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Landsat-assisted environmental mapping in the Arctic National Wildlife Refuge, Alaska

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L. Gaydos, J. Brown and P.J. Webber

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This report presents a Landsat-derived land cover map of the northwest portion of the Arctic National Wildlife Refuge, Alaska. The report is divided into two parts. The first is devoted to the land cover map with detailed descriptions of the mapping methods and legend. The second part is a description of the study area. The classification system used for the maps is an improvement over existing methods of describing tundra vegetation. It is a comprehensive method of nomenclature that consistently applies the same criteria for all vegetation units. It is applicable for large- and small-scale mapping and is suitable for describing vegetation complexes, which are common in the patterned-ground terrain of the Alaskan Arctic. The system is applicable to Landsat-derived land cover classifications. The description of the study area focuses on five primary terrain types: flat thaw-lake plains, hilly coastal plains, foothills, mountainous

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terrain, and river flood plains. Topography, landforms, soils and vegetation are described for each terrain type. The report also contains area summaries for the Landsat-derived map categories. The area summaries are generated for the five terrain types and for the 89 townships within the study areas. Two land cover maps at 1:250,000 are included.

PREFACE

This report was prepared by Dr. Donald A. Walker, Research Associate, Institute of Arctic and Alpine Research (INSTAAR), University of Colorado; William Acevedo, Senior Data Analyst, Technicolor Government Services, NASA/Ames Research Center; Dr. K.R. Everett, Professor, Institute of Polar Studies, Ohio State University; Leonard Gaydos, Chief, Geographic Investigations Office, U.S. Geological Survey (USGS), NASA/Ames Research Center; Dr. Jerry Brown, Chief, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL); and Dr. Patrick J. Webber, Professor and Director of INSTAAR, University of Colorado.

This report was prepared as input to the Environmental Impact Statement required under Section 1002 of the Alaska National Interest Land Conservation Act (ANILCA) of 1980. The experience gained with Landsat and geobotanical mapping in other parts of northern Alaska over the past eight years was applied to this large and relatively unknown region of northeastern Alaska. Much of the experience required to accomplish the project was gained through studies supported by the Department of Energy, USGS and CRREL. This specific study was supported by USGS and the U.S. Fish and Wildlife Service (USFWS).

James R. Wray, USGS, Reston, Virginia, was responsible for the design of the Landsat land cover map. Carol Hurr, USGS, Denver, and Dr. John Haugh, Department of the Interior, Reston, provided editorial and technical assistance in compiling early versions of the report. USFWS, under Dr. William Kirk's direction, organized the logistics for the initial field ground check in August 1981. Bob Bartles of the USFWS Barter Island field station and personnel of the Distant Early Warning (DEW) line site provided considerable assistance for the field work.

The report was reviewed by Dr. Vera Komárková, Research Associate, INSTAAR; Dr. Paula Krebs, Bureau of Land Management, Anchorage; Paul Brooks, Chief, USGS Alaska Program Office; Mark Shasby, Technicolor Government Services, Alaska Operation, Anchorage; Carolyn Merry, CRREL; and Carol Simmons, University of Colorado. John Hall of USFWS and Karen Howe of CRREL reviewed the NWI equivalents in Appendix C. The comments of the reviewers are greatly appreciated; they provided the basis for numerous changes in the original manuscript, parts of which are included in the Environmental Impact Statement and Baseline Studies for the Arctic National Wildlife Refuge.

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SUMMARY

This report describes the landforms, soils and vegetation in a 1.4-million-acre (5700-km^2) portion of the Arctic National Wildlife Refuge (ANWR) in Alaska. The area is being considered for seismic oil exploration activities scheduled to begin in December 1982. A colored land cover map of the study area at 1:250,000 scale was derived from Landsat data as part of this project and was used extensively in the terrain analysis. Descriptions of the environment are based on a seven-day reconnaissance trip in August 1981 that concentrated in four townships of the study area. The field data are supplemented with information from 1:60,000-scale, color-infrared and 1:18,000-scale, color aerial photographs. The report is divided into two parts. The first describes the Landsat map, the methods for making it, and the legend. The second is a description of the ANWR study area based on the major terrain types.

The Landsat-derived land cover map consists of a digital mosaic of portions of three Landsat scenes. The land cover classification consists of the following map categories: 1) Water, 2) Pond/Sedge Tundra Complex *or* Aquatic Tundra *or* shallow water, 3) Wet Sedge Tundra, 4) Moist/Wet Sedge Tundra Complex *or* Dry Prostrate Shrub, Forb Tundra, 5) Moist Sedge, Prostrate Shrub Tundra *or* Moist Sedge/Barren Tundra Complex (frost-scar tundra), 6) Moist Sedge Tussock, Dwarf Shrub Tundra, 7) Moist Dwarf Shrub, Sedge Tussock Tundra *or* Moist Sedge Tussock, Dwarf Shrub/Wet Dwarf Shrub Complex (water track complex), 8) Shrub Tundra, 9) Partially vegetated areas, 10) Barren gravel or rock, 11) Wet gravel or mud, and 12) Ice. The land cover classification system is briefly explained and equivalent units are given for six other vegetation, wetland and land cover classification systems.

The legend system is a solution to the current need for a tundra classification. The system is still being perfected, but it already meets the following criteria:

1) The system is applicable to both large- and small-scale mapping.
2) It consistently applies the same criteria to naming all community types.
3) It has a consistent method of naming vegetation complexes.
4) It is well suited for specific application to Landsat multispectral scanner data.

The study area is divided into five terrain types and the ocean. These types delineate relatively large areas with similar primary landforms. They are, with their percentage of the study area in parentheses, foothills (44.7%), river flood plains (24.6%), hilly coastal plains (22.4%), ocean (5.2%), flat thaw-lake plains (3.1%) and mountainous terrain (0.03%).

Foothills are the most common terrain type in the study area. Tundra with sedge tussocks and dwarf shrubs covers most foothill uplands. Dominant plants include sheathed cottongrass (*Eriophorum vaginatum*), numerous ericaceous shrubs, dwarf birch (*Betula nana*) and diamond-leafed willow (*Salix planifolia* ssp. *pulchra*). Shrub cover varies in upland tundra types and is responsible for much of the variation in spectral reflectances from moist tundra vegetation. Stream valleys, south-facing slopes and water tracks (drainage channels on slopes) are likely to have well-developed shrub communities. Frost scars occur on most upland surfaces and may cover up to 90% of the surface. Pergelic Cryaquolls or Pergelic Cryaquepts underlie much of the moist tundra, although Histic Pergelic Cryaquepts are common soils in water tracks.

River flood plains, which cover large portions of the study area, are highly complex landscapes that include present flood plains, former braided drainages, river deltas, bluffs, terraces, wet tundra, gravel bars, dunes, mud flats and river icings. Willow communities are common along the rivers.

Hilly coastal plains occur north of the foothills, particularly east of the Hulahula River. The vegetation and soils are a combination of those found in the foothills and those found in the flat thaw-lake plains. Wet sedge tundra covers about 23% of the unit, and complexes of moist and wet sedge tundra cover about 34%. Moist tundra types cover about 40% of the unit. Wet tundra areas are mostly confined to depressions between low ridges that have an east-west orientation. Nearly flat hill crests often have extensive thermokarst pits.

Flat thaw-lake plains are restricted to small areas near the coast and are dominated by wet sedge tundra and complexes of moist and wet sedge tundra. A large portion of these areas is covered by lacustrine complexes. The vegetation and soils are strongly controlled by microrelief associated with patterned ground, mainly ice-wedge polygons and strangmoor. The dominant plants are aquatic sedge (*Carex aquatilis*), other sedges and mosses. The dominant soils are Pergelic Cryaquepts and Histic Pergelic Cryaquepts, with thick, fibrous, organic surface horizons. In wetter areas these soils often form complexes with true organic soils, mainly Pergelic Cryohemists. Moderately well drained areas often have mineral soils, Pergelic Cryaquolls, in association with frost boils. The vegetation near the coast is affected by a steep summer gradient, with low temperatures near the coast and higher temperatures inland. Beaches, lagoons, estuaries and low-lying areas, which are all inundated by sea water during storm surges, support saline-tolerant plant communities and haline soils.

Mountainous terrain occurs only in a small portion of the study area, near Sadlerochit Spring. Surface forms consist of block fields, talus slopes, sorted stone nets, steep solifluction slopes, and rock outcrops. Soils are restricted to small areas where finer materials can collect. In less rocky areas, Pergelic Cryorthents form complexes with Pergelic Cryochrepts, Pergelic Cryaquepts, and occasionally, Cryohemists in solifluction areas. The land cover in most mountainous areas is classed as either barren or partially vegetated due to the dominance of rock, but fairly lush tundra vegetation occurs locally on partially stable terrain.

LANDSAT-ASSISTED ENVIRONMENTAL MAPPING IN THE ARCTIC NATIONAL WILDLIFE REFUGE, ALASKA

D.A. Walker, W. Acevedo, K.R. Everett, L. Gaydos, J. Brown and P.J. Webber

INTRODUCTION

The Alaska National Interest Lands Conservation Act (ANILCA) of 1980 created the present boundaries of the Arctic National Wildlife Refuge (ANWR). Under this legislation, 1.4 million acres (5700 km^2) of the northern portion of the refuge were opened to oil and gas exploration at the discretion of the Secretary of the Interior (Fig. 1). The area, henceforth referred to as the ANWR study area, is being considered for seismic oil exploration that would begin in December 1982.

An Environmental Impact Statement (EIS) was prepared to satisfy Section 1002d of ANILCA. A baseline study was prepared under Section 1002c of ANILCA to serve as the basis for the EIS and for regulating future exploration. The extent, location and carrying capacity of wildlife habitats are major emphases of the baseline studies, and vegetation maps are required for examining wildlife habitats. Because existing vegetation maps covering the study area were too general for habitat studies, a new 1:250,000-scale land cover map was suggested, and Landsat-assisted mapping was deemed the most practical approach in the limited time available. A Landsat-based land cover map (inserted in the back of this report) was produced between August 1981 and April 1982, and was partially verified by the three senior authors.

This report is divided into two parts. The first part is devoted to the land cover map, with discussions of the mapping methods and legend. The legend is a step toward a Landsat classification system for tundra. The second part consists of descriptions of the major terrain types within the ANWR study area.

A LAND COVER MAP OF THE ANWR STUDY AREA

There are two main objectives for this mapping project:

1) To produce a land cover map of the ANWR study area that has wide application for wildlife and land use studies.

2) To develop a legend that is appropriate for Landsat and that has application to other areas in northern Alaska.

A Landsat-derived land cover classification was deemed the most suitable approach for this mapping project for several reasons. First, the map had to be prepared in less than one year; Landsat-assisted mapping is the quickest method for mapping large areas. Second, the area is generally inaccessible for detailed mapping on the ground. Third, funds were insufficient for conventional mapping by aerial photointerpretation, and not all of the area was covered on aerial photographs. Finally, Landsat provides digital, geographically referenced information that lends itself well to geographic-based information systems. Other data bases can be registered to it, and analyses such as area measurements can be performed easily. Also, maps can be converted to different scales or the boundaries changed.

Our recent work in the Prudhoe Bay region (Walker and Acevedo, in preparation) has shown that excellent Landsat-derived land cover maps can be prepared for the tundra of the Arctic Coastal Plain. The Coastal Plain has two attributes that aid in interpreting Landsat data. First, the terrain is nearly flat or gently rolling, so deep shadows do not create problems in interpretation,

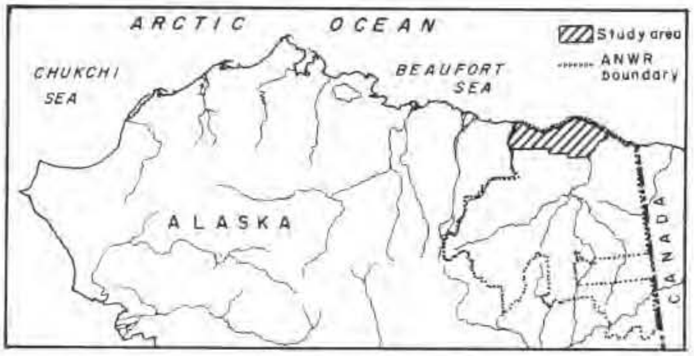

Figure 1. Location of the ANWR study area in northern Alaska.

as they do in mountainous areas. Second, the vegetation is all low growing; there are no trees to mask the terrain or other vegetation.

Legend development

Criteria for Landsat-derived tundra legends

Although Landsat-derived maps have been developed for several areas of northern Alaska (Belon et al. 1975, Nodler and LaPerriere 1977, Nodler et al. 1978, Lyon and George 1979, Morrissey and Ennis 1981), there has not yet been an attempt to develop a comprehensive Landsat land cover legend applicable to all areas of the Alaskan arctic tundra. There are, however, numerous classification systems that were examined for potential application to this mapping objective. These fit in three categories: remote-sensed land cover classifications (Anderson et al. 1976, Nodler and LaPerriere 1977), wetland classifications (Bergman et al. 1977, Cowardin et al. 1979), and vegetation classifications (Fosberg 1970, UNESCO 1973, Viereck and Dyrness 1980, Driscoll et al. 1981). A full discussion of the merits and problems of each system is beyond the scope of this report; none satisfied the objective of this project.

A satisfactory legend for Landsat-assisted mapping of tundra vegetation must meet several criteria. First, the legend must be based on the characteristics of tundra vegetation that can be recognized on Landsat imagery. Our experience with Landsat imagery and tundra has shown that there are two primary aspects of arctic Alaskan coastal tundra vegetation that affect its spectral reflectance—the amount of water on the surface and the percentage of shrubs in the vegetation canopy. Numerous secondary factors, such as the openness of the graminoid layer (the layer of grasslike plants), the color of the substrate, the amount of erect, dead graminoid vegetation, and the nutrient status of the site, also affect the reflectance. A classification system for Landsat-derived mapping should recognize the effect of moisture and shrub cover on spectral reflectance. The secondary factors are more difficult to classify consistently, but they should be considered during photointerpretation.

Second, a classification system should be flexible enough to describe the great variety of tundra communities. There has not yet been sufficient experience with Landsat imagery of tundra environments to establish a final set of units with which to categorize all tundra landscapes. Most approaches have attempted to force Landsat interpretations into rather rigid legend systems that have never been applied to detailed tundra mapping or that simply are not suitable for a Landsat approach.

Third, a classification system should use consistent criteria in naming vegetation units. This is emphasized in all major national and international mapping systems. Most of these systems recognize the importance of dominant growth forms. We have found that a combination of dominant growth forms and site moisture can be used consistently for preparing maps of tundra vegetation. The system should also have a consistent method of describing vegetation complexes (i.e. areas where there are mixtures of vegetation communities), which are particularly common in the patterned-ground landscapes of the Arctic.

Finally, the small-scale, Landsat-based legend units should be able to serve as a basis for more detailed community-level mapping without changing the system. It is also important that the system should be cross-referenced to the other classification systems currently in use in Alaska.

The classification system developed here satisfies these criteria. The classification system for small-scale maps, such as the 1:250,000-scale land cover map at the end of this report, is based on a method of describing plant communities at large scales (e.g. 1:6000 scale) that was developed for Prudhoe Bay, Alaska (Walker et al. 1980, Walker 1981). This large-scale nomenclature system is described first so that the basis of the smaller-scale, Landsat-level map units can be better understood. The map itself is a major step toward producing accurate vegetation maps for the entire Arctic Slope of Alaska.

Nomenclature for large-scale vegetation mapping

Community nomenclature for large-scale mapping (1:12,000 scale or larger) incorporates four major parts: 1) a site moisture term, 2) the dominant plant species in each part of the vegetation canopy, 3) the dominant plant growth forms, and 4) an overall physiognomic descriptor. These parts are always arranged in this sequence.

The site moisture term can be DRY, MOIST, WET, or if the vegetated area is permanently covered with water, AQUATIC. The site moisture term is followed by the names of the dominant plant taxa, usually one or more from each of the shrub, herb and cryptogam components of the vegetation. The number of taxa is kept to the minimum required to adequately distinguish the community from others on the map; the total never exceeds six.

The terms used for plant growth forms are: 1) TALL SHRUB (>2 m tall), 2) MEDIUM SHRUB (0.5-2 m), 3) DWARF SHRUB (0.1-0.5 m), 4) PROSTRATE SHRUB (<0.1 m), 5) TUSSOCK GRAMINOID, 6) NONTUSSOCK GRAMINOID, 7) FORB, 8) MOSS and 9) LICHEN. All low-growing woody plants (<0.1 m high), such as *Dryas integrifolia* and *Arctostaphylos rubra*, are classed as prostrate shrubs. The graminoid vegetation is further broken down into either sedge- or grass-dominated units. Cushion plants, such as *Saxifraga oppositifolia* and *Oxytropis nigrescens*, are included in the forb category. The lichen vegetation is further broken down into crustose- or fruticose/foliose-lichen-dominated units. If a vegetation unit is dominated by more than one growth form, each covering at least 30% of the ground, it will have more than one growth form in its name (e.g. MOIST SEDGE TUSSOCK, DWARF SHRUB TUNDRA).

The physiognomic descriptor TUNDRA is used for all arctic and alpine nonforested areas with generally continuous ground cover. The physiognomic term BARREN is applied to units with less than 30% vegetation cover. The site moisture term, the dominant plant growth forms, and the physiognomic descriptor have all upper-case letters, and the plant names are italicized. (The upper-case lettering applies only to large-scale community names and is not used for small-scale vegetation unit names.)

An example of a community name using this system is WET *Carex aquatilis, Drepanocladus brevifolius* SEDGE TUNDRA. A more complex example with two dominant growth forms is MOIST *Eriophorum triste, Dryas integrifolia, Salix arctica, Tomenthypnum nitens, Thamnolia subuliformis* SEDGE, PROSTRATE SHRUB TUNDRA.

Vegetation complexes are also described with a uniform nomenclature. A unit is considered a complex if it contains two or more distinct communities, and each community covers at least 30% of the area. In the Arctic, community mosaics occur mainly as a response to minor elevation differences associated with ice-wedge polygons, frost boils, water tracks, strangmoor, solifluction lobes and other kinds of patterned ground. Even at the 1:6000 scale most of the individual communities are too small to map without reference to vegetation complexes. In this nomenclature the term COMPLEX is attached to the end of the land cover name, and the major elements of the complex are separated by a slash (/). For example, a map unit composed of wet sedge tundra and moist sedge tundra is called a WET/ MOIST SEDGE TUNDRA COMPLEX. The most abundant unit of the complex is named first. A map unit with a wet, dwarf-shrub community occurring in the water tracks of sedge-tussock, dwarf-shrub tundra would be named MOIST SEDGE TUSSOCK, DWARF SHRUB/WET DWARF SHRUB TUNDRA COMPLEX.

At large scales, complexes of vegetation can be described by the nature of the surface form on which the complex occurs. For example, vegetation on a foothill area with water tracks would have the following explanation in the legend: MOIST SEDGE TUSSOCK, DWARF SHRUB/ WET DWARF SHRUB TUNDRA COMPLEX (water track complex):

a) Interfluves and upland tundra areas: MOIST *Eriophorum vaginatum, Betula nana, Salix planifolia, Ledum decumbens, Sphagnum* sp., *Cladina* sp. TUSSOCK SEDGE, DWARF SHRUB TUNDRA,

b) Water tracks: WET *Salix planifolia, Betula nana, Carex aquatilis, Sphagnum* sp. DWARF SHRUB TUNDRA.

The term "water track complex" could be used as a shorter synonym in general discussion.

Table 1. Four-level hierarchy for mapping tundra regions.

	Level			
	1	2	3	4
Application:	Very small scale maps	Small-scale, very general, Landsat-level maps	Small-scale, more detailed, Landsat-level maps	Large-scale maps with detailed ground reference data
Scale:	1:2,500,000 or smaller	1:500,000	1:12,000-1:500,000	1:400-1:12,000
Nomenclature:	1. Physiognomic descriptors	1. Physignomic descriptors 2. Site moisture	1. Physiognomic descriptors 2. Site moisture 3. Dominant plant growth forms	1. Physiognomic descriptors 2. Site moisture 3. Dominant plant growth forms 4. Species composition
Examples:	1. Tundra 2. Barrens	1. Wet Tundra 2. Moist Tundra	1. Wet Sedge Tundra 2. Moist Sedge, Prostrate Shrub Tundra 3. Moist/Wet Sedge Tundra Complex 4. Dry Prostrate Shrub Tundra/Barren Complex Map categories can include vegetation complexes or combinations of land-cover types.	1. WET *Carex aquatilis, Drepanocladus brevifolius* SEDGE TUNDRA 2. MOIST *Eriophorum triste, Dryas integrifolia, Salix arctica, Tomenthypnum nitens, Thamnolia subuliformis* SEDGE, PROSTRATE SHRUB TUNDRA Map categories can include vegetation complexes that require complete descriptions for each part of the complex.

† Highest—149 km/hr.
** Mean annual snowfall—115 cm.

Nomenclature for small-scale vegetation mapping

For small-scale, Landsat-level mapping, the details of community composition can rarely be included, but the site moisture term, the dominant plant growth forms, and the physiognomic descriptor can normally be retained in the land cover titles. There are, however, numerous exceptions. With Landsat it is sometimes difficult to separate rather distinct land cover types solely on the basis of spectral reflectance, and it may be necessary to describe a map category (i.e. one color on the map) with several land cover types. For example, "Pond/Sedge Tundra Complex; or Aquatic Tundra; or shallow water" describes a map category consisting of several very wet land cover types that could not be distinctly separated in the Landsat data.

Sometimes it may also be necessary to drop a part of the land cover title. For example, it may not be possible to distinguish Wet Medium Shrub Tundra from Wet Dwarf Shrub Tundra or Dry Medium Shrub Tundra, so the term Shrub Tundra could be used. Every attempt should be made to retain the complete title, since this increases the amount of information available on the map. However, in some cases the vegetation within a map category may vary so widely that it is not possible to use the nomenclature system at all. Partially vegetated areas are often of this nature.

At small scales the system is not rigid. It simply offers a means of describing tundra land cover as consistently as possible. The system for mapping at small scales is strongly rooted in the nomenclature systems for large-scale mapping in that there is a natural nesting of nomenclature at four levels (Table 1).

