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# VEGETATION MAPPING OF THE NATIONAL PETROLEUM RESERVE IN ALASKA USING LANDSAT DIGITAL DATA

By L. A. Morrissey and R. A. Ennis

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## ABSTRACT

The general vegetation associations of the 97,000-square-kilometer National Petroleum Reserve in Alaska have been mapped using computer-aided analysis of Landsat digital data. Digital analysis techniques used in the NPRA project utilized several computers which made it possible to use the most efficient system for each specific processing task. The land cover classification scheme devised was based on plant communities optimally delineated with multispectral data. The ten land cover categories include wet Meadow Tundra, Moist Meadow Tundra, Moist Meadow-Tussock Tundra Complex, Moist Tussock Tundra, Dry Mat and Cushion Tundra, Riparian Shrubland, Barrens, Deep Water, Shallow and Sedimented Water, and Ice and Snow. Recommendations for further research and potential applications for maximum utilization of the NPRA classification are discussed.

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# INTRODUCTION

The immense size, inaccessibility, and harsh climatic conditions of the North Slope of Alaska make the acquisition of resource information very difficult. Vegetation mapping projects on the North Slope to date have been either site specific or highly generalized. Vegetation maps produced by the Institute of Arctic and Alpine Research, University of Colorado, as part of the Research on Arctic Tundra Environments Program (RATE) include relatively small, intensively studied test sites (1:10,500 and 1:21,000 scale) (Komarkova and Webber, 1980). Highly generalized vegetation maps include the Major Ecosystems of Alaska map (Joint Federal-State Land Use Planning Commission for Alaska, 1973) and the Potential Natural Vegetation Map of Alaska by Kuchler (U.S. Geological Survey, 1970). Both maps delineate broadly defined vegetation units at small scales (1:2,500,000 and 1:7,500,000). There exists a great need for a vegetation map of the entire North Slope which delineates useful vegetative communities with a high degree of accuracy and resolution.

Landsat digital data provide an attractive alternative to traditional photointerpretation methods in remote and extensive regions such as the North Slope of Alaska. Two satellites in phased orbits scan the same 185-kilometer-square area on the ground at the same time of day every 9 days (Taranik, 1978). The resolution of the system is 80 meters but overlap along scan lines results in individual pixels (picture elements) measuring 79 by 57 meters (approximately 0.45 hectare). Measurements of reflected electromagnetic radiation from each pixel are made in four wavelength bands, the visible green (0.5 to 0.6 microns), visible red (0.6 to 0.7 microns), and two near infrared (0.7 to 0.8 and 0.8 to 1.1 microns). Each scene contains 7.58 million pixels of four-band data.

Computer-aided analysis techniques have been developed to effectively generate maps and statistics from Landsat digital data. Several vegetation mapping projects within Alaska have utilized these techniques. The U.S. Fish and Wildlife Service is exploring the use of Landsat data for compiling an inventory of wetlands in Alaska as part of the National Wetlands Inventory. Virginia Carter, U.S. Geological Survey (USGS), and James Morrow, Jet Propulsion Laboratory, have investigated the feasibility of using Landsat digital data for wetland studies. Their study involved supervised clustering and classification of three test sites on the North Slope (Carter and Morrow, 1977, unpublished field trip report). The feasibility of using Landsat digital data for caribou habitat mapping in western Alaska has been investigated by Lent and LaPerrier (1974). Researchers from the University of Alaska have completed a number of land resource projects in Alaska (Lyon and George, 1979). In conjunction with the Alaska Southcentral Water Resources Level B Study, University of Alaska researchers have completed a regional resource inventory using Landsat Multispectral scanner (MSS) data for southcentral Alaska (Krebs and others, 1978). George and others (1977) have completed a reindeer range inventory of portions of the Seward Peninsula, Alaska, from Landsat digital data. Ecosystem units and coastal processes in four regions of the Alaskan coastal zone have been mapped with Landsat digital data (Belon and others, 1975; Miller and

George, 1976). As part of NASA's Applications Systems Verification and Transfer Program, with the Bureau of Land Management, researchers of the University of Alaska and USGS have recently completed an inventory of wild land resources in the Denali area (Miller and others, 1978).

