatilis

Eriophorum angustifolium subspecies *subarcticum*

Equisetum fluviatile

CLOSED TALL SHRUB AND OPEN TALL SHRUB PLANT ASSOCIATIONS

***Salix alaxensis* plant association**

Feltleaf willow

10 sites



Figure 47. *Salix Alaxensis* plant association

Vegetation. *Salix alaxensis* (feltleaf willow) is typically the only species in the low to tall shrub layer ranging from 2 to 6 feet in height (Figure 47). The height of *Salix alaxensis* (feltleaf willow) is lower—often only 2 feet tall—on the north edge of GAAR. Its cover varies from 15 to 80%. Associate species include *Betula nana* (dwarf arctic birch), *Empetrum nigrum* (crowberry), *Arctostaphylos alpina* (alpine bearberry), *Dryas octopetala* subspecies *alaskensis* (white mountain avens), and *Salix planifolia* subspecies *pulchra* (diamondleaf willow), *Epilobium latifolium* (dwarf

fireweed), and *Equisetum arvense* (common horsetail). Bare-ground, rock and litter often have high cover.

Environmental characteristics. This is a minor type found throughout GAAR on newly deposited stream and river deposits. It typically occurs as stringers or patches amongst open forest map classes or tussock tundra and low shrub. The small streams typically are rocky and receive flash floods partially due to high stream gradients (up to 10° slope). The *Salix alaxensis* (feltleaf willow) type is also found on the major rivers on new alluvial deposits, such as point bars. The soil surface is either bare alluvium or a thin layer of dry to mesic organic matter—up to 1 inches thick—over silt, sand and rocks. Permafrost, if present, is typically deep (10+ inches). The sites are relatively dry except during flooding, and the pH varies from 5.1 to 7.6

***Salix lanata* subspecies *richardsonii* plant association**

Richardson willow

5 sites



Figure 48. *Salix lanata* subspecies *richardsonii* plant association

Vegetation. *Salix lanata* subspecies *richardsonii* is the dominant shrub species, ranging in height from 2 to 6 feet (Figure 48). Other low to tall shrubs occur—sometimes codominating—and include *Salix arbusculoides* (littletree willow), *Salix brachycarpa* (barren-ground willow), *Salix alaxensis* (feltleaf willow), *Salix novae-*

angliae (tall blueberry willow) and *Salix planifolia* subspecies *pulchra* (diamondleaf willow). Total low to tall shrub cover is often low, ranging from 25 to 63%. Understory species include *Vaccinium uliginosum* (bog blueberry), *Arctostaphylos rubra* (red-fruit bearberry), *Empetrum nigrum* (crowberry), *Dryas octopetala* (white mountain avens), *Calamagrostis purpurascens*, *Lupinus arcticus* (arctic lupine), *Equisetum variegatum* (small horsetail) and *Hylocomium splendens* (feather moss). Bare-ground, rock and bryophyte cover is typically low.

Environmental characteristics. This is a minor type found in the north half of GAAR on unstable surfaces including newly deposited stream and river deposits, the base of solifluction lobes, and active dunes. It occurs as stringers or patches amongst tussock tundra and low shrub. The dune sites are relatively dry, as are floodplain sites except during flooding. The small streams are typically rocky and receive flash floods partially due to high stream gradients (up to 10⁰ slope). On the major rivers the *Salix lanata* subspecies *richardsonii* (Richardson willow) plant association occurs on new alluvial deposits such as point bars. Permafrost, if present, is typically deep (10+ inches). On solifluction lobes the sites are moist to wet, and prostrate shrubs occupy the upslope and downslope positions.

***Salix lanata* subspecies *richardsonii*/Carex membranacea plant association**

Richardson willow/fragile sedge

1 site

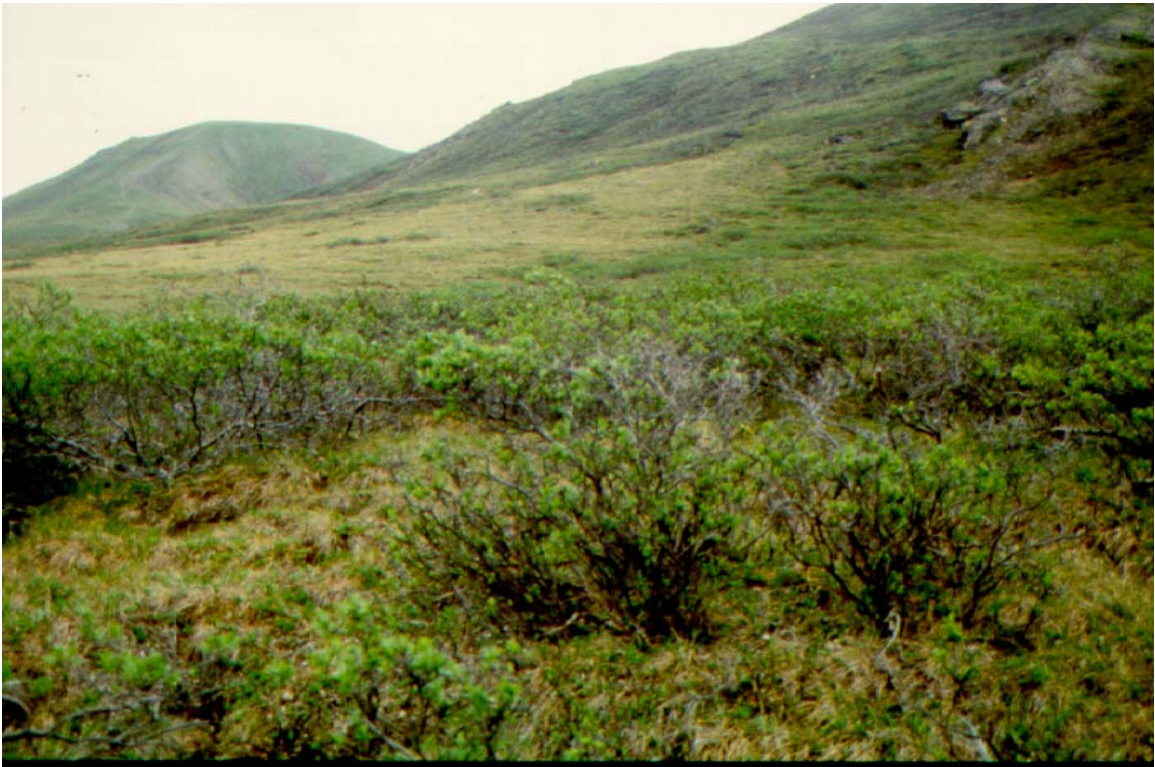


Figure 49. *Salix lanata* subspecies *richardsonii*/Carex membranacea plant association

Salix lanata subspecies *richardsonii* (Richardson willow) dominates the shrub layer—ranging up to 5 feet in height—and the tussock forming *Carex membranacea* (fragile sedge) dominates the herbaceous layer with at least 25% cover (Figure 49). Associate species include *Salix reticulata* (netleaf willow), *Cassiope tetragona* (four-angled cassiope), *Dryas octopetala* (white mountain avens) and moss species. The plant association appears to be uncommon in GAAR on moderate slopes. The one soil profile sampled had 1 foot of peat at which permafrost was encountered, the peat was moist to wet, and the pH 7.5.

SHRUB BIRCH-WILLOW-TUSSOCK TUNDRA PLANT ASSOCIATIONS

***Betula glandulosa*/Carex bigelowii plant association**

Resin birch/Bigelow sedge

3 sites



Figure 50. *Betula glandulosa*/Carex bigelowii plant association

Vegetation. This plant association is dominated by *Betula glandulosa* (resin birch) or *Betula nana* (dwarf arctic birch) with at least 25% cover and at least 25% *Carex bigelowii* (Bigelow sedge) cover (Figure 50). *Salix glauca* (grayleaf willow) is sometimes a strong codominant, and other species include *Empetrum nigrum* (crowberry), *Ledum palustre* subspecies *decumbens* (narrow leaf Labrador tea), *Vaccinium vitis-idaea* (low bush cranberry) and *Arctostaphylos alpina* (alpine

bearberry). Moss and lichen cover are both less than 5%. The plant association often grades into various prostrate shrub and low shrub landcover classes.

Environmental characteristics. The distribution of the plant association is not clear, but appears to be more common in areas dominated by tussock tundra on the north half of GAAR. Slopes range from 0° to 25° in moist-wet valley bottoms and on rolling hills. The sites are dominated by tussocks ranging in height up to 8 inches with water sometimes in the hollows. The tussocks overlay silt or sand. Permafrost was encountered at 7 inches at one site, and bedrock was reached at 12 inches on another.

***Betula glandulosa*/Carex aquatilis plant association**

Resin birch/water sedge

4 sites

Vegetation. This plant association is dominated by *Betula glandulosa* (resin birch) or *Betula nana* (dwarf arctic birch) and at least 25% cover of *Carex aquatilis* (water sedge). Other species include *Vaccinium uliginosum* (bog blueberry), *Salix planifolia* subspecies *pulchra* (diamondleaf willow), *Ledum palustre* (Labrador tea), *Andromeda polifolia* (bog rosemary), *Calamagrostis canadensis* (bluejoint grass) and *Sphagnum* (peat moss) species. The plant association often grades into herbaceous and low shrub landcover classes. Its distribution is not clear, but appears to be more common in the south half of GAAR on moist to wet valley sites.

***Betula glandulosa*/Eriophorum russeolum plant association**

Resin birch/russett cottongrass

2 sites

Vegetation. This plant association is dominated by *Betula glandulosa* (resin birch) or *Betula nana* (dwarf arctic birch) with at least 25% cover of *Eriophorum russeolum* (russett cottongrass). Other species include *Picea mariana* (black spruce), *Potentilla fruticosa* (shrubby cinquefoil), *Vaccinium uliginosum* (bog blueberry), *Ledum palustre* subspecies *groenlandicum* (Labrador tea), *Carex vaginata*, *Carex bigelowii* (Bigelow sedge), and *Hylocomium splendens* (feather moss). Moss and lichen cover are both less than 20%. The plant association is similar to the *Betula glandulosa*/*Carex bigelowii* plant association.

Environmental characteristics. The distribution of the plant association is not clear. Slopes range up to 5° in moist-wet valley bottoms and on rolling hills. Tussocks dominate the sites and overlay peat up to 1 foot deep over silt or sand. Permafrost was encountered at 12 and 20 inches.

***Vaccinium uliginosum*-*Ledum palustre*/Carex bigelowii plant association**

Bog blueberry-Labrador tea/Bigelow sedge

9 sites

Vaccinium uliginosum (bog blueberry) in combination with *Ledum palustre* (primarily subspecies *decumbens* [narrow-leaf Labrador-tea]) dominates the shrub layer, and *Carex bigelowii* (Bigelow sedge) dominates the herbaceous layer with at least 25% cover. Associate species include *Betula glandulosa* (resin birch), *Empetrum nigrum* (crowberry), *Vaccinium vitis-idaea* (low bush cranberry), *Eriophorum vaginatum* and *Hylocomium splendens* (feather moss). The distribution of the plant association is not clear but is likely more common in the south half of GAAR. The composition, structure and physical characteristics of the *Vaccinium uliginosum*-*Ledum palustre*/*Carex bigelowii* plant association are similar to the *Betula glandulosa*/*Carex bigelowii* plant association, the primary difference being *Betula glandulosa* (resin birch) is not the dominant shrub.

***Vaccinium uliginosum*-*Ledum palustre*/*Eriophorum russeolum* plant association**

Bog blueberry-Labrador tea/russett cottongrass

2 sites

Vaccinium uliginosum (bog blueberry) in combination with *Ledum palustre* (primarily subspecies *decumbens*, narrow-leaf Labrador-tea) dominates the shrub layer, and *Eriophorum russeolum* (russett cottongrass) dominates the herbaceous layer with at least 25% cover. Associate species include *Picea glauca* (white spruce), *Betula glandulosa* (resin birch), *Arctostaphylos alpina* (alpine bearberry), *Carex bigelowii* (Bigelow sedge) and *Hylocomium splendens* (feather moss). The plant association's distribution in GAAR is not clear. The composition, structure and physical characteristics of the *Vaccinium uliginosum*-*Ledum palustre*/*Eriophorum russeolum* plant association are similar to the *Betula glandulosa*/*Eriophorum russeolum* plant association, the primary difference being *Betula glandulosa* (resin birch) is not the dominant shrub. Tussocks dominate the sites and overlay peat up to 1 foot deep over silt or sand.

***Vaccinium uliginosum*-*Ledum palustre*/*Eriophorum vaginatum* plant association**

Bog blueberry-Labrador tea/tussock cottongrass

1 site

Vaccinium uliginosum (bog blueberry) in combination with *Ledum palustre* (primarily subspecies *decumbens* [narrow-leaf Labrador-tea]) dominates the shrub layer, and *Eriophorum vaginatum* (tussock cottongrass) dominates the herbaceous layer with at least 25% cover. Associate species include *Betula glandulosa* (resin birch), *Salix planifolia* subspecies *pulchra* (diamondleaf willow), *Carex bigelowii* (Bigelow sedge) and *Sphagnum* (peat moss). The plant association appears to be common in the south half of GAAR. The composition, structure and physical characteristics of the plant association are similar to that of the *Vaccinium uliginosum*-*Ledum palustre*/*Eriophorum russeolum* plant association, the principal difference being that *Eriophorum vaginatum* (tussock cottongrass) is the dominant herbaceous species.

***Salix lanata* subspecies *richardsonii*/Carex bigelowii plant association**

Richardson willow/Bigelow sedge

1 site



Figure 51. *Salix lanata* subspecies *richardsonii*/Carex bigelowii plant association

Vegetation. This plant association is dominated by *Salix lanata* subspecies *richardsonii* (Richardson willow) with at least 25% cover, and at least 25% cover of *Carex bigelowii* (Bigelow sedge; [Figure 51](#)). *Salix lanata* subspecies *richardsonii* is approximately 16 inches in height. Other species include *Vaccinium uliginosum* (bog blueberry), *Salix reticulata* (netleaf willow), *Equisetum arvense* (common horsetail), *Arctostaphylos rubra* (red-fruit bearberry), and *Eriophorum vaginatum* (tussock cottongrass). Moss cover is high. The plant association often grades into various prostrate shrub landcover classes and plant associations such as *Betula glandulosa*/Carex bigelowii.

Environmental characteristics. This is an incidental plant association occurring on moderate slopes in moist-wet valley bottoms and on rolling hills. Its distribution is not clear, but occurs in areas dominated by tussock tundra on the north half of GAAR. The tussocks range in height up to 8 inches with water sometimes in the hollows. The tussocks overlay peat over silt or sand. Bedrock was reached at 18 inches and the pH of the peat was 6.2.

***Salix planifolia* subspecies *pulchra*/*Carex bigelowii* plant association**

Diamondleaf willow/Bigelow sedge

3 sites



Figure 52. *Salix planifolia* subspecies *pulchra*/*Carex bigelowii* plant association

Vegetation. This plant association is dominated by *Salix planifolia* subspecies *pulchra* (diamondleaf willow) with at least 25% cover, and at least 25% cover of *Carex bigelowii* (Bigelow sedge; Figure 52). Other shrub species include *Betula nana* (dwarf arctic birch), *Ledum palustre* subspecies *decumbens* (narrow leaf Labrador tea) and *Salix reticulata* (netleaf willow). *Eriophorum russeolum* (russett cottongrass) and *Eriophorum vaginatum* (tussock cottongrass) are often codominant tussock forming species, and other herbaceous species include *Pedicularis lanata* and *Hierochloe alpina* (alpine holy grass). Moss cover ranges up to 60% and includes *Hylocomium splendens* (feather moss) and *Sphagnum* (peat moss) species. The plant association often grades into prostrate shrub landcover classes and plant associations such as *Betula glandulosa*/*Carex bigelowii*.

Environmental characteristics. This is a common type in areas dominated by tussock tundra on the north half of GAAR. It occurs on moderate slopes—up to 10°—in moist-wet valley bottoms and at the base of hills and mountains. The sites are dominated by tussocks ranging in height up to 8 inches with water sometimes in the hollows. The tussocks overlay peat up to 10 inches thick over silt or sand.

Permafrost was reached at 7 to 12 inches deep, and the pH of the peat ranged from 4.7 to 6.3. The water table was at the soil surface to 9 inches below the soil surface.

***Salix planifolia* subspecies *pulchra*/*Eriophorum russeolum* plant association**

Diamondleaf willow/russett cottongrass

1 site



Figure 53. *Salix planifolia* subspecies *pulchra*/*Carex aquatilis* plant association

Vegetation. This plant association is dominated by *Salix planifolia* subspecies *pulchra* (diamondleaf willow) with at least 25% cover, and at least 25% cover of *Eriophorum russeolum* (russett cottongrass). Other shrub species include *Betula nana* (dwarf arctic birch), *Ledum palustre* subspecies *decumbens* (narrow leaf Labrador tea) and *Vaccinium uliginosum* (bog blueberry). Other herbaceous species include *Carex bigelowii* (Bigelow sedge) and *Saxifraga nelsoniana*. Moss cover ranges up to 40% and includes *Sphagnum* (peat moss) species. The plant association often grades into prostrate shrub landcover classes and plant associations such as *Betula glandulosa*/*Carex bigelowii*.

Environmental characteristics. The distribution of the plant association is not clear, but it is likely a common type in areas dominated by tussock tundra in the north half of GAAR. It occurs on moderate slopes—up to 10°—in moist-wet valley bottoms and on hillsides. The sites are dominated by tussocks ranging in height up to 10 inches with water sometimes in the hollows. The tussocks overlay peat over silt or sand. Permafrost was reached at 6 inches deep, and the pH of the peat was 5.3.

***Salix planifolia* subspecies *pulchra*/Carex aquatilis plant association**

Diamondleaf willow/water sedge

1 site

Vegetation. This plant association is dominated by *Salix planifolia* subspecies *pulchra* (diamondleaf willow) with at least 25% cover, and at least 25% cover of *Carex aquatilis* (water sedge; [Figure 53](#)). Other shrub species include *Betula nana* (dwarf arctic birch), *Ledum palustre* subspecies *decumbens* (narrow leaf Labrador tea), *Empetrum nigrum* (crowberry), *Vaccinium uliginosum* (bog blueberry) and *Salix fuscescens*. Other herbaceous species include *Bistorta vivipara*, *Potentilla palustris* (marsh fivefinger) and *Pedicularis lanata*. Moss cover was 40% and included *Sphagnum* (peat moss) species. The plant association often grades into pure sites of *Carex aquatilis* (water sedge) and low shrub plant associations such as *Betula glandulosa*/*Carex bigelowii*.

Environmental characteristics. The distribution of the plant association is not clear, but it is likely a common type in areas dominated by tussock tundra on the north half of GAAR. It occurs on level areas in moist-wet valley bottoms. The sites are dominated by poorly formed tussocks of *Carex aquatilis* (water sedge) ranging in height up to 8 inches with water sometimes in the hollows. The tussocks overlay peat over silt or sand. Permafrost was reached at 20 inches in depth.

SHRUB BIRCH-ERICACEOUS-WILLOW PLANT ASSOCIATIONS

***Vaccinium uliginosum*-*Ledum palustre*/Sphagnum plant association**

Bog blueberry-Labrador tea/peat moss

1 site

Vaccinium uliginosum (bog blueberry) in combination with *Ledum palustre* (primarily subspecies *decumbens*) dominates the shrub layer, and *Sphagnum* (peat moss) species dominate the bryophyte layer with at least 35% cover. Associate species include *Empetrum nigrum* (crowberry), *Vaccinium vitis-idaea* (low bush cranberry), *Betula glandulosa* (resin birch), *Salix planifolia* subspecies *pulchra* (diamondleaf willow), *Eriophorum vaginatum* (tussock cottongrass), and *Carex bigelowii* (Bigelow sedge). The plant association appears to be common in the south half of GAAR.

***Vaccinium uliginosum*-*Ledum palustre* plant association**

Bog blueberry-Labrador tea

7 sites

Vaccinium uliginosum (bog blueberry) in combination with *Ledum palustre* (primarily subspecies *decumbens*) dominates the plant association. Associate species include *Betula glandulosa* (resin birch), *Vaccinium vitis-idaea* (low bush cranberry),

Empetrum nigrum (crowberry) and *Carex bigelowii* (Bigelow sedge). Moss species dominate the understory and include *Pleurozium schreberi*, *Polytrichum commune* and *Hylocomium splendens* (feather moss). The plant association often grades into various prostrate shrub (upslope), low shrub and tall shrub (downslope) landcover classes. The plant association may be common in the Kobuk Boot region of GAAR. The composition, structure and physical characteristics of the *Vaccinium uliginosum*-*Ledum palustre* plant association are similar to the *Betula glandulosa* plant association, the primary difference being *Betula glandulosa* is not the dominant shrub.

***Betula glandulosa* plant association**

Resin birch

7 sites



Figure 54. *Betula Glandulosa* plant association

Vegetation. *Betula glandulosa* or *Betula nana* dominate the plant association and no codominants occur (Figure 54). Associate species include *Salix planifolia* subspecies *pulchra* (diamondleaf willow), *Salix phlebophylla* (skeletonleaf willow), *Vaccinium vitis-idaea* (low bush cranberry), *Vaccinium uliginosum* (bog blueberry), *Empetrum nigrum* (crowberry), *Dryas octopetala* (white mountain avens), *Rhododendron lapponicum* (lapland rosebay) and *Hierochloe alpina* (alpine holy grass). Moss and fruticose lichen cover range up to 20 and 40%, respectively. This plant association often grades into various prostrate shrub (upslope), low shrub and tall shrub (downslope) landcover classes.

Environmental characteristics. This is a major type located throughout GAAR on

stable surfaces on mountain slopes, rounded mountain ridges (exposed bedrock), hill tops, and the river-side edge of river and stream terraces—terrace edges tend to be drier than sites further removed from the river. The *Betula glandulosa* plant association is common on slopes ranging from 0° to 45°. The soils are a thin layer of dry to dry-mesic organic matter—up to 10 inches thick—over silt, sand and rocks. Permafrost is typically deep (10+ inches), and pH varies from 4.9 to 5.9 (one site with a pH of 8.0).

Lichen-*Betula glandulosa* plant association

Lichen-resin birch

10 sites



Figure 55. Lichen-*Betula Glandulosa* plant association

Vegetation. This plant association is dominated by *Betula glandulosa* (resin birch) or *Betula nana* (dwarf arctic birch) with at least 25% cover, and an understory of greater than 40% fruticose lichen (Figure 55). Other shrub species may have high cover including *Ledum palustre* subspecies *decumbens* (narrow leaf Labrador tea), *Vaccinium uliginosum* (bog blueberry), *Vaccinium vitis-idaea* (low bush cranberry), *Loiseleuria procumbens* (alpine azalea) and *Empetrum nigrum* (crowberry). Fruticose lichens include *Cladina rangiferina*, *Cladina stellaris*, *Cetraria islandica*, and other *Cetraria* species. This plant association often grades into *spruce-lichen woodland*, and *prostrate shrub* map classes and various low shrub and tall shrub classes.

Environmental characteristics. This is a major plant association located on the south

half of GAAR on relatively stable surfaces in mountain valleys, mountain slopes, rounded mountain ridges (exposed bedrock) and alluvial fans. Slopes range from 0° to 30°. The soils are sand and sand mixed with cobble, and a thin peat layer may occur. The pH varies from 4.7 to 5.0.