Mapping method

The mapping methods consisted of 1) acquiring ground reference data from aerial photographs and field observations, 2) preparing the land cover classification from the digital Landsat data, and 3) composing and printing the final colored map. Computer-generated data provided detailed area summaries for each map category. In addition, a simplified, hand-drawn land cover map with polygonal map category boundaries was prepared for smaller-scale mapping programs.

Ground reference data

Ground reference data for the project were gathered during a USFWS-supported helicopter survey, 12–17 August 1981. The survey was concentrated in four townships (Fig. 2) that included the major landform features within the ANWR study area. This information was supplemented with extensive ground reference data gathered from similar Alaskan arctic areas outside ANWR during the past several years.

The field method consisted of locating large homogeneous areas of terrain on 1:60,000-scale, aerial, color-infrared photographs and then describing (from the air) the vegetation (e.g. wet sedge tundra; dwarf shrub, sedge tussock tundra; partially vegetated) and the landform (e.g. low-centered polygon; strangmoor; water tracks). In particularly homogeneous areas that appeared to be representative of common units, we took detailed notes of the vegetation, site factors and soils. Vegetation complexes were described if they were extensive and were associated with distinctive patterned-ground features. Each area was photographed from the air and the ground.

We spent most of the field time describing map units from aircraft. This could be done readily, since most of the vegetation and soils are similar to those we have encountered in other areas of northern Alaska. This method allowed us to cover as much terrain as possible with the limited amount of helicopter support. We took detailed notes regarding species composition in 35 stands of vegetation. We hope that these data will be supplemented with additional quantitative information in future years and will be presented in a separate report.

Computer classification of the Landsat data

The methods employed for producing the land cover classification from the Landsat data were those available at the USGS Geographic Investigations Office at Ames Research Center, Moffett Field, California (Morrissey and Ennis 1981). Three Landsat scenes were used in this analysis. The eastern two-thirds of the study area was covered by scene 22008–20420 (22 July 1980) acquired from the Canada Center for Remote Sensing. The remainder of the region was covered by scene 21633–20531 (13 July 1979), except for a small wedge in the southwest corner, which was covered by scene 2570–20462 (14 August 1976). Each scene had to be treated separately in the analysis to account for the variation in spectral response among scenes and because of phenological changes in vegetation from year to year. The manipulated results were later merged to create a land cover map for the entire study area.

A clustering algorithm was used to define discrete groups of pixels on the basis of their reflectance in the four Landsat spectral bands. The analyst selected the number of clusters based on experience with similar Landsat data and on an estimate of the desired number of clusters in the final classification. The numbers of clusters designated for this study were 28 for scene 2570–20462, 35 for scene 21633–20531, and 31 for scene 22008–20420. A systematic 10% sample of the pixels from each Landsat scene was used in the clustering algorithm. This algorithm sorts the Landsat data into classes such that the pixels within each class are as similar to each other as possible and pixels from different classes are as different from each other as possible. These clusters describe in statistical terms (means and covariances) the spectral properties of Landsat data (Swain 1972).

It was expected that these clusters would describe only general land cover units and not the specific units desired. Therefore, the ground reference data were used to full advantage. Landsat pixels from each of the four ground reference areas were clustered separately. The resulting clusters were used to define vegetation classes, while the 10% sample was used to select clusters representative of ice, water and barren land.

At this point some vegetation classes were still not well defined by clusters. These were classes that occurred rarely in the areas studied. It was likely that there were not enough pixels containing these vegetation types to allow them to be segregated into distinct clusters; hence, they were initially included in spectrally similar clusters. To handle these special cases, known occurrences were defined and mapped from the ground reference information. Pixels from these locations were then clustered independently, without consideration of other classes in the area, to produce sharper spectral classes.

Thus, a final set of clusters, as defined by spectral statistics, was produced for each scene. Each pixel in the scene was assigned to a cluster using discriminant function analysis to determine the cluster to which the pixel had the greatest probability of belonging (Gaydos and Newland 1978).

By viewing the results on a color image display, the analyst was able to enlarge small portions of the Landsat scene. He could also view only the pixels in a selected spectral class by assigning a color to that class. He then identified the vegetation in the spectral class based on field notes and high

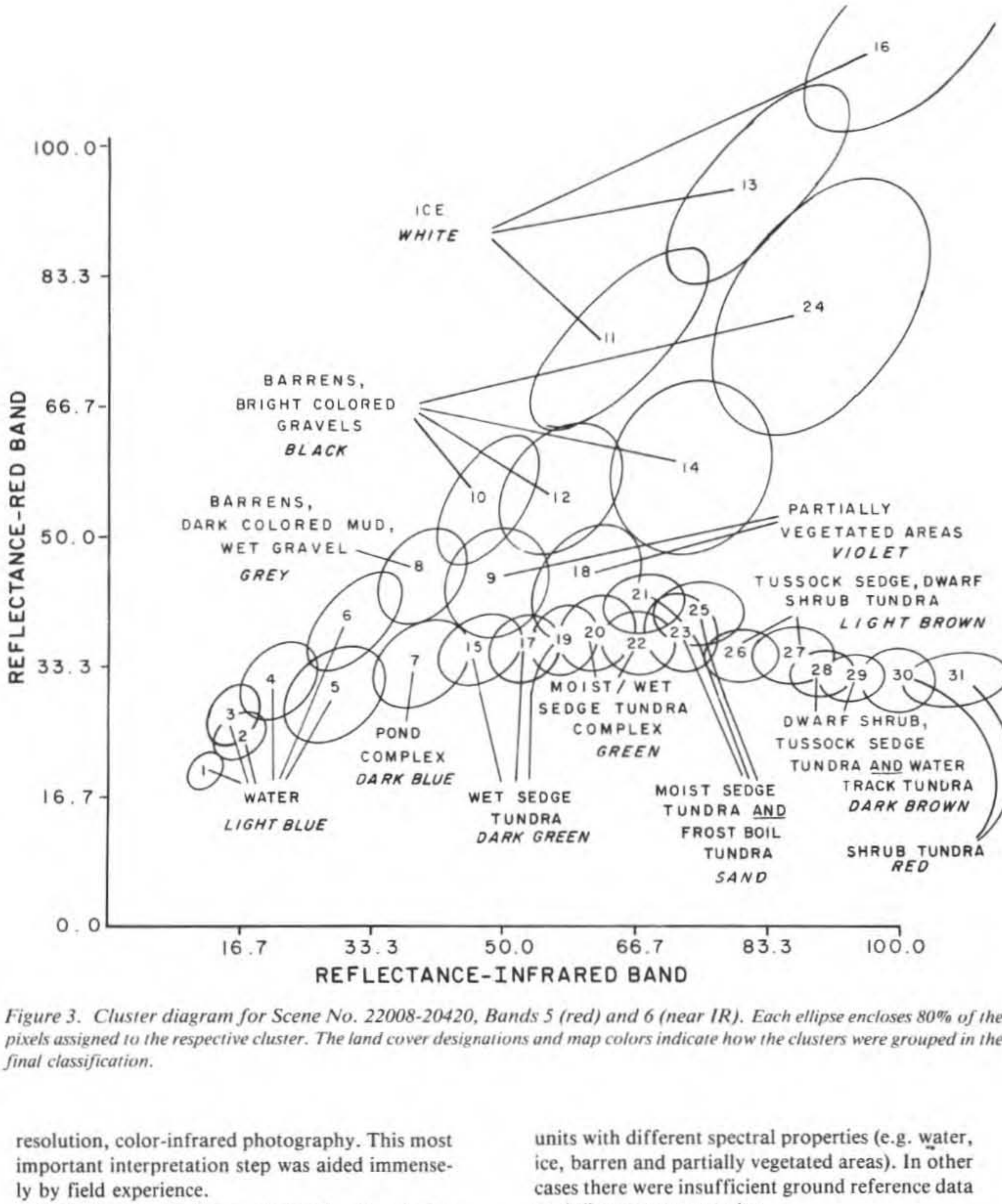

Figure 3. Cluster diagram for Scene No. 22008-20420, Bands 5 (red) and 6 (near IR). Each ellipse encloses 80% of the pixels assigned to the respective cluster. The land cover designations and map colors indicate how the clusters were grouped in the final classification.

resolution, color-infrared photography. This most important interpretation step was aided immensely by field experience.

Each cluster was interpreted and assigned to a map category, i.e. one or more land cover units represented by a single color on the map (Fig. 3). Often several clusters were included in a single map category. In some cases this was because a map category included a number of land cover units with different spectral properties (e.g. water, ice, barren and partially vegetated areas). In other cases there were insufficient ground reference data to define more categories.

The major units described are the ones that could be distinguished during the time available for interpretation in late 1981. We hope that the dissimilar vegetation types now within some map categories can be separated by breaking single spectral classes into several clusters. Digital terrain data are being used to help separate classes on the basis of slope. Class consistency was a primary goal. Care was taken to identify and resolve conflicts between the three Landsat scenes as the final 12 map categories were developed.

Colored map preparation

Geometric correction. Ground control points, i.e. surface features identifiable both on 1:63,360-scale topographic maps and in the Landsat data, were selected for computing the parameters needed for geometric correction of the Landsat data and registration to a Universal Transverse Mercator (UTM) projection. About 30 well-distributed control points were selected for each scene. These points were located on USGS 1:63,360-scale topographic maps and on gray-scale line-printer maps produced from the Landsat data at a scale of approximately 1:24,000. The points were used to define second-order, least-squares polynomial transformation equations relating latitude and longitude on the maps to row and column positions on the Landsat scenes. The coefficients in the polynomial equation were used for correcting each scene to a UTM projection (Zone 6). The geometric correction resulted in pixels that were 50 meters on a side.

Scene mosaic. Once the data were corrected to a common base, a single data set was formed from the mosaic of the three scenes. Common tie-points were identified where the scenes overlapped, and they were used to set mosaic parameters. The resulting mosaic of the classified scenes showed no apparent scene boundaries. This is a good qualitative indicator of the Landsat classification process and the consistency of the spectral class descriptions.

Data generalization. The original pixel data had a "salt and pepper" appearance, with many isolated pixels in otherwise homogeneous areas of color. This detracted from the appearance of the map without adding much information at the 1:250,000 scale. Thus, it was desirable to generalize the Landsat pixel data for cartographic presentation.

Accordingly the data were filtered in an attempt to remove tiny occurrences of map categories one or two pixels in size. The filtering was done by systematically moving a 3- × 3-pixel window across the classified data. In the first round the center pixel (the one being considered for reclassification) was assigned a weight of 4, while its adjacent neighbors, both horizontally and vertically, were assigned weights of 2, and the pixels on the diagonal were assigned weights of 1. Each map category showing in the window was rated by adding the weights, and the pixel in question (the center pixel of the group of 9) was assigned to the map category with the highest rating. The window was then moved to the next pixel. This 4-2-1 smoothing process eliminated many isolated pixels while preserving the shape of the remaining units. A second round of filtering was performed on the results from the first with a 2-1-1 smoothing, eliminating more single pixels and creating more homogeneous map areas.

Base map. A base map for the final, colored, Landsat-derived land cover map was compiled from a mosaic of the four USGS 1:250,000-scale quadrangles (Flaxman Island, Barter Island, Mt. Michelson and Demarcation Point). Projection information, township boundaries, and geographic names within the ANWR study area are on this map. This base map also contains the land cover unit descriptions and information on how the map was prepared.

Printing. A tape of the Landsat data was used to drive a large-format laser plotter to generate four color-separation plates (yellow, cyan, magenta and black) at 1:250,000 scale. Each pixel was reproduced as a matrix of 16 dots to reproduce the desired pattern for each color. Each 50-m pixel was plotted at 200-μm spot size to achieve the 1:250,000 scale.

The color-separation plates were registered to the base map and used to prepare the Landsat lithographs by a color additive process. The final map, "Vegetation and Land Cover, Arctic National Wildlife Refuge, Coastal Plain, Alaska," by W. Acevedo, D.A. Walker, L. Gaydos, and J. Wray is available from the U.S. Geological Survey as Map I-1443 and is included in this report as Plate 1.

Area summaries

The areas covered by each of the 12 map categories were calculated using a counting algorithm. Data were generated for the areas within three sets of boundaries: 1) the entire ANWR study area, 2) the 89 townships within the study area, and 3) the boundaries of the regional terrain types (see the second part of this report, which describes the major terrain types). This was accomplished by digitizing the respective boundaries, registering the boundaries to the Landsat land cover map, and applying the counting algorithm. The area summaries were calculated prior to filtering for map generalization.

Simplified land cover map

A more generalized map was prepared at the request of USFWS. This map was derived from an earlier unfiltered version of the Landsat-derived land cover map, which contained more isolated pixels than appear on Plate 1. Polygons were drawn around large areas with similar dominant land cover. This map is useful as input to small-scale regional or state-wide mapping programs. One place where this map is being used effectively is in the 1:250,000-scale geographic information system of the North Slope Borough. Since the map information is in polygon format instead of pixels, the map lends itself better to incorporation into the Integrated Terrain Unit Mapping approach that the Borough is using (Environmental Systems Research Institute 1982).

Results

Land cover maps

The Landsat-derived land cover map (Plate 1) has 12 map categories, which are briefly described in the map legend and are explained more fully in Appendix A. Several of the colors represent more than one land cover category. For example, dark blue represents three land cover types: Pond/Sedge Tundra Complex, Aquatic Tundra or shallow water. In most cases the land cover types within a single map category are not radically different. The exception is the light-green category (Unit IV), which may represent Dry Prostrate Shrub, Forb Tundra (*Dryas* river terraces) or Moist/Wet Sedge Tundra Complex. These units have also proved difficult to separate in Landsat studies in the National Petroleum Reserve in Alaska.* Photographs of most of the major land cover units are included in the second part of this report.

A thorough field check was conducted in the summer of 1982. The initial impression is that the map is very accurate and that there are no major problems with the classification. A full report of the field check and statistical analysis will be made separately.

Area summaries

The acreages and percentages for each map category are given in Appendix B. Table B1 contains acreage summaries for the entire ANWR study area. Table B2 contains the data for each terrain type. The sum of the areas for all map categories in the five terrain types listed in Table B2 is 1,556,830 acres, and the sum for all map categories in Table B1 is 1,640,626 acres. The difference of 83,796 acres is the amount of ocean within the ANWR study area. Table B3 contains the data for each of the 89 townships within the study area.

Discussion

We see an urgent need for tundra map legends that are compatible at large and small scales; the ultimate goal is a comprehensive mapping system that can be used both for the broad picture and for detailed site-specific studies.

In the past ten years we have mapped many areas of the Alaskan Arctic Coastal Plain and have experimented with various map legends, primarily at the scale of 1:6000 (Walker 1977, Walker and Webber 1980, Walker et al. 1980, Sohio Petroleum Co. 1981). The mapping system described here has been designed to provide vegetation information for composite mapping approaches such as geobotanical master maps (Everett et al. 1978, Walker et al. 1980) or the Integrated Terrain Unit mapping approach (Environmental Systems Research Institute 1982), where additional characteristics of the landscape, such as soils, landforms and slopes, are also mapped. Our system has the advantage that it contains only vegetation information and is independent of soil, landform, altitude, etc. Purists may want to separate the site-moisture descriptor, since this is a characteristic of the site; this is easy to do because it always appears in the same part of the vegetation titles.

Plentiful detailed ground reference data are the key to the success of any Landsat mapping program. The mapping system and legend described here is a "from-the-ground-up" approach, with its foundation in very detailed mapping programs that rely on large amounts of accurate ground reference data (Walker et al. 1980, Walker and Webber 1980).

Vegetation classification in Alaska is in a state of healthy turmoil. Several schemes are currently being applied to Alaskan tundra. Probably none of these will gain universal acceptance, but it is safe to say that they will all contribute in some way to a final statewide system. The current lack of a classification applicable to all Alaskan arctic tundra has prompted the development of the system described here. However, our system adds to the profusion of mapping approaches. Appendix C cross-references this system to six other major systems, showing the equivalent units in two other remote-sensor land cover classifications (Anderson et al. 1976, Nodler and LaPerriere 1977), two

*Personal communication with Paula Krebs, Bureau of Land Management, Anchorage, Alaska.

wetland classifications (Bergman et al. 1977, Cowardin et al. 1979) and two vegetation classifications (Viereck et al. 1981, UNESCO 1973).

The ANWR mapping project was perfectly suited for the application of modern technology using Landsat multispectral scanner data and advanced cartographic techniques. A high-quality, publishable map of the ANWR study area was produced within eight months of the beginning of the project. The map is a valuable reference for evaluating the potential impact of seismic operations within the wildlife refuge. The results can also be used as a basis for more detailed habitat studies. Since the data are in digital format, the map can be easily used in geographic information systems. The area measurements are most useful for the environmental descriptions of the major terrain types, and will also be useful for future studies within township-sized areas.

The current legend system is still being perfected, but it answers an immediate need for a tundra classification by meeting the following criteria:

1) The system is applicable to both large- and small-scale mapping.

2) It consistently applies the same criteria to all community names.

3) It has a consistent method of naming vegetation complexes.

4) It is well suited for specific application to Landsat multispectral scanner data.

DESCRIPTION OF THE ANWR STUDY AREA

General description

Physiography

The study area covers 5700 km² of the Arctic Slope north of 69°34′. It lies between the Canning and Aichilik rivers (142-146°W), and is contained within the White Hills section of the Arctic Coastal Plain physiographic province defined by Wahrhaftig (1965). The terrain is, for the most part, hilly and dissected by numerous streams that originate in the Sadlerochit, Romanzof and Franklin mountains of the Brooks Range.

The coastal area includes a chain of barrier islands that form the seaward limit of the ANWR study area. The coastline itself is irregular and contains many small bays, lagoons and spits. Extensive mud flats are associated with the Canning, Hulahula, Okpilak and Jago deltas. Most of the coastline is low lying, with only small bluffs less than 3 m high. At Camden Bay, where the land rises more steeply from the sea, there are bluffs up to 8 m high.

Along the coast there are small areas of flat coastal plain with oriented thaw lakes similar to the terrain of the Teshekpuk Lake section in the western part of the Arctic Coastal Plain (Wahrhaftig 1965). Most of the coastal plain within ANWR is gently rolling, with many small lakes and wet terrain mixed with small areas of uplands. Stream drainage patterns in the hilly coastal plains are better developed than in the flat thaw-lake plains, and the lake basins are contained between intervening small ridges and terrain irregularities. Hilly coastal-plain terrain is common between the Hulahula River and Pokok Bay, and stretches for about 35 km inland, where the true foothills begin.

The foothills occur west of the Hulahula River to the Canning and extend across the entire southern portion of the study area, with maximum elevations of about 360 m. A small amount of mountainous terrain, reaching an elevation of 975 m, occurs in the vicinity of Sadlerochit Spring.

There are many river systems. The Canning, Tamayariak, Katakturuk, Sadlerochit, Hulahula, Jago and Aichilik rivers have braided drainages and deltas that collectively cover a large portion of the ANWR study area.

Climate

The only regularly collected climatic data within the study area are from Barter Island (Table 2). This station lies within a belt of strong coastal influence. In summer it has fog about 25% of the time, and the mean July temperature is only about 5°C. These conditions only occur in a small portion of the study area, however. The inland portions experience higher summer temperatures; however, our observations during 1981 indicate that the inland areas are somewhat colder and wetter than areas at a similar distance from the sea in the Prudhoe Bay region (Haugen and Brown 1980), probably because of the higher elevations in ANWR.

Soils

Nearly the entire study area falls within the Coastal Plain Land Resource Region defined in the Exploratory Soil Survey of Alaska (Rieger et al. 1979). Within this region the survey recognized two soil associations (i.e. "segments of the landscape with distinctive topographic and soil patterns"): 1) Pergelic Cryaquolls-Histic Pergelic Cryaquepts, with loamy-textured mineral components occurring on nearly level to rolling topogra-

Table 2. Temperature, wind and precipitation data for Barter Island, Alaska (70°08′N, 143°35′W, 12 m elevation). (From Searby [1968] and Brower et al. [1977].)

Month	Temperature (°C)* Max.	Min.	Mean	Wind (km/hr)† Principal direction	Precipitation** (mm)
Jan	−23.2	−30.9	−27.1	23.9W	10.2
Feb	−25.2	−32.2	−28.7	22.3W	8.9
Mar	−22.1	−30.1	−26.1	21.7W	5.1
Apr	−13.0	−21.6	−17.3	19.0E	4.3
May	− 3.4	− 9.2	− 6.3	19.5E	6.4
June	3.9	− 1.5	1.2	18.0E	13.0
July	8.6	1.7	5.2	16.9E	22.4
Aug	7.3	1.5	4.4	18.4E	26.7
Sept	2.2	− 2.1	0.1	21.0E	23.9
Oct	− 5.2	−11.3	− 8.2	22.8E	21.3
Nov	−14.2	−21.2	−17.7	24.3E	10.2
Dec	−19.8	−27.3	−23.6	22.6W	7.4
Annual	− 8.7	−15.3	−12.0	24.1E	159.5

* Highest—25.6°C, Lowest— −50°C.
† Highest—149 km/hr.
** Mean annual snowfall—115 cm.

phy and 2) Pergelic Cryaquepts, with very gravelly mineral components occurring on nearly level topography.* The first unit occurs on the broad foothills and the coastal plain, and the second occurs on the braided river valleys and their associated terraces and deltas.

The only regional soil surveys for areas north of the Brooks Range are those describing the Prudhoe Bay production area and the Ogotoruk Creek watershed (Holowaychuk et al. 1966, Everett 1980b, Everett and Brown 1982). Brown (1962, 1966, 1969) developed a soils and landform map for approximately 19 km² in the Okpilak River area and described soils between the Jago and Hulahula rivers. In general the soils of the flat thaw-lake plains are similar to those described for the Prudhoe Bay region (Everett and Parkinson 1977, Parkinson 1978, Everett 1980b) and Barrow (Drew 1957, Drew and Tedrow 1957, 1961, Gersper et al. 1980). The soils of the Arctic Foothills have been described in detail by Tedrow (1977) and Everett (1981). In the route selection studies for the Alaskan Arctic Gas Study Company in 1974, Janz (Hettinger and Janz 1974) described several soils from the foothills near the Kongakut, Aichilik and Okerokovik rivers and from the flood plain of the Canning River.