USGS researchers have also been experimenting with Landsat in support of the Survey's national land use and land cover mapping effort (Ellefsen and others, 1977). Although this national effort relies upon high-resolution, high-altitude photographs, experience gained by those working with Landsat digital data indicates that it can be a reliable substitute for mapping certain vegetative cover classes in wild land areas at a detail comparable to that being achieved in the national program.

The National Petroleum Reserve in Alaska (NPRA) is the subject of an intensive planning effort as directed by the Naval Petroleum Reserve Production Act of 1976. The USGS was responsible for compiling a resource inventory in compliance with Section 105B, Environmental Impact Assessment. The Bureau of Land Management (BLM) was responsible for Section 105C, Land Use Study. Both efforts required a comprehensive vegetation map of the region. The USGS has mapped the vegetation of the 97,000-square-kilometer NPRA using Landsat digital data. This mapping also served as a prototype for producing USGS land use and land cover maps using Landsat digital data rather than high-altitude photographs as primary source material. If successful, these techniques can be applied in other high interest areas of the State to gradually build up a series of land use and land cover maps for Alaska.

## Study Area

The National Petroleum Reserve in Alaska, located on the North Slope of the Brooks Range, is bounded by the Beaufort Sea to the north, the Chukchi Sea to the west, the crest of the Brooks Range to the south, and the Colville River to the east (fig. 1). This large expanse of tundra includes three major physiographic provinces (Wahrhaftig, 1965): the Arctic Coastal Plain, the Arctic Foothills, and the Brooks Range. The Arctic Coastal Plain is characterized by thousands of lakes, extensive wetlands and polygonal ground features. The Arctic Foothills consist of tussock tundra on rolling terrain. The Brooks Range, with elevations up to 1,500 meters within the NPRA, is characterized by glaciated shale and sandstone outcrops supporting low-lying mat and cushion vegetation. The following discussion on tundra vegetation reflects the contributions of numerous investigators (Britton, 1967; Spetzman, 1959; and Murray, 1978).

Vegetation of the Arctic Coastal Plain consists of a mosaic of plant communities that reflect the patterns of ice wedge cracks of polygonal ground features. Polygonal ground patterns are produced by contraction of the ground in response to filling of the cracks by water, widening of the cracks by freezing and thawing in succeeding winters, and incremental expansion of the ice wedges (Lachenbruch, 1963). The size of the polygons vary from a few meters to 50 meters across. Polygonal patterns are the surficial expression of the vertical ice wedges and are of two general types: high-centered and low-centered polygons. High-centered polygons are characteristic of areas of integrated drainage with coarse