***Salix planifolia* subspecies *pulchra* (open) plant association**

Diamondleaf willow (open)

3 sites



Figure 56. *Salix planifolia* subspecies *pulchra* (open) plant association

Vegetation. *Salix planifolia* subspecies *pulchra* (diamondleaf willow) dominates or codominates the plant association along with *Salix glauca* (grayleaf willow) or *Salix alaxensis* (feltleaf willow; [Figure 56](#)). Associate species include *Vaccinium uliginosum* (bog blueberry), *Betula glandulosa* (resin birch), *Potentilla fruticosa* (shrubby cinquefoil), *Bromus pumpellianus*, *Festuca altaica*, *Equisetum arvense* (common horsetail) and *Hierochloe alpina* (alpine holy grass). Moss cover reaches 70% dominated by *Sphagnum* (peat moss) species or *Hylocomium splendens* (feather moss).

Environmental characteristics. This is a minor plant association found on recently deposited floodplain sites located throughout GAAR. The sites are typically level, dry to mesic, and subjected to periodic flooding. The soils are a thin layer of dry to dry-mesic organic matter over silt, sand and rocks. Permafrost was not encountered. The pH varies from 6.6 to 8.8.

CLOSED LOW WILLOW PLANT ASSOCIATIONS

***Salix planifolia* subspecies *pulchra* (closed) plant association**

Diamondleaf willow (closed)

7 sites

Vegetation. *Salix planifolia* subspecies *pulchra* (diamondleaf willow) dominates the plant association, and no codominants occur although *Betula glandulosa* and *Vaccinium uliginosum* (bog blueberry) often have high cover values. Associate understory species include *Equisetum arvense* (common horsetail), *Equisetum pratense*, *Eriophorum angustifolium* (tall cottongrass), *Petasites frigidus* (frigid coltsfoot) and *Salix reticulata* (netleaf willow). Moss cover reaches 90% and is dominated by *Sphagnum* (peat moss) species and *Hylocomium splendens* (feather moss).

Environmental characteristics. This is a common type located in the north half of GAAR. It is found on the edge of small streams, and on water tracks found on tussock tundra hillsides. Many of the small streams have terrace formation. The streams and water tracks occur on slopes ranging from 0° to 10°. Hummocks often form due to the presence of *Eriophorum angustifolium* (tall cottongrass) and *Carex aquatilis* (water sedge). The tussocks overlay a thin (0 to 9 inches) layer of peat over silt, sand and rocks. Permafrost is common, often at less than 10 inches deep. The soil pH varies from 5.4 to 7.0.

PROSTRATE SHRUB-ROCK PLANT ASSOCIATION

***Dryas octopetala*-rock plant association**

White mountain avens-rock

6 sites

Vegetation. This plant association is characterized by prostrate shrubs and 25 to 75% cover of rocks typically 0.5 to 8 inches in size that are often covered with crustose lichen (Figure 57). *Dryas octopetala* subspecies *alaskensis* (white mountain avens) dominates the plant association and no codominants occur. Other species include *Arctostaphylos alpina* (alpine bearberry), *Salix phlebophylla* (skeletonleaf willow), *Loiseleuria procumbens* (alpine azalea), *Carex scirpoidea*, *Carex microchaeta*, *Minuartia arctica* and *Epilobium latifolium* (fireweed). Moss and fruticose lichen cover ranges from 1 to 40%. The plant association often grades into the *sparse vegetation* landcover class and, on more stable sites, the *prostrate shrub-lichen*, and *prostrate shrub* landcover classes.



Figure 57. *Dryas octopetala*-rock plant association

Environmental characteristics. This is a major type located throughout GAAR on unstable surfaces such as talus slopes, slopes below bedrock outcrops, fellfield, frost boils on river terraces, areas of intense frost action in high mountain valley floors, rounded mountain ridges (exposed bedrock) with intense frost action, and sorted patterned ground. Slopes range from 0° to 50° . The soils are a thin layer of dry to mesic sand, litter or organic mat interspersed with exposed rock. The pH varies from 5.8 to 7.9.

PROSTRATE SHRUB-LICHEN PLANT ASSOCIATIONS

***Vaccinium uliginosum*/fruticose lichen plant association**

Bog blueberry/fruticose lichen

5 sites



Figure 58. *Vaccinium uliginosum*/fruticose lichen plant association

Vegetation. Fruticose lichen in combination with greater than 25% prostrate shrub cover dominate this plant association (Figure 58). Shrub species include various combinations of *Vaccinium uliginosum* (bog blueberry), *Vaccinium vitis-idaea* (low bush cranberry), *Ledum palustre* subspecies *decumbens* (narrow leaf Labrador tea), *Betula nana* (dwarf arctic birch), *Loiseleuria procumbens* (alpine azalea), *Dryas octopetala* (white mountain avens) and *Arctostaphylos rubra* (red-fruit bearberry). Lichens include *Cladina rangiferina*, *Stereocaulon* species, *Cetraria* species and *Alectoria* species. The plant association often grades into *spruce-lichen woodland*, *prostrate shrub*, and various low shrub and tall shrub landcover classes.

Environmental characteristics. This is a minor type located primarily in the south half of GAAR on relatively stable surfaces in mountain valleys, mountain slopes, rounded mountain ridges (exposed bedrock) and alluvial fans. Slopes range from 0° to 25°. The soils are a thin duff layer over dry to mesic silt, sand and cobble. The pH varies from 4.0 to 5.9.

PROSTRATE SHRUB PLANT ASSOCIATIONS

***Dryas octopetala*-*Carex* species plant association**

White mountain avens-sedge species

5 sites

Vegetation. This plant association is characterized by at least 25% cover of prostrate shrubs and 25% cover of herbaceous vegetation. The dominant prostrate shrubs include *Dryas octopetala* (white mountain avens), *Ledum palustre* subspecies *decumbens* (narrow leaf Labrador tea), *Salix arctica* (arctic willow), *Salix reticulata* (netleaf willow) and *Vaccinium uliginosum* (bog blueberry). The dominant herbaceous species are *Carex bigelowii* (Bigelow sedge) and *Equisetum arvense* (common horsetail). Other species include *Arctostaphylos alpina* (alpine bearberry), *Cassiope tetragona* (four-angled cassiope), *Salix phlebophylla* (skeletonleaf willow) and *Diapensia lapponica* (Lapland diapensia). Moss and lichen cover ranges from 5 to 30%. The plant association often grades into the *prostrate shrub* landcover class, or low shrub landcover classes.

Environmental characteristics. This is a minor type located throughout GAAR on unstable to stable surfaces such as mountain slopes, high mountain valley floors, rounded mountain ridges (exposed bedrock), and sorted patterned ground. Slopes range from 0° to 10°. The soils are a thin layer of dry to mesic sand, litter or organic mat interspersed with exposed rock.

***Dryas octopetala*-*Cassiope tetragona* plant association**

White mountain avens–four angled cassiope

10 sites

Vegetation. This plant association is characterized by *Dryas octopetala* (white mountain avens) in combination with other prostrate shrub species, and less than 25% cover of herbaceous species (Figure 59). Various combinations of *Cassiope tetragona* (four-angled cassiope), *Dryas octopetala* (white mountain avens), *Salix arctica* (arctic willow), *Salix reticulata* (netleaf willow), *Salix rotundifolia*, *Arctostaphylos rubra* (red-fruit bearberry), *Vaccinium uliginosum* (bog blueberry), *Diapensia lapponica* (Lapland diapensia) and *Empetrum nigrum* (crowberry) dominate the type. Other species include *Carex bigelowii* (Bigelow sedge), *Carex scirpoidea*, *Carex misandra* and *Equisetum arvense* (common horsetail). Moss cover ranges from 2 to 50%. The plant association often grades into various prostrate shrub

and low shrub landcover classes.

Environmental characteristics. This is a minor plant association located primarily on the north half of the Brooks Range and in the Noatak River Valley. It typically occurs as small patches on northerly facing hillside and mountain slopes. These slopes are often unstable with significant exposed rock. Slopes range from 15° to 55° . The soils are a thin layer of peat (1 to 6 inches) over silt, sand or rock. Tussock formation is uncommon. Most sites are dry to mesic, and a minority of sites had water tables between 4 and 18 inches deep. The pH varies from 4.4 to 6.8.



Figure 59. *Dryas octopetala*-*Cassiope tetragona* plant association

***Dryas octopetala* plant association**

White mountain avens

4 sites



Figure 60. *Dryas Octopetala* plant association

Vegetation. *Dryas octopetala* (white mountain avens) dominates the plant association and no codominants occur (Figure 60). Other species include *Salix planifolia* subspecies *pulchra* (diamondleaf willow), *Salix reticulata* (netleaf willow) and *Epilobium latifolium* (fireweed). Moss and fruticose lichen cover ranges from 10 to 20%. It is similar to the *Dryas octopetala*-rock type but with less exposed rock. The plant association often grades into the *sparse vegetation* landcover class and, on more stable sites, the *prostrate shrub-lichen* landcover class and other low shrub and tall shrub landcover classes.

Environmental characteristics. This is a major plant association located throughout GAAR on unstable to stable surfaces such as mountain slopes, high mountain valley floors, rounded mountain ridges (exposed bedrock), the river-side edge of river terraces, and sorted patterned ground. Slopes range from 0° to 30°. The soils are a thin layer of dry to mesic sand, litter or organic mat interspersed with exposed rock. The pH varies from 4.7 to 6.9.

***Dryas integrifolia* plant association**

Entire-leaf mountain avens

2 sites

Vegetation. The *Dryas integrifolia* (entire-leaf mountain-avens) plant association is characterized by *Dryas integrifolia* in combination with other prostrate shrub species including *Vaccinium uliginosum* (bog blueberry), *Arctostaphylos rubra* (red-fruit bearberry), *Salix arctica* (arctic willow), *Cassiope tetragona* (four-angled cassiope) and *Salix reticulata* (netleaf willow). Herbaceous species are common—greater than 25% cover—and include *Carex scirpoidea*, *Carex filifolia*, *Carex membranacea*, *Equisetum arvense* (common horsetail) and *Eriophorum russeolum* (russett cottongrass). Moss cover ranges up to 10%. The plant association often grades into various herbaceous, prostrate shrub and low shrub landcover classes.

Environmental characteristics. This is an incidental plant association located primarily on the north half of the Brooks Range. It typically occurs as small patches or strips on patterned ground. Slopes range from 0° to 2°. The soils are a thin layer of peat (1 to 2 inches) over silt, sand or gravel. Most sites are mesic and tussocks occur on the moister sites. No permafrost was encountered to 2 feet.

***Salix reticulata* plant association**

Netleaf willow

1 site



Figure 61. *Salix Reticulata* plant association

Vegetation. *Salix reticulata* (netleaf willow) dominates the plant association and no codominants occur (Figure 61). Other species include *Salix arctica* (arctic willow), *Dryas octopetala* (white mountain avens), *Salix planifolia* subspecies *pulchra* (diamondleaf willow) and *Carex capillaris*. Moss cover is 30% and bare-ground is common.

Environmental characteristics. The distribution of the plant association is not clear but appears to be an incidental type throughout GAAR on newly colonized floodplain deposits. The soils are a thin layer of moss over sand and silt, and no horizon development was evident. The pH is 6.8.

MESIC HERBACEOUS PLANT ASSOCIATIONS

***Calamagrostis canadensis* plant association**

Bluejoint

1 site

Vegetation. *Calamagrostis canadensis* (bluejoint grass) dominates the plant association (63% cover), and ranges up to 5 feet in height. Other vegetation includes minor cover of *Carex* and *Salix planifolia* subspecies *pulchra* (diamondleaf willow), and bryophyte cover at 88%.

Environmental characteristics. This is an incidental plant association found on moist sites on the south edge of the Brooks Range.

***Carex bigelowii* plant association**

Bigelow sedge

1 site

Vegetation. The *Carex bigelowii* (Bigelow sedge) plant association is dominated by tussocks of *Carex bigelowii* (Figure 62). *Salix lanata* subspecies *richardsonii* (Richardson willow), *Vaccinium uliginosum* (bog blueberry) and other low shrubs are present. The tussocks are approximately 12 inches tall with water, litter or moss often in the hollows. Height of *Carex bigelowii* is 6 inches.

Environmental characteristics. The distribution and patch size of the plant association is unclear. It probably is common on the north side of GAAR and in the Noatak Valley where tussock tundra dominates. The site sampled was on a colluvial slope (20°). During spring runoff and periods of high summer precipitation the sites are relatively wet with water often occupying the hollows. It may be mesic during drier periods and as the soil active layer increases in depth allowing better drainage. The hummocks rest on organic matter, rock or mineral soil. The pH is 6.7.



Figure 62. *Carex Bigelowii* plant association

***Carex lugens* plant association**

1 site

Vegetation. *Carex lugens* is the dominant species and *Salix reticulata* (netleaf willow), *Eriophorum vaginatum* (tussock cottongrass) and *Vaccinium uliginosum* (bog blueberry) are common associates. *Hylocomium splendens* (feather moss) carpets the ground layer. Tussock formation (30%) was less common than in other *mesic herbaceous* types.

Environmental characteristics. The distribution and patch size of the plant association is unclear. It probably is common on the north side of GAAR and in the Noatak Valley where tussock tundra dominates. The site sampled was on a 5⁰ colluvial slope. During spring runoff and periods of high summer precipitation the sites are relatively wet with water often occupying the hollows. It may be mesic during drier periods and as the soil active layer increases in depth allowing better drainage.

***Carex membranacea* plant association**

Fragile sedge plant association

2 sites

Vegetation. Sites are dominated by tussocks of *Carex membranacea* (fragile sedge;

Figure 63). *Dryas integrifolia* (entire-leaf mountain-avens), *Arctostaphylos rubra* (red-fruit bearberry) and *Vaccinium uliginosum* (bog blueberry) are also commonly present. The tussocks range up to 8 inches tall with water, litter or moss often in the hollows. Height of *Carex membranacea* is 6 inches.

Environmental characteristics. The distribution and patch size of the plant association is unclear. It probably is common on the north side of GAAR and in the Noatak Valley where tussock tundra dominates. The sites sampled are on glacial drift covered slopes (18°) and floodplain surfaces. During spring runoff and periods of high summer precipitation they are relatively wet with water often occupying the hollows. It may be mesic during drier periods and as the soil active layer increases in depth allowing better drainage. The hummocks rest on organic matter 2 to 12 inches deep over sand. Permafrost is at 8 to 14 inches, and pH ranges from 7.1 to 7.2.



Figure 63. *Carex Membranacea* plant association

***Eriophorum russeolum* plant association**

Russett cottongrass

2 sites

Vegetation. Sites are dominated by tussocks of *Eriophorum russeolum* (russett cottongrass; Figure 64). *Vaccinium uliginosum* (bog blueberry) and *Carex aquatilis* (water sedge) are often strong codominants. The tussocks range up to 12 inches tall with water, litter or moss commonly in the hollows. Height of *Eriophorum russeolum* averages 1 foot.

Environmental characteristics. The plant association is common on the north side of the Brooks Range and in the Noatak River valley. It occurs as large contiguous patches that often grade into the *shrub birch-willow-tussock tundra* landcover class. During spring runoff and periods of high summer precipitation the sites are relatively wet with water often occupying the hollows. It is mesic during drier periods and as the soil active layer increases in depth allowing better drainage. Slopes ranged from 0° to 10°. The hummocks rest on organic matter or mineral soil that is often saturated. The one pH value recorded was 6.4.



Figure 64. *Eriophorum Russseolum* plant association

***Eriophorum vaginatum* plant association**

Tussock cottongrass

3 sites

Vegetation. Sites are dominated by tussocks of *Eriophorum vaginatum* (tussock cottongrass). Low shrubs are typically strongly represented including *Ledum palustre* (Labrador tea), *Vaccinium uliginosum* (bog blueberry) and *Betula nana* (dwarf arctic birch). *Sphagnum* (peat moss) species and *Polytrichum* species are common mosses.

Environmental characteristics. The distribution and patch size of the plant association is unclear. It probably is common on the north side of GAAR and in the

Noatak Valley where tussock tundra dominates. The sites sampled were below 1,000 feet in elevation.

WET HERBACEOUS PLANT ASSOCIATIONS

***Arctophila fulva* plant association**

Pendent grass

3 sites



Figure 65. *Arctophila Fulva* plant association

Vegetation. *Arctophila fulva* (pendent grass) dominates the plant association, and no codominants were observed (Figure 65). *Arctophila fulva* height reaches 2 feet, however, it is often prostrate and less than 8 inches in height. The only other emergent species recorded was *Hippuris vulgaris* (mare's tail).

Environmental characteristics. This is a minor type located on sites with permanent to semi-permanent standing water such as the edge of ponds, lakes, sloughs, streams and even dune slacks. Water depth varies depending on flooding and precipitation, ranging up to 18 inches above the soil surface. The soils are typically silt or sand with no horizon development. The one pH value recorded was 6.7.

***Carex aquatilis* plant association**

Water sedge

3 sites

Vegetation. *Carex aquatilis* (water sedge) dominates the plant association, and no codominants occur (Figure 66). Species diversity varies from nearly pure *Carex aquatilis* to sites with a variety of low and prostrate shrubs, graminoids and forbs. These include *Salix planifolia* subspecies *pulchra* (diamondleaf willow), *Salix reticulata* (netleaf willow), *Betula glandulosa* (resin birch), *Potentilla palustris* (marsh fivefinger), *Menyanthes trifoliata* (buckbean), *Eriophorum angustifolium* (tall cottongrass) and *Carex lugens*. Sites with greater species diversity typically have tussock formation. Moss cover increases on drier sites.

Environmental characteristics. This is a major type located throughout GAAR on relatively level sites with permanent to semi-permanent standing water. These include low centered polygons, saturated river terraces, the edge of ponds, lakes, sloughs, streams and dune slacks (sampled at the mouth of the Killik River), and even water tracks on hillsides on the north slope of the Brooks Range. Water depth varies depending on flooding and precipitation, ranging up to 6 inches above the soil surface to 10 inches below. Approximately 50% of the sample sites are dominated by tussocks ranging up to 10 inches in height. The soils are typically organic matter and roots 1 to 20 inches over sand, silt and rock. Some sites have permafrost near the surface (8+ inches deep). The pH varies from 5.8 to 6.3.



Figure 66. *Carex Aquatilis* plant association

***Carex aquatilis*/Sphagnum species plant association**

Water sedge/peat moss species

2 sites

Vegetation. *Carex aquatilis* (water sedge) dominates the sites, often with high canopy cover of *Eriophorum* species, *Potentilla palustris* (marsh fivefinger) and *Equisetum fluviatile* (swamp horsetail). *Sphagnum* (peat moss) species are diagnostic in the moss layer.

Environmental characteristics. This plant association is found in the south half of GAAR in small patches. It is typically located on sites with permanent to semi-permanent standing water such as peatlands or as floating mats in shallow ponds.

***Carex limosa* plant association**

Shore sedge

3 sites

Vegetation. Sites are dominated by *Carex limosa* (shore sedge) and *Sphagnum* (peat moss). *Eriophorum russeolum* (russett cottongrass) was also common.

Environmental characteristics. The distribution and patch size of the plant association is unclear. It probably is common on the south side of GAAR where peatlands are common.

***Carex rostrata* plant association**

Beaked sedge

1 site

Vegetation. *Carex rostrata* (beaked sedge) codominates with *Equisetum fluviatile* (swamp horsetail) in the site sampled.

Environmental characteristics. The site sampled was in the Kobuk Boot region on a floodplain, however, the distribution and patch size of the plant association is unclear.

***Carex saxatilis* plant association**

1 site

Vegetation. *Carex saxatilis* dominates the plant association (Figure 67). Other species that occur include *Eriophorum angustifolium* (tall cottongrass) and *Salix planifolia* subspecies *pulchra* (diamondleaf willow).

Environmental characteristics. The distribution and patch size of the plant association is unclear. It probably is more common on the north side of GAAR and in the Noatak Valley where tussock tundra dominates. It is typically located on sites with permanent to semi-permanent standing water, such as the edge of ponds, lakes, and sloughs.



Figure 67. *Carex Saxatilis* plant association

***Eriophorum angustifolium* subspecies *subarcticum* plant association**

Tall cottongrass

2 sites

Vegetation. *Eriophorum angustifolium* subspecies *subarcticum* (tall cottongrass) dominates the sites, often with high canopy cover of *Carex podocarpa*, *Eriophorum russeolum* (russett cottongrass) and *Equisetum fluviatile* (swamp horsetail; [Figure 68](#)). Shrubs have low cover values and include *Salix reticulata* (netleaf willow), *Salix planifolia* subspecies *pulchra* (diamondleaf willow) and *Betula glandulosa* (resin birch). Tussock formation was minor.

Environmental characteristics. This plant association is found throughout GAAR in small patches. It is typically located on sites with permanent to semi-permanent standing water such as pond and lake edges, patterned fens and sloughs. Water depth ranges from 1 inch below the surface to 8 inches above and varies depending on flooding, runoff, active layer depth and precipitation. Permafrost was encountered at one site at 10 inches. Acidity ranges from 6.2 to 6.5.



Figure 68. *Eriophorum Angustifolium* plant association

***Equisetum fluviatile* plant association**

Swamp Horsetail

1 site

Vegetation. *Equisetum fluviatile* (swamp horsetail) dominates the plant association but typically has low cover. *Potentilla palustris* (marsh fivefinger) and *Carex aquatilis* (water sedge) may be found as codominants. *Equisetum fluviatile* often reaches 2 feet in height.

Environmental characteristics. The *Equisetum fluviatile* (swamp horsetail) plant association is found throughout GAAR in small patches. It is typically located on sites with permanent to semi-permanent standing water, such as the edge of ponds, lakes, and sloughs. Water depth was 8 inches and varies depending on flooding and precipitation.

3.8 SURFICIAL GEOLOGY INFLUENCES ON LANDCOVER

Surficial geology units—as defined and mapped by Hamilton (1999c)—were considered in developing the classification system because some units strongly affect the distribution and pattern of landcover on a time and space scale pertinent to the products being produced. For example, the floodplain surficial geology unit is strongly influences the type of vegetation and the pattern of landcover classes on floodplains exist at a spatial scale that can be recognized using Landsat imagery. This is not to imply that all surficial geology units delineated by Hamilton (1999c) strongly influence or reflect vegetation distribution.

However, in order to link the surficial geology units to landcover classes the units needed to be aggregated. For example, the aggregated unit termed floodplain is actually a combination of the alluvium, undifferentiated, modern alluvium, low alluvial-terrace deposits, alluvium, sand facies, and neoglacial outwash surficial units. This aggregated unit of floodplain is a better reflection of vegetation than each of its individual components. This aggregated surficial geology data layer included in the Interactive Map and the GAAR Landcover ArcView 3.1 product ([Table 1](#)).

The aggregated surficial geology units are described below, and a list of the original and aggregated units is given in [Appendix 3](#). Several surficial geology units and landforms that are described in this report but not defined by Hamilton (1999c) include patterned ground (sorted polygons, frost boils and ice wedge polygons), thermokarst, water tract, and frost scar. They reflect previously described Alaskan landscapes (Davidson 1996, Walker and Webber 1979, Krieg and Reger 1982, Embleton and King 1975).

Bedrock

Bedrock occurs at higher elevations and includes all the jagged rocky ridges, peaks, cirque headwalls and cirque basins in the Brooks Range (**Figure 69, 44** and the landcover map). Bedrock has little or no soil development, and colluvium, alluvial fans and glacial drift all occur downslope. Glaciation has shaped and exposed the bedrock, although presently only small headwater glaciers exist in GAAR. Frost action and weathering continue to fracture rock, causing continued rock fall and erosional landforms such as altoplanation terraces (mountain terraces), scarps, cliffs, and tors. Most precipitation runs off the surface because of shallow soils or a lack of soils, and relatively steep slopes. Bedrock was the only surficial geology unit from Hamilton (1999c) used to delineate this type, and covers 58% of GAAR's landmass ([Appendix 6](#)).