*The soil terminology follows the U.S. Soil Taxonomy (Soil Survey Staff 1975). Appendix D gives a brief explanation of this system.

Vegetation

The general character of Alaskan arctic vegetation has been thoroughly described by Britton (1957), Spetzman (1959) and Wiggins and Thomas (1962). The Arctic Foothills and Arctic Coastal Plain of northern Alaska are in the Tundra region of the Arctic as defined by Aleksandrova (1980). In this region, mesic habitats are mostly completely covered with low-growing plants, such as sedges, grasses, mosses, lichens, small herbs and dwarf shrubs. Taller shrubs are restricted to areas with protected southern exposures, where the amount of solar radiation is maximized. On the 1:2,500,000-scale major-ecosystem map of Alaska (Joint Federal-State Land Use Planning Commission for Alaska 1973) most of the study area is mapped as Moist Tundra, with several small areas dominated by Wet Tundra and with High Shrub occurring along the streams.

Detailed vegetation studies in the Arctic Coastal Plain of Alaska include those at Barrow (Tieszen 1978, Brown et al. 1980), Fish Creek (Lawson et al. 1978), Atkasook (Komárková and Webber 1980) and Prudhoe Bay (Walker et al. 1980, Walker 1981). Major studies in the foothills include those at Franklin Bluffs (Koranda 1960), Umiat (Churchill 1955), Cape Thompson (Johnson et al. 1966) and the Seward Peninsula (Sigafoos 1952, Racine 1975, Racine and Anderson 1979). Vegetation on arctic flood plains has been described by Bliss and Cantlon (1957) and Spetzman (1959). There are also a few vegetation studies from within the ANWR study area (Nodler and LaPerriere 1977, Oldemeyer et al. 1978, Murray 1980, Machilda and Oldemeyer 1980, Weiler 1980, Meyers 1981, Robus 1981). Much of the recent work in ANWR is related to USFWS habitat studies for caribou, muskox and waterfowl. The most extensive work from within the study area is that of Hettinger (Hettinger and Janz 1974), who described several vegetation types in the foothills near the Aichilik and Kongakut rivers and along the Canning River as part of the biological studies of the proposed Arctic Gas Pipeline route.

Descriptions of specific terrain types

Within the ANWR study area, there are five major terrain types that can be defined on the basis of dominant landforms: flat thaw-lake plains, hilly coastal plains, foothills, mountainous terrain and river flood plains. These are treated as distinct ecological entities with representative suites of landforms, soils and vegetation. The boundaries of the terrain types (Fig. 2) were drawn from a base consisting of a combination of the Landsat-derived land cover map (Plate 1) and the USGS 1:250,000-scale topographic maps. The primary landforms are easy to interpret on 1:60,000-scale aerial photographs. The following geobotanical summaries are based on the field work during August 1981, the results of the planimetry analysis (Table B2) and observations from other similar areas in northern Alaska.

Appendix E summarizes the dominant land cover units, landforms, soils and vegetation terrain types. The table, which can be used to compare regions, condenses much of the information presented here. It also contains more specific information about the dominant plant communities within the various land cover units.

Flat thaw-lake plains

Landforms and soils. The proximity of the Romanzof and Sadlerochit mountains to the coast results in a much narrower coastal plain than is found farther west, such as along the Trans-Alaska Pipeline and in the National Petroleum Reserve in Alaska. In ANWR, typical coastal-plain topography, with large, oriented thaw lakes, drained-lake basins and expanses of low-centered ice-wedge polygons, is found only in a few small areas, primarily near the flat, braided deltas of rivers (Fig. 4). This topography is best developed in the delta of the Canning River and for some 12-15 km eastward in a narrow coastal belt, as well as in a small area southwest of Barter Island. Flat thaw-lake plains compose only about 3% of the study area.

The thaw-lake plains appear to be remnants of a plain that was once more extensive. They are topographically similar to the plains east of the Can-

Figure 4. Flat thaw-lake terrain in the delta of the Canning River. The lakes here show only weak orientation.

Figure 5. Thaw-lake plain terrain with strangmoor.

Figure 6. (Hemic) Histic Pergelic Cryaquept soil.

Figure 7. Unit III, Wet Sedge Tundra. The areas between lakes and ponds are mostly wet sedge tundra. The entire area is contained within a large, partially drained lake basin with disjunct rims and strang features. The interpond areas contain about 20% moist tundra on the strangs and higher microsites.

ning River, being composed of more than 30% water, mostly in small (generally <260 ha), shallow, elliptical, oriented lakes. The areas between the lakes are poorly drained as a result of a very low surface hydrologic gradient and a thin active layer. Some microrelief is nearly always present, usually in the form of low-centered nonorthogonal polygons, strangmoor or low-centered polygons with pond complexes (Fig. 5).

The area is underlain by ice-rich permafrost at depths of about 40 cm. Except for polygon rims and slightly elevated microsites, the perched water table is very close to or slightly above the soil surface for most or all of the thaw period. Fibrous Histic Pergelic Cryaquepts (Fig. 6) or occasionally Histic Pergelic Cryaquolls and Pergelic Cryaquepts are common in the wet and very wet areas. Pergelic Cryaquolls occur on the mesic polygon rims. The soils are mostly neutral to slightly alkaline, even the saline fibrous Histic Pergelic Cryaquepts and Cryohemists along the coast.

Vegetation. The vegetation of the thaw-lake plains is similar to that described at Barrow (Britton 1957, Walker 1977, Tieszen 1978, Brown et al. 1980), Atkasook (Komárková and Webber 1980), Fish Creek (Lawson et al. 1978) and Prudhoe Bay (Webber and Walker 1975, Walker et al. 1980, Walker 1981). The dominant Landsat map categories (Plate 1, App. A) are Wet Sedge Tundra (46% cover) (Fig. 7, Land Cover Unit III), Water (19.5% cover), Moist/Wet Sedge Tundra Complex (12.6% cover) (Figs. 8 and 9, Land Cover Unit IV), Aquatic Tundra and Pond/Sedge Tundra Complex (8.4% cover) (Figs. 10 and 11, Land-Cover Unit II). Elevation differences of less than 0.5 m are major influences on the distribution of communities. Microtopography associated with the rims, basins and troughs of ice-wedge polygons creates distinct patterns of plant communities (Wiggins 1951, Britton 1957, Cantlon 1961, Walker 1981).

The patterns of plant succession in the flat thaw-lake plains are intimately linked to the oriented thaw-lake cycle (Hopkins 1949, Britton 1957, Carson and Hussey 1962, Billings and Peterson 1980, Everett 1980a). Although much has been written about thaw-lake mechanisms, the cycle and successional patterns are still incompletely understood (Mackay 1963). Probably the biggest questions concern the time scale, i.e. how long the cycle takes to operate and how long the present, wet, coastal-plain environment has existed.

A steep summer temperature gradient is of primary importance with respect to vegetation near the coast. Data from Prudhoe Bay and the Trans-Alaska Pipeline show that the mean July temperatures at the coast are within a few degrees of freezing due to the ice-covered Beaufort Sea. More

Figure 8. Unit IVa, Moist/Wet Sedge Tundra Complex. In this example the complex consists of about equal parts wet and moist tundra.

Figure 9. Ground view of Moist/Wet Sedge Tundra Complex. The relatively well drained area in the foreground has a diverse flora with sedges, prostrate willows, herbs and lichens, while the wetter areas (the darker patches with cottongrass) have mainly sedges and mosses.

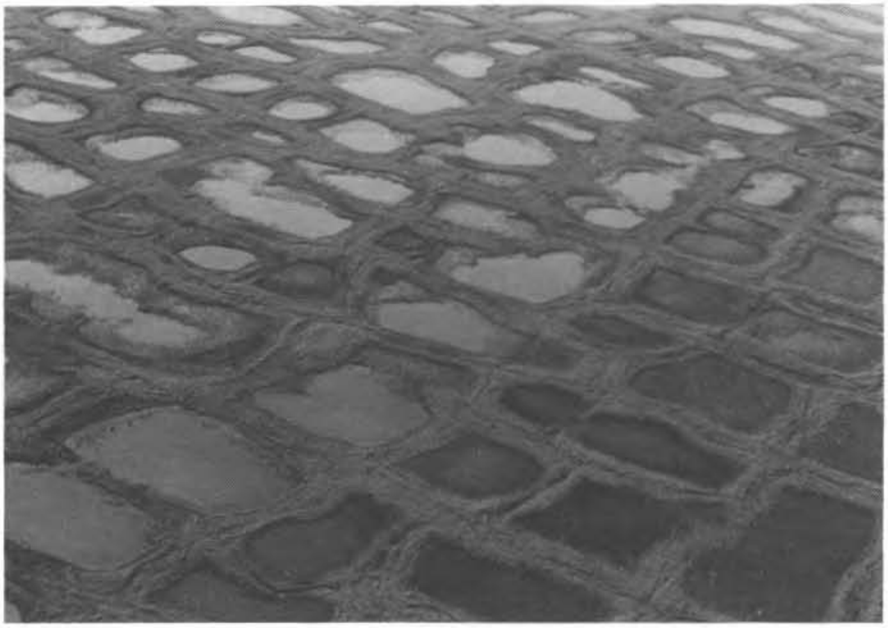

Figure 10. Unit IIa, Pond/Sedge Tundra Complex. This example shows ponds and aquatic communities in the basins of low-centered polygons, and Moist Sedge, Prostrate Shrub Tundra on the polygon rims.

Figure 11. Unit IIb, Aquatic Tundra. The circular clumps of vegetation are mainly aquatic sedge (Carex aquatilis). *The darker areas between clumps are pendant grass* (Arctophila fulva).

Figure 12. Unit IIId, Wet Sedge Tundra (saline facies). This area in the delta of the Katakturuk River is dominated by Hoppner sedge (Carex subspathacea) *and creeping alkali grass* (Puccinellia phryganodes). *The soils are saline (Halic Histic Pergelic Cryaquepts).*

moderate temperatures are found inland (Conover 1960, Cantlon 1961, Haugen and Brown 1980, Walker 1981). Low summer temperatures and low levels of summer solar radiation associated with coastal fog are primarily responsible for a distinctive band of coastal vegetation that has few shrub species, limited tussock formation, reduced moss and lichen growth, and fewer species in the total flora (Cantlon 1961, Clebsch and Shanks 1968, Walker 1981). This band of coastal tundra, which Cantlon (1961) termed "littoral tundra," lies north of the 7 °C mean July isotherm. Worldwide, this zone is equivalent to the arctic subregion of Aleksandrova's (1980) Tundra region. Near Barrow the coastal strip is about 100 km wide; at Prudhoe Bay it is about 25 km wide. Within ANWR the littoral band and the coastal plain in general are narrower, and the coastal temperature gradient is more compressed.

Along the northern limit of the littoral tundra band, there is a narrow strip of vegetation that is associated with the saline soils found immediately adjacent to the coast. This area is affected by wind-blown salt spray and occasional storm surges that flood large areas of inland tundra. Taylor (1981) divided this shoreline vegetation into six habitat types: tidal salt marsh (Fig. 12), upper-storm-zone salt marsh, gravelly beach, raised bench, coastal dunes and coastal bluffs. Coastal vegetation in northern Alaska has been described by Jefferies (1977), Taylor (1981) and Walker (1981). Within ANWR it has been studied by Meyers (1981) in the Beaufort Lagoon area.

The immediate coastal areas are characterized by sand and gravel beaches, spits and bars. These features compose only a small percentage of the study area but are locally important for the numerous birds that use them. Vegetation is sparse due to the very unstable substrate. A few species, such as sea purslane (*Honckenya peploides*), oyster leaf (*Mertensia maritima*) and common scurvy grass (*Cochlearia officinalis*), grow on slightly protected beach gravels. Barter Island is mostly covered with tundra, which is a remnant from when the island was part of the mainland. The other islands, however, are barrier islands that were never part of the mainland.

Hilly coastal plains

Landforms and soils. Hilly coastal plains cover 22% of the study area. Stretching inland between the Hulahula and Jago rivers is a complex region of gently undulating tundra with small thaw lakes and pond complexes. This area is quite different from the flat coastal plains. Stream drainages are better defined, and large expanses of well-drained terrain border many of the streams.

East of the Hulahula River, particularly be-

Figure 13. Vertical aerial photograph (scale 1:18,000) of gently rolling coastal-plain terrain in the vicinity of the Niguanak River, southeast of Barter Island. Numerous upland surfaces are oriented in an east-west direction; the relief associated with these features is less than 10 m. Note the large number of thermokarst pits on the upland surfaces, indicating high amounts of ground ice. (USFWS photo, 5 August 1981. Photo no. FWS-81AS 9-15-87.)

tween the Okpilak and Jago rivers and between the Niguanak and Sikrelurak rivers (Plate 1), there are many slightly elevated ridges and depressions that parallel the coast (Fig. 13); most have less than 10 m of relief contrast. The origin of these ridges is uncertain. On aerial photographs they appear to be either dunes or beach terraces from past marine transgressions. In 1982 a brief check of these features showed that they contain gravelly soils, so they could not be dunes. They may be expressions of the underlying geologic stratigraphy, as are those found in the foothills. The ridges occur up to elevations of 200 m on the northern flank of the foothills. Flat areas between the ridges contain complexes of wet and moist tundra associated with poorly developed ice-wedge polygons.

Some areas, such as those along the western side of the Niguanak River and in the coastal area just south of Pokok Bay, have hillier terrain with well-developed drainages. The vegetation and landforms closely resemble those of the foothills (described in the next section), except that the hills are less steep and thermokarst pits are more extensive on the broad hill crests. Elevations in the region rise gradually from near 30 m to about 100 m.

The soils on the ridges and gently sloping areas are similar to those in the foothills terrain type, while soils in the depressions resemble those of the flat thaw-lake plains. The gently sloping (5% or less) interfluves mostly have moist tussock tundra with flat-centered polygons. Frost scars occupy up to 30% of most surfaces and have Pergelic Cryaquept soils with loam and fine sandy loam textures. The soils between the frost scars are Pergelic Cryaquolls, commonly with 1-12 cm of sapric, organic-rich material as a surface horizon overlying mineral soil with a loam, or occasionally a silt loam, texture. In August the active layer is 35-45 cm deep. A water table does not develop in the polygon centers but may develop in the narrow troughs between polygons, where the soils are (fibric) Histic Pergelic Cryaquepts.

Vegetation. The vegetation, like the landforms and soils, is a mix of that of the flat thaw-lake plains and that of the foothills. The vegetation on the low ridges is mainly moist sedge tundra that may or may not contain cottongrass tussocks. The dominant land cover categories (App. A) are Moist Sedge, Prostrate Shrub Tundra and Moist Sedge/Barren Tundra Complex (Land Cover Unit V). The latter category is associated mainly with frost-scar terrain (Fig. 14, Land Cover Unit Vb). This unit covers 37.6% of the hilly coastal plain. Moist/Wet Sedge Tundra Complex is also important, covering 33.5% of the hilly coastal

Figure 14. Unit Vb, Moist Sedge/Barren Tundra Complex (frost-scar tundra). This is a typical frost-scar area on a gentle slope. Note the lack of cottongrass tussocks and dwarf shrubs. The vegetation between frost scars consists mainly of Bigelow's sedge (Carex bigelowii), *arctic avens* (Dryas integrifolia), *wide-leafed arctagrostis* (Arctagrostis latifolia), *the moss* Tomenthypnum nitens *and numerous fruticose lichens.*

plains. The depressions between the ridges contain thaw lakes (about 3% of the hilly coastal plains) and wet tundra (22.7%).

Foothills

Landforms and soils. Foothills (Fig. 15) cover about 45% of the study area. The hills typically have rounded, north-trending interfluves between the major drainages. The elevations of the hilltops range from 90 m at the coastward boundary to about 375 m at the southern limit of the study area. The major interfluves are subdivided into a finer-textured pattern of subparallel drainages. Superimposed on the north-south pattern is one that trends generally east-west, reflecting the strike of the underlying Cretaceous or Tertiary sandstones and shales. Outcrops of some of the flatter-lying, more competent units produce mesa-like elements on the interfluves (Fig. 15), while dipping strata produce discontinuous linear trends.

Between the Canning and Sadlerochit rivers, low foothills rise from Camden Bay to the base of the Sadlerochit Mountains, which are 30–55 km from the seacoast. The hills in this region are up to 380 m high. The crests of several of these hills, particularly in the vicinity of the Katakturuk River, have barren gravel outcrops (Fig. 16) similar

Figure 15. Foothills terrain south of Camden Bay. The upland surfaces are dominated by Moist Sedge Tussock, Dwarf Shrub Tundra. Note the flat or gently sloping mesa-like interfluves typical of the foothills west of the Sadlerochit River.

Figure 16. Discontinuous gravel outcrop in the foothills.

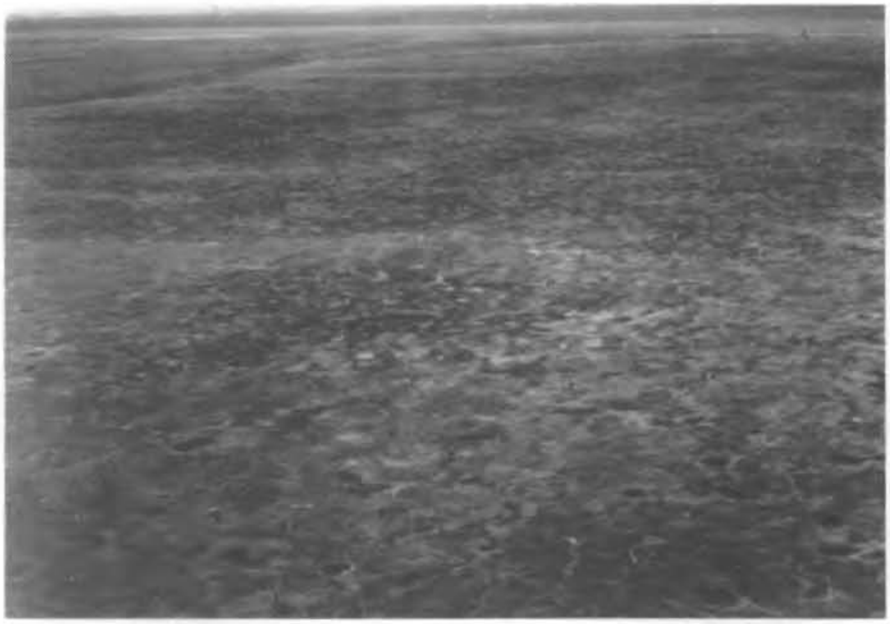

Figure 17. Foothills terrain with Land Cover Unit IVa, Moist/Wet Sedge Tundra Complex. Note the thermokarst pits. The dark areas are raised- or flat-centered polygons with Pergelic Cryaquoll soils.

Figure 18. Foothills soils. The wet areas have (fibric) Histic Pergelic Cryaquolls and/or (fibric) Histic Pergelic Cryaquepts.

to those in the White Hills and Franklin Bluffs. The Tamayariak River, the Katakturuk River, Marsh Creek, Carter Creek, Itkilyariak Creek and the Sadlerochit River are the main drainages. East of the Sadlerochit River the foothills are farther from the coast. The widest part of the coastal plain in ANWR is in the vicinity of the Jago River (Fig. 2); here the coastal plain is about 40 km wide. Another 20 km of foothills extend to the refuge boundary.

The crests of the hills can either be smoothly rounded or have complex patterns of soils and microscale landforms (Figs. 17 and 18), such as tussock-covered flat-centered polygons juxta-

Figure 19. Unit VIIc, Moist Sedge Tussock, Dwarf Shrub/Wet Dwarf Shrub Tundra Complex (Water track complex). The drainage channels are dominated by dwarf shrubs, mainly diamond-leafed willow (Salix planifolia *ssp.* pulchra) *and dwarf birch* (Betula nana *ssp.* exilis).

posed with patternless areas, strangmoor and low-centered polygons. Thermokarst pits are common and indicate substantial amounts of wedge ice. The better-drained elements of the hill crests have Pergelic Cryaquolls or Histic Cryaquolls with hemic- or sapric-textured organic horizons overlying dark-colored, organic-rich mineral material. Cryaquepts occur in frost scars, which may occupy up to 40% of the surface. Mineral horizons of both soils are loams or fine sandy loams with variable amounts of pebbles. The active layer ranges from about 30 cm thick beneath the Aquolls to more than 60 cm thick beneath the Aquepts. A water table is absent or well below the surface. The wet areas commonly have Histic (>20 cm of fibrous organic material) Pergelic Cryaquolls or, if the colors and organic carbon content below the histic epipedon do not conform to the criteria for a mollic epipedon, Histic Cryaquepts. In either case a water table occurs at or above the surface, and the active layer is between 40 and 45 cm deep. In the wettest areas there is enough buoyancy in the fibrous, organic, root-rich mat so that its true thickness is difficult to determine.

The hill slopes are generally greater than 5% and are covered with cottongrass tussocks. Areas referred to as water tracks (or "horsetail drainages" [Cantlon 1961]) are shallow channels that conduct snow meltwater and subsurface water during the thaw season. Parallel and sub-parallel water tracks are commonly present, giving the topography a ribbed appearance (Fig. 19). Strangmoor is often found in the channels, suggesting slow mass movement of the saturated soil. Willows and birches are concentrated in these features. The inter-water-track areas are tens to hundreds of meters wide, with relief from 0.15 to 1 m above the track. The water track portion of the slope presents a relatively smooth and graded cross section. Polygonal outlines are usually not apparent, although ice wedges may still be extensive beneath the slopes. The soils are Pergelic Cryaquolls or Pergelic and Histic Pergelic Cryaquepts (Fig. 20). In most cases, 4–15 cm of Hemic or Sapric organic matter overlie mineral material, which is often mixed with organic materials. The active layer thicknesses range from 30 to 50 cm. The presence of a water table is uncommon. Within the water tracks, Histic Pergelic Cryaquepts are the most common soils. The active layer depths range from 40 to 50 cm, and a water table is almost always present, commonly within 10 cm of the surface.