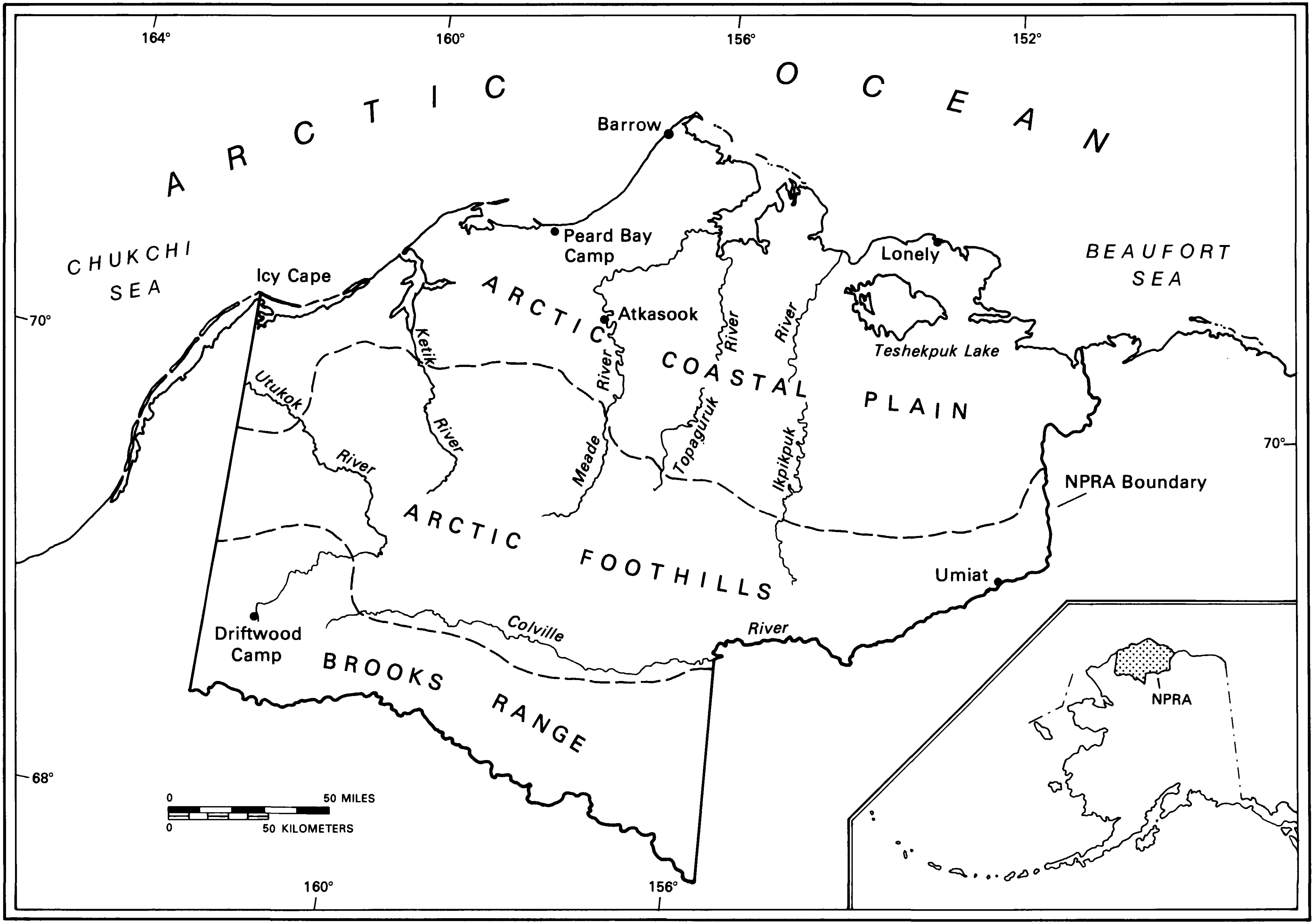


Figure 1.--Location map.

materials. They support mainly tussock-forming sedges in the center with marsh species along the troughs. Low-centered polygons have depressed cores with elevated rims and support grasses, sedges, mosses, and various forbs.

Tussock tundra is the dominant community of the Arctic Foothills province. Wet meadows occupy the low depressions and dry meadows with low mat and cushion vegetation cover the summits and ridges. Alder and willow thickets are found along major rivers and streams.

In the Brooks Range, rock outcrops on mountain ridges, and talus and rubble slopes in the higher elevations are sparsely vegetated while dry meadows occupy lower slopes and interfluves. Wet, boggy meadows are found adjacent to streams and lakes. Tussock tundra covers well-drained, gentle slopes.

Herbaceous perennials and prostrate shrubs are the most abundant life form in the Arctic (Johnson and Tieszen, 1973). Up to three layers can usually be distinguished in tundra plant communities. Meadow communities are represented by a surface layer of bare soil or moss with an upper layer of sedges, grasses, and shrubs. Tussock tundra areas consist of a base of moss or lichen, with an intermediate layer of heath and forbs, and an upper layer of tussock-forming sedges and prostrate shrubs. The layers are usually poorly developed since the total height of the vegetation rarely exceeds 45 centimeters.

Vegetation is one of the primary components of the Arctic Landscape and it is a fairly reliable and useful indicator of other environmental and ecological relationships. The interaction of Arctic plant communities with soils, soil moisture, depth of summer soil thaw, drainage, ground ice content of soil, and polygonal type has been summarized in table 1.