Figure 69. Landsat image of bedrock showing covering of prostrate shrub
[Scale = 1:63,360, Landsat TM bands 4,5,3 (RGB)]

Bedrock vegetation. Vegetation is generally absent in the higher elevations or is sparse due to the harsh climatic conditions, and shallow or no soils (see the landcover map). On stable areas the vegetation often forms continuous mats of low growing vegetation (lichen, prostrate shrub), and, moving downslope, shrubs and trees occur. For all bedrock in GAAR, forests cover 11.7%, tall or low shrubs 24.0%, prostrate shrubs 29.8%, herbaceous vegetation 4.7%, and bare-ground, sparsely vegetated and water 24.7%, and mosaic/patterned vegetation and shadow indeterminate 5.0% (Table 13).

Table 13. Percent cover of landcover classes for the major surficial geology features in GAAR

Landcover classes	Bedrock	Colluvial	Alluvial fan	Glacial drift	Organic	Lacustrine	Flood plain	Total: GAAR project area
Dense-open white spruce forest	0.03	0.02	0.36	0.08	0.07	0.17	0.61	0.08
Open spruce forest, species unknown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Open black spruce-like forest	3.04	9.27	9.45	11.42	33.02	25.28	17.65	6.95
Open white spruce-like forest	2.99	2.83	2.51	2.66	1.08	1.56	2.01	2.80
Spruce woodland	3.99	3.84	7.66	8.41	20.88	16.23	8.30	5.68
Spruce-lichen woodland	0.37	0.77	1.43	1.60	11.77	7.06	1.70	0.97
Closed paper birch-aspen forest	0.23	0.15	0.12	0.20	0.01	0.17	0.18	0.21
Closed balsam poplar forest	0.02	0.06	0.11	0.11	0.09	0.30	0.82	0.09
Open paper birch-aspen forest	0.32	0.43	0.61	0.50	0.61	0.61	0.53	0.39
Open balsam poplar forest	0.04	0.18	0.36	0.36	1.46	1.34	0.95	0.21
Closed spruce-broadleaf forest	0.32	0.33	0.29	0.36	0.26	0.47	1.02	0.36
Open spruce-broadleaf forest	0.33	0.50	0.67	0.56	0.20	0.52	1.34	0.45
Closed tall shrub	4.13	2.24	4.13	2.65	4.03	2.44	3.84	3.54
Open tall shrub	4.13	1.93	2.92	3.01	5.33	3.91	3.93	3.63
Shrub birch-willow-tussock tundra	3.02	13.99	8.61	13.78	2.50	4.92	6.17	6.93
Shrub birch-ericaceous-willow	12.48	12.19	18.14	18.01	6.05	8.27	11.61	13.87
Closed low willow	0.24	0.89	0.60	0.61	0.04	0.42	1.24	0.43
Prostrate shrub-rock	8.73	5.62	4.09	2.72	0.31	1.29	1.83	6.32
Prostrate shrub-lichen	2.01	1.04	2.11	1.36	0.05	0.88	0.62	1.67
Prostrate shrub	19.03	13.00	14.37	12.46	0.83	5.27	6.76	15.85
Dry herbaceous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mesic herbaceous	4.46	10.82	10.33	12.71	8.76	9.57	7.45	7.44
Wet herbaceous	0.26	0.57	1.46	1.23	1.49	0.82	1.68	0.64
Aquatic herbaceous	0.00	0.00	0.02	0.01	0.00	0.02	0.12	0.01
Sparsely vegetated	10.51	5.89	4.36	1.59	0.02	0.85	4.71	7.18
Bare-ground	13.68	8.71	2.50	1.15	0.34	1.02	6.66	9.20
Silty water	0.05	0.08	0.60	0.29	0.20	0.93	5.50	0.38
Clear water	0.05	0.06	0.31	0.71	0.49	2.69	1.75	0.58
Snow/Ice	0.42	0.59	0.12	0.10	0.00	0.03	0.43	0.43
Sand dunes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mosaic/patterned vegetation	0.02	0.01	0.92	0.46	0.09	2.65	0.21	0.19
Shadow/indeterminate	5.02	3.76	0.78	0.75	0.00	0.15	0.28	3.41

Colluvium

Colluvial deposits are unconsolidated surface materials that have been transported downslope and deposited on the lower slopes ([Figures 70 and 71](#)). Colluvium is moved by landslides, flow slides, talus rubble, rock-glaciers, solifluction and unconsolidated runoff. Solifluction and rock-glaciers are described below. It covers 6.8% of the land within GAAR ([Appendix 6](#)).

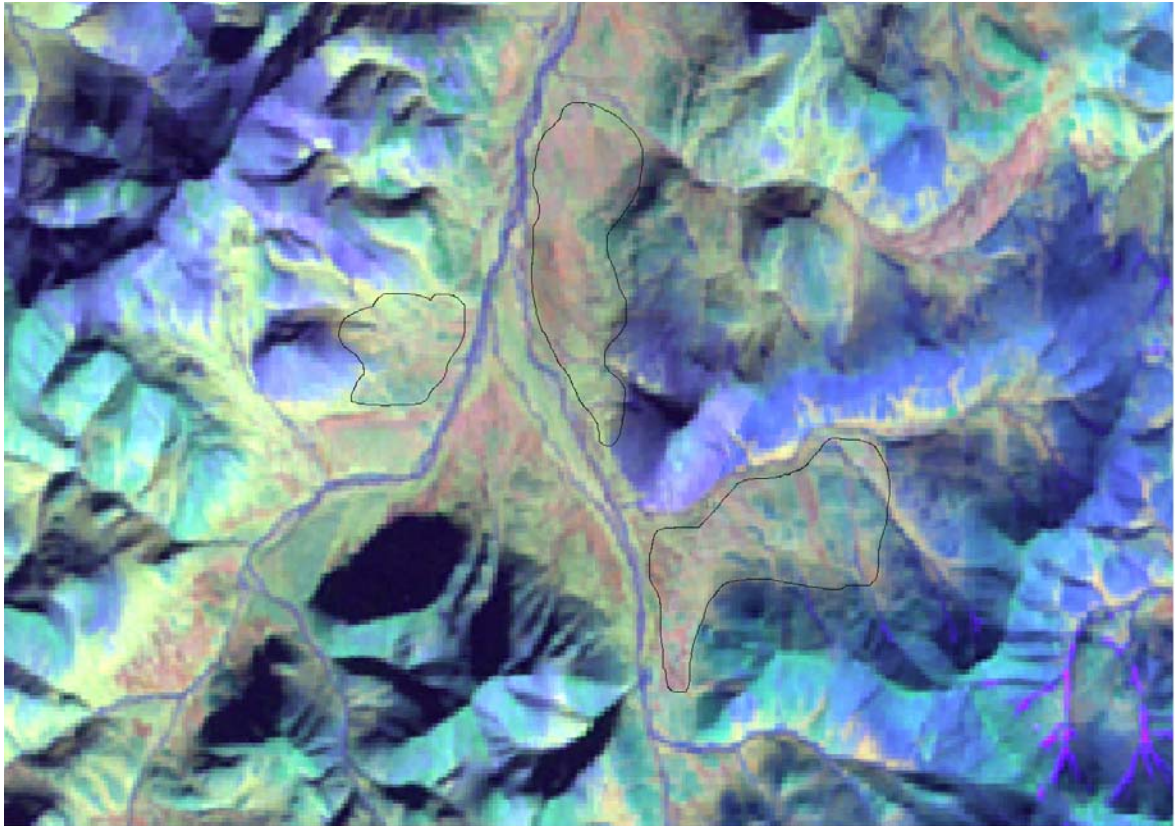


Figure 70. Landsat image of colluvial slope in arctic foothills ecoregion
[Scale = 1:63,360, Landsat TM bands 4,5,3 (RGB)]



Figure 71. Colluvial slope in the arctic foothills ecoregion



Figure 72. Solifluction Lobes

Solifluction. Solifluction (or gelifluction) is the flow of soil in association with frozen ground, and is a type of colluvium (Ritter 1986; [Figure 72](#)). During the spring and summer thaw, water in the active layer cannot penetrate below the permafrost table. Soils are often saturated, and the loss of friction and cohesion causes them to behave like viscous fluids. The soil thus slowly ‘flows.’ The downslope fronts of the solifluction lobes are marked by near-vertical scarps as high as six feet ([Figure 73](#)). This form of mass wasting commonly occurs on slopes between 5° and 20° . Steeper slopes tend to drain off excess water. Silty soils are the most susceptible to solifluction, whereas gravelly and sandy soils are so permeable and easily drained that they rarely flow. Solifluction was commonly observed on various colluvial and glacial drift deposits.

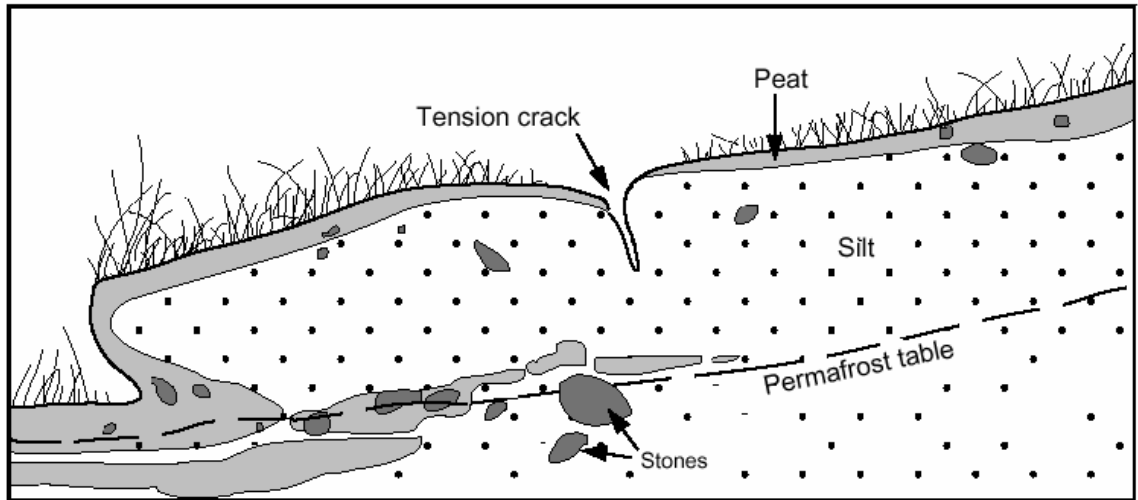


Figure 73. Idealized cross-section of a solifluction lobe

In GAAR, it is likely that solifluction deposits are actively forming over a wide area. Well-formed lobes are an easily recognizable indication of the process; however, solifluction may be active and important at altitudes lower than where such lobes occur. We observed stands of willows growing on many of the advancing fronts, and prostrate shrubs on the upper portions of the lobes. Occasionally, the upper portions were marked by tension cracks in the vegetation and organic soil layer.

Rock Glacier. Rock glaciers are tongue-shaped or lobate masses of unsorted, angular frost-rived material with interstitial ice (Figure 74). They are another type of colluvium and a distinctive feature in the high mountains. They typically originate in cirques or in high, steep-walled recesses. All the rock glaciers observed were free of vegetation.

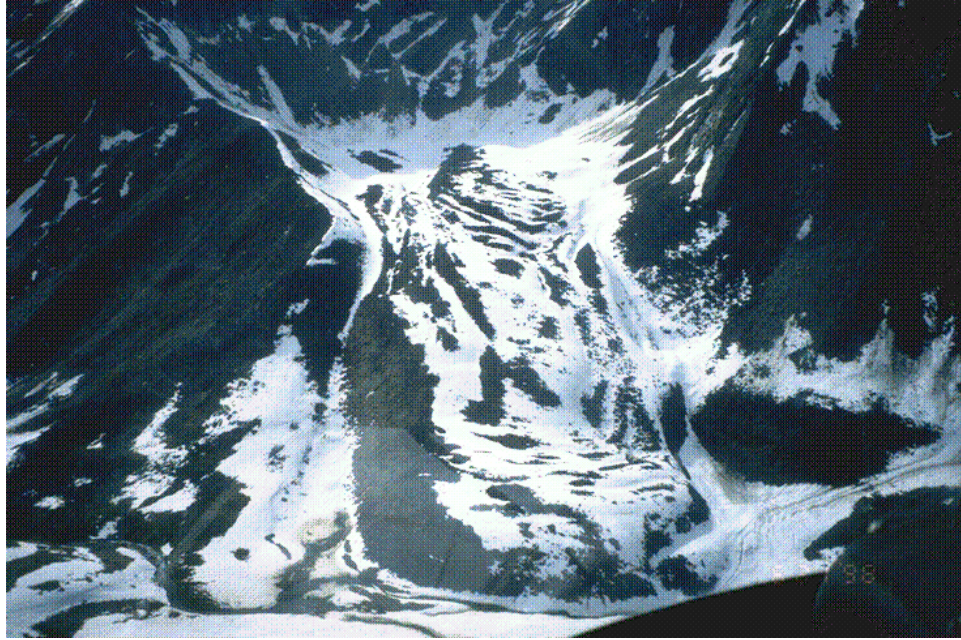


Figure 74. Rock glacier in the Brooks Range ecoregion

Colluvium vegetation. For all colluvium in GAAR, forests cover 18.4%, tall or low shrubs 31.2%, prostrate shrubs 19.7%, herbaceous vegetation 11.4%, and bare ground, sparsely vegetated, and water 15.3% and mosaic/patterned vegetation and shadow indeterminate 3.77% ([Table 13](#)).

Alluvial Fans

Alluvial fans are common throughout the mountainous ecoregion of GAAR, covering 1.5 of its landmass ([Figure 75](#), [Appendix 6](#)). Alluvial fans are an erosional-depositional system in which rock and sediment are transported down-valley and deposited where it emerges from the confines of a narrow valley into a larger valley or plain. They tend to be fan-shaped in plan view; a segment of a cone radiating away from a single point source. The point of deposition can shift away from the mountain front to well down the original fan surface if the stream has become entrenched. The stream emerges down-fan and deposits its material forming a new fan on top of the older deposits. On an alluvial fan, some areas are actively forming whereas other areas are inactive.

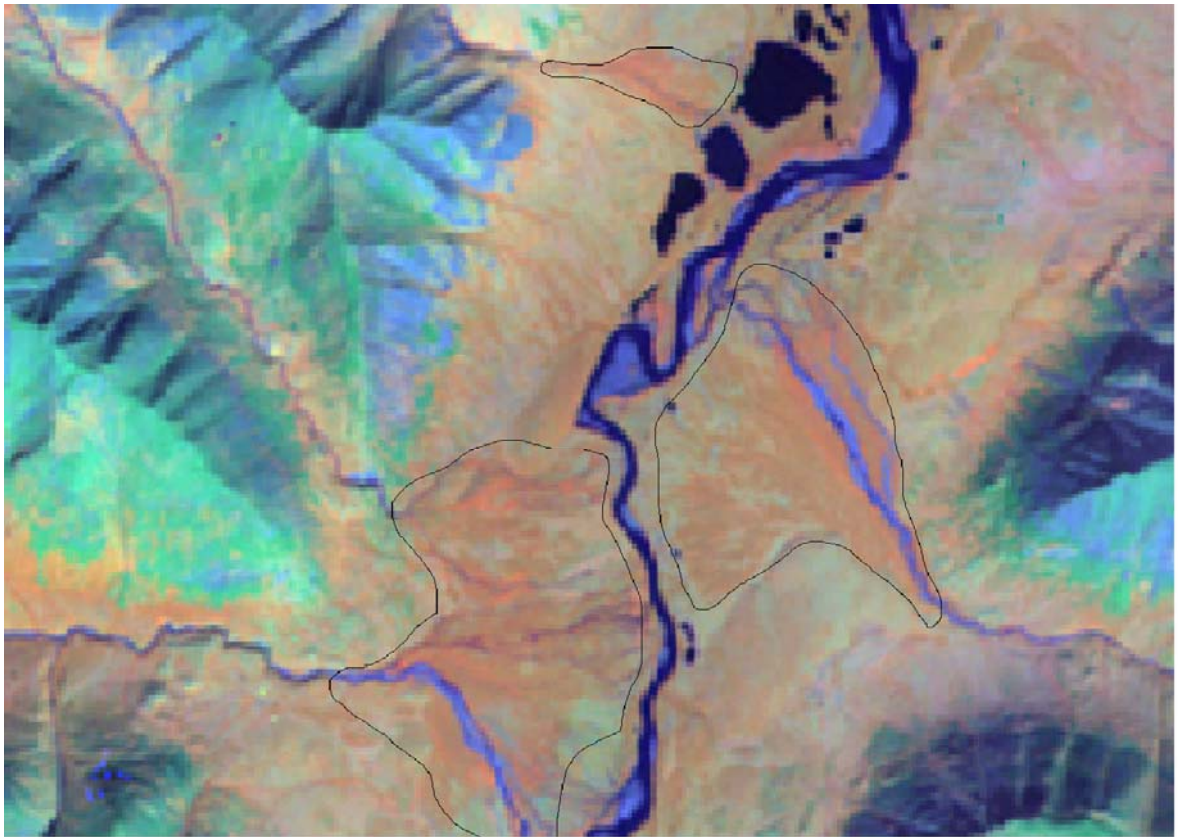


Figure 75. Landsat image of an alluvial fan north of treeline
[Scale = 1:63,360, Landsat TM bands 4,5,3 (RGB)]

Slushflows and flooding in side-canyons can add significant debris to alluvial fans. In winter, snow avalanches strip the frost-loosened bedrock from the valley walls and deposits it on valley bottoms. Both slushflow and flooding remove this debris and deposit it on alluvial fans. Slushflows occur when rapid snowmelt during May and June causes wet-snow avalanches that flush the debris out of the canyons onto the alluvial fans. Flooding may occur if late summer heavy rains funnel water into steep channels. The flooding picks up soil, rocks, and vegetation, and scours out the channels. The debris is then deposited in fans at the base of the mountain.

Fan morphology is relatively consistent. The slope of an alluvial fan decreases as you move downfan. Near the mountain front, fans are relatively steep although rarely exceeding 10° (Ritter 1986). They gradually flatten at their lower extremity. The steepest gradients are usually associated with coarse-grained materials. The presence of boulders strewn across fan surfaces suggests periodic slushflow activity.

Alluvial fan vegetation. Vegetation reflects the differences in active versus inactive fan areas, and different vegetation successional stages are evident. Disturbance species—such as willows (*Salix* species) and alder (*Alnus* species)—prefer the active areas, just as they colonize recently deposited floodplain materials. The inactive

older deposits tend to reflect the vegetation found on stable surfaces adjacent to the fans such as on colluvium and glacial drift. On the south half of GAAR, for example, spruce forests are common on both fans and glacial drift ([Figure 76](#), [Appendix 4](#)).



Figure 76. Alluvial fan in the South half of GAAR

Some fans have a high cover of the landcover classes *prostrate shrub-lichen* and *spruce-lichen woodland*. North of treeline, low shrubs and tussock tundra are common on fans ([Figure 77](#)). Tall shrubs rarely occurred on other surficial geology units north of treeline except for floodplains type. For all alluvial fans in GAAR, forests cover 23.6%, tall or low shrubs 34.4%, prostrate shrubs 20.7%, herbaceous vegetation 11.8%, and bare ground, sparsely vegetated, water, 7.9% and mosaic/patterned vegetation and shadow indeterminate 1.7% ([Table 13](#)).



Figure 77. Alluvial fan North of treeline

Glacial Drift, Terraces, and Sand-Silt Deposits

Glacial drift, terraces and sand-silt deposits were aggregated into a single group. This was due to—in general—sharing similar landcover classes and the units were often intermixed with each other.

Glacial Drift. This surficial geology type is somewhat of an agglomeration of different deposits that dominate the valley bottoms and mountain sideslopes ([Figure 78](#)). It covers 27% of GAAR (Table 13). Glacial drift is defined as material transported by a glacier and then deposited either directly from the ice or from the melt water. In GAAR, these deposits are predominantly of late Pleistocene age, however, older (Miocene) and younger (Holocene) deposits can be found. Numerous types of glacial drift occur including moraines, kettle-kame topography, eskers, drumlins, glacial till and outwash. Glacial till is the dominant feature and is formed by sediment originating directly from glacial ice and typically has no discernible sediment stratification. *Inactive* glacial outwash is included in this section—*active* outwash is placed in the floodplain surficial geology unit.

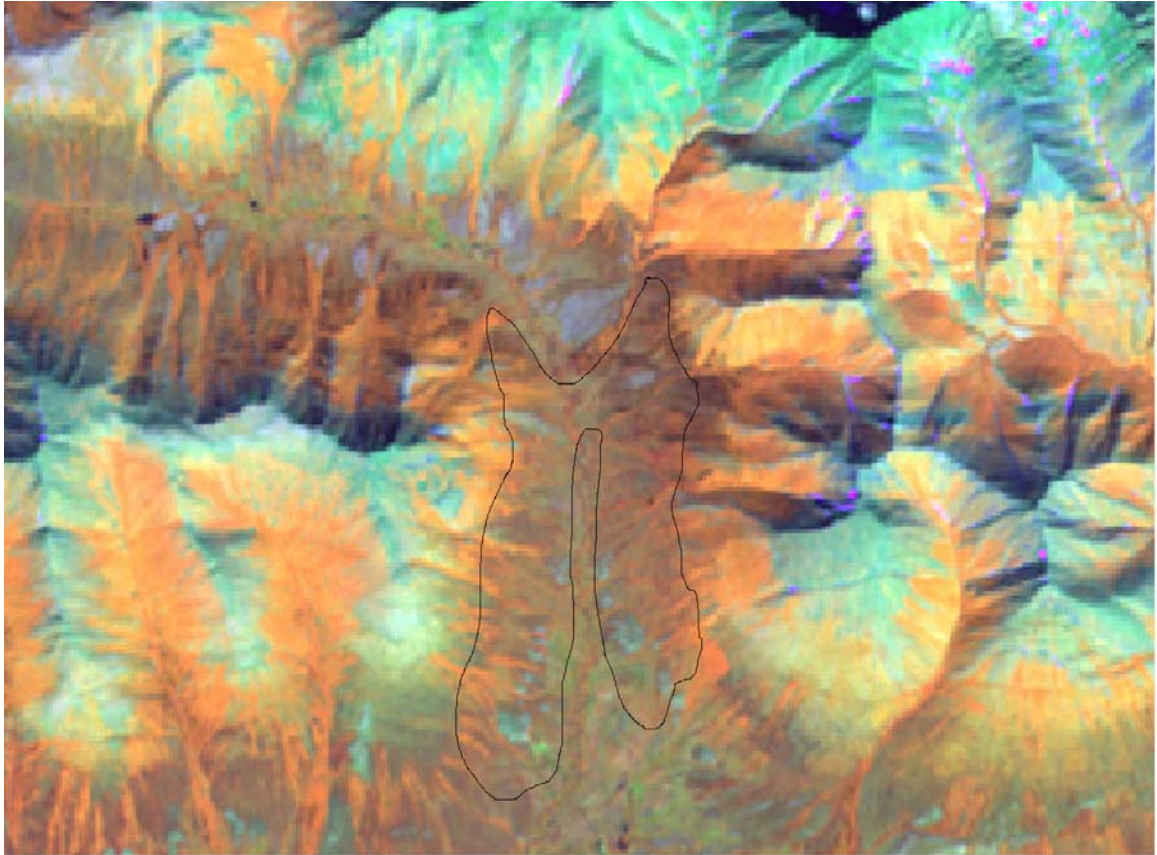


Figure 78. Landsat image of glacial till in the south half of GAAR
[Scale = 1:63,360, Landsat TM bands 4,5,3 (RGB)]

Various processes and other surficial geology types occur on the glacial drift type. These include thermokarst, frost scarring, polygonal ground, pingos and water tracks. Alluvial fans and colluvial slopes often cover glacial drift, and glacial drift is subjected to solifluction—a type of colluvial process. Rivers can also rework glacial deposits forming floodplains.