Frost scars are almost always a component of tussock tundra and can compose up to 50% of a given surface, with anywhere from a few percent to 75% showing some activity (i.e. having bare mineral soil exposed). Where slope breaks occur,

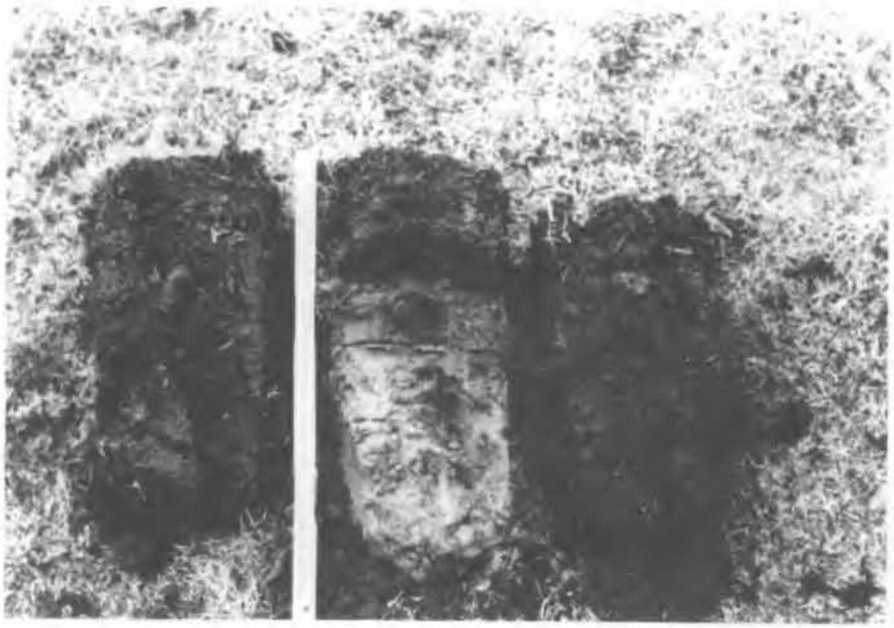

Figure 20. Soils of the water track areas showing a complex pedon (excluding the tussock element) typical of such terrain (Pergelic Cryaquoll, left; Pergelic Cryaquept, center; and Histic Pergelic Cryaquoll, right).

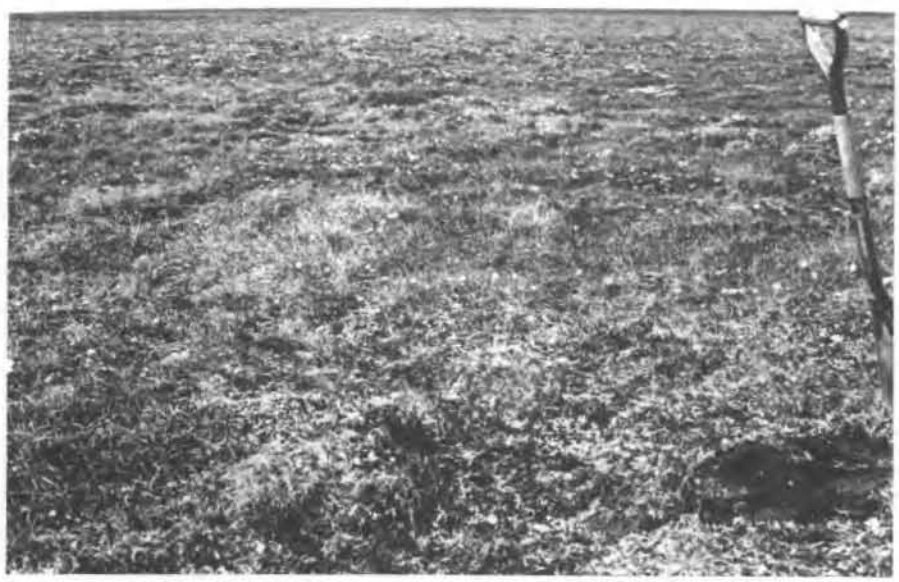

Figure 21. Frost-scar terrain in the foothills.

both the density and the activity of frost scars commonly increase (Fig. 21); in these cases 65–80% of the surface may be composed of active frost scars. Frost-scar soils (Fig. 22) are composed of grayish brown, usually mottled, sandy-textured mineral material. Under the present taxonomic system, the soil pedon is considered a Ruptic-Aqueptic Cryaquoll.

Where bedrock is very close to the surface, as shown in Figure 16, frost scars and/or patterned barren gravel may compose 70–80% of the surface. Because these surfaces are exposed, snow cover is thin or absent, and abrasion by blowing snow may be severe. However, well-developed soils may occur beneath stable microsites. The soils are Pergelic (lithic) Cryumbrepts if sufficient

Figure 22. Common soil pedon consisting of Pergelic Cryaquept and Histic Pergelic Cryaquoll. The soil complex is designated Ruptic-Entic Histic Pergelic Cryaquoll.

organic matter is present or Pergelic (lithic) Cryochrepts if it is not. The active layer is greater than 1 m deep, and ice volumes are generally low.

Solifluction forms, such as discontinuous stripes of frost scars or lobes, are common downslope from some outcrops and where slope breaks exceed 7–10%. This is due principally to the water added by melting snowbanks. Microrelief is relatively great. The high moisture environment and the microrelief make such areas quite susceptible to vehicular impacts.

Vegetation. The vegetation in the foothills is predominantly Moist Sedge Tussock, Dwarf Shrub Tundra (Fig. 23 and 24, Land Cover Unit VI), which covers 53.8% of the foothills terrain type. In some areas shrubs are dominant and the land cover class is Moist Dwarf Shrub, Sedge Tussock Tundra (Fig. 25, Land Cover Unit VIIa).

The vegetation in water tracks is often dominated by dwarf shrubs, mainly dwarf birch (*Betula nana*) and diamond-leafed willow (*Salix planifolia* ssp. *pulchra*). Land cover within water track complexes is generally classed as Moist Sedge Tussock, Dwarf Shrub/Wet Dwarf Shrub Tundra Complex (water track complex) (Land Cover Unit VIIc). A few steep, mainly south-facing slopes have well-developed Shrub Tundra (Fig. 26, Land Cover Unit VIII). Dense shrubs with a sedge understory grow along many stream margins.

Tussock tundra can have a bewildering array of subtypes that are difficult to classify. These are related to factors such as slope stability, soil moisture, cryoturbation and successional history. The effect of frost activity is of primary importance (Hopkins and Sigafoos 1951, Sigafoos 1952, Churchill 1955, Racine and Anderson 1979). Frost-scar tundra is widespread in the foothills. In areas with neutral or slightly alkaline soils, this has important implications for the vegetation. Upland tundra soils are normally acidic due to thick peat layers and the accumulation of organic acids. *Sphagnum* moss, numerous ericaceous shrubs, and other bog species, such as cloudberry (*Rubus chamaemorus*), are adapted to an acidic environment. Where the soil is more alkaline, as in places where frost stirring has brought alkaline parent material to the surface, many of these species are replaced by a different suite of upland tundra plants, including arctic avens (*Dryas integrifolia*), Bigelow's sedge (*Carex bigelowii*), wooly willow

Figure 23. Unit VIa, Moist Sedge Tussock, Dwarf Shrub Tundra (Upland tussock tundra, acidic facies) on foothills south of Camden Bay. The lighter-colored upland surfaces are due to a spectacular floral display of cottongrass. The darker drainages have Moist Sedge, Prostrate Shrub communities.

Figure 24. Cottongrass tussocks in Unit VIa. This unit occurs on acidic soils. The main shrubs are diamond-leafed willow (Salix planifolia *ssp.* pulchra), *dwarf birch* (Betula nana *ssp.* exilis), *bog blueberry* (Vaccinium uliginosum) *and mountain cranberry* (V. vitis-idaea).

Figure 25. Unit VIIa, Moist Dwarf Shrub, Sedge Tussock Tundra (Upland dwarf-shrub, tussock tundra). This unit occurs on the least-disturbed upland surfaces. The dwarf shrubs are dominant.

Figure 26. Unit VIII, Shrub Tundra. This site is on a steep, south-facing slope of a rocky ridge near the Jago River.

(*Salix lanata*), the moss *Tomenthypnum nitens* and the grass *Arctagrostis latifolia*. Frost-scar tundra is most common on slopes and is particularly common in the western part of the study area.

With the present Landsat map categories, it is not possible to distinguish frost-scar tundra (Land Cover Unit Vb) from Moist Sedge, Prostrate Shrub Tundra (Land Cover Unit Va). However, the latter type occurs along stream drainages near the coast, where tussocks and dwarf shrubs are not extensive.

The broad tops of gentle hills are usually stable and have peat accumulations. The soils are consequently acidic, supporting thick *Sphagnum* peat with cottongrass tussocks (*Eriophorum vaginatum*) and dwarf shrubs, such as dwarf birch (*Betula nana*), diamond-leafed willow (*Salix planifolia* ssp. *pulchra*), Labrador tea (*Ledum decumbens*), bog blueberry (*Vaccinium uliginosum*) and mountain cranberry (*V. vitis-idaea*).

East of the Hulahula River there is a noticeable boundary between Units V and VI corresponding approximately to the break in slope between the flatter plains and the foothills (Plate 1). North of this boundary the soils are characteristically less acidic than to the south. To the north, mesic sites typically have cottongrass tussocks with basiphilous taxa such as arctic avens (*Dryas integrifolia*), woolly willow (*Salix lanata*), net-veined willow (*S. reticulata*) and purple mountain saxifrage (*Saxifraga oppositifolia*), with mosses such as *Tomenthypnum nitens, Ditrichum flexicaule, Distichium capillaceum*, and *Hylocomium splendens*. To the south the secondary taxa normally are more acidiphilous and include the taxa mentioned in the preceding paragraph.

Mountainous terrain

Landforms and soils. Mountainous terrain occurs in the vicinity of Sadlerochit Spring and covers only about 0.03% of the study area (Figs. 27 and 28). This area is mostly above 600 m and is underlain by quartzitic sandstones that compose portions of the Sadlerochit Mountains. These areas were not visited during the 1981 field work. Most of the comments here are general and are based on information gathered from similar areas west of the study area. An idealized section of mountainous terrain is shown in Figure 29.

Ridge crests have only sporadic occurrences of soils and vegetation, with complex ground patterns and rock land. The soils on ridges are mainly Pergelic Cryorthents, or Cryumbrepts (Fig. 30) if the textures are fine enough, mixed with frost features. Upper, steeper portions of most alpine slopes are mantled by scree or blocky talus. These deposits commonly display block stripes and/or block-bordered terraces. Ice commonly fills the interstices of the finer cobble and gravel-sized fragments below the large surface blocks. Pockets of Pergelic Cryumbrepts, Cryochrepts, or on occasion, Pergelic Cryaquolls occur in finer-textured

Figure 27. Mountainous terrain in the Sadlerochit Mountains. Alpine tundra (Unit IXb) occurs on the peaks and ridges.

Figure 28. Sadlerochit Spring. Many unusual plant communities are associated with the spring.

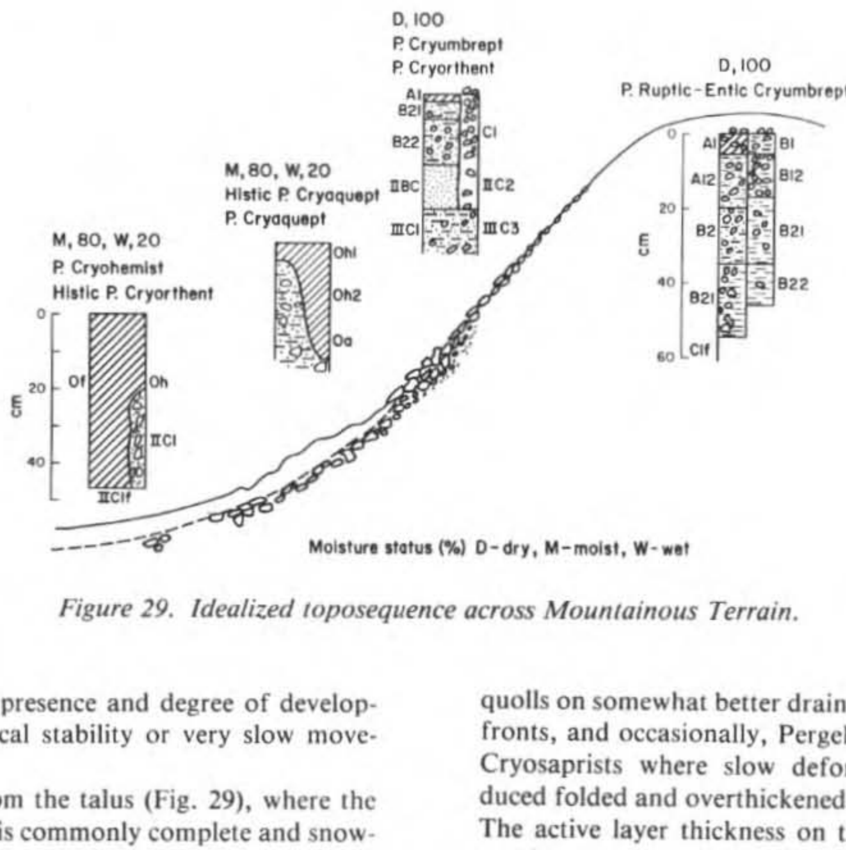

Figure 29. Idealized toposequence across Mountainous Terrain.

materials. Their presence and degree of development indicate local stability or very slow movement.

Downslope from the talus (Fig. 29), where the vegetation cover is commonly complete and snowbanks develop, the slopes display a variety of solifluction forms, including turf-banked terraces, lobes and stripes. A complex of soils is found on these slopes, including Pergelic or Histic Pergelic Cryaquepts in wet depressions, Pergelic Cryaquolls on somewhat better drained terraces or lobe fronts, and occasionally, Pergelic Cryohemists or Cryosaprists where slow deformation has produced folded and overthickened organic horizons. The active layer thickness on these slopes varies considerably, ranging from 70 cm or more in the wetter areas to less than 30 cm on some of the better-drained microtopographic elements with organic-rich soils. Where coarse, blocky talus underlies the solifluction slope, moving water may distribute mineral material over the surface of otherwise organic-rich soils. Solifluction slopes are naturally unstable, with a complex of perched water tables and subsurface drainage. They are very susceptible to vehicle traffic, which can produce mechanical and thermal erosion.

Vegetation. The vegetation communities in alpine areas are complex and are interspersed with unvegetated rock and talus slopes. The character of the vegetated slopes varies considerably. Alpine floras are exceptionally diverse due to the wide range of lithologies, soils, altitude, snow depths, exposure to wind, and site moisture. The more completely vegetated areas have extensive moss mats with numerous small shrubs, such as mountain avens (*Dryas octopetala*), prostrate willows (e.g. *Salix arctica, S. chamissonis,* and *S. phlebophylla*) and small forbs (Land Cover Unit IXb; Partially vegetated areas, Alpine tundra). There are few detailed vegetation studies of the Brooks Range; the most relevant is that of Batten (1977), who described the vegetation of the Lake Peters area. On the Landsat classification, mountainous areas are depicted as either partially vegetated (Land Cover Unit IXb) or barren (Land Cover Unit X).

River flood plains

Landforms and soils. This terrain type includes the present channels and braided drainages as well as the adjacent abandoned channels and deltas. River flood plains cover 24.6% of the study area. The present river flood plain consists of the active channel and usually one or more terraces (Fig. 31). An idealized section across a river channel is shown in Figure 32.

The major rivers within the study area have braided channels ranging in width from about 0.1 to 4 km. The diamond-shaped islands between channels are probably inundated at least sporadically in most years during the period of meltoff (usually late May to early June). Two types of islands are recognized. The first consists of unvegetated gravels and gravelly sands (or silts in the delta region). These areas are flooded annually and are subject to intensive water and ice scouring. There is not any soil or vegetation on these features, and they are described as river wash. The second type of island is somewhat higher above the main channel. The soils consist of various thicknesses of silt, silt loam, loam and fine sandy loam over gravel and gravelly sands. In the most stable situations a thin Al horizon has developed, and some mottling occurs in the fine sediments. The active layer normally exceeds 1 m. The soils are classified as Cryorthents. Most islands are complexes of Cryorthents and river wash.

In a few cases, where fine sandy surface sediments have been reworked into low discontinuous sand dunes, Cryopsamment soils occur, with thaw depths in excess of 1 m. Sand dunes are, however, rare in the study area and are confined mostly to

Figure 30. Pergelic Cryumbrept soil. This soil is common in alpine crest areas.

Figure 31. The Canning River. Such areas contain varied habitats including barren and partially vegetated river gravels in the channel areas; willows and Dryas *terrace communities are in the older channels to the right.*

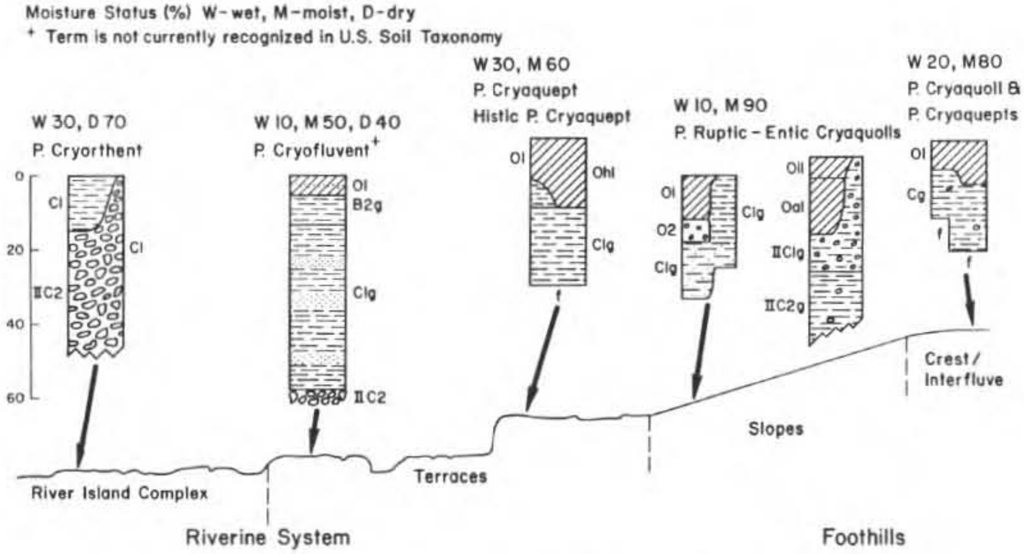

Figure 32. Idealized toposequence across River Flood Plains and Foothills.

the deltas of the Canning and Jago rivers. These features are small, mostly less than 1.5 m high, and are composed of fine sand with a significant silt component.

Beyond the confines of the braided river channel complex are a number of paired and nonpaired terraces, most of which are above the influence of snow-melt flooding. The youngest terraces commonly retain the patterns of channels and islands. For the most part, the soils of the terraces are Cryorthents (Fig. 33) and are well drained. The overlying fine materials may be 20 cm or more thick and are commonly bedded. The coarser layers are composed of fine sands. They are like Fluvent soils of more southern climates; however, the soil taxonomy does not allow for Fluvents in perma-

Figure 33. Pergelic Cryorthent soil on a Dryas *river terrace (Unit IVb). This soil resembles a Fluvent of more southern areas.*

frost areas. The organic-rich surface (A) horizon may be up to 15 cm thick.

The channel areas are poorly drained, with fibrous organic (0) horizons 20 cm or more thick overlying mottled gray silts and silt-loams. Permafrost is usually encountered within 0.5 m. These soils are Pergelic Cryaquepts. A surface pattern consisting of 1- to 2-m-diameter polygon cells (reticulate pattern of Everett [1980a]) is common on the better drained island elements. Some terraces may lack any surface pattern and consist mostly of wet graminoid tundra, while others may have weakly expressed polygons with disjunct rims and/or strangmoor.

Away from the river (Fig. 32) there is poorer drainage, with Cryorthents and Fluvent-like soils giving way to Pergelic and Histic Pergelic Cryaquepts in which the surface organic horizon is composed of fibrous sedge peat and roots. The active layer also decreases in response to the highly organic soils and poorer drainage. Disjunct low-centered polygons and/or strangmoor mask the traces of the river island pattern. The soils of the riverine areas, with few exceptions, are nearly neutral in pH or are moderately alkaline.

Steep bluff slopes (≥24%) along the rivers and a narrow strip along their crests are included within the riverine area (Fig. 32). Bluffs may be undergoing active erosion or they may be fossil, in that they rise above long inactive river terraces. In either case they are subject to rapid natural failure by mudflow and/or solifluction. The result is commonly a complex of soils. Solifluction lobes with over-thickened (cumlic) A horizons may stand 50 cm or more above the surrounding slope. Wetter areas occur upslope from the solifluction lobes. The soils are mostly Pergelic Cryaquolls, but Pergelic Cryaquepts may be important locally.

Steep drainage gradients associated with bluffs often produce a microtopographic reversal, i.e. the conversion of low-centered polygons to high-centered polygons due to erosion of the polygon troughs (Everett 1980a). During the course of this reversal the low, highly organic-rich centers (often

Pergelic Cryaquepts or Histic Pergelic Cryaquepts) undergo drainage and oxidation. Commonly the soils are enriched with mineral materials eroded from the exposed bluff or derived as eolian material from the river-island complex below. The resulting soils are well-drained Pergelic Cryoborolls. The organic-rich surface horizons are underlain by variable thicknesses of oxidized, sandy-textured materials that thaw to depths of 1 m or more. The processes of topographic reversal are quickly attenuated inland from the bluff edge; within a distance of 100 m, low-centered polygons (or some other surface pattern) are generally well developed. The addition of wind-blown fine sand can usually be recognized for distances well beyond 100 m. Bluff crests and their soils undergo natural profile disruption by cryoturbation and wind abrasion. Because they are exposed, they are commonly snow-free during winter.

Another important feature of the larger braided rivers is aufeis, or river icings (Fig. 34). These large ice bodies form during winter in sections of the rivers where there is constriction between the river bed and the overlying ice. The resulting hydrostatic pressure cracks the ice and permits water to flow over the surface, where it freezes in a thin layer. In normal winters, numerous layers will form thick aufeis deposits, which do not entirely melt the following summer. These features often occur downstream from perennial springs, which supply a constant source of water during the winter (Childers et al. 1977).