## LANDSAT DATA PREPARATION

### Acquisition of Landsat Scenes

Landsat scenes were selected on the basis of cloud cover, season of the year, and orbital path. Complete coverage of NPRA was obtained with portions of ten Landsat scenes. Dates range from July 6 to August 26, in a 2-year time span (1975-1976). All but one of the original ten scenes were cloud-free, and each frame was one of a pair or triplet of sequential scenes along an orbital path (fig. 2). From west to east, frame overlap was as great as 50 percent. This overlay was necessary to cover the entire NPRA, and allowed numerous options for the final mosaicking. One cloudy scene (covering the Barrow area) was replaced with a cloud-free scene from July 1977 after the preliminary classification was complete.

### Computer Systems

Digital image analysis techniques, developed by USGS analysts at NASA-Ames Research Center, utilized several computers for the NPRA mapping project (fig. 3) which made it possible to use the most efficient system for each specific processing task.

Table 1.--Plant communities in relation to landscape elements.

| Community | Depth of[2] Soil Thaw | Soil[2] Moisture | Drainage[3] | Ground Ice[4] Content | Ice Wedge[5] Polygons | Soil Type[6] |
|---|---|---|---|---|---|---|
| Dry Mat and Cushion Tundra[1] | deep | low | integrated | low | N/A | Arctic Brown |
| Moist Tussock Tundra | shallow | low | integrated | high | high-centered | Plant Tundra |
| Moist Meadow-Tussock Tundra Complex | intermediate | intermediate | integrated | intermediate | high and low-centered | Upland Tundra |
| Moist Meadow Tundra | intermediate | intermediate | impeded | low | low-centered | Meadow Tundra |
| Wet Meadow Tundra | shallow | high | impeded | low | low-centered | Meadow Tundra |

Sources:

[1] Johnson and Tieszen 1973

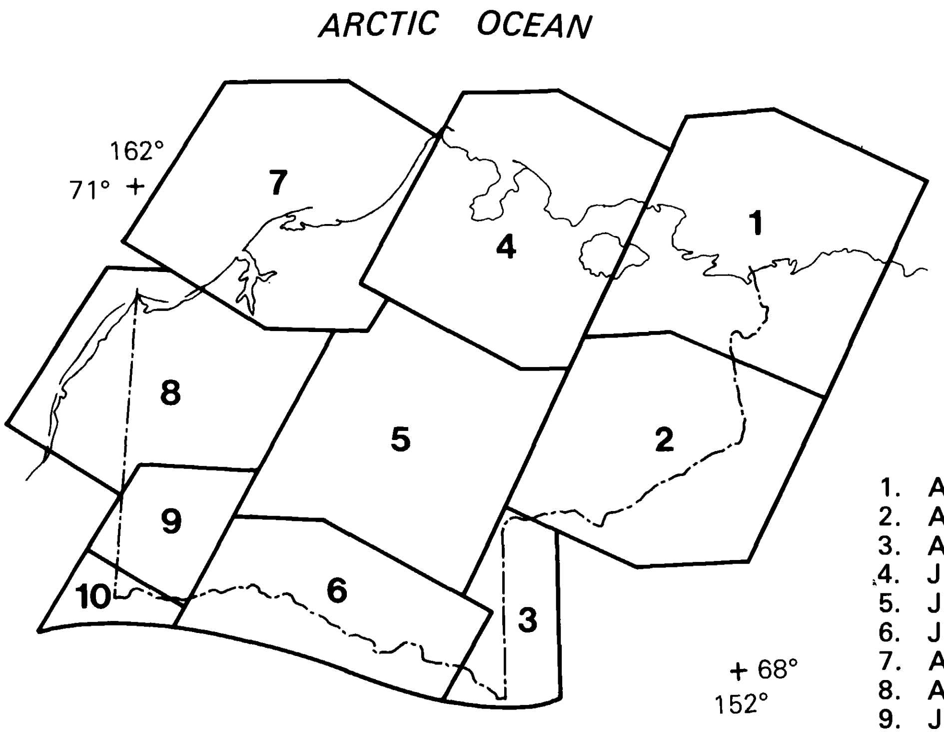
[2] Webber and others 1977

[3] Everett 1975

[4] Hussey and Michelson 1966

[5] Webber and Walker 1975

[6] Tedrow 1977



| | | |
|---|---|---|
| 1. | AUGUST 1, 1976 | 2557–21150 |
| 2. | AUGUST 1, 1976 | 2557–21152 |
| 3. | AUGUST 1, 1976 | 2557–21155 |
| 4. | JULY 12, 1977 | 2182–21175 |
| 5. | JULY 23, 1975 | 2182–21400 |
| 6. | JULY 23, 1975 | 2182–21403 |
| 7. | AUGUST 25, 1976 | 2581–21484 |
| 8. | AUGUST 25, 1976 | 2581–21491 |
| 9. | JULY 6, 1975 | 2165–21461 |
| 10. | JULY 6, 1975 | 2165–21463 |

Figure 2.--Index to Landsat scenes used in the NPRA analysis.

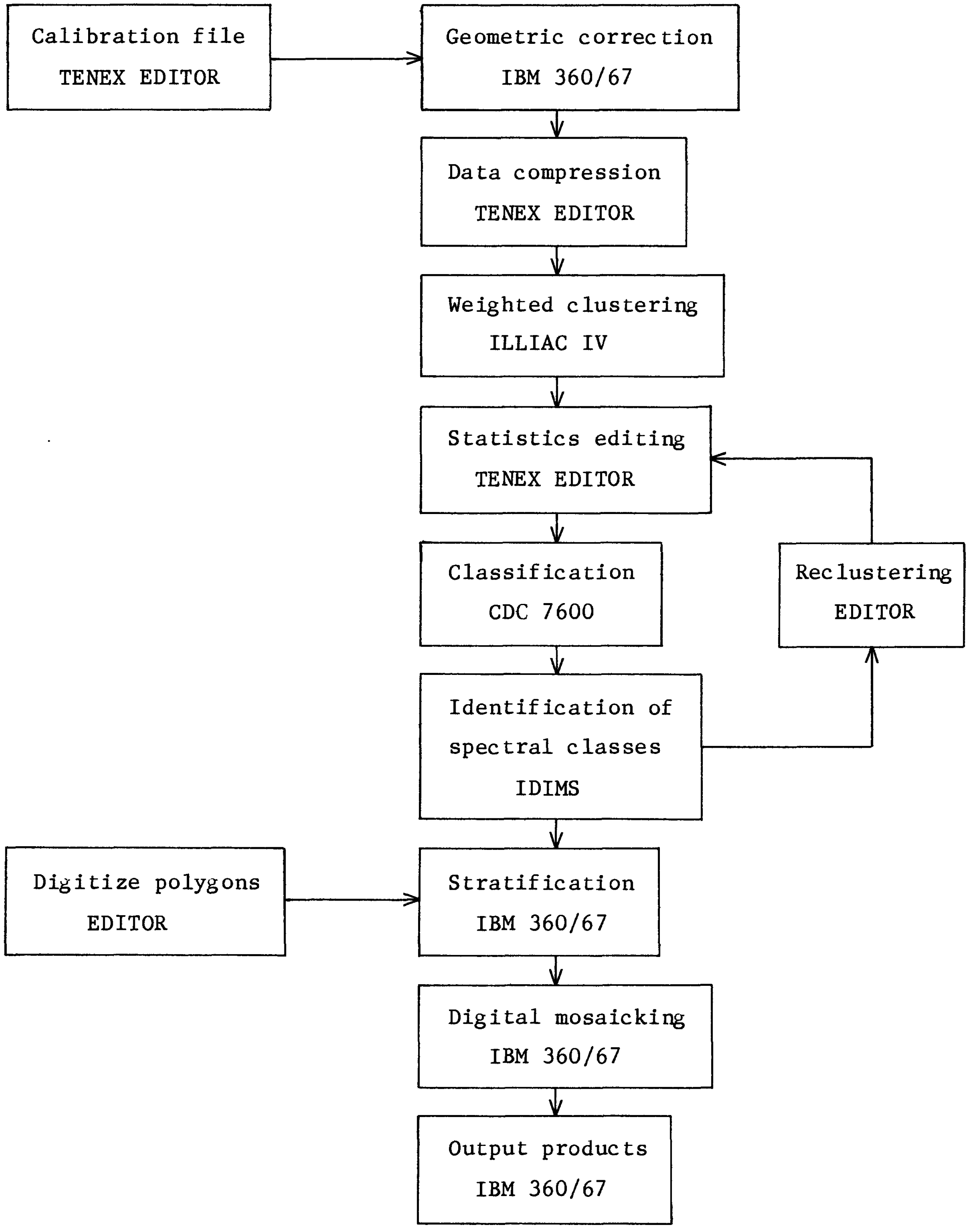


Figure 3.--Major processing tasks and computer systems utilized for the NPRA analysis.