Terraces. Terraces are floodplains and outwash plains that have been horizontally and vertically removed from the regular flooding of a river. The ultimate cause of this removal from the river's influence is down-cutting by the river. These surfaces are typically gravel and sandy gravel, capped by floodplain deposits of silt, sand, or peat up to 3 to 6 feet thick. Older surfaces may be also covered by thicker eolian silt, peatland, and thaw-lake deposits.

Sand-Silt deposits. Sand and silt occur in a variety of forms within GAAR, and a few examples follow.. Some silt and sand is deposited initially by slow-moving streams within basins partly dammed by end moraines. These deposits commonly grade downward into lacustrine deposits and are often dissected by postglacial streams. Other sand-silt deposits are formed by loess, and now are poorly stratified sandy silt, organic silt, and silty peat. Abundant ice often occurs in the form of lenses, wedges,

and interstitial grains. Another example is upland silt deposits formed from loess and the layers are subsequently mixed by frost action with local organic matter and weathering products (Hamilton, 1999c).

Active dunes and inactive dunes both occur within GAAR (Figures 40a and b). The most extensive dunes observed were parabolic and longitudinal dunes along the Killik River near the north flank of the Brooks Range (Killik River quadrangle) and a series of subparallel ridges on the Alatna River floodplain near the south margin of the range (Survey Pass quadrangle, Hamilton 1999c). The location and formation of dunes depend primarily on the availability of sand, and wind direction. The main source of sand and silt is the sediment load delivered by the various rivers and deposited on outwash plains, floodplains or deltas. Once the sediment is deposited, winds form the dunes. The eventual quasi-equilibrium in sand dunes represents a balance between erosion and deposition, and requires the forward movement of the entire feature.

Glacial drift vegetation. For all of the glacial drift in GAAR, forests cover 26.3%, tall or low shrubs 38.1%, prostrate shrubs 16.5%, herbaceous vegetation 13.9%, and bare ground, sparsely vegetated, water 3.8% mosaic/patterned vegetation and shadow indeterminate 1.2% (Table 13). On glacial drift in the south half of GAAR, the vegetation generally changes, moving downslope, from prostrate shrubs to either low or tall shrubs, then to open forest (Figure 78). On the relatively level valley bottoms lichen-woodland is common on drier sites, and woodlands and peatlands occupy the wetter sites.

On the north half of GAAR—north of treeline—the vegetation generally changes, moving downslope, from prostrate shrubs to either low shrubs or tussock tundra (Figure 79). On level valley bottoms wet-herbaceous vegetation or tussock tundra will dominate. Small but consistent pockets of well drained river bluffs and frost boils—areas of bare soil caused by frost action—also occur and are dominated by prostrate shrubs or resin birch (*Betula glandulosa*).

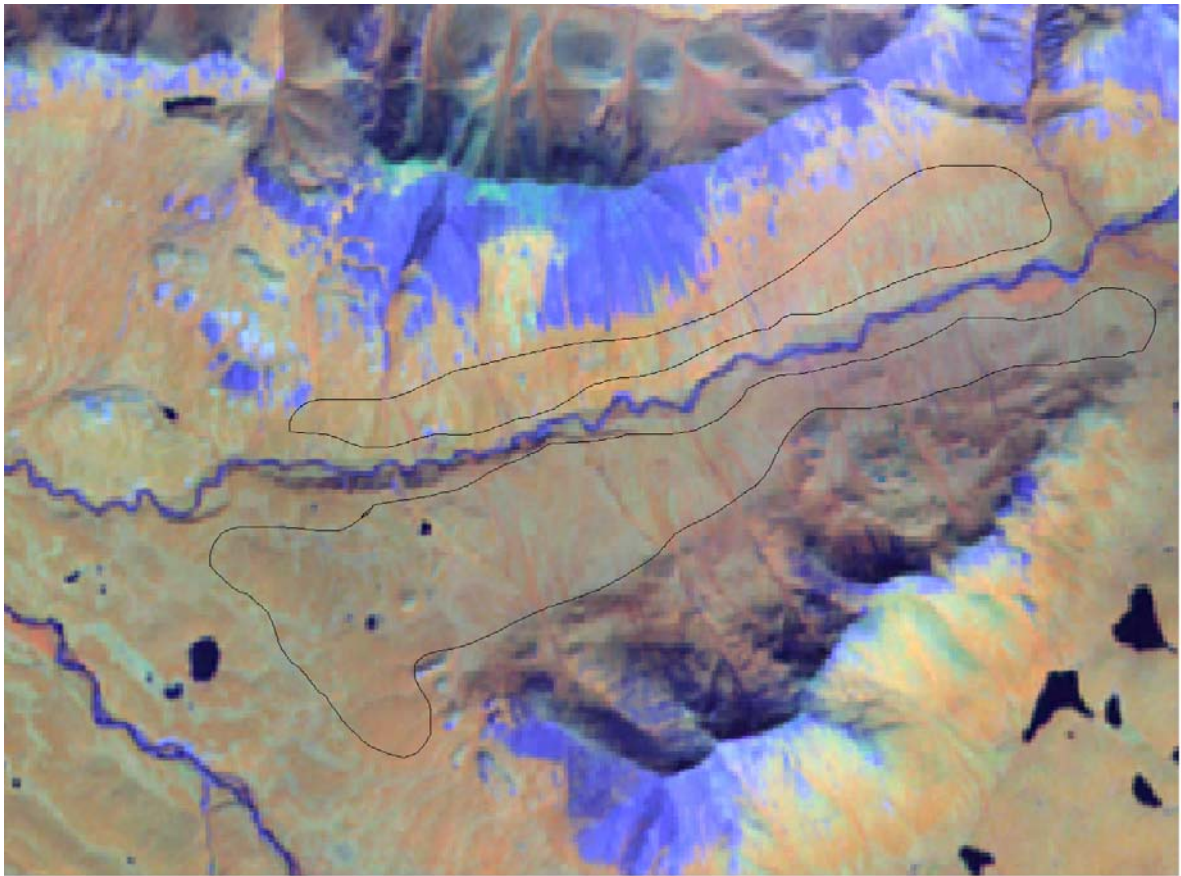


Figure 79. Landsat image of glacial till north of treeline
[Scale = 1:63,360, Landsat TM bands 4,5,3 (RGB)]

Lacustrine Deposits

Lacustrine deposits occupy the valley bottoms, as do glacial drift and floodplains ([Figure 80](#)). This deposit is derived from materials deposited in lake water and exposed when the water level is lowered or the land is raised. Lacustrine deposits have a high percentage of thermokarst formed lakes and covers 1.2% of GAAR.

For all of the lacustrine deposits in GAAR, forests cover 53.7%, tall or low shrubs 19.9%, prostrate shrubs 7.4%, herbaceous vegetation 10.4%, and bare ground 5.5% and mosaic/patterned vegetation and shadow indeterminate 2.8% ([Table 13](#)).



Figure 80. Landsat image of lacustrine deposits
[Scale = 1:63,360, Landsat TM bands 4,5,3 (RGB)]

Floodplain

Floodplains are composed of glacial and non-glacial rivers, sandbars and low terraces that are still actively flooded. The soils include both poorly-drained permafrost rich soils, lake silts and clays, and well-drained alluvial loams, sands and gravels. Surficial geology deposits included in this type are ‘modern alluvium’ and ‘undifferentiated alluvium.’ Floodplains are widely distributed and cover 4% of the landmass of GAAR ([Appendix 6](#)).

Active glacial outwash plain is included in this section due to its similarity to floodplains—*inactive* glacial outwash is included in the glacial drift description. Glacial outwash forms when glacially fed rivers deposit their sediment in stream channels and the associated plain. Due to continual channel shifting the sediment is spread across an area called an outwash plain. Outwash plains typically have braided rivers consisting of multiple, wide, shallow channels characterized by rapid erosion, deposition and channel shifts. Many of the drainage systems in GAAR have small headwater glaciers but the influence of these glaciers on the drainages appears to be minor and, consequently, outwash plains are uncommon in GAAR.

Floodplains are formed by non-glacial fed rivers. In GAAR, they often rework lacustrine and glacial drift deposits. The formation of new land on floodplains is well documented. Along a meandering river—meandering rivers have one or two main channels—alluvium is deposited on convex curves in the river channel (Figure 81). The opposing concave bank is cut, providing sediment for deposition on convex curves downstream and creating a series of similar bands of alluvial deposits. The channel thus meanders laterally across the floodplain. Vegetation growing on new deposits near the river may be contrasted with that on older deposits inland to recognize and measure successional processes. Alluvium is also deposited on the soil surface during flooding further raising the soil surface height, but because surface height is a function of floodwater height it eventually stabilizes.

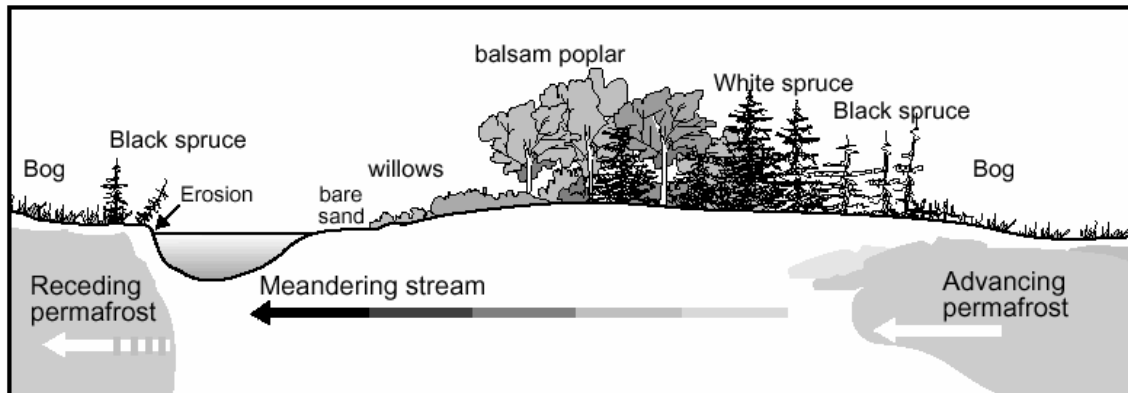


Figure 81. Idealized cross-section of geomorphic and vegetation succession on a flood-plain (adapted from Krieg and Reger 1982)

Terraces play a major role in plant community structure and composition. Deposits with high permeability become progressively drier as they are vertically and horizontally removed from the active channels. This is due to decreased soil water recharge from channel seepage. Vegetation responds to these gradients in soil moisture with changes in composition and structure. On older terraces, in contrast, permafrost forms and creates an impermeable layer that, in turn, leads to a wetter environment. Ponds, such as meander scrolls and oxbows, are common on floodplains (Figure 82). A meander scroll is formed on the convex side of river bends by alluvial deposition. As alluvium is deposited, it forms point bars and further inland an undulating topography of levees and depressions. The meander scroll depressions are often filled with standing water or act

as overflow channels during high flows. Oxbows are formed when a river abruptly changes course cutting off a stream segment. Typically, the oxbow will partially fill with water. The effect of permafrost on ponds is not clear, but it appears the formation of ground ice alters pond shape and depth.



Figure 82. Oxbows on floodplain altered by ground ice

Floodplain vegetation. On forested floodplains and outwash plains on the south-half of GAAR, new alluvial bars or abandoned stream channels are invaded by sapling balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*), willow (*Salix* species) and alder (*Alnus* species) species (Figure 83). In time, balsam poplar and white spruce dominate the sites and form sparse to dense forests. If the soils remain well drained then white spruce will eventually dominate as balsam poplar reaches senescence. However, if ground ice forms, leading to poorly-drained soils, then black spruce (*Picea mariana*) will invade along with other moisture tolerant species such as peat moss (*Sphagnum* [peat moss] species). The balsam poplar map class was not observed on other surficial geology types except in the Kobuk Boot area on uplands.



Figure 83. Landsat image of floodplain surficial geology type in the south half of GAAR [Scale = 1:63,360, Landsat TM bands 4,5,3 (RGB)]

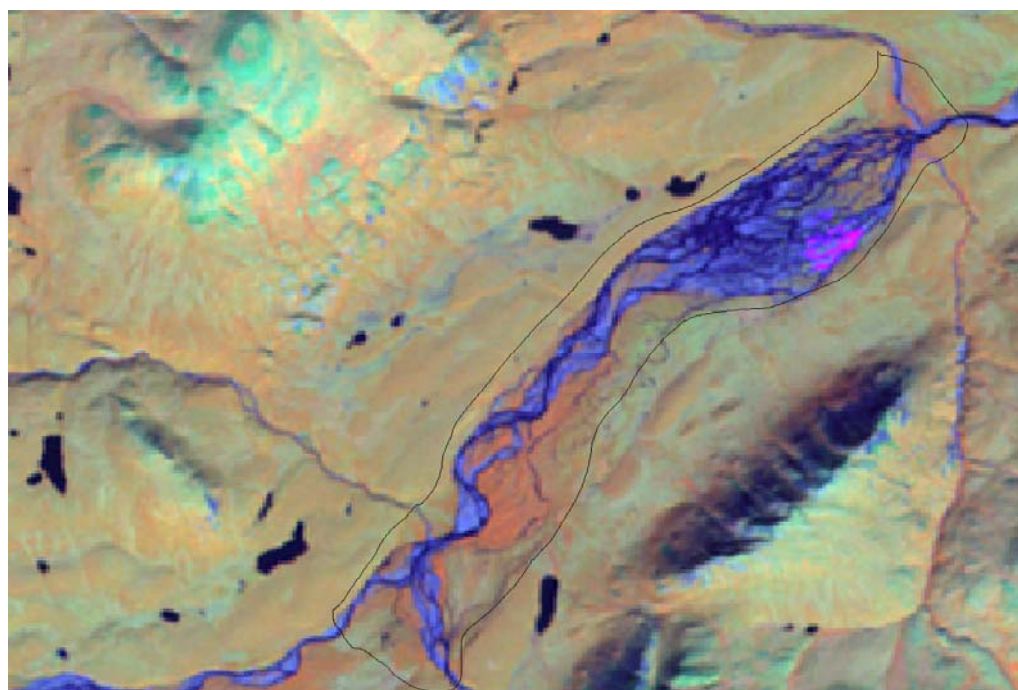


Figure 84. Landsat image of the floodplain surficial geology type in the north half of GAAR [Scale = 1:63,360, Landsat TM bands 4,5,3 (RGB)]



Figure 85. River floodplain north of treeline dominated by willows (*Salix*) and tussock tundra

North of treeline, new alluvial bars or abandoned stream channels are invaded by river beauty (*Epilobium latifolium*, dwarf fireweed), arctic wormwood (*Artemisia arctica*) and shrub species such as feltleaf willow (*Salix alaxensis*) and grayleaf willow (*Salix glauca*) (Figures 84 and 85). If the soils remain well drained, then willows may continue to dominate. However, if ground ice forms, leading to poorly-drained soils, then tussock tundra and wet herbaceous meadows form. Tall shrubs rarely occur north of treeline except on recently disturbed portions of floodplains and alluvial fans. Small streams are common in GAAR, but were usually not captured by either the Landsat imagery or the surficial geology maps due to their narrow widths. On small streams in the south half of GAAR, willow and alder species dominate the narrow floodplains and stream banks (Figure 86). On small streams in the north half of GAAR the narrow floodplains are dominated by open and closed shrub stands composed of *Salix planifolia* subspecies *pulchra*, and *Betula glandulosa* (resin birch), and herbaceous vegetation (Figure 87). For floodplains large enough—greater than 90 feet width—to be captured by Landsat imagery, forests covered 35.1%, tall or low shrubs 26.8%, prostrate shrubs 9.2%, herbaceous vegetation 9.5%, and bare ground, sparsely vegetated, water and patterned ground 19.5% (Table 13).



Figure 87. Stream in the north half of GAAR whose floodplain is dominated by willow (*Salix*)



Figure 88. Pingo (~40 m diameter) in alluvial valley

Organic Deposits

Organic deposits (i.e., peatlands, muskeg) are composed of three to six feet of accumulated peat in areas of restricted drainage with water tables at or close to the peat surface. The peat generally grades laterally into organic silt and silty peat near the bases of solifluction slopes (Hamilton 1999c). Organic deposits are generally

restricted to forested areas beyond the south flank of the Brooks Range. They occupy former lake basins and other closed depressions, alluvium along some valley floors, and are abundant on older glacial drift deposits within the boreal forest. These deposits cover 0.7% of GAAR ([Table 13](#)).

The gradient of nutrient availability and water sources for organic deposits is typically divided into nutrient rich (fen) and nutrient poor (bog) peatlands. Fens are wetlands with wet organic soils, dominated by aquatic, emergent, and dwarf shrubs, or raised peat dominated by shrubs and trees. Ground water, the primary water source in a fen, is nutrient rich because of its contact with mineral soils. Waters may be acidic or basic, but typically with a pH above 4.7. Water is lost through evapotranspiration, seepage (infiltration through the soil), and surface outflow.

Bogs are wetlands with organic soils, typically dominated by *Sphagnum* (peat moss) species, sedges, grasses, or reeds. Bogs require depressions (ponds) in level areas where precipitation exceeds evapotranspiration. Precipitation is the primary water source in a bog, with little or no ground-water flow. Consequently the sites are nutrient-poor and acidic, commonly with a pH less than 4.7. The water table is at or close to the surface most of the year. Because of the continuum of site and vegetation change within a peatland, it is often difficult to clearly separate a fen from a bog in the field.

Peatland Vegetation. In level areas, bogs and fens generally exhibit recognizable and consistent vegetation zonation patterns that are directly associated with different water depths. The vegetation, on a wet to dry moisture gradient, typically changes from aquatic (pond), to emergent, to mesic herbaceous, to carr (shrub-dominated wetland), to dwarf tree. Not all the vegetation zones are always expressed, and the zonation may change abruptly, such as from a pond to a carr. Beavers typically have a major effect on the development and maintenance of fens by creating pools, forming hummocks with their dams, and consuming woody vegetation. Fens on ground with a slight gradient and with heavy subsurface and surface waterflow often develop a patterned ground of vegetated ridges, and vegetated or unvegetated hollows filled with water. The major vegetation cover observed during the 1998 field season was peat moss (*Sphagnum*) and stunted black spruce. For all of the lacustrine deposits in GAAR, forests cover 53.7%, tall or low shrubs 19.9%, prostrate shrubs 7.4%, herbaceous vegetation 10.4%, and bare ground sparsely vegetated, water 5.5% and mosaic/patterned vegetation and shadow indeterminate 2.8% ([Table 13](#)).

Pingo. Pingos are uncommon yet widespread throughout GAAR ([Figure 88](#)). They are ice-filled conical hills or mounds, 20 to 400 m in diameter and 10 to 70 m high. Closed-system pingos form in nearly level areas when unfrozen ground water migrates under hydrostatic pressure to a site where the permafrost is domed up to form a mound. An open-system type is generally smaller and forms on sloping ground where water beneath or within the permafrost penetrates the permafrost under high hydraulic pressure, which heaves the overlying material to form a mound. Radiometric dating indicates that most pingos in Alaska are less than 4,000 to 7,000

years old, however, many are less than 1,000 and even 100 years old. Vegetation on pingos is not described in this report.

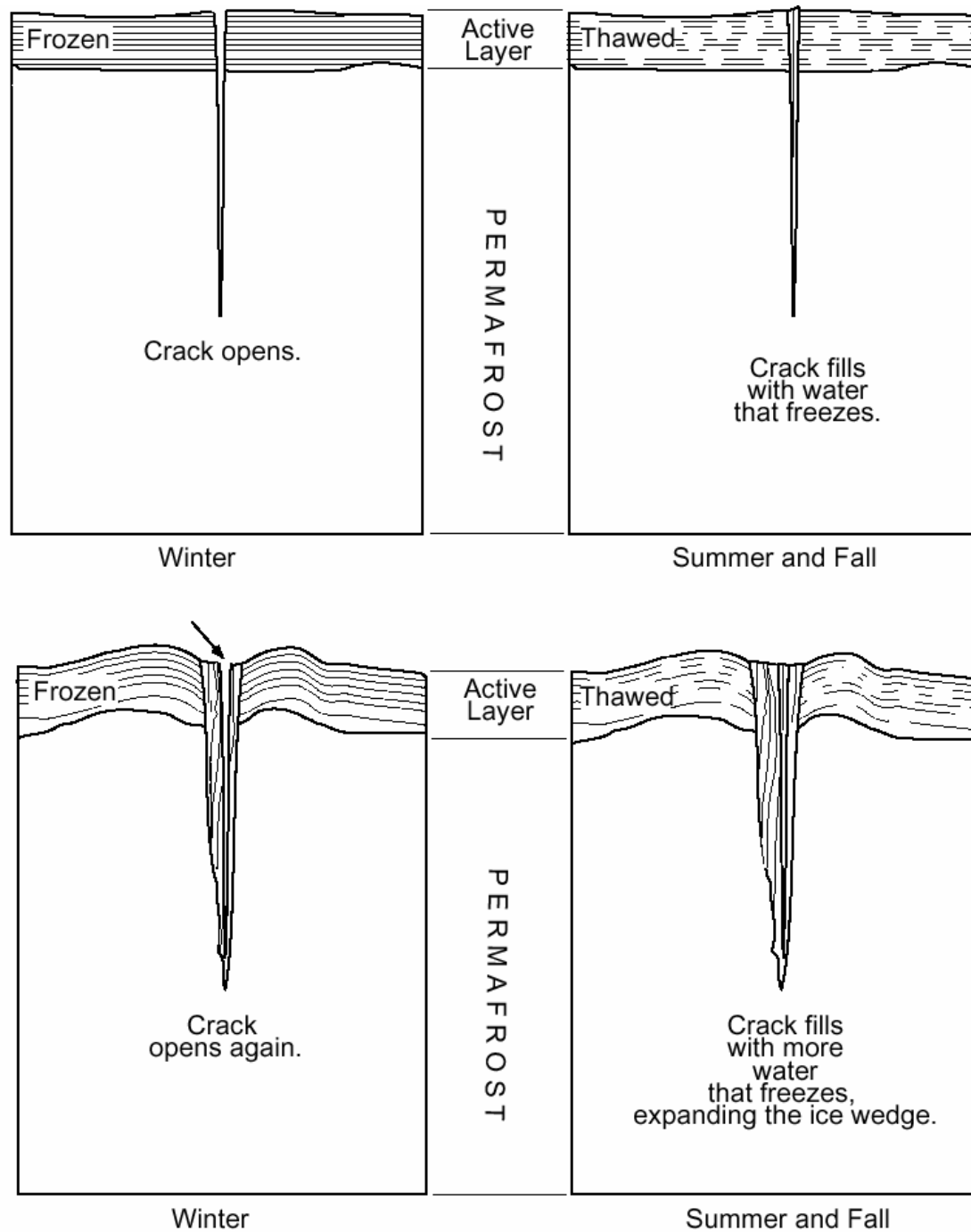


Figure 89. Idealized representation of the formation of an ice wedge polygon according to the contraction crack theory (Lachenbruch 1962)

Other Surficial Geology Types Not Listed on the Surficial Geology Map. Several surficial geology types that strongly influence vegetation are described but were not listed by Hamilton (1999c) including patterned ground, thermokarst and water tracts.