Vegetation. The vegetation types associated with river systems are quite variable. The braided channels (Fig. 31) are subject to intense disturbance during spring breakup, and meandering streams and braided rivers are constantly changing their channels. The first plants to colonize river gravels include the river beauty (*Epilobium latifolium*) and arctic wormwood (*Artemisia arctica*). Slightly more stable areas are often only partially vegetated but may contain a wide variety of taxa (Land Cover Unit IXa; Partially vegetated areas, River bars). These are among the most floristically rich sites in the region (Fig. 35).

Willows (*Salix* spp.) are common on partially vegetated gravel bars, and may form dense shrub thickets; however, these thickets are not nearly as extensive as the willow communities along rivers farther west, such as on the Sagavanirktok, Kuparuk and Colville rivers. This is apparent on the Landsat classification and color-infrared photos. This situation contrasts markedly with impressions gained from earlier maps of the region (Viereck and Little 1972, University of Alaska, Arctic Environmental Information and Data Center 1975). The major ecosystem map of Alaska (Joint Federal-State Land Use Planning Commission for Alaska 1973) shows extensive high-brush communities covering about 20% of the study area.

Figure 34. One of the numerous river icings along the Canning River, 27 July 1981.

Figure 35. Partially vegetated river bar on the Katakturuk River. The main flowering plant is pale paintbrush (Castilleja caudata).

Figure 36. Meandering tundra stream. Note the willows, particularly on the inside of the bends.

However, on the Landsat classification (Table B1) there is less than 0.2% cover of shrub tundra within the entire study area. Dense shrubs within major river drainages (Table B3) cover only 0.002% of the study area. Most willow communities along the major rivers are fairly open, with large components of gravel and riparian forbs. On the Landsat classification it is not possible to distinguish between the river areas that are vegetated with tall willows and those that are partially vegetated with prostrate shrubs and/or forbs (Fig. 35). Even if all the partially vegetated areas within this terrain type were dominated by shrub willows, willow shrublands would total no more than 1.25% of the study area (Table B3).

Dense willow communities also occur along

*Figure 37. Unit IVb, Dry Prostrate Shrub, Forb Tundra (*Dryas *river terrace). This unit typically occurs on reticulate-patterned river terraces with small soil polygons 20–40 cm in diameter. Barren, frost-disturbed areas are common. The primary taxa here are arctic avens* (Dryas integrifolia), *blackish oxytrope* (Oxytropis nigrescens), *alpine milk-vetch* (Astragalus alpinus) *and common cottongrass* (Eriophorum triste).

some of the smaller drainages outside the major flood plains (Fig. 36), where the soils are somewhat more stable. In most cases these drainages are narrow and unlikely to appear on the Landsat image. Smaller streams and interchannel areas of the larger rivers have lush sedge and willow stands. The heights of the willows vary according to the amount of winter snow cover and the summer temperature regime. Willows near the coast are mostly prostrate; near the southern boundary of the study area, shrubs can exceed 2 m in height.

Dryas-dominated river terraces are common features associated with the larger rivers (Fig. 37, Land Cover Unit IVb). These terraces are usually just above the main channels and are especially common along the Canning River. On the Landsat classification these terraces have spectral signatures similar to that of Moist/Wet Sedge Tundra Complex (Land Cover Unit IVa). The low reflectance of these terraces is due to the mat of arctic avens (*Dryas integrifolia*) and the lack of light-colored, erect, dead vegetation. These terraces are important for many species of wildlife; arctic ground squirrels, foxes and lemmings are attracted to the dry, sandy soils for burrowing sites, and grizzly bears are often seen hunting for the smaller animals in these areas. On the Landsat classification it would be helpful to separate the dry terraces from the more abundant but less floristically and faunistically rich Moist/Wet Sedge Tundra Complex. This may be possible on Landsat scenes taken later in the summer or fall, when there is a color contrast between these two types.

CONCLUSIONS

This analysis has emphasized several important features of the ANWR study area:

1) Thaw-lake plains cover only about 3% of the study area, but units where wet tundra habitats are likely to occur (Land Cover Units I, II, III and IV) cover about 40% of the region. These areas are particularly sensitive to surface exploration and are valuable as waterfowl habitat.

2) The area is mostly hilly and covered by moist tundra of varying character. Units IV, V and VI are the dominant land cover types, covering 55% of the region. Frost-scar tundra covers large areas of the uplands. However, there is currently spectral confusion between frost-scar tundra and other land cover units. We hope that this problem can be eliminated by reclustering the data and/or by use of digital elevation models (DEM).

3) River flood plains and braided river deltas cover nearly 25% of the study area. This has im-

portant implications for the many wildlife species that utilize habitat associated with rivers.

4) Riparian shrub communities are not nearly as extensive as indicated on previous maps of the region. Only 0.2% of the area has dense shrubs. Open shrub communities along the rivers account for no more than 1.25% of the area.

We recommend using the results of this study as a basis for selecting areas within each of the major terrain types for detailed studies, including making master maps and investigating the soils, vegetation, geomorphic processes and wildlife use. The four areas we visited in 1981 would be good study sites, and we recommend adding an alpine site near Sadlerochit Spring and a flat thaw-lake plain site southwest of Barter Island. These studies would help in evaluating the overall reliability of the Landsat map and would aid in evaluating the potential impact of seismic exploration within the wildlife refuge.

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APPENDIX A: DESCRIPTIONS OF LANDSAT LAND COVER CATEGORIES FOR ANWR

In most cases the colors on the Landsat image include several types. The dominant types are described here, but not in order of importance.

	Color	*Unit*	*Vegetation*	*Landform and soil*
I	Light blue	**Water**	**I. Water.** Water bodies generally larger than 1 acre: ocean, lakes, and rivers.	**I.** No soil identified.
II	Dark blue	**Pond/Sedge Tundra Complex** or **Aquatic Tundra** or **shallow water**	**IIa. Pond/Sedge Tundra Complex.** Very wet tundra areas that have numerous small bodies of water, such as drained lake basins with small ponds, polygons and strangmoor. Relatively well drained tundra of varying character may cover up to 50% of the unit. Low-centered polygon complexes with standing water in their centers are usually included in this unit.	**IIa.** Principal landforms of the pond complex are numerous shallow ponds < 1 ha, low-centered polygons (often with standing water in their centers), and string bogs (strangmoor). The very wet elements of the unit have, in order of abundance, Histic Pergelic Cryaquepts, usually with 20 cm or more of fibrous organic materials over gleyed (reduced) mineral soil; Pergelic Cryaquepts with < 20 cm of fibrous organic over gleyed mineral material; or Cryofibrists/Cryohemists with >40 cm of fibrous organic over gleyed mineral soil. Positive microrelief elements, especially well-developed (>20 cm) rims of the low-centered polygons, have Pergelic Cryaquolls, occasionally Pergelic Cryaquepts with 5–10 cm of highly decomposed organic matter overlying gleyed mineral soil. Pergelic Cryosaprists are rare and are the organically oxidized extensions of the Cryofibrists or Cryohemists.
			IIb. Aquatic Tundra. Emergent communities that cover areas greater than 1 acre. The primary taxon in deeper water, up to 1 m deep, is *Arctophila fulva* (pendant grass). In water less than 30 cm deep, the main taxa are *Carex aquatilis* (aquatic sedge), *Eriophorum scheuchzeri* (arctic cottongrass) and *E. angustifolium* (common cottongrass).	**IIb.** Normally soils have not been described in areas where *Arctophila fulva* is mapped. The substrate in such environments consists commonly of a suspension of detrital organic materials, often with a significant component of mineral materials held in a matrix of plant roots. The underlying mineral soils may be uniformly gleyed, or on occasion, mottled, the result of oxidation around aerenchymous roots. Such soils are placed provisionally with the Pergelic Cryaquepts. Similar soils with increasing amounts of fibrous biomass occur within the shallowest (>30 cm) water depths.
III	Dark green	**Wet Sedge Tundra**	**IIIa. Wet Sedge Tundra (noncomplex).** Relatively wet tundra with little or no standing water and only a few well-drained microsites associated with polygon rims, strangmoor, hummocks, etc. Much of this tundra is flooded in early summer, but it generally drains of standing water by midsummer and remains saturated throughout the summer. Relatively large areas of noncomplex wet tundra occur in the deltas of the larger rivers, particularly the Canning River, and in drained lake basins and along some river channels. The primary taxa are numerous sedges, including *Carex aquatilis* (aquatic sedge), *Eriophorum angustifolium* (common cottongrass), *E. russeolum* (russett cottongrass), *C. rotundata* (round-fruited sedge), *C. saxatilis* (rocky sedge) and a few herbs, including *Pedicularis sudetica* ssp. *albolabiata* (sudetan lousewort), *Saxifraga hirculis* (bog saxifrage),	**IIIa.** These areas have seasonal standing water (after snow melt) but by midsummer the thickening active layer, together with evapotranspiration, removes the standing water, leaving a saturated soil. Free water is encountered within a very few centimeters of the surface. Patterned ground features are poorly developed and consist of large disjunct polygons, hummocks and strangmoor; the strangs are often coextensive with the low polygon rims. There is not much positive microrelief. The soils are wet, predominantly Pergelic Cryaquepts or Histic Pergelic Cryaquepts, both of which have fibrous organic horizons. In certain cases where organic and neutral to alkaline mineral substrate is present, Histic Pergelic Cryaquolls occur.

	Color	Unit	Vegetation	Landform and soil
			Melandrium apetalum (nodding lychnis), *Caltha palustris* (marsh marigold) and *Potentilla palustris* (marsh five-finger). Mosses are mainly *Drepanocladus* spp., *Scorpidium scorpioides*, *Campylium stellatum*, *Calliergon* spp. and *Sphagnum* spp.	
			IIIb. Wet Sedge Tundra (very wet complexes). Complexes of wet tundra with up to 50% water or emergent vegetation. Low-centered polygon complexes with extensive thermokarst pits, or complex thermokarst areas in the Foothills commonly have this vegetation subunit. Nonaquatic portions of the complex may be tundra of varying character.	**IIIb.** In contrast to IIIa these areas have more strongly expressed surface patterns and microrelief but contain significant amounts of standing water in the form of thermokarst pools or the centers of low-centered polygons. Such areas are typical of broad crests in the Foothills and portions of the rolling Coastal Plain. Moist tussock and tussock frost-scar slopes in this subregion have Pergelic Cryaquolls and/or Ruptic-Entic Cryaquolls. Pergelic Cryaquolls commonly form associations with Pergelic and Histic Pergelic Cryaquepts where low-centered polygons are well expressed. Histic Pergelic Cryaquolls are the principal soils of low, flat-centered polygons, a form common to Unit IIIb. Complexes of Pergelic Cryaquepts, Pergelic Cryaquolls and Histic Pergelic Cryaquepts characterize the unit generally.
			IIIc. Wet Sedge Tundra (moist complexes). Complexes of wet tundra with up to 40% moist tundra of varying character. Low-centered polygon complexes with well-developed polygon rims, and string bogs with closely spaced strangs commonly have this kind of vegetation.	**IIIc.** This subunit differs from the others principally in terms of its better drainage. It includes extensive areas of well-developed low-centered polygons and areas of string bogs in which the strangs are more closely spaced, reflecting a more clearly defined hydraulic gradient. Pergelic and Histic Pergelic Cryaquepts are common in the strangs. Complexes and associations of Pergelic Cryaquolls and Pergelic and Histic Pergelic Cryaquepts are common to the rest of the subunit.
			IIId. Wet Sedge Tundra (saline facies). Areas near the coast that are periodically inundated with salt water. The primary taxa are *Carex subspathacea* (Hoppner sedge), *Puccinellia phyrganodes* (creeping alkaligrass), *C. ursina* (bear sedge), *Stellaria humifusa* (low chickweed) and *Cochlearia officinalis* (common scurvy grass). Some saline areas have numerous ponds and are likely to be classed as Pond/Sedge Tundra Complex (IIa).	**IIId.** These near-coast areas may display any of the landform subunits of Classes II or III. The soils in recently flooded areas are morphologically little different from those of the unflooded parts. Chemically, however, they may have conductivities that range from 12,000 to $>18{,}000$ μmhos/cm and should probably be considered as Halic Pergelic Cryaquepts. Where saline conditions have prevailed for a protracted period of time and salt-tolerant plants such as *Puccinellia phryganodes* and *Carex subspathacea* are established on the dead *Carex aquatilis*, there is a pronounced change in the texture of the accumulating organic matter.
IV	Light green	**Moist/Wet Sedge Tundra Complex** or **Dry Prostrate Shrub, Forb Tundra (*Dryas* river terraces)**	**IVa. Moist/Wet Sedge Tundra Complex.** Areas of moist sedge tundra mixed with up to 40% wet sedge tundra. Flat areas with low- or flat-centered polygon complexes (common in drained lake basins) or strangmoor (more common in river delta systems and on gentle slopes) usually have a large percentage of wet tundra in the polygon troughs, basins, thermokarst pits and interstrang areas.	**IVa.** Occurs on flat upland areas or in old, drained lake basins where flat-centered polygons form complexes with thermokarst pits or strangmoor. Wet areas may compose up to 40% of any given area. The moist/wet sedge tundra is also common on gentle slopes with flat-centered polygons. The IVa subunit is most extensive east of the Hulahula River. Soils of the moist areas (polygon

Color		Unit	Vegetation	Landform and soil
			The spectral signature of these areas is likely to vary depending on the percentage of moist tundra, the season and the summer rainfall. Moist areas may or may not have cottongrass tussocks, depending on the proximity to the coast. Common taxa in moist tundra areas include the sedges *Eriophorum triste* (common cottongrass), *E. vaginatum* (sheathed cottongrass), *Carex bigelowii* (Bigelow's sedge), *C. membranacea* (fragile sedge); the prostrate shrubs *Dryas integrifolia* (arctic avens), *Salix reticulata* (net-veined willow), *S. lanata* (woolly willow); and the forbs *Pedicularis lanata* (woolly lousewort), *Polygonum bistorta* (bistort), *Stellaria laeta* (long-stalked stitchwort) and *Senecio atropurpureus* ssp. *frigidus* (arctic senecio). Common bryophytes include *Tomenthypnum nitens*, *Hylocomium splendens*, *Ptilidium ciliare*, *Orthothecium chryseum* and *Ditrichum flexicaule*. Common lichens are *Thamnolia subuliformis*, *Cetraria* spp., *Dactylina arctica*, *Cladonia* spp. and *Cladina* spp.	centers especially) are Pergelic Cryaquolls. Those of the wet sites are Histic Pergelic Cryaquolls or Histic Pergelic Cryaquepts. In areas where frost scars are common, the soil complex is best described as consisting of Ruptic-Entic Pergelic Cryaquolls.
			IVb. Dry Prostrate Shrub, Forb Tundra (*Dryas* river terraces). River terraces that have a dense prostrate mat of *Dryas integrifolia* with numerous small forbs and prostrate shrubs. This unit is quite dark on aerial photographs and Landsat data and has a spectral signature signature similar to either Wet Sedge Tundra (III) or Moist/Wet Sedge Tundra Complex (IVa), although this unit is physiognomically very different from either of these other units. This is an extensive unit along rivers, particularly along the Canning River, and is used heavily by ground squirrels, lemmings and bears. It may be possible to distinguish these terraces in some other phenological stage on Landsat scenes taken later in the summer. The primary taxa are the prostrate shrubs *Dryas integrifolia* (arctic avens), *Salix reticulata* (net-veined willow), *S. rotundifolia* (round-leafed willow), and *Salix ovalifolia* (oval-leafed willow); the herbs *Astragalus alpinus* (alpine milk-vetch), *Oxytropis nigrescens* (blackish oxytrope), *Equisetum arvense* (common horsetail), *Artemisia arctica* (arctic wormwood), *Silene acaulis* (moss campion), *Chrysanthemum integrifolium* (entire-leafed chrysanthemum), *Saxifraga oppositifolia* (purple mountain saxifrage), *Carex membranacea* (fragile sedge) and *Eriophorum triste* (common cottongrass); and the mosses *Distichium capillaceum* and *Ditrichum flexicaule*.	**IVb.** These terraces are generally components of the riverine complex. Except under unusual circumstances they are not flooded, being a meter or more above the active terraces or river island complex. Surfaces of these terraces still display the river island and channel features. The former commonly displays polygonal cracks and has soils resembling Fluvents with 15–50 cm of interlayered silts, sands and organic materials overlying river-wash sands and gravels. The depth of thaw is >1 m and no water table occurs. Former channels are wet to moist and have Pergelic Cryaquept soils.
V	Sand	**Moist Sedge, Prostrate Shrub Tundra** or **Moist Sedge/Barren Tundra Complex (frost-scar tundra)**	**Va. Moist Sedge, Prostrate Shrub Tundra.** Moderately well drained areas, located primarily along the northern part of the Foothills and in drainages. The principal taxa are similar to those described for Moist/Wet Sedge Tundra Complex (IVa). These areas may have up to 20% cover of cottongrass tussocks. Wetter facies near streams are likely to have no tussocks and high percentages of prostrate shrubs,	**V.** This cover class is mostly in the northern or rolling foothills of the wildlife refuge and is often difficult to separate from Unit IVa in that it occupies broad sloping interfluves with flat-centered polygons. The soils are Pergelic Cryaquolls with a small percentage of Pergelic Cryaquepts. Portions of the slopes have a very high percentage of frost scars, in some cases 80–90%. These areas are espe-

	Color	Unit	Vegetation	Landform and soil
			including *Salix arctica* (arctic willow) and *S. pulchra* (diamond-leaved willow), and herbs such as *Petasites frigidus* (Lapland butterbur), *Saxifraga punctata* (cordate-leaved saxifrage), *Carex aquatilis* (aquatic sedge), *Saxifraga hirculus* (bog saxifrage) and *Valeriana capitata* (capitate valerian). Near the coast on slightly elevated microsites, moist tundra areas are likely to contain large components of a prostrate shrub, crustose lichen type. This type is a rather sparse community, including *Dryas integrifolia* (arctic avens), *Salix pulchra* (diamond-leafed willow), *Carex bigelowii* (Bigelow's sedge), *S. phlebophylla* (veiny-leafed willow), *Luzula arctica* (arctic wood-rush), with considerable ground cover of small hummocks with the moss *Dicranum elongatum* covered by white crustose lichens (mainly *Ochrolechia frigida* and *Lecanora epibryon).*	cially common on crests with bedrock outcrops at or close to the surface and areas low on the slopes near drainages. Soils of the frost scars are Pergelic Cryaquepts (or Entisols). More stable areas between the frost scars (10-50% of the surface) have Pergelic Cryaquolls. The active layer thickness ranges from near a meter in the scars to between 40 and 60 cm beneath the Cryaquolls. Portions of the long, low slopes are characterized by Moist Sedge Tussock, Dwarf Shrub/Wet Dwarf Shrub Tundra Complex (water track complex) (VIIc).
			Vb. Moist Sedge/Barren Tundra Complex (frost-scar tundra). Primarily well-drained areas with as much as 90% of the surface covered by frost boils or frost rings. Vegetation on the frost scars is generally sparse, with such taxa as *Juncus biglumis* (two-flowered rush), *Petasites frigidus* (Lapland butterbur), *Dryas integrifolia* (arctic avens), *Chrysanthemum integrifolium* (entire-leaved chrysanthemum) and *Saxifraga oppositifolia* (purple mountain saxifrage), and the mosses *Rhacomitrium lanuginosum*, *Bryum* spp., *Distichium capillaceum*, *Drepanocladus uncinatus*, etc. Inter-frost-scar areas near the coast are usually Moist Sedge, Prostrate Shrub Tundra (Va) dominated by *Carex bigelowii* (Bigelow's sedge), *Dryas integrifolia* (arctic avens), *Arctagrostis latifolia* (wide-leafed arctagrostis) and *Equisetum arvense* (common horsetail), and the moss *Tomenthypnum nitens.* In the Foothills, frost-scar tundra occurs mainly on slopes and ridge tops and is likely to have scattered *Salix lanata* (woolly willow) or *S. glauca* (northern willow) 10-40 cm tall. This unit is extensive but is difficult to separate on the Landsat data. On the Flaxman scene, it is more often classified as Unit V (sand), while on the Canadian scene it often appears as Unit IV (light green).	
VI	Light brown	**Moist Sedge Tussock, Dwarf Shrub Tundra**	**VIa. Moist Sedge Tussock, Dwarf Shrub Tundra (upland tussock tundra, acidic facies).** Relatively well drained upland tussock tundra primarily in the Foothills, with a high percentage cover of cottongrass tussocks and dwarf or prostrate shrubs. In this unit the tussocks are usually dominant, with 20-70% cover. On acidic soils the dwarf shrubs include *Salix pulchra* (diamond-leafed willow), *Betula nana* (dwarf birch), *Ledum decumbens* (narrow-leafed Labrador tea), *Vaccinium uliginosum* (bog blueberry), *V. vitis-idaea* (moun-	**VI.** Two facies, acid and alkaline, are recognized in this Foothills unit. Landforms are principally long slopes dominated by cottongrass tussocks that obscure flat-centered polygons. The acidic facies of this unit occur in association with deeper organic layers or with sandy and gravel conglomerate units of the underlying Cretaceous and/or Tertiary bedrock and are particularly common in the area east of the Sadlerochit River. The soils are Pergelic Cryaquepts and form a complex with numerous frost scars (Ruptic-Entic Pergelic

	Color	Unit	Vegetation	Landform and soil
			tain cranberry), *Empetrum nigrum* (crowberry) and *Arctostaphylos rubra* (bearberry), and the bryophytes are mainly *Hylocomium splendens*, *Sphagnum* spp., *Aulacomnium palustre* and *Ptilidium ciliare*. Lichens are dominated by *Cladonia* spp. and *Cladina* spp.	Cryaquepts). Histic Pergelic Cryaquepts are common where water-track units occur. Alkaline facies of this cover class are most common west of the Katakturuk River, and the soil complex is Ruptic-Entic Pergelic Cryaquolls. Water tables are generally absent in the moist portions of both facies except in water tracks and near the foot and crest of the slope. Pergelic Cryochrepts are present on the few well-drained areas within this unit.
			VIb. Moist Sedge Tussock, Dwarf Shrub Tundra (upland tussock tundra, alkaline facies). On more neutral or basic soils, important taxa associated with the cottongrass tussocks include *Dryas integrifolia* (arctic avens), *Carex bigelowii* (Bigelow's sedge), *Salix arctica* (arctic willow), *S. reticulata* (net-leafed willow), *S. lanata* (woolly willow) and *Arctagrostis latifolia* (wide-leafed arctagrostis); the chief moss is *Tomenthypnum nitens*, and the lichens are mainly *Cetraria* spp. The alkaline soils are most often a result of the frost stirring of basic parent materials, and barren frost scars can cover a large percentage of this unit. It is unclear whether this type is more commonly classed as Unit V (sand) or VI (light brown).	
			Both VIa and VIb may have up to 30% coverage of other vegetation types, mainly Moist/Wet Sedge Tundra Complex (IVa) or Wet Sedge Tundra (III).	
VII	Dark Brown	**Moist Dwarf Shrub, Sedge Tussock Tundra** or **Moist Sedge Tussock, Dwarf Shrub/Wet Dwarf Shrub Complex (water track complex)**	**VIIa. Moist Dwarf Shrub, Sedge Tussock Tundra (upland dwarf shrub, tussock tundra).** Similar to VIa except here the shrubs, mainly *Salix pulchra* (diamond-leafed willow) and *Betula nana* (dwarf birch), are dominant and may reach heights of up to 50 cm.	**VIIa.** The soils of this subunit are generally similar to those of Unit VI.
			VIIb. Moist Dwarf Shrub, Sedge Tussock Tundra (birch tundra). High-centered polygons and palsas with dwarf shrub communities dominated by *Betula nana* (dwarf birch) and *Eriophorum vaginatum* (sheathed cottongrass). These areas occur on high-centered polygons toward the southern end of the coastal plain and in low thermokarst drainage areas in the Foothills. In some communities the birch is completely dominant and the cottongrass is absent. Other typical taxa in these sites are *Rubus chamaemorus* (cloudberry), *Ledum decumbens* (narrow-leafed Labrador tea), *Pedicularis labradorica* (Labrador lousewort), *Vaccinium vitis-idaea* (mountain cranberry), *Sphagnum* mosses dominate the ground layer with numerous *Cladonia* and *Cladina* lichens.	**VIIb.** This subunit occurs principally in the headwater areas of many small, often beaded drainages in the Foothills area. In such areas thermal erosion combines with natural thermokarst to produce high-centered polygons, which may have a meter or more of microrelief. Soils that in uneroded portions of the headwater basins are Histic Pergelic Cryohemists are converted to (Sapric) Histic Pergelic Cryaquolls or Pergelic Cryosaprists because of the better drainage afforded by the microrelief. A feature of headwater basins and some broad interluves (Unit III), especially in the southern part of the Foothills, are birch-covered peat plateaus (generally palsas) that stand 0.5–1 m above the surrounding wet sedge tundra. The soils of these features are fibrous Histic Pergelic Cryaquepts in which large volumes of segregation ice occur. Ice volumes increase with depth, and individual layers may be a meter or more thick.