The ERTS Data Interpreter and TENEX Operations Recorder (EDITOR) software package, developed by the Center for Advanced Computation, University of Illinois at Urbana-Champaign, provided the mainstay of the interactive image analysis capability. The EDITOR package is available on the TENEX (modified DEC System PDP-10) at Bolt, Beranek, and Newman, Inc. (BBN) and on the ILLIAC IV parallel processing computer at Ames Research Center. Both computers are on the Advanced Research Projects Agency (ARPA) Network. Access to the ARPA Network allowed optimum use of four computers: the TENEX and ILLIAC IV as well as the IBM 360/67 at Ames and the IBM 360/91 at the University of California at Los Angeles. The IBM 360/91 was used for geometric correction tasks, while the IBM 360/67 was used for reformatting, display, and stratification. Interactive analysis was done on the TENEX while the efficiency of the ILLIAC IV was utilized for large clustering runs. Off-net computers included the CDC 7600 for maximum likelihood classification and the HP 3000 and Comtal Display with IDIMS (Interactive Digital Image Manipulation System) software for class identification and verification.

## Geometric Correction

The multispectral scanner data were geometrically corrected to remove distortions inherent in the data and to permit registration to a map base. The data were reformatted to remove skew caused by the Earth's rotation beneath the satellite track and then rotated to north. Approximately 15 control points were distributed throughout each scene. The control points were located on a 1:500,000-scale Landsat Band 7 image and the corresponding topographic maps at 1:250,000 scale. Using EDITOR software and a digitizer, the latitude and longitude from topographic maps and row and column coordinates from the Landsat data of these points were recorded. Calibration files relating row and columns coordinates to latitude and longitude, were established using a least-squares linear transformation between the two coordinate systems.

Parameters from the calibration file were then computed to establish a reference system of row and column coordinates to latitude and longitude coordinates. This calibration file made it possible to use maps for data extraction, analysis, and display (Gaydos and Newland, 1978).

## IMAGE CLASSIFICATION

### Clustering and Classification

Clustering and classification strategies adopted by the authors for processing of the NPRA data involved an initial unsupervised approach, modified by the use of supervised techniques in the final classification. In an unsupervised approach, multispectral data is partitioned into a number of spectrally distinct groups, whereas the supervised approach develops clusters based on the spectral content of selected land

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cover sites. The large number of Landsat scenes, cost, and time constraints necessitated an initial unsupervised approach which with ground visits and color infrared (CIR) photographs provided the basis for improvement of the classifications by supervised techniques.

Distinct groupings of the multispectral data from the four bands were established using cluster analysis procedures first implemented for remote sensing purposes at the Laboratory for Applications of Remote Sensing, Purdue University (Swain, 1972) and later incorporated into the EDITOR system by the Center for Advanced Computation (Ray and others, 1975).

A data reduction program available in EDITOR subsequently enables clustering of an entire Landsat scene on the ILLIAC IV. The program maintains a count of the number of pixels which have the same reflectance values in the four bands. Though the data reduction program will condense an entire scene, grouping of spectral values must be made if scene contrast is great. To eliminate possible "round-off" errors that would result, only one quarter of the data (every other line and column) in each Landsat scene was utilized. The resulting 25 percent sample far exceeded the 0.3 of one percent sample (TENEX limitation) possible without data reduction. The much larger sample increases the probability of sampling nonextensive land cover types.