Patterned Ground. Regions with perennially frozen ground often have their surface materials arranged into distinct geometric shapes. The features, collectively known as patterned ground, include polygons, nets, circles and stripes (Washburn 1956). In general, the geometric pattern changes with increasing slope from polygons and circles on level ground, to nets and then stripes on steeper surfaces. Whether the geometric shape was formed by sorting or not has an effect on the type and size of patterned ground and its vegetation (Ritter 1986). Three types of patterned ground are described below: sorted polygons, ice wedge polygons, and frost boils. These units were not mapped by Hamilton (1999c).

For sorted polygons, sorting separates the coarse from the fine soil particles, and typically produces a surface feature of fine materials bordered by stones in a variety of geometric shapes; polygons, circles, nets and stripes. Sorted polygons are bounded by straight segments composed of stones that surround a central core of finer material. They range up to 10 m in diameter. One general theory behind the formation of sorted polygons is that soil heaving separates the coarse and fine sediments, and repeated freezing and thawing moves the stones upward and outward.

The smaller grains with greater cohesion contract farther inward and downward during thawing. The process continues until the adjacent polygons meet. The coarse materials form circular or polygonal rims with finer materials in the center (Ballard 1973).

Sorted circles are similar to sorted polygons but circular in outline. Sorted stripes are linear alignments of soil, vegetation and stones on slopes. They are strips of stone separated by broad zones of finer sediment and vegetation. The strips are up to several meters in width and 100 m in length.

Sorted polygons and circles were observed on glacial drift on rounded foothills and mountain slopes on the north edge of GAAR. Vegetation ranged from absent on the rims with prostrate shrubs in the center, to shrubs on the edge with no vegetation in the polygon center.

Ice wedge polygons are typically connected in a polygonal pattern that is similar to the pattern produced by mud cracks. They are formed by large masses of ice—called ice wedges—which grow in thermal contraction cracks in permafrost (Figure 89). Thermal tension on the ground surface leads to frost fractures only millimeters wide that penetrate the active layer and permafrost. The ground cracking typically occurs in winter when ground temperatures reach their annual minimum. In spring, water from melting snow freezes in these cracks and produces a vertical vein of ice. During the summer months the permafrost warms and horizontal compression caused by re-expansion of the permafrost results in the upturning of permafrost, forming elevated perimeters of the polygon. In winter, renewed thermal tension reopens the vertical

crack that is presumed to be a zone of weakness. Another sliver of ice is added when the spring meltwater enters the renewed crack and freezes. Over the centuries, these incremental cracks produce ice wedges that may be 2 m wide at the top. Troughs often form the boundaries between polygons and generally indicate ice wedges that are 1 to 2 m wide at the top. The diameter of ice wedge polygons ranges from several to more than 30 meters.

Ice wedge polygons are a common feature on level ground of glacial drift, lacustrine and floodplain surficial geology deposits of the arctic foothills and the interior forested lowlands and uplands ecoregions. They also occur in the larger mountain valley bottoms of the Brooks Range ecoregion on glacial drift and lacustrine deposits.

Vegetation of ice wedge polygons is dependent on surface elevation and soil moisture. Some polygons have perimeters that are elevated relative to the center of the polygon and are termed low-center polygons. These polygon centers often have standing water and support emergent or tussock vegetation. Low shrubs often dominate their edges. Other polygons have depressed perimeters relative to the center of the polygon and are termed high-center polygons. Their centers do not have standing water and may be dominated by prostrate shrubs and their edges by low shrubs. Low center polygons indicate that ice wedges are actually growing and that sediments are being actively upturned. High center polygons indicate that erosion, deposition, or thawing is more prevalent than the up-pushing of the sediments along the sides of the wedge.

Frost boils are areas of bare soil, which are sufficiently disturbed by frost action to prevent plant colonization. On slopes, fine material in unsorted circles moves slowly downslope producing banked or “stepped” frost boils (from Gabriel and Talbot, 1984). Frost boils were observed on river terraces and on low angle hills on the north edge of the Brooks Range.

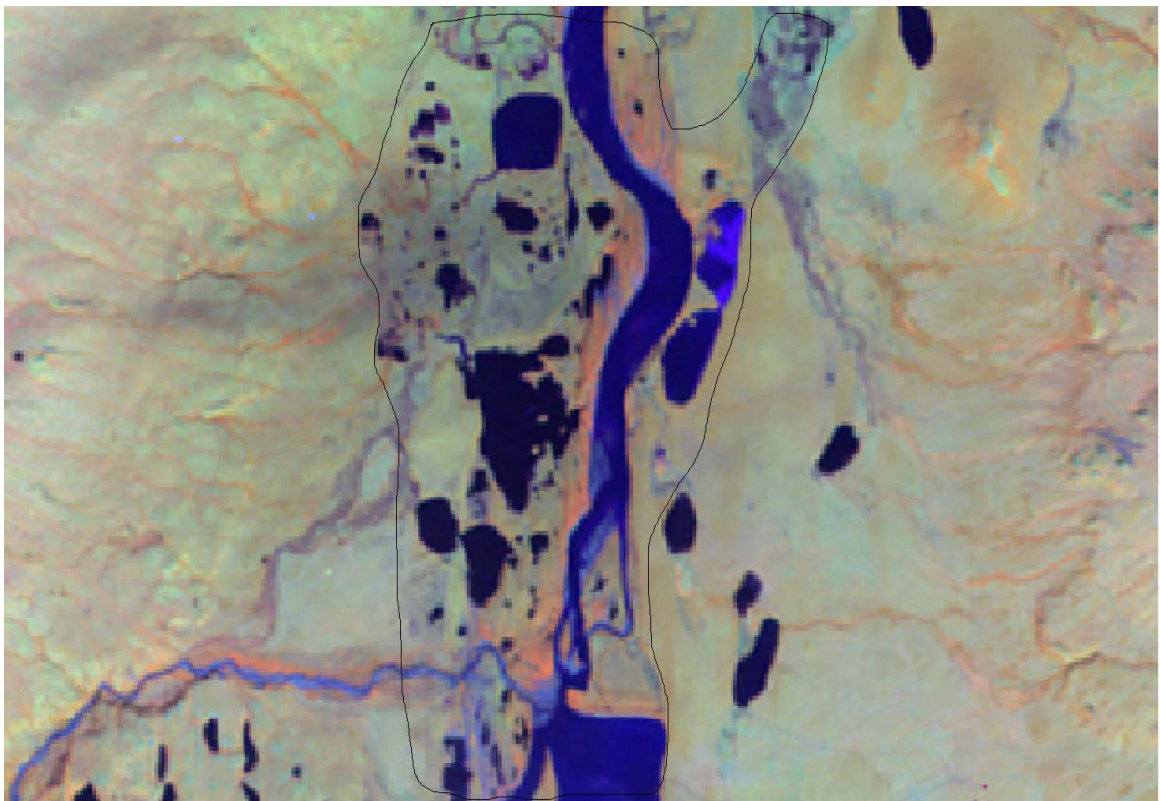


Figure 90. Landsat image of thermokarst [Scale = 1:63,360, Landsat TM bands 4,5,3 (RGB)]



Figure 91. Thermokarst north of Anaktuvuk Pass

Thermokarst. Thermokarst is the collapse of the soil surface due to the thawing of ice rich permafrost (Figures 90 and 91). The ground around thermokarst is supersaturated—often with ice lenses and layers—because it contains more water in the solid state than the ground could possibly hold if the water were in the liquid state. The melting of ground ice is due to either vertical soil degradation when the surface thermal properties are altered, or lateral degradation such as where lake water laterally erodes its banks, including ground ice. Many of the processes that lead to thermokarst are initiated by broad climate changes, but minor events such as fires, clearing of forest vegetation, shifting stream channels, and removal of the peat surface will upset the thermal balance and produce thermokarst.

Thermokarst is a common feature in areas with low relief and level land such as in mountain valleys and the regions north and south of the Brooks Range. It occurs on a variety of surficial geology deposits—sand, lacustrine, glacial drift, and floodplain—throughout GAAR. Most thermokarst ponds have steep banks and consequently support little emergent vegetation.

Water Tract. Many of the rolling hills and mountain sideslopes covered by tussock tundra have narrow water tracks running downslope (Figure 92). Water tracks are shallow depressions that have significantly greater water flow than the adjacent tussock tundra. They also commonly have horizontal soil ridges that pool the water. These ridges suggest some mass movement of the soil. The water tracks are commonly dominated by open water, diamondleaved willow (*Salix planifolia* subspecies *pulchra*) and sedges (*Carex* species).



Figure 92. Water tracts on a loess covered bedrock outcrop in the arctic foothills ecoregion

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GLOSSARY

Most of the ecological terms below are from Hamilton (1999c), Gallant et al. (1995), Anderson et al. (1998), Viereck et al. (1992) and Gabriel and Talbot (1984).

Albedo—Same as reflectivity. The percentage of incoming radiation that is reflected by a natural surface such as a ground, ice, snow, water, clouds, or particulates in the atmosphere.

Albers equal area projection—the Albers Equal Area projection is a method of projection on which the areas of all regions are shown in the same proportion of their true areas. The meridians are equally spaced straight lines converging at a common point, which is normally beyond the pole. The angles between them are less than the true angles. The parallels are unequally spaced concentric circular arcs centered on the point of convergence of the meridians. The poles are normally circular arcs enclosing the same angle as that enclosed by the other parallels of latitude for a given range of longitude. Albers Equal Area is frequently used in the ellipsoidal form for maps of the United States in the National Atlas of the United States, for thematic maps, and for world atlases. It is also used and recommended for equal-area maps of regions that are predominantly east-west in extent.

Alliance—A physiognomically uniform group of plant associations sharing one or more dominant or diagnostic species, which as a rule are found in the uppermost stratum of the vegetation (Grossman et al. 1998).

Alluvial fans—Erosional-depositional system in which rock and sediment are transported down-valley and deposited where it emerges from the confines of the valley into a larger valley or plain. They tend to be fan-shaped in plan view; a segment of a cone radiating away from a single point source.

Alluvial—Characterized by the deposition of sediment by a stream or other running water at any point along its course.

Alpine—The zone on mountain tops between permanent snow and the cold limits of trees.

Annual—Plant species that complete their life-cycle within a single growing season.

Aquatic—Refers to sites with vegetation that is submerged, floating, or growing in permanent water.

Attributes—Attributes, also called feature codes or classification attributes, are used to describe map information represented by a node, line, or area. For example, an attribute code for an area might identify it to be a lake or swamp; an attribute code for a line might identify a road, railroad, stream, or shoreline.

Bare-ground—Refers to (1) a landcover class with less than 15% vegetation cover, and (2) a soil surface devoid of vegetation.

Bedrock—Refers to exposed rock typically at higher elevations and includes all the jagged rocky ridges, peaks, cirque headwalls and cirque basins in the Brooks Range. It has little or no soil development.

Biennial—Plant species that complete their life-cycles within two growing seasons.

Binary—Numerical system using the base 2.

Bit—Contraction of binary digit, which in digital computing represents an exponent of the base 2.

Boreal—Northern biogeographical region typically referring to subpolar and cold temperate areas.

Brackish—Tidal water with a salinity of 0.5-30 parts per thousand.

Brightness—Magnitude of the response produced in the eye by light.

Broad-leaved—Describes a plant with leaves that have well-defined leaf blades and are relatively wide in outline (shape) as opposed to needle-like or linear; leaf area is typically greater than 500 square millimeters or 1 square inch.

Bryophyte—Nonvascular, terrestrial green plant, including mosses, hornworts, and liverworts.

Bunch grass—Multi-stemmed (Caespitose) life form of grasses characterized by clumps of erect shoots that slowly spread horizontally by tillers, generally creating distinct individual plants spaced across the ground; often applied to sedges and other graminoids with similar life forms.

Byte—A group of eight bits of digital data.

Caespitose (cespitose) —Describes a low branching pattern from near the base that forms a multi-stemmed or a bunched appearance.

Canopy cover—The% of the ground in the polygon covered by the gross outline of an individual plant's foliage (canopy), or the outline collectively covered by all individuals of a species or life-form within the polygon (Daubenmire 1959).

Classification—Process of assigning individual pixels of an image to categories, generally on the basis of spectral reflectance characteristics.

Cliff—Any high, very steep to perpendicular, or overhanging face of a rock outcrop.

Cold-deciduous—Describes a plant that sheds its leaves as a strategy to avoid seasonal periods of low temperature, often initiated by photoperiod; applied to vegetation adapted to seasonal cold season influences (temperate).

Colluvium—Unconsolidated surface materials that have been transported downslope and deposited on the lower slopes. Colluvium is moved by landslides, flow slides, talus rubble, rock-glaciers, solifluction and unconsolidated runoff.

Contrast—The ratio between the energy emitted or reflected by an object and its immediate surroundings.

Contrast stretching—Expanding a measured range of digital numbers in an image to a larger range, to improve the contrast of the image and its component parts.

Creeping—Describes the pattern of stems growing at or just beneath the surface of the ground and usually producing roots at nodes.

Crustose lichen—Lichen life form that grows in intimate contact with its substrate, lacks a lower cortex and rhizoids (root-like structures), and is impossible to separate from the substrate without destroying the thallus; lichen with an unlobed, flattened thallus, growing adnate to the substrate.

Cubic convolution—A high order resampling technique in which the brightness value of a pixel in a corrected image is interpolated from the brightness values of the 16 nearest pixels around the location of the corrected pixel.

Cushion plant—A low, woody, plant life form so densely branched that it forms a compact canopy that is pad- or bolster-like in appearance; usually with microphyllous foliage; characteristic of alpine and tundra plants.

Datum—In surveying, a reference system for computing or correlating the results of surveys. There are two principal types of datums: vertical and horizontal. A vertical datum is a level surface to which heights are referred. In the United States, the generally adopted vertical datum for leveling operations is the national geodetic vertical datums of 1929 (differing slightly from mean sea level). The horizontal datum, used as a reference for position, is defined by: the latitude and longitude of an initial point, the direction of a line between this point and a specified second point, and two dimensions which define the spheroid. In the United States, the initial point for the horizontal datum is location at Meades Ranch in Kansas.

Deciduous—Describes a woody plant that seasonally loses all of its leaves and becomes temporarily bare-stemmed.

DEM—Digital Elevation Models—The U.S. Geological Survey produces five primary types of digital elevation model data: they are:

7.5-minute DEM (30- x 30-m data spacing, cast on Universal Transverse Mercator (UTM) projection or 1- x 1-arc-second data spacing). Provides coverage in 7.5- x 7.5-minute blocks. Each product provides the same coverage as a standard USGS 7.5-minute map series quadrangle. Coverage: Contiguous United States, Hawaii, and Puerto Rico.

1-degree DEM (3- x 3-arc second data spacing). Provides coverage in 1- x 1-degree blocks. Two products (three in some regions of Alaska) provide the same coverage as a standard USGS 1- x 2-degree map series quadrangle. The basic elevation model is produced by or for the Defense Mapping Agency (DMA), but is distributed by USGS in the DEM data record format. Coverage: United States.

30-minute DEM (2- x 2-arc-second data spacing). Consists of four 15- x 15-minute DEM blocks. Two 30-minute DEMs provide the same coverage as a standard USGS 30- x 60-minute map series quadrangle. Saleable units will be 30- x 30-minute blocks, that is, four 15- x 15-minute DEMs representing one half of a 1:100,000-scale map. Coverage: Contiguous United States, Hawaii.

15-minute Alaska DEM (2- x 3-arc-second data spacing, latitude by longitude). Provides coverage similar to a 15-minute DEM, except that the longitudinal cell limits vary from 20 minutes at the southernmost latitude of Alaska to 36 minutes at the northern most latitude limits of Alaska. Coverage of one DEM will generally correspond to a 1:63,360-scale quadrangle.

7.5-minute Alaska DEM (1- x 2-arc-second data spacing, latitude by longitude). Provides coverage similar to a 7.5-minute DEM, except that the longitudinal cell limits vary from 10 minutes at the southernmost latitude of Alaska to 18 minutes at the northernmost latitude limits of Alaska.

Detector—Component of a remote sensing system that converts electromagnetic radiation into a recorded signal.

Digital image processing—computer manipulation of the digital-number values of an image.

Digital image—an image where the property being measured has been converted from a continuous range of analogue values to a range expressed by a finite number of integers, usually recorded as binary codes from 0 to 255, or as one byte.

Digital number (DN)—Value assigned to a pixel in a digital image.

Digitization—Process of converting an analog display into a digital display.

Digitizer—Device for scanning an image and converting it into numerical format.

Dominant—An organism, group of organisms, or taxon that by its size, abundance, or coverage exerts considerable influence upon an association's biotic (such as structure and function) and abiotic (such as shade and relative humidity) conditions.

DTM-Digital Terrain Model—A DTM is a land surface represented in digital form by an elevation grid or lists of three-dimensional coordinates.

Ecoregions—Landscape units defined based on similar patterns in potential natural communities, soils, hydrologic function, landform, topography, lithology, climate, and natural processes such as nutrient cycling, productivity, succession, and natural disturbance regimes associated with flooding, wind, or fire. Climate, as modified by topography, is the dominant criterion at the scale mapped for GAAR.

Edge enhancement—Image-processing technique that emphasizes the appearance of edges and lines.

Edge—A boundary in an image between areas with different tones.

Electromagnetic radiation—Energy propagated in the form of and advancing interaction between electric and magnetic fields. All electromagnetic radiation moves at the speed of light.

Electromagnetic spectrum—Continuous sequence of electromagnetic energy arranged according to wavelength or frequency.

Enhancement—Process of altering the appearance of an image so that the interpreter can extract more information.

Eolian—Wind blown sand and silt deposits.

Ephemeral forb vegetation—Annual associations or synusia that, during favorable periods, dominate areas that are usually sparsely vegetated or unvegetated for most of the year.

Epiphyte—Vascular plant that grows by germinating and rooting on other plants or other perched structures; sometimes called "air plants."

Evergreen—Describes a plant that has green leaves all year round.

False-color image—A color image where parts of the non-visible EM spectrum are expressed as one or more of the red, green, and blue components, so that the colors produced by the Earth's surface do not correspond to normal visual experience. Also called a false-color composite (FCC). The most commonly seen false color images display the very-near infrared as red, red as green, and green as blue.

False-color photograph—Another term for IR color photograph.

Field of View—Essentially the synthesis of the IFOV from the scanning process of the radiometer.

Field Verification Area—An area sampled during the field season composed of multiple polygons.

Floodplain—A fluvial plain formed by non-glacial fed rivers. Along a meandering river—meandering rivers have one or two main channels—alluvium is deposited on convex curves in the river channel. The opposing concave bank is cut, providing sediment for deposition on convex curves downstream and creating a series of similar bands of alluvial deposits. The channel thus meanders laterally across the floodplain.

Foliose lichen—Lichen life form that is leafy in appearance and loosely attached to its substrate; lichen with a lobed, flattened thallus growing loosely attached to the substrate, the lobes flattened or inflated with distinctly differentiated upper and lower surfaces; umbilicate lichens are included.

Forb—A broad-leaved herbaceous plant.

Fresh water—Water with a salinity of less than 0.5 parts per thousand.

Frost boils—These are areas of bare soil which are sufficiently disturbed by frost action to prevent plant colonization. On slopes, fine material in unsorted circles moves slowly downslope producing banked or “stepped” frost boils (from Gabriel and Talbot. 1984).

Frost Scar—These are exposed bare mineral soil formed by frost action in the soil.

Fruticose lichen—Lichen life form that is bunched, shrubby or "hairy" in appearance and loosely attached to its substrate; lichen with the thallus branched, the branches solid, or hollow and round, or flattened without distinctly differentiated upper and lower surfaces; squamulose lichens are included.

GCP—Ground-control point.

Geographic information system (GIS)—A data-handling and analysis system based on sets of data distributed spatially in two dimensions. The data sets may be map oriented, when they comprise qualitative attributes of an area recorded as lines, points, and areas often in vector format, or image oriented, when the data are quantitative attributes referring to cells in a rectangular grid usually in raster format. It is also known as a geobased or geocoded information system.

Geometric correction—Image-processing procedure that corrects spatial distortions in an image.

Geomorphic process—Refers to the mechanical transport of organic and inorganic material such as mass movement, surface erosion, the transport of material (silt) by water, and biogenic soil movement by root throw and animals.

Glacial drift—the material transported by a glacier and then deposited either directly from the ice or from the melt water. Numerous types of glacial drift occur including moraines, kettle-kame topography, eskers, drumlins, glacial till and outwash.

Glacial outwash—Fluvial plains formed when glacially fed rivers deposit their sediment in stream channels and the associated plain. Due to continual channel shifting the sediment is spread across an area called an outwash plain. Outwash plains typically have braided rivers consisting of multiple, wide, shallow channels characterized by rapid erosion, deposition and channel shifts.

Glacial till—A surface formed by sediment originating directly from glacial ice and typically has no discernible sediment stratification.

GPS—Global Positioning System—The GPS is a worldwide satellite navigation system that is funded and supervised by the U.S. Department of Defense. GPS satellites transmit specially coded signals. These signals are processed by a GPS receiver that computes extremely accurate measurements, including 3-dimensional position, velocity, and time on a continuous basis.

Graminoid—Grasses and grass-like plants, including sedges and rushes.

Grassland—Vegetation dominated by perennial graminoid plants.

Ground layer—Applies to the herbaceous layer.

Ground receiving station—Facility that records data transmitted by a satellite, such as Landsat.

Ground-control point—A geographic feature of known location that is recognizable on images and can be used to determine geometric corrections.

Growth form—The shape or appearance of a plant; it primarily reflects the influence of growing conditions.

Herbaceous—A vascular plant without significant woody tissue above or at the ground; an annual, biennial, or perennial plant lacking significant thickening by secondary woody growth, with perennating buds borne at or below the ground surface (hemicryophytes, geophytes, helophytes, and therophytes of Raunkier).

High-pass filter—A spatial filter which selectively enhances contrast variations with high spatial frequencies in an image. It improves the sharpness of images and is a method of edge enhancement.

Hypertext—The use of links between related words, graphics, or documents that allow the user to jump to associated topics or definitions when reading menus or help files.

Ice wedge polygons—Refers to patterned ground with polygons typically connected in a polygonal pattern that is similar to the pattern produced by mud cracks. They are formed by large masses of ice—called ice wedges—that grow in thermal contraction cracks in permafrost.

IFOV—Instantaneous Field of View. The solid angle through which a detector is sensitive to radiation. It forms one limit to the resolution of an imaging system.

Image—pictorial representation of a scene recorded by a remote sensing system. Although image is a general term, it is commonly restricted to representations acquired by non-photographic methods.

Interactive processing—Method of image processing in which the operator views preliminary results and can alter the instructions to the computer to achieve desired results.

Interpretation key—Characteristic or combination of characteristics that enable an interpreter to identify an object on an image.

Interpretation—The process in which a person extracts information from an image.

IR color photograph—Color photograph in which the red-imaging layer is sensitive to photographic IR wavelengths, the green-imaging layer is sensitive to red light, and the blue-imaging layer is sensitive to green light. Also known as camouflage detection photographs and false-color photographs.

Kernel—Two-dimensional array of digital numbers used in digital filtering.

Krummholz—Growth form assumed by tree species at the upper treeline or in the alpine zone; characterized by a creeping and multi-stemmed growth pattern due to desiccation and physical damage caused by wind and blowing ice crystals near the upper treeline; the same species grows as an erect, single-stemmed tree at lower elevation.

Lacustrine deposits—derived from materials deposited in lake water and exposed when the water level is lowered or the land is raised.