	Color	Unit	Vegetation	Landform and soil
			VIIc. Moist Sedge Tussock, Dwarf Shrub/Wet Dwarf Shrub Tundra Complex (water track complex). Slopes in the Foothills with water tracks. In these areas the sedge tussock, dwarf shrub tundra forms a complex with shrub communities in the water tracks. The height and density of the water track shrubs vary, but the dominant taxon is generally *Salix pulchra* (diamond-leafed willow). Other important taxa in water tracks include *Salix arctica* (arctic willow), *Betula nana* (dwarf birch), *Carex aquatilis* (aquatic sedge), *Eriophorum angustifolium* (common cottongrass) and other taxa typically found in Wet Sedge Tundra (IIIa).	**VIIc.** This unit differs from Unit VI primarily because of the increased abundance of water tracks, up to 30% of some slopes. These drainage channels run downslope, curving toward small streams. Soils in the tracks are primarily (Fibric) Histic Pergelic Cryaquepts. Intertrack areas are drier, with Pergelic Cryaquepts or Pergelic Cryaquolls. A shallow water table is present in the tracks. Thaw in the tracks is somewhat greater than on intertrack areas.
VIII	Red	**Shrub Tundra**	**VIIIa. Shrub Tundra (noncomplex).** South-facing slopes in the Foothills with communities dominated by dwarf and medium-height (up to 2 m) willows, birches and/or alders. These sites are relatively warm and often rocky with a variety of microsites, which contribute to great species diversity. Typical taxa include *Salix* spp. (willows), *Betula glandulosa* (shrub birch), *Alnus crispa* (mountain alder), *Lupinus arcticus* (arctic lupine), *Artemisia tilesii*, (Tilesius' wormwood), *A. arctica* (arctic wormwood), *Aconitum delphinifolium* (delphinium-leafed monkshood), *Delphinium brachycentrum* (northern dwarf larkspur), *Potentilla fruticosa* (shrubby cinquefoil), *Bromus pumpellianus* (arctic brome-grass), *Equisetum arvense* (common horsetail), *Festuca altaica* (rough fescue), *Senecio lugens* (black-tipped groundsel), *Castilleja caudata* (pale paintbrush), *Carex microchaeta* (small-bristled sedge), *Arnica frigida* (nodding arnica), *A. alpina* (alpine arnica), *Petasites frigidus* (Lapland butterbur), *Saxifraga tricuspidata* (three-toothed saxifrage), *Vaccinium uliginosum* (bog blueberry), *V. vitis-idaea* (mountain cranberry), *Aster siberica* (Siberian aster), *Ledum decumbens* (narrow-leafed Labrador tea) and *Empetrum nigrum* (crowberry).	**VIIIa.** This unit is common on steep (25-65%) slopes in the southern part of the Foothills and on vegetation-covered slopes in the alpine areas of the wildlife refuge. Such slopes are characterized by one or more forms of mass wasting, most commonly solifluction. Non-soil and different kinds of soil are often juxtaposed, forming a mosaic composed of Pergelic Cryorthents, Pergelic Histic Pergelic Cryaquolls (Pergelic and Histic Pergelic Cryaquepts where ice bedrock types are near the surface), and in some cases Pergelic Cryosaprists.
			VIIIb. Shrub Tundra (water track complex). This unit is very similar to VIIc, except here the water track shrub communities dominate. The unit also appears in some stream drainages, with abundant medium-height and tall willows.	**VIIIb.** This subunit is similar to VIIc except the water track portion of the complex is dominant. In stream drainages the soils are formed on alluvium and may be Pergelic Cryaquepts, Pergelic Cryorthents or soils similar to those of IVb.
IX	Violet	**Partially vegetated areas**	**IXa. River bars.** Partially vegetated river bars have a wide diversisty of taxa that include *Epilobium latifolium* (river beauty), *Artemisia* spp. (wormwoods), *Salix* spp. (willows), *Castilleja caudata* (pale paintbrush), *Hedysarum alpinum* (alpine hedysarum), *H. mackenzii* (Mackenzie's hedysarum), *Arctostaphylos rubra* (bearberry), *Oxytropis campestris* (yellow oxytrope), *Anemone parviflora*, (small-	**IXa.** River bars are included in river island complexes. Those that lack vegetation or soils are treated as river-wash deposits. Some bars or river islands, although subject to seasonal flooding and scouring, receive mostly silts and sands. Those that are partly vegetated have soils that are similar to those of Unit IVb and are Pergelic Cryorthents. The principal difference is that the silt and/or

Color	Unit	Vegetation	Landform and soil
		flowered anemone), *Equisetum arvense* (common horsetail), *Trisetum spicatum* (spiked trisetum), *Deschampsia caespitosa* (tufted hairgrass) and *Astragalus alpinus* (alpine milk-vetch).	sand upper horizon is generally < 10 cm thick and lacks zones of organic materials.
		IXb. Alpine tundra. Many alpine tundra areas appear to be partially vegetated because of the large amount of barren talus and rocks. The character of alpine tundra varies considerably, but the more completely vegetated areas have extensive moss mats (mainly *Hylocomium splendens*) with numerous prostrate shrubs, such as *Dryas octopetala* (mountain avens), *Salix phlebophylla* (veiny-leafed willow) and *S. chamissonis* (Chamisson's willow), and herbs such as *Carex microchaeta* (small-bristled sedge), *Geum glaciale* (glacier avens), *Saxifraga bronchialis* (spotted saxifrage), *S. davurica* (davurian saxifrage), *S. tricuspidata* (three-toothed saxifrage), *S. serpyllifolia* (thyme-leaved saxifrage); and many lichens including *Cladina* spp., *Nephroma expallidum*, *Cetraria* spp., *Dactylina arctica* and *Sphaerophorus globosus*.	**IXb.** Alpine areas, above the solifluction slopes that are often shrub covered (Unit VIII), are composed of partially vegetated, steep (>50%) talus slopes and narrow crests; the flatter ones have sorted and unsorted stone nets and/or frost scars. The stable areas that support most of the vegetation have Pergelic Cryorthent soils and, if sufficient fines are present, Pergelic Cryochrepts. The soil pattern is Ruptic-Entic Pergelic Cryorthents and/or Cryochrepts, both with a Sapric organic surface horizon up to 5 cm thick.
		IXc. Sorted stone nets. Some extensive sorted polygons occur in the Jago and Okpilak drainages. These contain rocks covered by lichens such as *Umbilicaria* spp., *Lecanora* spp., *Lecidea* spp., *Rhizocarpon* spp. and *Alectoria minuscula*.	**IXc.** Large block-bordered polygons and block fields are noted in the southern parts of the Jago and Okpilak drainages. In some cases Ruptic-Entic Pergelic Cryochrepts and/or Cryaquepts are developed on the finer-textured materials in the polygon centers.
		IXd. Beaches. Some coastal beaches and mud flats are sparely vegetated with *Carex subspathacea* (Hoppner sedge) and *Puccinellia phryganodes* (creeping alkali-grass) and other taxa similar to wet saline tundra (IIId).	**IXd.** Beaches generally do not have sufficient stability to develop soils. In the few cases when they are developed under sedges, they are Cryorthents.
		IXe. Sand dunes. Dune communities occur in the delta of the Canning River. Species are similar to those occurring on river bars (IXa). The most sparsely vegetated dunes are dominated by *Elymus arenarius* (dune grass). More stable dunes have communities similar to the *Dryas* river terrace community (IVb).	**IXe.** Sand dunes are not abundant in the wildlife refuge, occurring mostly in the delta regions of the Canning and Jago rivers. Where sufficient vegetation exists to stabilize or partially stabilize them, the soils are Pergelic Cryopsamments. The active layer is >1 m thick. Wet sandy materials between the dunes have Pergelic Cryaquept soils. No soil is recognized on active dunes lacking vegetation.
X Black	**Barren gravel or rock**	**X. Barren gravel or rock.** Light-colored barren gravel or rock occurs in a variety of places that include bare river gravels, gravel and sand spits, alpine barrens and cultural barrens such as the runway and roads at Barter Island. Some gravelly ridge tops in the Foothills are in this unit. These areas actually have a rich but sparse flora that includes *Potentilla biflora* (two-flowered cinquefoil), *Dryas octopetala* (mountain avens), *Artemisia arctica* (arctic wormwood), *Castilleja caudata* (pale paintbrush), *Pedicularis verticillata* (boreal Jacob's-ladder) and other taxa similar to gravel river bars (IXa).	**X.** Barren gravel areas are mostly included in the river island complex and do not have soils (river wash deposits, subunit IVb). The water tables reflect river water level, and permafrost is deep or absent. Some gravel barrens and rock outcrop areas occur, especially on uplands. Here a water table is absent and ice-rich permafrost, if present at all, lies at depths >1 m.

	Color	Unit	Vegetation	Landform and soil
XI	Gray	**Wet gravel or mud**	**XI. Barren mud or wet gravel.** This unit has a somewhat darker spectral signature than Unit X. It includes extensive areas of barren mud in the deltas of rivers and wet gravels in the rivers and beaches. Some dark-colored barren rocks in the mountains are also in this unit.	**XI.** These areas are within the riverine system and occur mostly in the delta areas, although wet gravels may occasionally be formed on flat uplands and beaches. In most cases shallow water tables and a thick active layer occur. No soils are recognized.
XII	White	**Ice**	**XII. Ice.** River icings (aufeis) occur in the braided stream channels of most of the larger rivers.	**XII.** No soils are designated for aufeis areas.

APPENDIX B: AREA SUMMARIES

Table B1. Acreage summaries of the vegetation of the Coastal Plain portion of the Arctic National Wildlife Refuge.

The water category includes ocean within the study area boundary.

Land Cover Unit		Acres	Percentage of Study Area
I.	Water	101,355	6.2
II.	Pond/Sedge Tundra Complex; Aquatic Tundra; or shallow water	16,964	1.0
III.	Wet Sedge Tundra	260,057	15.8
IV.	Moist/Wet Sedge Tundra Complex; or Dry Prostrate Shrub, Forb Tundra (<u>Dryas</u> river terraces)	270,565	16.5
V.	Moist Sedge, Prostrate Shrub Tundra; or Moist Sedge/Barren Tundra Complex (frost-scar tundra)	434,512	26.5
VI.	Moist Sedge Tussock, Dwarf Shrub Tundra	414,550	25.3
VII.	Moist Dwarf Shrub, Sedge Tussock Tundra; or Moist Sedge Tussock, Dwarf Shrub/Wet Dwarf Shrub Complex (water track complex)	51,148	3.1
VIII.	Shrub Tundra	3,142	0.2
IX.	Partially vegetated area	27,678	1.7
X.	Barren gravel or rock	27,642	1.7
XI.	Wet gravel or mud	28,402	1.7
XII.	Ice	4,612	0.3
		1,640,626	100.0

Table B2. Area measurements, by survey township and land cover class, in percent and acres.*

Township	Class	RangeE 23	RangeE 24	RangeE 25	RangeE 26	RangeE 27	RangeE 28	RangeE 29	RangeE 30	RangeE 31	RangeE 32	RangeE 33	RangeE 34	RangeE 35	RangeE 36	RangeE 37	RangeE 38	RangeE 39	RangeE 40	Class	Township
T 9 N	I		21.9	33.4	89.4						88.7	85.2	49.1	62.3	97.6					I	T 9 N
	II		4.2	8.4	0.7						0.2	0.5	4.7	5.1	-					II	
	III		64.3	42.0	7.0						-	6.2	17.0	16.4	-					III	
	IV		0.2	7.1	0.1						-	3.5	1.3	9.6	-					IV	
	V		-	0.4	-						-	0.3	0.4	1.3	-					V	
	VI		-	0.0	-						-	0.0	-	-	-					VI	
	VII		-	-	-						-	-	-	-	-					VII	
	VIII		-	-	-						-	-	-	-	-					VIII	
	IX		0.3	0.4	-						1.0	1.1	4.9	2.5	-					IX	
	X		2.9	3.0	0.6						5.3	2.0	3.7	1.1	1.4					X	
	XI		6.2	5.0	2.2						4.8	1.2	18.9	1.7	1.0					XI	
	XII		-	0.3	-						-	-	0.0	0.0	-					XII	
	Percent		100	100	100						100	100	100	100	100					Percent	
	Acres		10,954	16,148	1,755						2,655	13,718	13,876	10,795	2,146					Acres	
T 8 N	I		3.2	3.9	27.8	55.8	71.2		46.2	33.6	29.3	16.8	9.1	1.6	6.1	18.5	8.4			I	T 8 N
	II		1.9	2.3	8.1	4.1	5.6		2.5	1.4	1.7	3.3	3.3	1.3	5.6	2.0	1.0			II	
	III		70.1	64.1	43.8	21.7	13.4		8.5	9.5	28.7	36.7	24.3	45.0	31.7	38.0	23.7			III	
	IV		2.4	2.6	6.4	5.4	2.6		27.5	33.5	13.9	25.6	39.0	33.4	23.8	24.8	22.3			IV	
	V		0.0	0.6	2.2	5.8	3.4		11.9	17.4	3.1	7.7	23.3	11.1	28.5	13.6	36.2			V	
	VI		-	0.0	0.2	0.6	0.4		0.4	1.9	-	0.1	0.3	0.0	-	-	-			VI	
	VII		-	-	0.0	0.0	-		-	-	-	-	-	-	-	-	-			VII	
	VIII		-	-	0.0	0.0	0.0		-	-	-	-	-	-	-	-	-			VIII	
	IX		5.0	5.4	1.2	0.1	0.0		3.0	1.5	7.2	3.7	0.5	2.8	2.1	0.9	3.8			IX	
	X		2.4	2.3	2.0	0.2	0.3		-	0.1	1.9	1.4	0.1	3.0	1.6	1.1	3.1			X	
	XI		14.7	18.8	8.1	2.7	3.0		-	1.1	14.2	4.7	0.1	1.8	0.6	1.1	1.0			XI	
	XII		0.3	0.0	0.2	3.6	0.1		-	-	-	-	0.0	0.0	0.0	0.0	0.5			XII	
	Percent		100	100	100	100	100		100	100	100	100	100	100	100	100	100			Percent	
	Acres		15,724	22,910	22,773	15,491	3,838		235	10,593	20,280	22,152	22,469	22,314	22,602	18,013	5,286			Acres	
T 7 N	I	3.1	1.6	0.6	0.1	1.5	4.4	18.1	5.3	0.5	1.3	1.2	2.4	4.2	1.1	2.4	8.0	44.8		I	T 7 N
	II	0.4	0.8	0.6	0.3	0.8	0.1	0.5	0.1	0.5	0.3	1.3	1.6	3.2	0.8	2.1	0.8	1.4		II	
	III	42.7	25.8	13.6	26.8	8.1	29.7	10.0	0.6	2.9	33.7	20.1	23.6	30.9	7.6	26.1	12.8	21.5		III	
	IV	16.4	9.8	12.8	18.4	9.2	19.1	11.1	8.4	17.1	39.1	45.2	43.9	35.0	22.8	17.9	16.0	18.0		IV	
	V	3.1	19.2	36.2	28.3	48.3	29.6	38.9	52.4	47.3	16.4	27.3	27.3	17.8	65.9	47.1	59.0	7.9		V	
	VI	0.6	11.6	23.0	15.3	27.5	9.9	14.2	30.8	28.0	1.4	0.3	1.1	0.0	0.3	0.2	-	-		VI	
	VII	0.0	2.6	8.2	4.8	3.8	1.3	2.2	0.1	0.0	-	-	-	-	-	-	-	-		VII	
	VIII	-	0.6	1.3	0.5	0.8	0.1	0.3	-	-	-	-	-	-	-	-	-	-		VIII	
	IX	6.1	5.9	0.4	0.2	-	0.3	0.3	0.9	2.5	4.0	2.0	0.0	2.2	0.8	3.1	1.8	3.1		IX	
	X	6.1	2.4	2.1	5.0	0.0	5.2	2.1	1.2	0.3	1.4	1.8	0.1	4.8	0.6	1.0	1.2	1.5		X	
	XI	11.7	11.3	1.2	0.0	-	0.3	1.7	0.2	0.9	2.4	0.8	-	1.3	0.0	0.1	0.2	1.7		XI	
	XII	9.8	8.4	0.0	0.3	-	0.0	0.6	0.0	-	-	-	0.0	0.6	0.1	0.0	0.2	0.1		XII	
	Percent	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100		Percent	
	Acres	7,915	23,126	22,873	22,840	22,828	21,071	19,867	17,217	22,118	22,406	21,951	22,202	22,055	22,137	22,167	21,657	7,607		Acres	