Landsat (formerly ERTS)—The Landsat program, first known as the Earth Resources Technology Satellite (ERTS) Program, is a development of the National Aeronautics and Space Administration (NASA) in association with NOAA, USGS, and the Space Imaging. The activities of these combined groups led to the concept of dedicated Earth-orbiting satellites, the defining of spectral and spatial requirements for their instruments, and the fostering of research to determine the best means of extracting and using information from the data. The first satellite, ERTS 1, was launched on July 23, 1972. The second satellite was launched on January 22, 1975. Concurrently, the name of the satellites and program was changed to emphasize its prime area of interest (land resources). The first two satellites were designated as Landsats 1 and 2. Landsat 3 was launched on March 5, 1978. Landsat 4 was launched on July 16, 1982. Landsat 5 (launched March 1, 1984) is currently in service providing selected data to worldwide researchers. Both Landsat 4 and 5 are carry the Thematic Mapper (TM) sensor.

Lichen—An organism generally recognized as a single plant that consists of a fungus and an alga or cyanobacterium living in symbiotic association.

Life form—The shape or appearance of a plant that mostly reflects inherited or genetic influences.

Light—Electromagnetic radiation ranging from 0.4 to 0.7Fm in wavelength that is detectable by the human eye.

Line drop out—The loss of data from a scan line caused by malfunction of one of the detectors in a line scanner.

Low shrub—Low-growing shrub life form between 0.3 and 3.5 feet tall.

Matted—Describes a creeping plant that by reiterative growth has overlapping stems and forms a low, dense ground cover.

Mesic—Sites are moist and tussocks may dominate. Permanent standing water is not present.

Mid-infrared (MIR)—The range of EM wavelengths from 8 to 14 Fm dominated by emission of thermally generated radiation from materials; also known as thermal infrared.

Mixed forest—Describes vegetation in which evergreen and deciduous species each generally contribute 25-75% to the total canopy cover.

Mixed pixel—A pixel whose DN represents the average energy reflected or emitted by several types of surface present within the area that it represents on the ground; sometimes called a mixel.

Montane—Describes the zone in mountainous regions where the influence of altitude (vertical relief) results in local climatic regimes that are sufficiently different from those in the adjacent lowlands as to cause a complex vertical climate-vegetation-soil zonation; includes vegetation at the base of a mountain when it is different from lowland vegetation.

Mosaic—Composite image or photograph made by piecing together individual images or photographs covering adjacent areas.

MSS—Refers to the Landsat Multispectral Scanner System (MSS) satellite based imaging sensor. The MSS simultaneously senses radiation using an array of six detectors in each of four spectral bands from 0.5 to 1.1 micrometers (visible to near infrared region of the electromagnetic spectrum. This system was a precursor to the higher spatial(geometric) and spectral (7 bands) Landsat TM system.

Multispectral classification—Identification of terrain categories by digital processing of data acquired by multispectral scanners.

Multispectral scanner—Scanner system that simultaneously acquires images of the same scene at different wavelengths.

Nadir—The point on the ground vertically beneath the satellite.

NDVI-Normalized Difference Vegetation Index—The NDVI is computed by calculating the ratio of the VI (vegetation index, i.e., the difference between Channel 2 and 1) and the sum of Channels 2 and 1. Thus $NDVI = (\text{channel 2} - \text{channel 1}) / (\text{channel 2} + \text{channel 1})$.

Near-infrared (NIR)—the shorter wavelength range of the infrared region of the EM spectrum, from 0.7 to 2.5 μm . It is often divided into very-near infrared (VNIR) covering the range accessible to photographic emulsions (0.7 to 1.0 μm), and the short-wavelength infrared (SWIR) covering the remainder of the NIR atmospheric window from 1.0 to 2.5 μm .

NN-Nearest Neighbor Resampling—When correcting image data points, the nearest neighbor technique assigns for each new pixel that pixel value which is closest in relative location to the newly computed pixel location.

Nonvascular plant—A plant without specialized water or fluid conductive tissue (xylem and phloem); includes bryophytes, lichens, and algae.

Orbit—Path of a satellite around a body such as the earth, under the influence of gravity.

Ortho-Correction—Correction applied to satellite imagery to account for terrain-induced distortion.

Path and row index—System for locating Landsat MSS and TM images.

Patterned ground—Refers to regions with perennially frozen ground that often have their surface materials arranged into distinct geometric shapes. The features, collectively known as patterned ground, include polygons, nets, circles and stripes.

Pavement—A relatively flat surface of consolidated material, generally exposed bedrock.

Perennial—Plant species with a life-cycle that characteristically lasts more than two growing seasons and persists for several years.

Picture element—In a digitized image, the area on the ground represented by each digital number. Commonly contracted to pixel.

Pingo—These are ice-filled conical hills or mounds, 20 to 400 m in diameter and 10 to 70 m high.

Pixel—Contraction of picture element.

Plant association—The finest level of both the Viereck et al. (1992) and National Vegetation Classification System (Grossman et al. 1998) classifications. It is defined as “a plant community type of definite floristic composition, uniform habitat conditions, and uniform physiognomy” (Flahault and Schroter 1910).

Prostrate shrub—Shrub life form growing less than 0.3 feet tall.

Pulvinate mosses—Mosses growing in cushion-like mats or clumps.

Raster format—A means of representing spatial data in the form of a grid of DN, each line of which can be used to modulate the lines of a video raster.

Raster—A raster image is a matrix of row and column data points whose values represent energy being reflected or emitted from the object being viewed. These values, or pixels, can be viewed on a display monitor as a black-and-white or color image. The scanned and illuminated area of a video display, produced by a modulated beam of electrons sweeping the phosphorescent screen line by line from top to bottom at a regular rate of repetition.

Ratio image—An image prepared by processing digital multi-spectral data as follows: for each pixel, the value for one band is divided by that of another. The resulting digital values are displayed as an image.

Registration—Process of superposing two or more images or photographs so that equivalent geographic points coincide.

Remote sensing—Collection and interpretation of information about an object without being in physical contact with the object.

Resampling—The calculation of new DN for pixels created during geometric correction of a digital scene, based on the values in the local area around the uncorrected pixels.

Resolution—Ability to separate closely spaced objects on an image or photograph. Resolution is commonly expressed as the most closely spaced line-pairs per unit distance that can be distinguished. Also called spatial resolution.

RMSE-Root Mean Square Error—The RMSE statistic is used to describe accuracy encompassing both random and systematic errors. The square of the difference between a true test point and an interpolated test point divided by the total number of test points in the arithmetic mean. The square root of this value is the root mean square error.

Rock Glacier—Tongue-shaped or lobate masses of unsorted, angular frost-rived material with interstitial ice. They typically originate in cirques or in high, steep-walled recesses.

Saltwater—Water with a salinity of greater than 30 parts per thousand.

Satellite—An object in orbit around a celestial body.

Saturation—In the IHS system, represents the purity of color. Saturation is also the condition where energy flux exceeds the sensitivity range of a detector.

Scale—Ratio of distance on an image to the equivalent distance on the ground.

Scene—Area on the ground that is covered by an image or photograph.

Scree—A sheet of coarse rock debris covering a mountain slope without an adjacent cliff.

Scrub—Vegetation dominated by shrubs, including thickets.

Seasonal—Showing periodicity related to the seasons; applied to vegetation exhibiting pronounced seasonal periodicity marked by conspicuous physiognomic changes.

Sensor—Device that receives electromagnetic radiation and converts it into a signal that can be recorded and displayed as either numerical data or an image.

Shaded Relief—Shading added to an image that makes the image appear to have three dimensional aspects. This type of enhancement is commonly done to satellite images and thematic maps utilizing digital topographic data to provide the appearance of terrain relief within the image.

Shrub—A perennial woody species with a life form that is usually less than 4 to 5 meters or 13 to 16 feet in height; typically, plants have several stems arising from or near the ground, but this term includes short tuft-tree, bamboo, and woody vine species; length of vine may exceed 5 meters; shrub species growth form may be taller than 5 meters or single-stemmed under certain environmental conditions.

Signal to noise ratio (S/N)—the ratio of the level of the signal carrying real information to that carrying spurious information as a result of defects in the system.

Signal—Information recorded by a remote sensing system.

Solifluction (or gelifluction)—The flow of soil in association with frozen ground. During the spring and summer thaw, water in the active layer cannot penetrate below the permafrost table. Soils are often saturated, and the loss of friction and cohesion causes them to behave like viscous fluids. The soil thus slowly ‘flows.’ The downslope fronts of the solifluction lobes are marked by near-vertical scarps as high as 2 m.

Sorted circles—Similar to sorted polygons but circular in outline.

Sorted polygons—Refers to patterned ground where sorting separates the coarse from the fine soil particles, and typically produces a surface feature of fine materials bordered by stones in a variety of geometric shapes; polygons, circles, nets and stripes.

Sorted stripes—Refers to patterned ground that consists of linear alignments of soil, vegetation and stones on slopes. They are strips of stone separated by broad zones of finer sediment and vegetation. The strips are up to several meters in width and 100 m in length.

Sparsely vegetated—Describes vegetation with low total plant cover (between 15 and 25%) that is scattered; areas with high cover of crustose lichen and no other vegetation are included here.

Spectral reflectance—Reflectance of electromagnetic energy at specified wavelength intervals.

Spheroid—Mathematical figure closely approaching the geoid in form and size and used as a surface of reference for geodetic surveys. A reference spheroid or ellipsoid is a spheroid determined by revolving an ellipse about its shorter (polar) axis and used as a base for geodetic surveys of a large section of the Earth (such as the Clarke spheroid of 1866 which is used for geodetic surveys in the United States).

Stomata—Pores or openings for gas exchange that are generally concentrated on leaf surfaces.

Subalpine—Upper mountain vegetation immediately below the cold limits of tree and tall shrub growth.

Sun-synchronous orbit—A polar orbit where the satellite always crosses the Equator at the same local solar time.

Sun-synchronous—Earth Satellite orbit in which the orbit plane is nearly polar and the altitude is such that the satellite passes over all places on earth having the same latitude twice daily at the same local sun time.

Supervised classification—Digital-information extraction technique in which the operator provides training-site information that the computer uses to assign pixels to categories.

Tall shrub—Tall-growing shrub life form greater than 3.5 feet tall.

Talus—A sloping accumulation of coarse rock fragments at the base of a cliff.

Temperate—Geographically, the region between the polar and tropical regions; climatically, the region is moderate with distinct seasons of alternating long, warm summers and short, cold winters.

Terraces—Floodplains and outwash plains removed from frequent flooding due to down-cutting of the river.

Texture—Frequency of change and arrangement of tones on an image.

Thematic Data—Thematic data layers in a data set are layers of information that deal with a particular theme. These layers are typically related information that logically go together. Examples of thematic data would include a data layer whose contents are roads, railways, and river navigation routes.

Thematic Mapper (TM)—A cross-track scanner deployed on Landsat that records seven bands of data from the visible through the thermal IR regions.

Thermal Infrared—Phase used to describe the middle wavelength ranges in the infrared portion of the electromagnetic spectrum. Ranging between 3 microns and 20 microns, most remote sensing applications utilize the 8- to 13-micron range. This is emitted energy whereas other infrared (near infrared) is reflected energy.

Thermokarst—Refers to the collapse of the soil surface due to the thawing of ice rich permafrost, resulting in ponds and hills.

TM—Thematic mapper.

Topographic Map—Map that presents the horizontal and vertical positions of the features represented; distinguished from a plainimetric map by the addition of relief in measurable form.

Topography—Configuration (relief) of the land surface; the graphic delineation or portrayal of that configuration in map form, as by contour lines; in oceanography the term is applied to a surface such as the sea bottom or a surface of given characteristics within the water mass.

Training area—A sample of the Earth's surface with known properties; the statistics of the imaged data within the area are used to determine decision boundaries in classification.

Training site—Area of terrain with known properties or characteristics that is used in supervised classification.

Treeline—A zone where the normal growth of trees is limited; cold temperatures often combined with drought form the upper or arctic treeline, and drought combined with hot temperatures form lower or arid treeline.

Tundra—The treeless region north of the Arctic Circle (arctic tundra) or above the treeline of high mountains (alpine tundra) and on some sub-Antarctic islands; characterized by very low winter temperatures, short cool summers, permafrost below a surface layer subject to summer melt, short growing season, and low precipitation.

Tussock—Graminoid life form consisting of bunch-like tufts, sometimes more than 1 meter or 3 feet tall, in which the hard, old, withered leaves are intermingled with the fresh, young, green leaves.

Type—A general term used in place of “vegetation type” or “alliance”. Plant associations are often referred to as “types”, but the term generally is not applied to alliances, and needs to be corrected in descriptions where it's used.

Understory—General term that in these descriptions applies to the shrub and herbaceous layers of a vegetation type, as well as the tree regeneration layer. We have tried to use “shrub layer” or “herbaceous layer” in most cases, but understory is used in some places. “Undergrowth” is the more specific term used for shrub and herbaceous layers in forests or woodland vegetation types, and has been little used in these descriptions.

Unsupervised classification—digital information extraction technique in which the computer assigns pixels to categories with no instructions from the operator.

UV—Ultraviolet region of the electromagnetic spectrum ranging in wavelengths from 0.01 to 0.4m.

Vascular plant—Plant with water and fluid conductive tissue (xylem and phloem); includes seed plants, ferns, and fern allies.

Water Tract—Many of the rolling hills and mountain sideslopes covered by tussock tundra have narrow water tracks running downslope. Water tracks are shallow depressions that have significantly greater water flow than the adjacent tussock tundra.

Wet—Refers to sites where the dominant vegetation is emergent—not submerged or floating—and semi-permanent or standing water is present.

Woody plant—Plant species life form with woody tissue and buds on that woody tissue near or at the ground surface or above; plants with limited to extensive thickening by secondary woody growth and with perennating buds; includes phanerophytes and chamaephytes of Raunkier.

Woody—Containing lignified plant tissue.

WRS-Worldwide Reference System—The WRS is a global indexing scheme designed for the Landsat program based on nominal scene centers defined by path and row coordinates.

Xeromorphic—Describes plants with morphological and physiological characters that tolerate persistently low water availability, such as succulence, specialized leaf surfaces for light reflectance or water retention, opportunistic leaf growth, leaf-size reduction with increased thickness and sunken stomata, revolute margins, or stem and leaf modification to form thorns or spines.

Appendix 1. Key to landcover classes for GAAR

Key to Growth Form Groups

1. Tree canopy cover is greater than or equal to 10% for needleleaf trees, or greater than or equal to 25% for deciduous or deciduous-needleleaf mix 2
1. Tree canopy cover less than 10% or absent 4
2. Greater than or equal to 75% of the total tree cover is needleleaf.....Needleleaf forest types
2. Less than 75% of the total tree cover is needleleaf.....3
3. Greater than or equal to 75% of the total tree cover is deciduous.....Broadleaf forest types
3. Deciduous and needleleaf trees each contribute 25-75% of the total tree cover Mixed forest types
4. Shrub cover is greater than or equal to 25%.....5
4. Shrub cover is less than 25%.....7
5. Shrub height is greater than or equal to 3.5 ft., or greater than or equal to 2 ft. for *Salix alaxensis* and *Salix lanata* north of the Brooks Range Tall shrub types
5. Shrub height is less than 3.5 ft.....6
6. Shrub height is between 0.3-3.5 ft Low shrub types
6. Shrub height is less than 0.3 ft; site contains less than 25% tussocks Prostrate shrub types
7. Herbaceous cover is greater than or equal to 25%..... Herbaceous Types
7. Herbaceous cover is less than 25%.....8
8. Total vegetation cover is 15-25% Sparsely vegetated
8. Total vegetation cover is less than 15%..... Bare-ground

Key to Needleleaf Forest Types

1. Tree canopy cover is between 50-65%; growth form and habitat of needleleaf trees is white spruce-like, that is they grow in well drained, sunny areas, with little knarled or stunted growth Dense-open white spruce forest
1. Tree canopy cover is less than 50%.....2
2. Tree canopy cover is between 25-49% 3
2. Tree canopy cover is between 10-24%; unless greater than 25% fruticose lichen present, then canopy cover may reach 35%.....4
3. Growth form and habitat of needleleaf trees are black spruce-like, that is they grow in wet or saturated soils, north facing slopes, possibly with knarled or stunted growth Open black spruce-like forest

3. Growth form and habitat of needleleaf trees are white spruce-like, that is they grow in well drained, sunny areas, with little knarled or stunted growth..... Open white spruce-like forest
4. Fruticose lichen cover is greater than or equal to 25% Spruce-lichen woodland
4. Fruticose lichen cover is less than 25% Spruce woodland

Key to Broadleaf Forest Types

1. Tree canopy cover is 60-100% 2
1. Tree canopy cover is 25-59% 3
2. Paper birch and aspen, individually or combined, with > 50% of the total tree cover Closed paper birch-aspen forest
2. Balsam poplar with >50% of the total tree cover Closed balsam poplar forest
3. Paper birch and aspen, individually or combined, with >50% of the total tree cover Open paper birch-aspen forest
3. Balsam poplar with >50% of the total tree cover Open balsam poplar forest

Key to Mixed Forest Types

1. Tree canopy cover is 60-100% Closed spruce-broadleaf forest
1. Tree canopy cover is 25-59% Open spruce-broadleaf forest

Key to Tall Shrub Types

1. Tall shrub cover is 75-100%..... Closed tall shrub
1. Tall shrub cover is 25-74%..... Open tall shrub

Key to Low Shrub Types

1. Greater than or equal to 25% of the site is covered by tussocks . Shrub birch-willow-tussock tundra
1. Less than 25% of the site is covered by tussocks 2
2. Low shrub cover is 25-74%..... Shrub birch-ericaceous-willow
2. Low shrub cover is 75-100%; and greater than or equal to 2/3 of the total low shrub cover is willow Closed low willow

Key to Prostrate Shrub Types

1. 33-74% of the total cover is bareground Prostrate shrub-rock
1. Less than 33% of the total cover is bareground.....2
2. Greater than or equal to 25% of the total cover is fruticose lichen Prostrate shrub-lichen
2. Less than 25% of the total cover is fruticose lichen Prostrate shrub

Key to Herbaceous Types

1. Vegetation is terrestrial; not submerged, floating, or growing in permanent water 2
1. Vegetation submerged, or floating, or growing in permanent water Aquatic herbaceous
2. Dominant vegetation is growing on well drained, dry sites Dry herbaceous
2. Dominant vegetation is growing on moist or wet sites 3
3. Dominant vegetation is growing on moist sites, site may be dominated by tussocks; little to no standing water Mesic herbaceous
3. Dominant vegetation is emergent; semi-permanent or standing water present Wet herbaceous

Appendix 2. The mean and range in elevation for field sampled polygons based on comparison with digital elevation model

Landcover classes	# of samples	Mean Elev (ft)	Min Elev (ft)	Max Elev (ft)
Dense-open white spruce forest	2	1,190	896	1,391
Open spruce forest, unknown	15	0	0	0
Open black spruce-like forest	16	1,284	322	2,743
Open white spruce-like forest	27	1,568	466	2,822
Spruce woodland	34	1,871	679	2,897
Spruce-lichen woodland	11	1,773	735	2,759
Closed paper birch-aspen forest	5	1,454	906	2,244
Closed balsam poplar forest	4	910	804	1,168
Open paper birch-aspen forest	3	1,209	787	1,604
Open balsam poplar forest	4	1,525	801	1,801
Closed spruce-broadleaf forest	7	1,343	302	2,225
Open spruce-broadleaf forest	9	1,458	840	2,139
Closed tall shrub	34	2,074	896	3,534
Open tall shrub	45	2,103	653	4,029
Shrub birch-willow-tussock tundra	52	2,310	610	3,363
Shrub birch-ericaceous-willow	176	2,495	302	4,797
Closed low willow	11	2,227	1,201	3,422
Prostrate shrub-rock	45	3,569	1,030	5,423
Prostrate shrub-lichen	10	3,062	1,549	4,157
Prostrate shrub	127	2,975	1,604	5,030
Dry herbaceous	0	0	0	0
Mesic herbaceous	85	2,517	505	4,682
Wet herbaceous	37	2,252	899	3,501
Aquatic herbaceous	2	804	804	804
Sparsely vegetated	22	4,068	1,762	5,430
Bare-ground	24	3,241	607	5,985
Silty water	7	1,580	577	1,703
Clear water	15	1,446	679	3,248
Snow/Ice	12	5,536	1,946	7,149
Sand dunes	0	0	0	0
Mosaic/patterned vegetation	0	0	0	0
Shadow/indeterminate	0	0	0	0

Appendix 3. Aggregated surficial geology units—from Hamilton (1999)—used for the surficial geology map.

Primary surficial geology units	Aggregated surficial geology units
Bedrock	Bedrock
Colluvium deposits	Colluvium, undivided Avalanche tracks and deposits Flow-slide deposits Landslide deposits Protalus rampart deposits Rock-glacier deposits, active Rock-glacier deposits, inactive Solifluction deposits Talus rubble, active Talus rubble, inactive
Alluvial fan deposits	Fan deposits Subunit f _i Subunit f-s (silt fans) Fan-delta deposits Subunit fd _i Deposits of steep alpine fans Subunit af _i
Glacial drift, terraces, and sand-silt deposits	Glacial drift Neoglaciation (Fan Mountain Glaciation) Neoglacial drift, undivided Drift of neoglacial phase ii Drift of neoglacial phase i Itkillik Glaciation Drift of Itkillik age, undifferentiated Drift of late Itkillik age Subunit ik ₃ (kame and kame-terrace deposits) Subunit im (meltwater deposits) Drift of Itkillik phase ii Subunit ik ₂ (kame and kame-terrace deposits) Drift of Itkillik phase i Subunit id _{1A} (drift of itkillik phase ia) Subunit id _{1B} (drift of itkillik phase 1b) Subunit (id ₁) Subunit ik ₁ (kame and kame-terrace deposits) Outwash of Itkillik age, undifferentiated Outwash of Late itkillik age Outwash of Itkillik phase ii Subunits io _{2A} and io _{2B}

	Outwash of Itkillik phase i
	io _{1A} and io _{1B}
	Inwash of Itkillik age, undifferentiated
	Inwash of late Itkillik age
	Inwash of Itkillik phase ii
	Inwash of Itkillik phase i
	Sagavanirktok River Glaciation
	Drift of Sagavanirktok river age, undifferentiated
	Subunit (sd)
	Drift of late Sagavanirktok river age
	Drift of early Sagavanirktok river age
	Outwash of Sagavanirktok river age
	Subunits so ₁ and so ₂
	Anaktuvuk River Glaciation
	Drift of Anaktuvuk river age
	Subunit (ad) d
	Outwash of Anaktuvuk river age
	Gunsight Mountain Glaciation
	Drift of Gunsight mountain age
	Subunit (Tgmd)
	Terraces
	Terrace Deposits
	Terrace gravel, undifferentiated
	Terrace gravel, low-level
	Terrace gravel, high-level
	Terrace gravel of presumed Tertiary age
	Terrace deposit, undifferentiated
	Terrace deposit, high-level
	Terrace deposit, low-level
	Gravel deposits, undifferentiated
	Subunit gr-fn
	Piedmont gravel
	Sand and silt
	Dune sand
	Sand-basin deposits
	Ice-rich silt deposits
	Upland silt deposits
Lacustrine deposits	Lacustrine deposits
	Beach deposits
	Deltaic deposits
	Deltaic deposits of Itkillik age
	Deltaic deposits of Sagavanirktok river age
	Glacial-lake deposits
	Glacial-lake deposits of Itkillik phase i
	Glacial-lake deposits of Sagavanirktok river age

Floodplain deposits	Alluvium, undifferentiated
	Modern alluvium
	Low alluvial-terrace deposits
	Alluvium, sand facies
	Neoglacial outwash
Organic deposits	Muskeg

Appendix 4. Percent cover of landcover classes for the major surficial geology features in the interior forested lowlands and uplands ecoregion and south of treeline in the Brooks Range ecoregion, including the 10 mile buffer.