Township	Class	Range E 23	Range E 24	Range E 25	Range E 26	Range E 27	Range E 28	Range E 29	Range E 30	Range E 31	Range E 32	Range E 33	Range E 34	Range E 35	Range E 36	Range E 37	Range E 38	Range E 39	Range E 40
T 6 N	I	4.0	0.1	-	-	-	0.1	-	0.3	0.5	0.7	0.0	3.0	0.6	1.7	1.8	0.1	9.7	56.9
	II	-	-	0.0	-	-	0.0	-	0.0	0.8	0.1	0.1	1.7	0.8	1.3	1.1	0.1	1.0	4.8
	III	11.8	0.4	0.2	1.5	2.2	2.2	1.7	0.3	2.4	16.6	3.1	29.8	18.6	22.1	25.5	27.6	49.7	31.9
	IV	5.9	0.1	1.0	4.3	4.6	12.3	6.5	2.1	9.2	43.4	18.2	33.5	34.9	24.2	21.7	32.1	24.9	3.0
	V	45.4	25.4	30.7	36.8	32.6	36.1	32.6	21.5	35.9	26.6	65.8	29.6	37.4	48.8	46.4	35.6	12.4	0.1
	VI	26.2	67.9	52.7	47.0	45.6	34.3	51.9	74.7	46.3	5.3	10.6	0.9	0.1	0.0	-	-	0.0	-
	VII	0.5	3.5	12.9	7.5	11.8	10.9	5.2	0.1	0.0	-	-	-	-	-	-	-	-	-
	VIII	0.2	2.6	1.7	0.4	0.4	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-
	IX	-	-	-	-	0.0	0.1	0.0	0.2	3.5	3.5	1.0	0.4	2.2	0.7	1.5	2.4	1.8	1.1
	X	0.3	0.0	0.8	2.5	2.8	3.8	1.9	0.8	0.8	1.7	1.1	1.0	4.6	1.1	1.9	1.8	0.3	0.4
	XI	5.7	-	0.0	-	0.0	0.0	-	-	0.6	2.1	0.1	0.1	0.7	0.0	0.0	-	0.2	1.8
	XII	-	-	-	-	-	0.0	0.0	-	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.3	-	-
	Percent	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Acres	15,856	22,395	23,166	23,164	23,017	23,011	23,052	22,487	22,309	22,519	22,137	22,342	22,287	22,378	22,360	22,256	22,139	7,411
T 5 N	I	2.3	0.7	1.2	0.1	-	-	-	-	0.1	0.3	0.4	1.7	1.0	0.9	0.1	-	-	0.7
	II	-	-	-	0.1	-	-	-	-	0.4	0.1	0.2	0.8	0.6	0.4	0.1	0.0	0.0	1.6
	III	4.7	0.6	3.3	1.7	4.9	0.3	0.1	0.4	4.8	8.1	6.3	14.5	14.2	8.1	10.9	36.2	58.9	63.1
	IV	2.2	0.1	0.2	7.0	10.4	4.9	2.5	3.4	20.5	38.6	19.6	30.2	30.2	21.6	36.9	44.4	35.8	28.6
	V	52.3	32.4	42.9	29.5	23.5	18.8	11.5	6.1	30.0	25.0	38.8	37.0	43.4	61.0	50.1	18.0	3.7	0.2
	VI	20.8	63.3	51.0	51.7	32.7	35.2	60.8	84.9	35.2	19.3	31.4	13.0	2.2	2.5	1.3	0.2	-	-
	VII	1.8	2.0	0.8	6.9	22.4	36.6	21.4	4.1	0.1	0.0	0.0	-	-	-	-	-	-	-
	VIII	0.5	0.9	0.5	0.1	0.7	3.7	0.4	-	-	-	-	-	-	-	-	-	-	-
	IX	-	-	-	0.0	0.0	-	1.0	0.8	6.3	2.5	2.1	1.2	3.7	1.9	0.5	0.8	1.5	4.2
	X	0.4	-	0.1	2.9	5.4	0.5	2.3	0.3	1.9	3.7	0.8	1.0	4.0	2.9	0.1	0.4	-	-
	XI	15.0	-	0.0	-	-	-	-	-	0.5	1.2	0.4	0.6	0.7	0.1	-	0.0	0.1	1.6
	XII	-	-	0.0	-	0.0	-	0.0	-	0.2	1.2	-	0.0	0.0	0.6	-	0.0	-	-
	Percent	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Acres	13,089	22,658	22,463	23,185	23,220	23,000	22,537	22,464	22,220	22,409	22,149	22,302	22,151	22,379	22,343	21,322	12,197	1,894
T 4 N	I									2.4	0.0	-	0.1	0.0	0.0	-	-	-	
	II									2.3	0.1	-	0.2	0.0	0.0	0.0	0.0	-	
	III									3.5	0.6	0.6	5.7	8.4	2.8	0.5	13.7	28.2	
	IV									9.4	2.9	3.3	15.8	22.3	11.5	3.0	25.7	53.3	
	V									19.9	12.6	8.7	28.1	20.5	22.8	28.6	30.2	11.8	
	VI									48.8	76.3	83.2	45.3	43.4	59.9	66.7	29.1	-	
	VII									2.0	4.9	3.9	0.4	0.5	0.4	1.0	0.2	-	
	VIII									0.1	0.1	0.0	-	-	0.0	-	-	-	
	IX									5.3	1.5	0.1	3.4	2.5	1.6	0.0	0.8	6.1	
	X									4.6	0.8	0.2	0.9	2.1	0.9	0.2	0.3	0.6	
	XI									0.3	0.2	-	0.1	0.3	0.1	-	0.0	-	
	XII									1.4	-	-	-	0.0	-	-	-	-	
	Percent									100	100	100	100	100	100	100	100	100	
	Acres									22,163	22,389	21,783	22,177	21,986	22,189	21,976	15,274	359	
T 3 N	I												0.0	-	-	0.3	-		
	II												0.0	-	0.0	0.0	-		
	III												0.4	0.0	0.8	1.1	12.5		
	IV												1.8	1.0	4.8	2.1	31.2		
	V												8.2	3.8	11.3	9.8	17.8		
	VI												71.7	75.7	77.8	84.5	37.0		
	VII												14.5	18.6	3.9	2.2	1.5		
	VIII												1.0	0.4	0.0	-	-		
	IX												1.6	0.3	1.2	-	-		
	X												0.8	0.2	0.2	0.0	-		
	XI												0.0	0.0	0.0	-	-		
	XII												-	-	-	-	-		
	Percent												100	100	100	100	100		
	Acres												22,352	22,072	22,345	18,514	1,716		

VEGETATION AND LAND COVER

ARCTIC NATIONAL WILDLIFE REFUGE

COASTAL PLAIN, ALASKA

U. S. Geological Survey Map I-1443, 1982

*— Class number and order correspond to that in map legend. A full township of 36 sq. mi. contains 23,040 acres (9,331 hectares). Map legend includes study area totals and area conversion factors. From the land cover data base in digital format many other map and statistical products are possible.

Table B3. Planimetry data for the Arctic National Wildlife Refuge study area.

Land cover unit	Acres of study area	Hectares of study area	Percentage of terrain type	Percentage of study area
A. Flat Thaw-Lake Plains				
I	9,771	3,954	19.4	0.6
II	4,227	1,711	8.4	0.3
III	23,282	9,422	46.1	1.4
IV	6,462	2,615	12.8	0.4
V	3,723	1,507	7.4	0.2
VI	413	167	0.8	*
VII	38	15	0.1	*
VIII	50	20	0.1	*
IX	317	128	0.6	*
X	674	273	1.3	*
XI	936	379	1.9	0.1
XII	577	234	1.1	*
Total	50,470	20,425	100.0	3.1
B. Hilly Coastal Plains				
I	6,634	2,685	1.8	0.4
II	4,260	1,724	1.2	0.3
III	83,484	33,785	22.7	5.1
IV	123,476	49,970	33.6	7.5
V	136,846	55,380	37.2	8.3
VI	7,158	2,897	2.0	0.4
VII	0	0	0.0	0.0
VIII	0	0	0.0	0.0
IX	3,086	1,249	0.8	0.2
X	2,461	996	0.7	0.2
XI	300	121	0.1	*
XII	283	115	0.1	*
Total	367,988	148,922	100.2	22.4
C. Foothills				
I	1,816	735	0.3	0.1
II	761	308	0.1	0.1
III	9,969	4,034	1.4	0.6
IV	39,108	15,827	5.3	2.4
V	224,545	90,871	30.6	13.7
VI	394,701	159,732	53.8	24.1
VII	50,963	20,624	7.0	3.1
VIII	3,091	1,251	0.4	0.2
IX	2,653	1,074	0.4	0.2
X	5,571	2,255	0.8	0.3
XI	328	133	0.1	*
XII	41	17	*	*
Total	733,547	296,861	100.2	44.8
D. Mountainous Terrain				
I	80	32	9.5	*
II	101	41	12.0	*
III	50	20	6.0	*
IV	23	9	2.7	*
V	63	26	7.5	*
VI	32	13	3.8	*
VII	18	7	2.2	*
VIII	2	1	0.2	*
IX	302	122	36.0	*
X	147	60	17.5	*
XI	21	9	2.5	*
XII	0	0	0.0	*
Total	839	340	99.9	*
E. River Flood Plains				
I	17,645	7,141	4.4	1.1
II	7,063	2,858	1.8	0.4
III	138,575	56,080	34.3	8.5
IV	100,217	40,557	24.8	6.1
V	69,055	27,946	17.1	4.2
VI	12,826	5,191	3.2	0.8
VII	648	262	0.2	*
VIII	34	14	*	*
IX	20,438	8,271	5.1	1.3
X	17,806	7,206	4.4	1.1
XI	15,985	6,469	4.0	1.0
XII	3,694	1,495	0.9	0.2
Total	403,986	163,490	100.2	24.7
Grand Total	1,556,830	630,038		

* <0.1

APPENDIX C: APPROXIMATE EQUIVALENT UNITS IN SEVERAL SYSTEMS OF LAND COVER, WETLAND AND VEGETATION CLASSIFICATIONS USED IN NORTHERN ALASKA

	Other Remote Sensor Land Cover Classifications		Wetland Classifications		Vegetation Classifications	
1981 ANWR Landsat classification	National USGS classification system, Level II (Anderson et al. 1976)	ANWR Landsat classification (Nodler and LaPerriere 1977)	Pt. Storkerson wetlands (Bergman et al. 1977)	National Wetland Inventory (Cowardin et al. 1979)	Alaska, Level IV where possible (Viereck et al. 1981)	International (UNESCO 1973)
I. Water	50 Water	II. Water, Shadows	V. Deep Open	M1OWL, E1OWL, POWH, L1OWH, R1OWH, R2OWH, R3OWH	None	None
IIa. Pond/Sedge Tundra Complex	84 Wet Tundra	II. Water, Shadows VI.A) Shallow Water Communities	VI. Basin-Complex	PEM5H/OW	None	None
IIb. Aquatic Tundra	84 Wet Tundra	VI.A) Shallow Water Communities	IV. Deep Arctophila or III. Shallow Arctophila or II. Shallow Carex	PEM5H, PEM5F, L2EM3H	3.C(3) b. Fresh grass marsh	V.E.16. Rooted fresh water communities & higher altitude forb forms
IIIa. Wet Sedge Tundra (noncomplex)	84 Wet Tundra	V.A) Wet Sedge Meadows (includes smooth wet sedge meadows, low-center polygon wet sedge meadows, and string bogs)	I. Flooded Tundra	PEM5E	3.C(1). a. Wet sedge meadow tundra 3.c(1). b. Wet sedge grass meadow tundra	V.C.8b. Graminoid sod-form tundra
IIIb. Wet Sedge Tundra (very wet complexes)	84 Wet Tundra	VI.B) Flooded Sedge Meadow	Complex of II. or IIb. and Uplands	PSS1H/EM5 PEM5H/OW	Complexes dominated by 3.C.(1)a.	V.C.8b. Graminoid sod-form tundra; IV.E2b String bog
IIIc. Wet Sedge Tundra (moist complexes)	84 Wet Tundra	V.A) Wet Sedge Meadows	Mostly Uplands	PSS1C/EM5 PSS1F/EM5	Complexes dominated by 3.C.(1)a.	V.C.8b. Graminoid sod-form tundra
IIId. Wet Sedge Tundra (saline facies)	84 Wet Tundra	V.B) Salt Grass Meadows	VIII. Coastal Wetlands	E2EM5P	3.C.(4)e. Halophytic sedge wet meadow	V.C.8b. Graminoid sod-form tundra
IVa. Moist/Wet Sedge Tundra Complex	85 Mixed Tundra	VII. Intermediate Wet Moist Tundra	Complex of I. and uplands	PSS1C/EM5 B, C OR E	Complexes dominated by 3.C(1)g. Sedge-willow tundra, or 3.C(1)I. Sedge-Dryas tundra	V.C.8b. Graminoid sod-form tundra
IVb. Dry Prostrate Shrub, Forb Tundra (Dryas river terraces)	82 Herbaceous Tundra	VIII. Dryas Terrace Community	None	Upland, PSS1A, PSS1B	2C.(1)c. Dryas herb tundra 2.C(1)h. Prostrate shrubs and herbs on flood plains	IV.B.3b. Cold deciduous creeping or matted thicket
Va. Moist Sedge, Prostrate Shrub Tundra	82 Herbaceous Tundra	VIII.A) Upland Sedge Meadow	None	Upland, PSS1B/EM5	3.C.(1)g. Sedge-willow tundra or 3.C.(1).I. Sedge-Dryas tundra	V.C.8b. Graminoid sod-form tundra
Vb. Moist Sedge/Barren Tundra Complex (frost-scar tundra)	82 Herbaceous Tundra	XI. Hummocky frost-heaved ground	None	Upland, PSS1B/EM5	Complex of 3.C(1)g. or 3.C(1)I. and barrens	V.C.8b. Graminoid sod-form tundra

App. C. (cont.)

1981 ANWR Landsat classification	Other Remote Sensor Land Cover Classifications: National USGS classification system, Level II (Anderson et al. 1976)	ANWR Landsat classification (Nodler and LaPerriere 1977)	Wetland Classifications: Pt. Storkerson wetlands (Bergman et al. 1977)	National Wetland Inventory (Cowardin et al. 1979)	Vegetation Classifications: Alaska, Level IV where possible (Viereck et al. 1981)	International (UNESCO 1973)
VIa. Moist Sedge Tussock, Dwarf Shrub Tundra (upland tussock tundra, acidic facies)	82 Herbaceous Tundra	IX.B) Tussock Meadow	None	Upland, PSS1B/EM5	3.C.(2)d. Sedge tussock-mixed shrub	V.C.8a. Graminoid bunch-form tundra
VIb. Moist Sedge Tussock, Dwarf Shrub Tundra (upland tussock tundra, alkaline facies	92 Herbaceous Tundra	IV.B) Tussock Meadow	None	Upland, PSS1B/EM5	3.C.(2)d. Sedge tussock-mixed shrub; 3.C(2)d. Sedge tussock-willow	V.C.8a. Graminoid bunch-form tundra
VIIa. Moist Dwarf Shrub, Sedge Tussock Tundra (upland dwarf shrub, tussock tundra)	82 Shrub Tundra	IV.B) Tussock Meadow	None	Upland, PSS1B/EM5	3.C(2)d. Sedge tussock-mixed shrub	V.C.8z. Graminoid bunch-form tundra
VIIb. Moist Dwarf Shrub, Sedge Tussock Tundra (birch tundra)	82 Shrub Tundra	IV.B) Tussock Meadow	None	Upland, PSS1B/EM5	2.3.(3)h. Dwarf birch-ericaceous shrub-sphagnum bog	IV.E. Mossy bog formations with dwarf shrub IV.D.1a. Ceaspitose dwarf-shrub moss tundra
VIIc. Moist Sedge Tussock, Dwarf Shrub/Wet Dwarf Shrub Tundra Complex (water track complex)	82 Mixed Tundra	IV.B) Tussock Meadow	None	Complex of Upland and PSS1B/EM5	Complex of 3.C(2)d. Sedge-tussock-mixed shrub and 2.B(3)n. Willow-sedge fen or 2.B(2)a. Low willow	V.C.8a. Graminoid bunch-form tundra
VIII. Shrub Tundra	82 Shrub Tundra	None	None	Upland	2B.(2) Closed low shrub	III.B.3b. Subalpine or sub-polar deciduous thicket
IXa. Partially vegetated areas (river bars)	77 Mixed Barren Land	IV. Partially vegetated ground	None	R4SB, R2FL, R3FL, R2BB, R3BB	Several types including: 3D.(1)a. Serial herbs 2.C.(1)h. Prostrate shrubs and herbs on floodplains 2.B.(3)b. Low willow	V.D.2b(3) Episodical forb communities III.B.3b. Subalpine or sub-polar deciduous thicket
IXb. Partially vegetated areas (alpine tundra)	77 Mixed Barren Land	IV. Partially vegetated ground	None	Upland	Several types including: 3.D.(1)c. Alpine herbs 3.D.(1)b. Alpine herb-sedge (snowbed) 2.C.(1)I. Mat and cushion-sedge tundra 2.C.(1)k. *Dryas* tundra 3.E.(2)a. Crustose lichens	V.C.7b. Alpine and subalpine meadows of higher latitudes
IXc. Partially vegetated areas (sorted stone nets)	77 Mixed Barren Land	IV. Partially vegetated ground	None	Upland	3E.(2)a. Crustose lichens 2.C.(1)g. Open lichen	None

IXd. Partially vegetated areas (beaches)	72 Beaches	IV. Partially vegetated ground	None	M2BBP, M2FLN, E2FLN	3.D(3)d. Halophytic wet meadow	None
IXe. Partially vegetated areas (sand dunes)	77 Mixed Barren Land	IV. Partially vegetated ground	None	Upland	3.A(4)c. Dune elymus	None
X. Barren gravel or rock	77 Mixed Barren Land	III. Barrens	None	Upland or R4SB, R2FL, R3FL, R2BB, R3BB	None or 3.E(2)a. Crustose lichens	None
XI. Wet gravel or mud	77 Mixed Barren Land	III. Barrens	None	Upland or R4SB, E2FL, R2FL, R3FL, R2BB, R3BB	None	None
XII. Ice	90 Perennial Snow or Ice	I. Ice, snow, aufeis	None	None	None	None

APPENDIX D: SOIL TAXONOMY

The word "soil," as used in this report, refers to the thawed layer of ground observed in August. The nomenclature is that of the U.S. Department of Agriculture, Soil Conservation Service Manual 430, 1981 Draft and Handbook 436 (Soil Survey Staff 1975) unless otherwise noted in the text.

Of the ten soil orders recognized in *Soil Taxonomy* (Soil Survey Staff 1975), four are found in ANWR (App. A). Soils belonging to the order Mollisols are extensive. They occur in all terrain types, particularly in the Foothills and Hilly Coastal Plain. Mollisols are dark-colored mineral soils. The dark color is a reflection of at least 2.5% organic carbon in the upper 18 cm of the profile. In addition to the dark color, Mollisols have a base saturation greater than 50%, i.e. Mollisols are neutral or slightly alkaline in reaction (pH). Wet Mollisols are classified as Aquolls, *aqu* indicating an aquic (reducing) moisture regime and *oll* indicating the soil order Mollisols. The prefix *Cry* appears at the Great Group level of classification for all soils found in ANWR and indicates a mean annual temperature less than 8 °C. The term Pergelic (permanently frozen) appears at the subgroup level of all ANWR soils. Thus, Pergelic Cryaquoll defines a cold, wet, dark-colored, base- and organic-rich mineral soil underlain by permanently frozen material. Pergelic Cryaquolls occurring in very wet areas may have a surface horizon with greater than 20 but less than 40 cm of organic material. These soils are designated as Histic Pergelic Cryaquolls (the term Histic indicates an organic surface horizon greater than 20 cm thick). Mollisols on well-drained sites are termed Pergelic Cryoborolls.

Inceptisols are mineral soils that have only weakly differentiated soil horizons. This is due primarily to the ineffectiveness of the leaching process in the cold, wet tundra. Organic carbon in the Inceptisols is not evenly distributed in a distinct mollic epipedon (dark-colored, base-rich surface horizon) as in the Mollisols. Aquepts (*ept* indicates the soil order) are wet Inceptisols that commonly show some degree of mottling (iron oxidation) in the mineral soil below the organic surface horizon. Mineral soils generally are gray, reflecting a saturated, reducing environment. In some cases an organic surface horizon greater than 20 cm thick forms the epipedon (surface horizon) and the soils are termed Histic Pergelic Cryaquepts. Wet Inceptisols lacking such an epipedon are simply termed Pergelic Cryaquepts. Most Cryaquepts show some quantity of organic matter mixed in the subsurface horizons, presumably concentrating at or near the seasonal permafrost table. Many Cryaquepts developed in silt, silt loam, or fine sandy loam materials display thixotropic characteristics and will flow spontaneously upon vibration. Cryaquepts are common components of soil complexes and are often associated with Mollisols, particularly where they occur in frost scars. In such cases the complex is termed Ruptic-(interrupted) Cryaqueptic Cryaquoll. The term Entic (Entisol) may replace Cryaqueptic if frost-scar soils show little or no horizon development.

Relatively well drained and stable sites, especially on ridge crests, have Pergelic Cryumbrepts, which are Inceptisols with an umbric (dark-colored, base-poor) surface horizon underlain by an acid (base-poor) subhorizon. Similar soils lacking the umbric surface horizon are usually designated Cryochrepts.

Entisols are soils with little or no horizon development. They are common on unstable sites such as sand dunes, flood plains and talus areas. Cryopsamments are sandy Entisols that are subject to blowing and drifting. Cryorthents are coarser and are composed of gravels, rocks and materials found in recent mudflows, glacial deposits and stabilized river alluvium.

Perhaps the least extensive and least predictable in occurrence are the organic soils (Histosols). These soils have a surface horizon composed of greater than 40 cm of organic materials and generally greater than 60% organic matter overlying gray, sometimes mottled, fine-textured mineral materials. Normally these soils are very wet, to the extent that the organic materials are buoyant or partially so. They occur on flat areas, either on ridge crests or in lowlands. Three taxa of cold Histosols are recognized: Pergelic Cryofibrists (fibrous, low-density organic matter), Pergelic Cryosaprists (nonfibrous, highly decomposed and dense organic matter) and Cryohemists (intermediate organic matter characteristics). Histosols may have any pH, although in ANWR most are nearly neutral in reaction.

APPENDIX E: SUMMARY OF PRINCIPAL LANDSAT LAND COVER CATEGORIES WITHIN THE TERRAIN TYPES OF THE ANWR STUDY AREA, WITH ASSOCIATED LANDFORMS, SOILS AND VEGETATION

Terrain Type	Principal Landsat land cover categories	Percent of total ANWR study area	Principal landforms	Principal soils	Typical vegetation communities
Thaw Lake Plains	III. Wet Sedge Tundra (includes saline facies)	1.4	Disjunct low-centered polygons Strangmoor Low-centered polygons Low hummocks	Histic Pergelic Cryaquepts Pergelic Cryaquepts Pergelic Cryohemists Pergelic Cryofibrists	WET Carex aquatilis, Eriophorum angustifolium, Drepanocladus spp. SEDGE TUNDRA AQUATIC Carex aquatilis SEDGE TUNDRA WET Carex subspathacea, Puccinellia phryganodes SEDGE TUNDRA (in saline areas)
	I. Water	0.6	Ponds and lakes	None	None
	IV. Moist/Wet Sedge Tundra Complex	0.4	Low-centered polygons Low hummocks Mixed high- and low-centered polygons	Pergelic Cryaquolls Pergelic Cryaquepts Pergelic Cryosaprists Histic Pergelic Cryaquepts	MOIST Eriophorum triste, Dryas integrifolia, Tomenthypnum nitens, Thamnolia subuliformis SEDGE, PROSTRATE SHRUB TUNDRA MOIST Carex aquatilis, Salix pulchra, Salix rotundifolia, Dicranum spp. PROSTRATE SHRUB TUNDRA MOIST Carex spp., Dryas integrifolia, Salix rotundifolia, Dicranum spp., Ochrolechia frigida SEDGE, PROSTRATE SHRUB, CRUSTOSE LICHEN TUNDRA WET Carex aquatilis, Eriophorum angustifolium, Drepanocladus spp. SEDGE TUNDRA
	II. Pond/Sedge Tundra Complex or Aquatic Tundra	0.3	Ponds, lakes Strangmoor Mixed polygons	Histic Pergelic Cryaquepts Pergelic Cryaquepts Pergelic Cryofibrists Pergelic Cryohemists	AQUATIC Carex aquatilis SEDGE TUNDRA AQUATIC Arctophila fulva GRASS TUNDRA WET Carex aquatilis, Eriophorum angustifolium, Drepanocladus spp. SEDGE TUNDRA
Hilly Coastal Plains	V. Moist Sedge, Prostrate Shrub Tundra or Moist Sedge/Barren Tundra Complex	8.4	Flat-centered polygons Disjunct low-centered polygons Featureless, low hills Frost scars	Pergelic Cryaquolls Pergelic Cryaquepts Pergelic Cryofibrists Ruptic-Entic Pergelic Cryaquolls	MOIST Carex bigelowii, Eriophorum triste, Salix arctica, S. pulchra, Dryas integrifolia, Tomenthypnum nitens, Hylocomium splendens, Cetraria spp. SEDGE, PROSTRATE SHRUB TUNDRA MOIST Eriophorum vaginatum, Dryas integrifolia, Carex bigelowii, Tomenthypnum nitens, Hylocomium splendens, Cetraria spp. TUSSOCK SEDGE, PROSTRATE SHRUB TUNDRA DRY Petasites frigidus, Arctagrostis latifolia, Salix rotundifolia, Juncus biglumis BARREN (on frost scars; inter-frost-scar areas have previous two communities)
	IV. Moist/Wet Sedge Tundra Complex	7.3	See same land cover heading for Thaw Lake Plains		
	III. Wet Sedge Tundra	5.1	See same land cover heading for Thaw Lake Plains (excludes saline facies)		

Terrain Type	Principal Landsat land cover categories	Percent of total ANWR study area	Principal landforms	Principal soils	Typical vegetation communities
Foothills	VI. Moist Sedge Tussock, Dwarf Shrub Tundra	24.1	Featureless hillcrests and slopes Flat-centered polygons	Pergelic Cryaquolls Pergelic Cryaquepts Pergelic Cryosaprists	MOIST Eriophorum vaginatum, Betula nana, Salix pulchra, Ledum decumbens, Vaccinium uliginosum, V. vitis-idaea, Sphagnum spp., Hylocomium splendens, Cladonia spp. TUSSOCK SEDGE, DWARF SHRUB TUNDRA
	V. Moist Sedge, Prostrate Shrub Tundra or Moist Sedge/Barren Tundra Complex	13.7	See same land cover heading for Hilly Coastal Plains		
	VII. Moist Dwarf Shrub, Sedge Tussock Tundra	3.1	Featureless hillcrests and slopes Palsas	Pergelic Cryaquolls Pergelic Cryaquepts Pergelic Cryosaprists	MOIST Betula nana, Salix pulchra, Eriophorum vaginatum, Vaccinium spp., Ledum decumbens, Sphagnum spp. DWARF SHRUB, TUSSOCK SEDGE TUNDRA MOIST Betula nana, Ledum decumbens, Sphagnum spp. DWARF SHRUB TUNDRA
	or Moist Sedge Tussock, Dwarf Shrub/Wet Dwarf Shrub Complex		Water track complexes	Pergelic Cryohemists Pergelic Cryofibrists Histic Pergelic Cryaquepts (in water tracks)	MOIST Eriophorum vaginatum, Betula nana, Salix pulchra, Ledum decumbens, Vaccinium spp., Sphagnum spp., Hylocomium splendens, Cladonia spp. TUSSOCK SEDGE, DWARF SHRUB TUNDRA WET Salix pulchra, Betula nana DWARF SHRUB TUNDRA (in water tracks)
Mountainous Terrain	IX. Partially vegetated areas	0.02	Solifluction lobes and terraces Sorted and nonsorted stone nets and stripes Block fields Talus slopes	Pergelic Cryorthents Pergelic Cryochrepts Pergelic Cryaquepts	MOIST Carex microchaeta, Dryas octopetala, Salix rotundifolia, S. chamissonis, Saxifraga bronchialis, Hylocomium splendens, Cladina spp. SEDGE, PROSTRATE SHRUB, FORB TUNDRA DRY Dryas octopetala, Salix reticulata, Carex microchaeta, Geum glaciale, Rhytidium rugosum, Cetraria spp. PROSTRATE SHRUB TUNDRA DRY Umbilicaria spp., Lecidea spp., Rhizocarpon spp. LICHEN, BARREN TUNDRA (on rocks)
	X. Barren gravel or rock	0.009	Talus slopes Bedrock	None	None or DRY Umbilicaria spp., Lecidea spp., Rhizocarpon spp., LICHEN, BARREN TUNDRA
River Flood Plains	III. Wet Sedge Tundra	8.4	See same land cover heading for Thaw Lake Plains		
	IV. Moist/Wet Sedge Tundra Complex	6.1	See same land cover heading for Thaw Lake Plains		
	or Dry Prostrate Shrub, Forb Tundra		River terraces with reticulate pattern Featureless stabilized dunes	Pergelic Cryopsamment	DRY Dryas integrifolia, Salix reticulata, Astragalus alpinus, Equisetum arvense, Carex membranacea, Oxytropis nigrescens, Distichium capillaceum PROSTRATE SHRUB, FORB TUNDRA

V. Moist/Wet Sedge, Prostrate Shrub Tundra or Moist Sedge/Barren Tundra Complex	4.2	See same land cover heading under Hilly Coastal Plains		
IX. Partially vegetated areas	1.25	River islands, bars and terraces, deltas Sand dunes	Pergelic (Fluventic)* Cryorthents Pergelic Cryopsamments	DRY Salix alaxensis, Salix spp., Arctostaphylos rubra, Hedysarum alpinum, Castilleja caudata, Oxytropis campestris, Astragalus alpinus MEDIUM SHRUB, FORB, BARREN TUNDRA DRY Epilobium latifolium, Artemisia arctica, Castilleja caudata, Androsace chamaejasme, Bromus pumpellianus, Festuca rubra FORB, GRASS, BARREN TUNDRA DRY Dryas integrifolia, Oxytropis nigrescens, Salix ovalifolia, Artemisia borealis PROSTRATE SHRUB, BARREN TUNDRA
X. Wet gravel or mud	2.06	River channels	Pergelic Cryorthents	None

* Unofficial taxonomic name.

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1. Arctic National Wildlife Refuge. 2. Geobotanical mapping. 3. Landsat. 4. Mapping. 5. Soils. 6. Vegetation classification.
(see Card 2)

Walker, D.A.
Landsat-assisted environmental mapping....
1982 (Card 2)

I. Acevedo, W. II. Everett, K.R. III. Gaydos, L. IV. Brown, J. V. Webber, P.J. VI. United States. Army. Corps of Engineers. VII. Cold Regions Research and Engineering Laboratory, Hanover, N.H. VIII. Series: CRREL Report 82-37.

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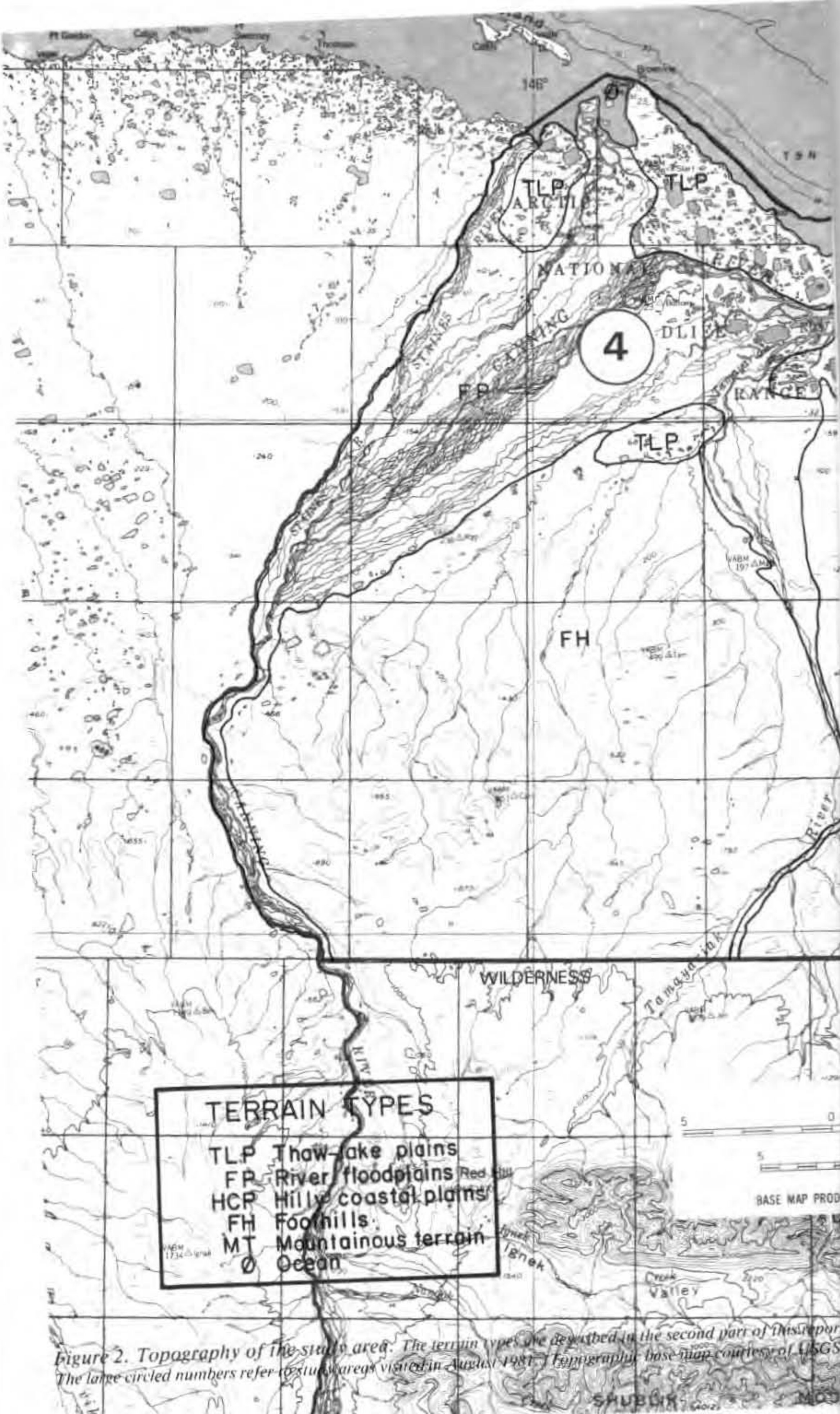
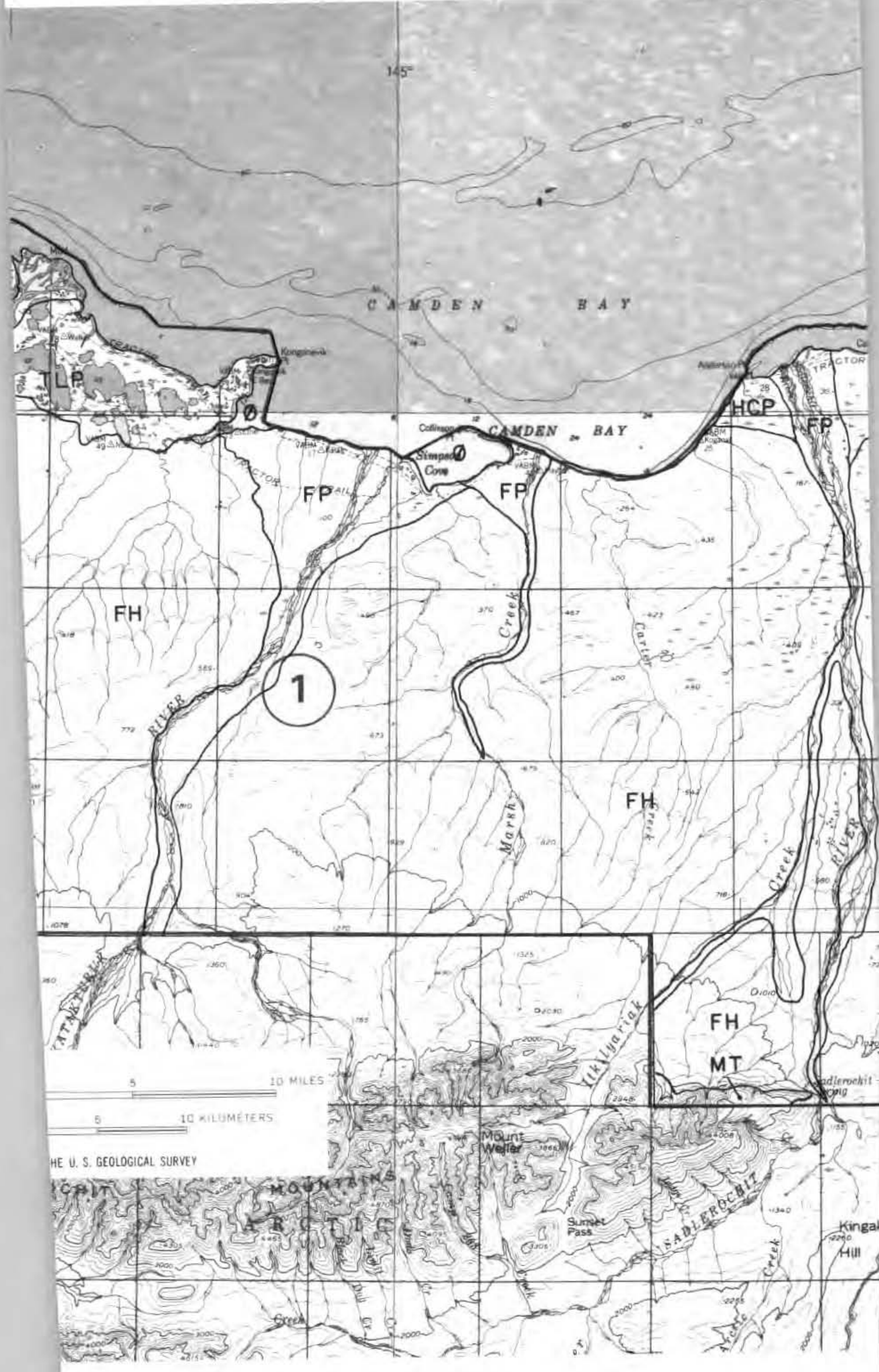
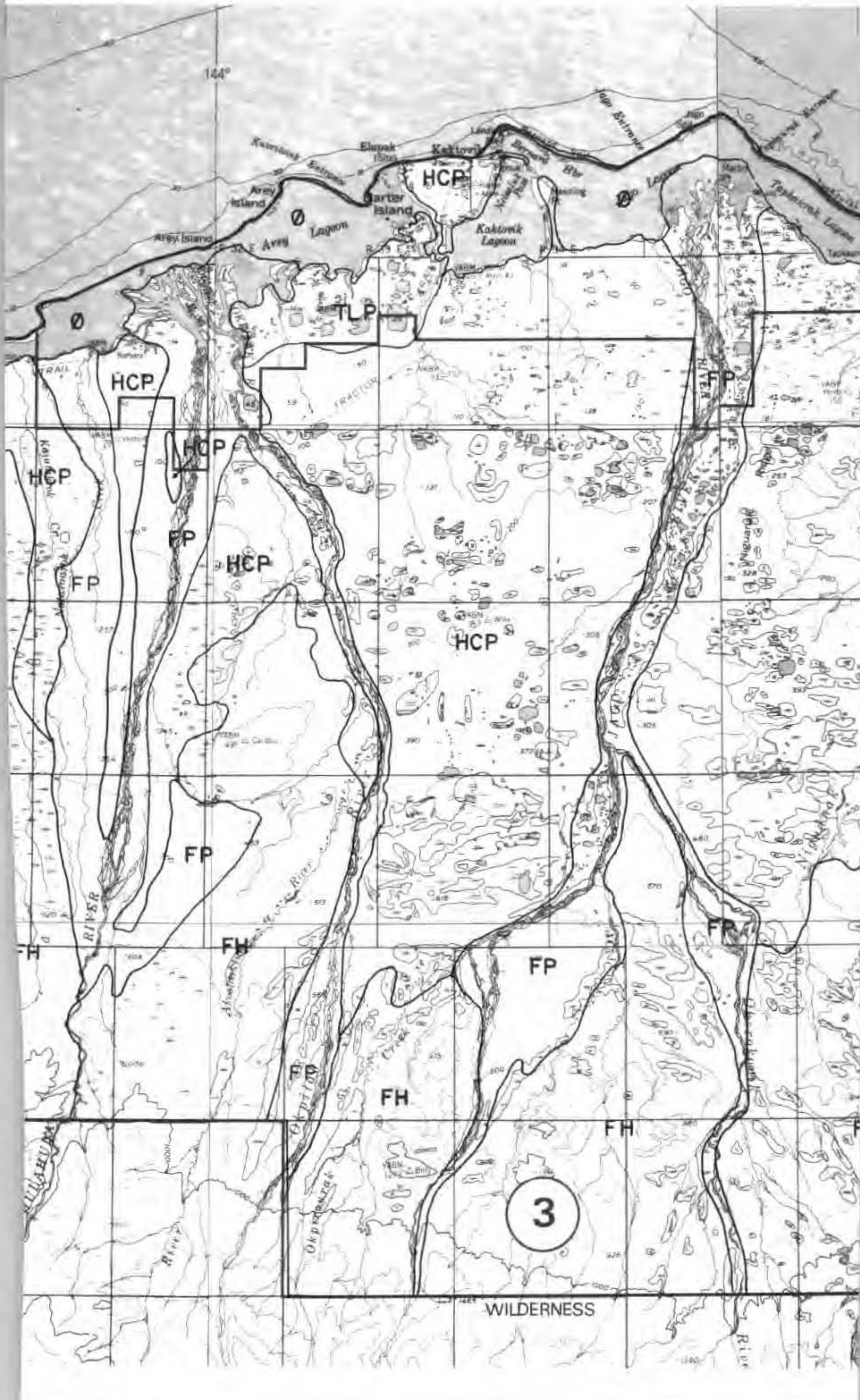


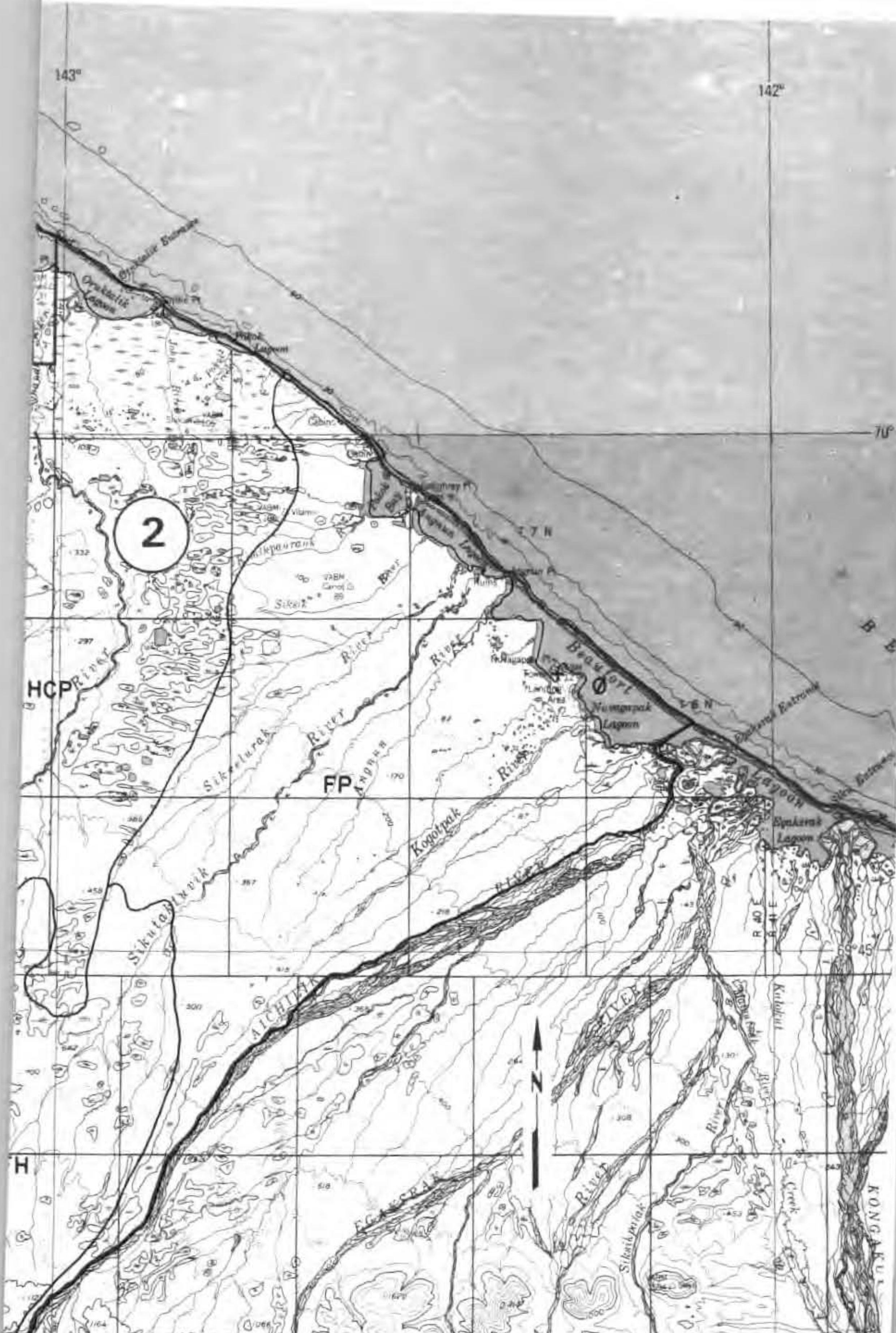
Figure 2. Topography of the study area. The terrain types are described in the second part of this report. The large circled numbers refer to study areas visited in August 1981. (Topographic base map courtesy of USGS.



145°
CAMDEN BAY
TLP
HCP
FP
FH
MT
Kongmeruk
Collinson
Simpson Cove
TRACTOR
Creek
Carter
Marsh
RIVER
Creek
FH
1
Mount Weller
Sunset Pass
SADLEROCHIT
MOUNTAINS
ARCTIC
Kingak Hill
Sadlerochit Spring
Itkilyariak
5 10 MILES
5 10 KILOMETERS
THE U. S. GEOLOGICAL SURVEY



144°
Kaktovik
Barter Island
Arey Island
Arey Lagoon
Kaktovik Lagoon
Ø
HCP
TLP
FP
FH
TRAIL
RIVER
3
WILDERNESS



143°
142°
70°
2
HCP
FP
H
Beaufort
Lagoon
Nuvagapak Lagoon
Siksrak Lagoon
Sikulatuvik
Sikselurak
River
Angnun
Kogotpak
Aichilik
Egaksrak
Kongakut
Kukulik
Creek
Sikrikpilak
Ekaluakat
Cabins
Ruins
Kingak
Lagoon
N