	Drift,								
Landcover classes	Bed-rock	Collu-vium	Alluvial fan	terraces sand	Lacus-trine	Flood plain	Organic deposit	Total percent	Total acres
Needleleaf forest									
Dense-open white spruce forest	0.05	0.06	0.92	0.18	0.21	1.00	0.07	0.15	10,333
Open black spruce-like forest	5.82	26.18	23.81	25.36	30.94	28.97	33.02	13.90	955,652
Open white spruce-like forest	5.72	7.98	6.31	5.92	1.91	3.29	1.08	5.60	384,879
Spruce-lichen woodland	0.71	2.18	3.61	3.55	8.64	2.79	11.77	1.93	132,760
Spruce woodland	7.63	10.84	19.30	18.68	19.86	13.63	20.88	11.35	780,729
Broadleaf forest									
Closed paper birch-aspen forest	0.43	0.42	0.31	0.45	0.00	0.29	0.01	0.42	28,634
Closed balsam poplar forest	0.04	0.17	0.27	0.24	0.36	1.35	0.09	0.18	12,135
Open paper birch-aspen forest	0.61	1.21	1.54	1.10	0.75	0.86	0.61	0.78	53,838
Open balsam poplar forest	0.08	0.50	0.90	0.81	1.64	1.55	1.46	0.41	28,519
Mixed forest									
Closed spruce-broadleaf forest	0.61	0.94	0.73	0.79	0.58	1.67	0.26	0.72	49,522
Open spruce-broadleaf forest	0.63	1.40	1.69	1.24	0.64	2.20	0.20	0.91	62,342
Tall Shrub									
Closed tall shrub	6.47	4.63	4.04	3.77	2.67	2.74	4.03	5.35	368,239
Open tall shrub	7.81	5.21	6.05	6.23	4.65	5.65	5.33	7.03	483,606
Low shrub									
Shrub birch-willow-tussock tundra	2.36	1.40	4.48	5.69	4.38	2.19	2.50	3.18	218,801
Shrub birch-ericaceous-willow	15.95	7.60	11.84	14.34	6.78	5.72	6.05	14.17	974,737
Closed low willow	0.28	0.09	0.37	0.18	0.38	0.90	0.04	0.28	19,025
Prostrate shrub									
Prostrate shrub-rock	3.88	2.71	0.27	0.43	0.87	0.13	0.31	2.61	179,393
Prostrate shrub-lichen	2.49	1.18	0.51	0.47	0.36	0.22	0.05	1.70	116,888
Prostrate shrub	18.71	7.53	3.61	3.57	1.54	2.33	0.83	12.74	876,079
Herbaceous types									
Dry herbaceous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Mesic herbaceous	4.54	2.95	4.56	4.71	7.96	4.68	8.76	4.62	317,532
Wet herbaceous	0.21	0.14	0.69	0.43	0.61	1.07	1.49	0.33	23,016
Aquatic herbaceous	0.00	0.00	0.06	0.02	0.03	0.19	0.00	0.02	1,304
Other									
Sparsely vegetated	6.47	4.83	0.98	0.49	0.22	1.61	0.02	4.36	299,538

Bare-ground	5.24	5.53	1.98	0.46	0.82	6.18	0.34	3.92	269,708
Clear water	0.06	0.05	0.67	0.26	0.79	6.22	0.20	0.47	32,426
Silty water	0.06	0.10	0.16	0.29	2.03	2.14	0.49	0.65	44,610
Snow/Ice	0.15	0.51	0.03	0.03	0.00	0.19	0.00	0.14	9,625
Mosaic/patterned vegetation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	560
Shadow/indeterminate	2.91	3.44	0.22	0.19	0.01	0.07	0.00	1.98	136,138

Appendix 5. Percent cover of landcover classes for the major surficial geology features north of treeline in GAAR including the 10 mile buffer

Landcover classes	Bed-rock	Colluvium	Alluvial fan	Drift, terraces sand	Lacus-trine	Flood plain	Organic deposit	Total percent cover	Total acres
Needleleaf forest									
Dense-open white spruce forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Open black spruce-like forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Open white spruce-like forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Spruce-lichen woodland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Spruce woodland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Broadleaf forest									
Closed paper birch-aspen forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Closed balsam poplar forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Open paper birch-aspen forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Open balsam poplar forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Mixed forest									
Closed spruce-broadleaf forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Open spruce-broadleaf forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Tall Shrub									
Closed tall shrub	1.55	0.92	4.19	1.73	0.00	1.38	5.55	1.73	118,814
Open tall shrub	0.09	0.13	0.85	0.37	0.00	0.56	1.25	0.23	15,917
Low shrub									
Shrub birch-willow-tussock tundra	3.74	20.90	11.34	20.41	0.00	7.33	12.39	10.69	734,374
Shrub birch-ericaceous-willow	8.68	14.71	22.30	21.03	0.00	14.92	20.78	13.57	932,290
Closed low willow	0.19	1.33	0.75	0.96	0.00	0.64	1.77	0.59	40,332
Prostrate shrub									
Prostrate shrub-rock	14.05	7.21	6.61	4.59	0.00	3.18	4.48	10.04	689,786
Prostrate shrub-lichen	1.48	0.96	3.17	2.09	0.00	3.21	1.25	1.64	112,548
Prostrate shrub	19.38	16.00	21.45	19.73	0.00	21.94	13.67	18.96	1,302,495
Herbaceous types									
Dry herbaceous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Mesic herbaceous	4.38	15.14	14.13	19.27	0.00	16.75	11.76	10.26	704,931
Wet herbaceous	0.32	0.81	1.97	1.88	0.00	1.73	2.63	0.95	64,952
Aquatic herbaceous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Other									
Sparsely vegetated	14.95	6.47	6.58	2.49	0.00	3.67	9.55	10.01	687,878

Bare-ground	22.95	10.45	2.85	1.71	0.00	1.92	7.39	14.49	995,580
Silty water	0.03	0.09	0.55	0.32	0.00	1.54	4.39	0.29	19,889
Clear water	0.05	0.03	0.41	1.06	0.00	5.64	1.13	0.52	35,734
Snow/Ice	0.73	0.63	0.18	0.15	0.00	0.13	0.80	0.71	49,025
Mosaic/patterned vegetation	0.03	0.02	1.52	0.83	0.00	14.50	0.51	0.38	26,006
Shadow/indeterminate	7.34	3.94	1.14	1.21	0.00	0.78	0.61	4.84	332,616

Appendix 6. Percent cover of surficial geology types north and south of treeline in Gates of the Arctic National Park and Preserve, including the 10 mile buffer.

Surficial geology deposits	North of treeline	South of treeline	Total for GAAR project area
Bedrock	55.04	60.33	57.68
Colluvial	8.76	4.80	6.78
Alluvial fan	1.81	1.19	1.50
Glacial Drift, Terraces, Sand-silt De	30.05	24.58	27.32
Lacustrine	0.43	1.92	1.17
Floodplain	3.42	5.34	4.38
Organic	0.00	1.41	0.71

*Large bodies of water and glaciers were not included in this summary because they are not surficial geology units

Appendix 7. The mean slope (%) for each landcover class *

Landcover classes	# of samples	Mean Slope (%)
Dense-open white spruce forest	2	2.2
Open spruce forest, unknown	15	9.7
Open black spruce-like forest	16	14.3
Open white spruce-like forest	27	13.7
Spruce woodland	34	15.5
Spruce-lichen woodland	11	10.4
Closed paper birch-aspen forest	5	30.1
Closed balsam poplar forest	4	1.1
Open paper birch-aspen forest	3	14.0
Open balsam poplar forest	4	2.0
Closed spruce-broadleaf forest	7	12.6
Open spruce-broadleaf forest	9	14.8
Closed tall shrub	34	21.4
Open tall shrub	45	18.9
Shrub birch-willow-tussock tundra	52	6.9
Shrub birch-ericaceous-willow	176	14.1
Closed low willow	11	13.3
Prostrate shrub-rock	45	17.9
Prostrate shrub-lichen	10	18.7
Prostrate shrub	127	17.7
Dry herbaceous	0	0.0
Mesic herbaceous	85	7.6
Wet herbaceous	37	4.0
Aquatic herbaceous	2	0.0
Sparsely vegetated	22	29.3
Bare-ground	24	39.7
Silty water	7	3.6
Clear water	15	8.7
Snow/Ice	12	16.0
Sand dunes	0	0.0
Mosaic/patterned vegetation	0	0.0
Shadow/indeterminate	0	0.0

* Slope was derived from 1:63,360 DEM data for the project area at a 30m grid spacing. Due to contour relics (spikes/troughs) in the source DEM, a 5x5 low pass (smoothing) filter was required before the slope data could be used. The resulting slope values should therefore be considered primarily as a relative index (not absolute slope %). In physical terms, the effect of the 5x5 filter slope processing can generally be considered equivalent to assuming a constant slope length of

Appendix 8. Cross walk of hierarchical levels between the GAAR landcover map classification (adapted from Viereck et al. 1992) and the national vegetation classification system (Grossman et al. 1998). Note that the National Vegetation Classification System in Alaska is preliminary.

GAAR landcover classes			National Vegetation Classification System landcover classes		
II	III	IV	Formation	Alliance*	Formation code Comments
Needleleaf forest	Dense-open needleleaf forest	Dense-open white spruce forest	Cylindrical-crowned temperate or subpolar needle-leaved evergreen forest	<i>Picea glauca</i> forest*	I.A.8.N.d. GAAR uses 50-65% forest cover; NVCS uses 25-60%. Both use >75% evergreen cover
			Temporarily flooded temperate or subpolar needle-leaved evergreen forest	<i>Picea glauca</i> forest*	I.A.8.N.e.
			Cylindrical-crowned temperate or subpolar needle-leaved evergreen woodland	<i>Picea glauca</i> woodland*	II.A.4.N.c.
			Temporarily flooded temperate or subpolar needle-leaved evergreen woodland	<i>Picea glauca</i> woodland*	II.A.4.N.d.
Open needleleaf forest	Open needleleaf forest	Open black spruce-like forest	Cylindrical-crowned temperate or subpolar needle-leaved evergreen woodland	<i>Picea mariana</i> woodland*	II.A.4.N.c. GAAR uses 25-49% forest cover; NVCS uses 25-60%. Both use >75% evergreen cover
			Temporarily flooded temperate or subpolar needle-leaved evergreen woodland	<i>Picea mariana</i> woodland*	II.A.4.N.d.
			Seasonally flooded temperate or subpolar needle-leaved evergreen woodland	<i>Picea mariana</i> woodland*	II.A.4.N.e.
			Saturated temperate or subpolar needle-leaved evergreen woodland	<i>Picea mariana</i> woodland*	II.A.4.N.f.
		Open white spruce-like forest	Cylindrical-crowned temperate or subpolar needle-leaved evergreen woodland	<i>Picea glauca</i> woodland*	II.A.4.N.c.

GAAR landcover classes				National Vegetation Classification System landcover classes		
II	III	IV	Formation	Alliance*	Formation code	Comments
			Temporarily flooded temperate or subpolar needle-leaved evergreen woodland	<i>Picea glauca</i> woodland*	II.A.4.N.d.	
	Woodland	Spruce-lichen woodland	Lichen vegetation with a sparse tree layer	---	VI.B.1.N.c	GAAR uses 10-24% forest cover; NVCS uses <25% trees and in the shrubland or nonvascular subclasses
		Spruce woodland	Needle-leaved evergreen shrubland (group)	<i>Picea glauca</i> shrubland*	III.A.3.	
Broadleaf forest	Closed broadleaf forest	Closed paper birch-aspen forest	Montane or boreal cold-deciduous forest	<i>Betula papyrifera</i> forest	I.B.2.N.b.	GAAR and NVCS both use >60% forest cover, and >75% broadleaf
		Closed balsam poplar forest	Montane or boreal cold-deciduous forest	<i>Populus tremuloides</i> forest	I.B.2.N.b.	
			Temporarily flooded cold-deciduous forest	<i>Populus deltoides</i> temporarily flooded	I.B.2.N.d.	
Open broadleaf forest	Open broadleaf forest	Open paper birch-aspen forest	Cold-deciduous woodland	<i>Betula papyrifera</i> woodland	II.B.2.N.a.	GAAR and NVCS both use 25-59% forest cover, and >75% broadleaf
		Open balsam poplar forest	Temporarily flooded cold-deciduous woodland	<i>Populus deltoides</i> woodland	II.B.2.N.b.	
Mixed forest	Closed mixed forest	Closed spruce-broadleaf forest	Mixed needle-leaved evergreen - cold-deciduous forest	<i>Picea glauca-Betula papyrifera</i> forest*	I.C.3.N.a.	GAAR and NVCS both use >60% forest cover, and 25-75% mix of broadleaf and evergreen

GAAR landcover classes		National Vegetation Classification System landcover classes			
II	III	IV	Formation	Alliance*	Formation code Comments
			Temporarily flooded mixed needle-leaved evergreen - cold-deciduous forest	<i>Picea glauca-Populus balsamifera</i> forest*	I.C.3.N.b.
Open mixed forest		Open spruce-broadleaf forest	Mixed needle-leaved evergreen - cold-deciduous woodland	<i>Picea mariana-Betula papyrifera</i> woodland*	II.C.3.N.a. GAAR and NVCS both use 25-59% forest cover, and 25-75% mix of broadleaf and evergreen
			Mixed needle-leaved evergreen - cold-deciduous woodland	<i>Picea glauca-Betula papyrifera</i> woodland*	II.C.3.N.a.
Tall Shrub	Closed tall shrub		Subalpine or subpolar cold-deciduous shrubland	<i>Betula glandulosa</i> *	III.B.2.N.b GAAR uses >3.5 ft and >75% shrub cover; NVCS uses >1.5 ft and >25% cover for shrubland
			Subalpine or subpolar cold-deciduous shrubland	<i>Alnus viridis</i> ssp. <i>crispa</i> *	III.B.2.N.b
			Subalpine or subpolar cold-deciduous shrubland	<i>Alnus viridis</i> ssp. <i>sinuata</i> *	III.B.2.N.b
			Intermittently flooded cold-deciduous shrubland	---	III.B.2.N.c.
			Temporarily flooded cold-deciduous shrubland	<i>Alnus viridis</i> ssp. <i>crispa</i> *	III.B.2.N.d
			Seasonally flooded cold-deciduous shrubland	---	III.B.2.N.e.
			Semipermanently flooded cold-deciduous shrubland	---	III.B.2.N.f.
Open tall shrub			Subalpine or subpolar cold-deciduous shrubland	<i>Salix lanata</i> ssp. <i>richardsonii</i> *	III.B.2.N.b GAAR uses >3.5 ft and >25-74% shrub cover; NVCS uses >1.5 ft and >25% cover for shrubland
			Subalpine or subpolar cold-deciduous shrubland	<i>Alnus viridis</i> ssp. <i>crispa</i> *	III.B.2.N.b

GAAR landcover classes		National Vegetation Classification System landcover classes		
II	III	IV	Formation	Alliance*
			Subalpine or subpolar cold-deciduous shrubland	<i>Alnus viridis</i> ssp. <i>sinuata</i> *
			Intermittently flooded cold-deciduous shrubland	---
			Temporarily flooded cold-deciduous shrubland	<i>Alnus viridis</i> ssp. <i>crispa</i> *
			Temporarily flooded cold-deciduous shrubland	<i>Salix alaxensis</i> *
			Temporarily flooded cold-deciduous shrubland	<i>Salix lanata</i> ssp. <i>richardsonii</i> *
			Seasonally flooded cold-deciduous shrubland	---
			Semipermanently flooded cold-deciduous shrubland	---
Low shrub	Closed low shrub	Closed low willow	Subalpine or subpolar cold-deciduous shrubland	---
			Intermittently flooded cold-deciduous shrubland	---
			Temporarily flooded cold-deciduous shrubland	<i>Salix planifolia</i> ssp. <i>pulchra</i>
			Caespitose cold-deciduous dwarf-shrubland (possible crosswalk)	---
			Caespitose needle-leaved or microphyllous evergreen dwarf-shrubland	---

Formation code	Comments
III.B.2.N.b	
III.B.2.N.c	
III.B.2.N.d	
III.B.2.N.d	
III.B.2.N.d	
III.B.2.N.e	
III.B.2.N.f	
III.B.2.N.b	GAAR uses 0.3-3.5 ft and >75% shrub cover; NVCS uses >1.5 ft for shrubland and <1.5 ft for dwarf-shrubland, and >25% shrub cover
III.B.2.N.c	
III.B.2.N.d	
IV.B.2.N.a	
IV.A.1.N.a	

GAAR landcover classes			National Vegetation Classification System landcover classes		
II	III	IV	Formation	Alliance*	Formation code
	Open low shrub	Shrub birch-willow-tussock tundra	Temporarily flooded cold-deciduous shrubland	---	III.B.2.N.d
					GAAR uses 0.3-3.5 ft and 25-74% shrub cover; NVCS uses >1.5 ft for shrubland and <1.5 ft for dwarf-shrubland, and >25% cover
			Seasonally flooded cold-deciduous shrubland	---	III.B.2.N.e.
			Semipermanently flooded cold-deciduous shrubland	---	III.B.2.N.f.
			Saturated cold-deciduous shrubland	<i>Betula glandulosa</i> *	III.B.2.N.g
			Saturated cold-deciduous shrubland	<i>Vaccinium uliginosum</i> *	III.B.2.N.g
			Saturated cold-deciduous shrubland	<i>Salix lanata</i> ssp. <i>richardsonii</i> *	III.B.2.N.g
			Saturated cold-deciduous shrubland	<i>Salix planifolia</i> ssp. <i>pulchra</i> *	III.B.2.N.g
			Caespitose cold-deciduous dwarf-shrubland (possible crosswalk)	---	IV.B.2.N.a
			Saturated cold-deciduous dwarf-shrubland	---	IV.B.2.N.d
			Subalpine or subpolar cold-deciduous shrubland	<i>Vaccinium uliginosum</i> *	III.B.2.N.b
			Subalpine or subpolar cold-deciduous shrubland	<i>Betula glandulosa</i> *	III.B.2.N.b
			Intermittently flooded cold-deciduous shrubland	---	III.B.2.N.c.
			Temporarily flooded cold-deciduous shrubland	<i>Salix planifolia</i> ssp. <i>pulchra</i>	III.B.2.N.d
			Seasonally flooded cold-deciduous shrubland	---	III.B.2.N.e.

GAAR landcover classes			National Vegetation Classification System landcover classes		
II	III	IV	Formation	Alliance*	Formation code Comments
			Semipermanently flooded cold-deciduous shrubland	---	III.B.2.N.f.
			Saturated cold-deciduous shrubland	<i>Vaccinium uliginosum</i> *	III.B.2.N.g
			Caespitose cold-deciduous dwarf-shrubland (possible crosswalk)	---	IV.B.2.N.a
			Saturated cold-deciduous dwarf-shrubland (possible crosswalk)	---	IV.B.2.N.d
Prostrate shrub	Prostrate shrub-rock		Creeping or matted needle-leaved or microphyllous evergreen dwarf-shrubland	<i>Dryas octopetala</i> *	IV.A.1.N.b GAAR uses <0.3 ft and >25% shrub cover; NVCS uses <1.5 ft and >25% shrub cover
			Creeping or matted needle-leaved or microphyllous evergreen dwarf-shrubland	<i>Cassiope tetragona</i>	IV.A.1.N.b
			Creeping or matted cold-deciduous dwarf-shrubland	---	IV.B.2.b.
			Mixed evergreen - cold-deciduous dwarf-shrubland	---	IV.C.2.a.
Prostrate shrub-lichen			Caespitose cold-deciduous dwarf-shrubland	<i>Vaccinium uliginosum</i> *	IV.B.2.a.
			Creeping or matted cold-deciduous dwarf-shrubland	---	IV.B.2.b.
			Mixed evergreen - cold-deciduous dwarf-shrubland	---	IV.C.2.a.
			Lowland lichen vegetation	---	VI.B.1.N.a
			Montane/submontane temperate or subpolar lichen vegetation dominate the nonvascular cover	---	VI.B.1.N.b
			Lichen vegetation with a sparse dwarf-shrub layer	---	VI.B.1.N.d

GAAR landcover classes			National Vegetation Classification System landcover classes			
II	III	IV	Formation	Alliance*	Formation code	Comments
	Prostrate shrub		Caespitose needle-leaved or microphyllous evergreen dwarf-shrubland	<i>Dryas octopetala</i> *	IV.A.1.N.a	
			Caespitose needle-leaved or microphyllous evergreen dwarf-shrubland	<i>Dryas integrifolia</i> *	IV.A.1.N.a	
			Creeping or matted needle-leaved or microphyllous evergreen dwarf-shrubland	---	IV.A.1.N.b	
			Creeping or matted cold-deciduous dwarf-shrubland	<i>Salix reticulata</i>	IV.B.2.b.	
			Creeping or matted cold-deciduous dwarf-shrubland	<i>Salix rotundifolia</i> (= <i>Salix dodgeana</i>)	IV.B.2.b.	
			Mixed evergreen - cold-deciduous dwarf-shrubland	---	IV.C.2.a.	
Herbaceous types	Dry herbaceous		Short alpine or subalpine dry bunchgrass grassland	<i>Festuca altaica</i> *	V.A.5.N.h.	GAAR and NVCS both use herbaceous >25% cover
	Mesic herbaceous		Medium-tall sod temperate or subpolar grassland	<i>Calamagrostis canadensis</i> *	V.A.5.N.c.	
			Seasonally flooded temperate or subpolar grassland	---	V.A.5.N.k.	
			Semipermanently flooded temperate or subpolar grassland	---	V.A.5.N.l.	
			Saturated temperate or subpolar grassland	<i>Carex lugens</i>	V.A.5.N.m	
			Saturated temperate or subpolar grassland	<i>Carex membranacea</i>	V.A.5.N.m	
			Saturated temperate or subpolar grassland	<i>Eriophorum russeolum</i>	V.A.5.N.m	

GAAR landcover classes			National Vegetation Classification System landcover classes			
II	III	IV	Formation	Alliance*	Formation code	Comments
			Saturated temperate or subpolar grassland	<i>Eriophorum vaginatum</i>	V.A.5.N.m	
			Medium-tall temperate or subpolar grassland with a sparse cold-deciduous shrub layer	---	V.A.7.N.g.	
			Short temperate or subpolar grassland with a sparse cold-deciduous shrub layer	<i>Carex bigelowii</i>	V.A.7.N.l.	
			Saturated temperate or subpolar grassland with a sparse cold-deciduous shrub layer	---	V.A.7.N.p.	
			Short temperate or subpolar lowland grassland with a sparse cold-deciduous shrub layer	---	V.A.8.N.b.	
			Short sod polar grassland	---	V.A.9.N.a.	
			Short bunch polar grassland	---	V.A.9.N.b.	
			Seasonally flooded polar grassland	---	V.A.9.N.c.	
			Low temperate or subpolar perennial forb vegetation	---	V.B.2.N.b.	
Wet herbaceous			Semipermanently flooded temperate or subpolar grassland	<i>Arctophila fulva</i>	V.A.5.N.l.	
			Semipermanently flooded temperate or subpolar grassland	<i>Carex aquatilis</i>	V.A.5.N.l.	
			Semipermanently flooded temperate or subpolar grassland	<i>Carex limosa</i>	V.A.5.N.l.	
			Semipermanently flooded temperate or subpolar grassland	<i>Carex rostrata</i>	V.A.5.N.l.	
			Semipermanently flooded temperate or subpolar grassland	<i>Carex saxatilis</i>	V.A.5.N.l.	
			Semipermanently flooded temperate or subpolar grassland	<i>Eriophorum angustifolium</i>	V.A.5.N.l.	
			Semipermanently flooded temperate or subpolar grassland	<i>Equisetum fluviatile</i>	V.B.2.N.e.	
			perennial forb vegetation			

GAAR landcover classes			National Vegetation Classification System landcover classes			
II	III	IV	Formation	Alliance*	Formation code	Comments
			Saturated temperate perennial forb vegetation	---	V.B.2.N.f.	
Aquatic herbaceous			Permanently flooded temperate or subpolar hydromorphic rooted vegetation	---	V.C.2.N.a	
Sparsely vegetated			Sparse vegetation (Subclass)	---	VII.	GAAR uses 15-25% total vegetation cover; NVCS uses 0.1-25% cover
Bare-ground						GAAR uses <15% total vegetation cover; NVCS uses 0%

* Alliance names followed by * indicate the alliance was not defined in NVCS. The name was given by the authors of this report and corresponds to the name that most likely will be assigned by NVCS in the future.

--- means no alliance was defined or could be assigned.

Appendix 9. List of plant species identified during ground sampling, 1998	
Scientific Binomial	Six Letter Code
Trees	
<i>Betula papyrifera</i>	BETPAP
<i>Picea glauca</i>	PICGLA
<i>Picea mariana</i>	PICMAR
<i>Picea species</i>	PICEAX
<i>Populus balsamifera</i>	POPBAL
Shrubs	
<i>Alnus crispa</i>	ALNCRI
<i>Alnus incana</i>	ALNINC
<i>Andromeda polifolia</i>	ANDPOL
<i>Androsace chamaejasme</i>	ANDCHA
<i>Arctostaphylos alpina</i>	ARCALP
<i>Arctostaphylos rubra</i>	ARCRUB
<i>Arctostaphylos uva-ursi</i>	ARCUVA
<i>Artemisia alaskana</i>	ARTALA
<i>Artemisia arctica</i>	ARTARC
<i>Artemisia borealis</i>	ARTBOR
<i>Artemisia glomerata</i>	ARTGLO
<i>Betula glandulosa</i>	BETGLA
<i>Betula nana</i>	BETNAN
<i>Cassiope tetragona</i>	CASTET
<i>Chamaedaphne calyculata</i>	CHACAL
<i>Dryas integrifolia</i>	DRYINT
<i>Dryas octopetala</i> subspecies <i>alaskensis</i>	DRYOCTALA
<i>Empetrum nigrum</i>	EMPNIG
<i>Ledum decumbens</i>	LEDDEC
<i>Ledum groenlandicum</i>	LEDGRO
<i>Loiseleuria procumbens</i>	LOUPRO
<i>Oxycoccus species</i>	OXYCOC
<i>Potentilla fruticosa</i>	POTFRU
<i>Pyrola minor</i>	PYRMIN
<i>Rhododendron lapponicum</i>	RHOLAP
<i>Ribes triste</i>	RIBTRI
<i>Rosa acicularis</i>	ROSACI
<i>Rubus arcticus</i>	RUBARC
<i>Salix myrtilifolia</i>	SALMYR
<i>Salix species</i>	SALIXX
<i>Salix alaxensis</i>	SALALA
<i>Salix arbusculoides</i>	SALARB

<i>Salix arctica</i>	SALARC
<i>Salix barclayi</i>	SALBAR
<i>Salix brachycarpa</i>	SALBRA
<i>Salix chamissonis</i>	SALCHA
<i>Salix fuscescens</i>	SALFUS
<i>Salix glauca</i>	SALGLA
<i>Salix lanata</i> subspecies <i>richardsonii</i>	SALLANRIC
<i>Salix monticola</i>	SALMON
<i>Salix novae-angliae</i>	SALNOV
<i>Salix phlebophylla</i>	SALPHL
<i>Salix planifolia</i> subspecies <i>pulchra</i>	SALPLAPUL
<i>Salix reticulata</i>	SALRET
<i>Salix rotundifolia</i>	SALROT
<i>Shepherdia canadensis</i>	SHECAN
<i>Spiraea beauverdiana</i>	SPIBEA
<i>Vaccinium uliginosum</i>	VACULI
<i>Vaccinium vitis-idaea</i>	VACVIT
Graminoids	
<i>Arctagrostis latifolia</i>	ARCLAT
<i>Arctophila fulva</i>	ARCFUL
<i>Bromus pumpellianus</i> var. <i>arcticus</i>	BROPUM
<i>Bromus</i> species	BROMUS
<i>Calamagrostis canadensis</i>	CALCAN
<i>Calamagrostis lapponica</i>	CALLAP
<i>Calamagrostis purpurascens</i>	CALPUR
<i>Calamagrostis</i> species	CALAMA
<i>Carex aquatilis</i>	CARAQU
<i>Carex bigelowii</i>	CARBIG
<i>Carex capillaris</i>	CARCAP
<i>Carex dioica</i> subspecies <i>gynocrates</i>	CARDIOGYN
<i>Carex filifolia</i>	CARFIL
<i>Carex krausei</i>	CARKRA
<i>Carex limosa</i>	CARLIM
<i>Carex lugens</i>	CARLUG
<i>Carex membranacea</i>	CARMEM
<i>Carex microchaeta</i>	CARMIC
<i>Carex misandra</i>	CARMIS
<i>Carex obtusata</i>	CAROBT
<i>Carex podocarpa</i>	CARPOD
<i>Carex rariflora</i>	CARRAR
<i>Carex rostrata</i>	CARROS

<i>Carex rupestris</i>	CARRUP
<i>Carex saxatilis</i>	CARSAX
<i>Carex scirpoidea</i>	CARSCI
<i>Carex species</i>	CAREXX
<i>Carex tenuiflora</i>	CARTEN
<i>Carex vaginata</i>	CARVAG
<i>Elymus innovatus</i>	ELYINO
<i>Eriophorum angustifolium</i>	ERiang
<i>Eriophorum russeolum</i>	ERIRUS
<i>Eriophorum species</i>	ERIOPH
<i>Eriophorum vaginatum</i>	ERIVAG
<i>Festuca altaica</i>	FESALT
<i>Festuca baffinensis</i>	FESBAF
<i>Festuca brachyphylla</i>	FESBRA
<i>Festuca rubra</i>	FESRUB
<i>Festuca species</i>	FESTUC
<i>Hierochloa alpina</i>	HIEALP
<i>Juncus species</i>	JUNCUS
<i>Juncus triglumis</i>	JUNTRI
<i>Kobresia myosuroides</i>	KOBYMY
<i>Luzula confusa</i>	LUZCON
<i>Luzula groenlandica</i>	LUZGRO
<i>Luzula multiflora</i>	LUZMUL
<i>Luzula kjellmaniana</i>	LUZKJE
<i>Luzula species</i>	LUZULA
<i>Luzula tundricola</i>	LUZTUN
<i>Poa arctica</i>	POAARC
<i>Poa glauca</i>	POAGLA
<i>Poa leptocoma</i>	POALEP
<i>Poa pratensis</i>	POAPRA
<i>Poa species</i>	POAXXX
<i>Scirpus species</i>	SCIRPU
<i>Trisetum spicatum</i>	TRISPI
Forbs	
<i>Aconitum delphinifolium</i>	ACODEL
<i>Anemone drummondii</i>	ANEDRU
<i>Anemone narcissiflora</i>	ANENAR
<i>Anemone parviflora</i>	ANEPAR
<i>Anemone richardsonii</i>	ANERIC
<i>Anemone species</i>	ANEMON
<i>Antennaria friesiana</i>	ANTFRI

<i>Antennaria monocephala</i>	ANTMON
<i>Arenaria capillaris</i>	ARECAP
<i>Arnica alpina</i>	ARNALP
<i>Arnica frigida</i>	ARNFRI
<i>Artemisia tilesii</i>	ARTTIL
<i>Aster sibiricus</i>	ASTSIB
<i>Aster species</i>	ASTERX
<i>Astragalus alpinus</i>	ASTALP
<i>Astragalus species</i>	ASTRAG
<i>Astragalus umbellatus</i>	ASTUMB
<i>Bistorta plumosa</i>	BISPLU
<i>Bistorta vivipara</i>	BISVIV
<i>Boschniakia rossica</i>	BOSROS
<i>Boykinia richardsonii</i>	BOYRIC
<i>Boykinia species</i>	BOYKIN
<i>Bupleurum americanum</i>	BUPAME
<i>Bupleurum triradiatum subspecies arcticum</i>	BUPTRIARC
<i>Caltha palustris</i>	CALPAL
<i>Cardamine bellidifolia</i>	CARBEL
<i>Cardamine digitata</i>	CARDIG
<i>Cardamine hyperborea</i>	CARHYP
<i>Caryophyllaceae family</i>	CARYOP
<i>Castilleja species</i>	CASTIL
<i>Castilleja elegans</i>	CASELE
<i>Castilleja hyperborea</i>	CASHYP
<i>Cerastium species</i>	CERAST
<i>Chrysanthemum integrifolium</i>	CHRINT
<i>Diapensia lapponica</i>	DIALAP
<i>Dodecatheon frigidum</i>	DODFRI
<i>Dodecatheon species</i>	DODECA
<i>Draba alpina</i>	DRAALP
<i>Epilobium angustifolium</i>	EPIANG
<i>Epilobium latifolium</i>	EPILAT
<i>Equisetum arvense</i>	EQUARV
<i>Equisetum fluviatile</i>	EQUFLU
<i>Equisetum pratense</i>	EQUpra
<i>Equisetum scirpoides</i>	EQUSCI
<i>Equisetum species</i>	EQUISE
<i>Equisetum variegatum</i>	EQUVAR
<i>Eutrema edwardsii</i>	EUTEDW
<i>Galium boreale</i>	GALBOR
<i>Gentiana propinqua</i>	GENPRO

<i>Geum glaciale</i>	GEUGLA
<i>Geum species</i>	GEUMXX
<i>Hedysarum alpinum</i>	HEDALP
<i>Hedysarum hedysaroides</i>	HEDHED
<i>Hippurus vulgaris</i>	HIPVUL
<i>Lagotis glauca</i>	LAGGLA
<i>Linnaea borealis</i>	LINBOR
<i>Lomatogonium rotatum</i>	LOMROT
<i>Lupinus arcticus</i>	LUPARC
<i>Lupinus species</i>	LUPINU
<i>Lycopodium alpinum</i>	LYCALP
<i>Lycopodium annotinum</i>	LYCANO
<i>Lycopodium selago</i>	LYCSEL
<i>Melandrium apetalum</i>	MELAPE
<i>Menyanthes trifoliata</i>	MENTRI
<i>Mertensia paniculata</i>	MERPAN
<i>Minuartia arctica</i>	MINARC
<i>Minuartia elegans</i>	MINELE
<i>Minuartia macrocarpa</i>	MINMAC
<i>Minuartia obtusiloba</i>	MINOBT
<i>Myosotis alpestris</i>	MYOALP
<i>Oxytropis bryophila</i>	OXYBRY
<i>Oxytropis campestris</i>	OXYCAM
<i>Oxytropis koyukukensis</i>	OXYKOK
<i>Oxytropis maydelliana</i>	OXYMAY
<i>Oxytropis maydelliana</i>	OXYMAY
<i>Oxytropis nigrescens</i>	OXYNIG
<i>Oxytropis species</i>	OXYTRO
<i>Oxytropis varians</i>	OXYVAR
<i>Oxytropis viscida</i>	OXYVIS
<i>Oxytropix scammaniana</i>	OXYSCA
<i>Papaver macounii</i>	PAPMAC
<i>Papaver macounii</i>	PAPMAC
<i>Papaver radicum</i>	PAPRAD
<i>Papaver species</i>	PAPAVE
<i>Parnassia kotzebuei</i>	PARKOT
<i>Parnassia palustris</i>	PARPAL
<i>Parrya nudicaulis</i>	PARNUD
<i>Parrya species</i>	PARRYA
<i>Pedicularis capitata</i>	PEDCAP
<i>Pedicularis kanei</i>	PEDKAN
<i>Pedicularis labradorica</i>	PEDLAB

<i>Pedicularis lanata</i>	PEDLAN
<i>Pedicularis lapponica</i>	PEDLAP
<i>Pedicularis</i> species	PEDICU
<i>Pedicularis sudetica</i>	PEDSUD
<i>Pedicularis verticillata</i>	PEDVER
<i>Petasites frigidus</i>	PETFRI
<i>Petasites hyperboreus</i>	PETHYP
<i>Phlox alaskensis</i>	PHLALA
<i>Polemonium acutiflorum</i>	POLACU
<i>Polemonium boreale</i>	POLBOR
<i>Polemonium</i> species	POLEMO
<i>Polygonum bistorta</i>	POLBIS
<i>Polygonum</i> species	POLYGO
<i>Potentilla biflora</i>	POTBIF
<i>Potentilla palustris</i>	POTPAL
<i>Potentilla uniflora</i>	POTUNI
<i>Pyrola asarifolia</i>	PYRASA
<i>Pyrola grandiflora</i>	PYRGRA
<i>Ranunculus</i> species	RANUNC
<i>Ranunculus sulphureus</i>	RANSUL
<i>Rumex arcticus</i>	SALARC
<i>Saussurea angustifolia</i>	SAUANG
<i>Saxifraga bracteata</i>	SAXBRA
<i>Saxifraga bronchialis</i> subspecies <i>funstonii</i>	SAXBROFUN
<i>Saxifraga calycina</i>	SAXCAL
<i>Saxifraga davurica</i>	SAXDAV
<i>Saxifraga eschscholtzii</i>	SAXESC
<i>Saxifraga flagellaris</i>	SAXFLA
<i>Saxifraga hieracifolia</i>	SAXHIE
<i>Saxifraga hirculus</i>	SAXHIR
<i>Saxifraga nelsoniana</i>	SAXNEL
<i>Saxifraga nivalis</i>	SAXNIV
<i>Saxifraga oppositifolia</i>	SAXOPP
<i>Saxifraga punctata</i>	SAXPUN
<i>Saxifraga punctata</i> subspecies <i>nelsoniana</i>	SAXPUNNEL
<i>Saxifraga reflexa</i>	SAXREF
<i>Saxifraga</i> species	SAXIFR
<i>Saxifraga tricuspidata</i>	SAXTRI
<i>Selaginella sibirica</i>	SELSIB
<i>Senecia fuscatus</i>	SENFUS
<i>Senecio atropurpureus</i>	SENATR
<i>Senecio lugens</i>	SENLUG

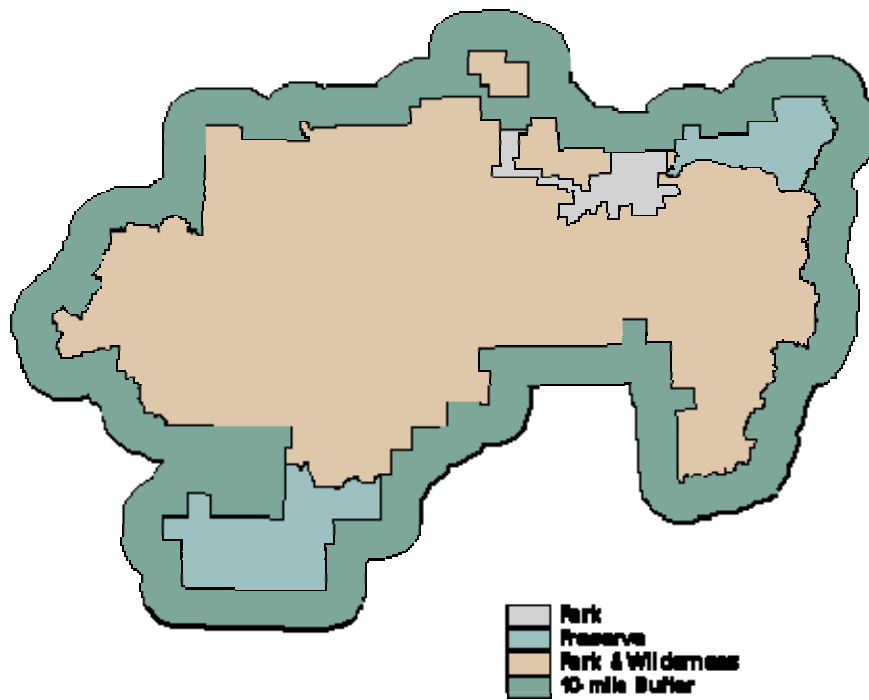
<i>Senecio resedifolius</i>	SENRES
<i>Senecio tundricola</i>	SENTUN
<i>Silene acaulis</i>	SILACA
<i>Silene acaullis</i>	SILACA
<i>Smelowskia calycina</i>	SMECOL
<i>Solidago multiradiata</i>	SOLMUL
<i>Stellaria longipes</i>	STELON
<i>Stellaria species</i>	STELLA
<i>Thalictrum alpinum</i>	THAALP
<i>Tofieldia coccinea</i>	TOFCOC
<i>Tofieldia pusilla</i>	TOFPUL
<i>Tofieldia species</i>	TOFIEL
<i>Valeriana capitata</i>	VALCAP
Mosses	
<i>Calliergon stramineum</i>	CALSTR
<i>Dicranum species</i>	DICRAN
<i>Hylocomium splendens</i>	HYLSPL
<i>Polytrichum species</i>	POLYTR
<i>Sphagnum species</i>	SPHAGN
Lichens	
<i>Alectoria species</i>	ALECTO
<i>Cetraria species</i>	CETRAR
<i>Cladina rangiferina</i>	CLARAN
<i>Cladina species</i>	CLADIN
<i>Cladonia species</i>	CLADON
<i>Coelocaulon species</i>	COELOC
<i>Dactylina species</i>	DACTYL
<i>Masonhalea richardsonii</i>	MASRIC
<i>Nephroma species</i>	NEPHRO
<i>Peltigera species</i>	PELTIG
<i>Stereocaulon species</i>	STEREO

Appendix 10a. Percent cover and acreage of landcover classes for the different land jurisdictional categories for GAAR

	Percent cover					Acres				
	GAAR plus 10 mile buffer	GAAR minus 10 mile buffer	Park & Wilderness	National Preserve	National Park	GAAR plus 10 mile buffer	GAAR minus 10 mile buffer	Park & Wilderness	National Preserve	National Park
Landcover classes										
Needleleaf forest										
Dense-open white spruce forest	0.04%	0.03%	0.03%	0.00%	0.00%	5,889.86	2,123.62	2,123.62	0.00	0.00
Open black spruce-like forest	8.08%	5.38%	2.54%	2.84%	0.00%	1,110,745.51	455,245.11	214,758.83	240,486.27	0.00
Open white spruce-like forest	3.00%	2.31%	1.53%	0.78%	0.00%	412,165.06	195,600.88	129,957.14	65,643.74	0.00
Spruce woodland	5.93%	4.95%	3.98%	0.97%	0.00%	815,661.00	419,348.54	337,375.47	81,973.07	0.00
Spruce-lichen woodland	0.64%	0.44%	0.21%	0.23%	0.00%	87,922.66	37,039.73	17,452.43	19,587.29	0.00
Broadleaf forest										
Closed paper birch-aspen forest	0.14%	0.06%	0.06%	0.00%	0.00%	19,729.29	5,383.79	5,330.83	52.97	0.00
Closed balsam poplar forest	0.07%	0.05%	0.05%	0.00%	0.00%	10,131.69	3,968.38	3,968.38	0.00	0.00
Open paper birch-aspen forest	0.23%	0.19%	0.11%	0.08%	0.00%	31,259.33	16,369.26	9,658.93	6,710.33	0.00
Open balsam poplar forest	0.09%	0.07%	0.06%	0.02%	0.00%	12,360.39	6,276.18	4,662.94	1,613.23	0.00
Mixed forest										
Closed spruce-broadleaf forest	0.24%	0.20%	0.15%	0.05%	0.00%	33,047.67	16,900.11	12,633.00	4,267.11	0.00
Open spruce-broadleaf forest	0.30%	0.19%	0.13%	0.06%	0.00%	41,309.13	15,897.99	10,776.81	5,121.17	0.00
Tall Shrub										
Closed tall shrub	2.89%	2.80%	2.37%	0.41%	0.01%	397,866.40	236,976.53	201,055.49	34,677.96	1,243.08
Open tall shrub	2.98%	3.02%	2.69%	0.33%	0.00%	410,129.65	255,845.38	227,831.00	27,673.91	340.46
Low shrub										
Shrub birch-willow-tussock tundra	6.73%	5.36%	4.96%	0.12%	0.28%	925,309.02	453,755.86	419,873.78	10,121.77	23,760.31
Shrub birch-ericaceous-willow	15.19%	16.15%	15.04%	0.61%	0.50%	2,088,107.33	1,367,227.77	1,273,438.44	51,822.23	41,967.10

	Percent cover					Acres				
	GAAR plus 10 mile buffer	GAAR minus 10 mile buffer	Park & Wilderness	National Preserve	National Park	GAAR plus 10 mile buffer	GAAR minus 10 mile buffer	Park & Wilderness	National Preserve	National Park
Landcover classes										
Closed low willow	0.18%	0.15%	0.14%	0.00%	0.01%	24,455.23	12,586.46	11,709.92	412.29	464.25
Prostrate shrub										
Prostrate shrub-rock	6.06%	7.23%	6.08%	0.80%	0.34%	832,698.76	612,154.71	515,184.05	67,823.14	29,147.51
Prostrate shrub-lichen	1.15%	1.12%	0.98%	0.12%	0.02%	158,345.72	94,637.37	82,563.72	10,259.80	1,813.86
Prostrate shrub	17.21%	18.10%	16.75%	0.76%	0.58%	2,365,852.61	1,532,279.77	1,418,316.12	64,472.09	49,491.56
Herbaceous types										
Dry herbaceous	0.00%	0.00%	0.00%	0.00%	0.00%	0.00	0.00	0.00	0.00	0.00
Mesic herbaceous	6.21%	4.47%	3.90%	0.34%	0.23%	853,264.81	378,775.20	330,472.14	28,511.93	19,791.13
Wet herbaceous	0.26%	0.17%	0.13%	0.02%	0.02%	36,218.70	14,157.56	10,788.65	1,466.17	1,902.73
Aquatic herbaceous	0.00%	0.00%	0.00%	0.00%	0.00%	331.98	205.04	205.04	0.00	0.00
Other										
Sparsely vegetated	7.29%	9.32%	8.32%	0.61%	0.38%	1,001,931.25	789,008.31	704,677.48	51,983.74	32,347.09
Bare-ground	8.88%	11.89%	10.69%	0.76%	0.44%	1,221,000.68	1,006,572.89	905,084.75	64,591.46	36,896.68
Clear water	0.52%	0.47%	0.40%	0.05%	0.02%	71,507.91	39,488.97	33,469.99	4,599.35	1,419.63
Silty water	0.63%	0.58%	0.36%	0.15%	0.07%	86,552.40	49,151.50	30,388.98	12,883.78	5,878.74
Snow/Ice	0.36%	0.49%	0.40%	0.08%	0.01%	49,013.22	41,367.83	33,924.01	6,637.70	806.11
Sand dunes	0.00%	0.00%	0.00%	0.00%	0.00%	10.04	0.00	0.00	0.00	0.00
Mosaic/Pattern Vegetation	0.18%	0.03%	0.00%	0.00%	0.02%	24,431.35	2,258.64	165.32	84.46	2,008.87
Shadow/Indeterminate	4.52%	4.81%	3.70%	0.97%	0.13%	621,280.43	407,003.44	313,696.62	81,996.55	11,310.28
Totals	100.00%	100.00%	85.76%	11.17%	3.08%	13,748,529.08	8,467,606.79	7,261,543.89	945,473.52	#####

Appendix 10b. Administrative Park Boundaries in the GAAR Study Area



The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior



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