This "weighted file" created with the reduction program on the TENEX at BBN was then transferred over the ARPA Network to the ILLIAC IV where it was clustered into a number of spectrally distinct clusters as specified by the analyst. Depending on the complexity of the scene, between 20 and 40 clusters were specified for each. Clustering time on the ILLIAC IV for each scene of four bands ranged from 8 to 56 seconds, varying with spectral complexity of the scene. Each cluster provided a set of statistics, including mean, variance, and covariance matrix of the four-band data. Preliminary examination of the statistics, including separability (distance between cluster means), determined whether the clusters were statistically distinct. Clusters with few points or with high variances (greater than 10) were deleted while clusters with low (less than 0.75) separability, indicating spectral overlap, were pooled. Statistics were transferred to the IBM 360/67 to be punched on cards. The card decks were used on the CDC 7600 where a maximum likelihood classification was performed on the full scenes, assigning each pixel to the specific cluster it most nearly resembled. The assumption is made in the unsupervised approach that the spectral classes correspond to the desired resource categories and represent most of the spectral variability within the scene.

An examination of the statistics suggested groupings of spectral classes that reduced the number of spectral classes for each frame to 10 resource types. This made it possible to assign a distinct color to every grouped class for display on a film recorder. Four- by five-inch negatives were produced and enlarged to a scale of 1:250,000 to fit available USGS quadrangle maps.

## Ground Data Collection

The Bureau of Land Management (BLM) provided logistic support for the 5-week field season in 1977. The crew included personnel from BLM, two botanists from the University of Alaska, two wildlife biologists from Alaska State Fish and Game Service, and three geographers from USGS. The classifications of each of the ten scenes were initially evaluated in two ways. Lineprinter maps generated on the IBM 360 at 1:24,000 scale were used for individual class identification, while film recorder color enlargements at 1:250,000 scale derived from unsupervised classification provided the basis for regional land cover verification.

Thirty field sites were chosen by BLM personnel for intensive study. The selected sites were digitized from topographic maps, the data extracted from the data tapes, and displayed as lineprinter maps at a scale of 1:24,000. Within each field site, homogeneous land cover types were delineated and located in the field. Due to the great distances between field sites and inaccessibility of the region, a helicopter was required to transport field crews.

Within each field site, a number of spectrally homogeneous areas were visited. Information including ground photographs, species listings, density, diversity, slope, drainage, soil, and vegetation/terrain relationships were recorded. Vertical aerial photographs recorded specific ground cover components and horizontal photographs were taken to give an indication of the overall appearance of the vegetation. Aerial photographs from the helicopter recorded vegetation along flight traverses.

Regional land cover patterns were delineated from the film recorder enlargements. Land cover types were identified on the enlargements while flying between intensive field sites. The identification of extensive land cover types on the enlargements further verified conclusions drawn from the intensive field sites.

Many of the sites were covered by multiple Landsat frames. This enabled identification of spectral classes from more than one scene per field site. The comparison and evaluation of the accuracy of classes from overlapping scenes also provided the basis for later decisions concerning mosaicking of the ten scenes.

The location of base camps at Driftwood, Peard Bay, and Camp Lonely (see fig. 1), in conjunction with limited helicopter range, restricted the fieldwork. Proportionally less field time was spent in the Arctic Foothills province than any other. The southeast portion of the Reserve, south of Teshekpuk Lake to Umiat, was not visited. However, interpretation of the aerial photographs indicated the region was not as complex as other portions of the NPRA and that a major part of the region supported tussock tundra.

## Land Cover Classification Scheme

Completion of the field season and preliminary identification of the spectral classes provided the basis for the development of the classification scheme. The land cover categories devised for the NPRA project were based on land cover types which could be delineated optimally with multispectral satellite data. The names of the plant communities are based on a modification of the mapping system developed by Walker and others (1979).

The classification scheme is based on physiognomy, that is, plant communities which are similar in lifeform. The plant communities are described according to dominant species, site moisture, and associated landscape elements. Within the same physiognomic unit local variations in species composition may be present; however, the overall appearance will be similar. Photographs of the major plant communities are shown in figures 3-5 and descriptions of each land cover class follow:

### Wet Meadow Tundra

The dominant vegetation consists of a mat of sedges, primarily *Carex aquatilis*, with *Eriophorum angustifolium* the next most common. Also present are various other sedges, forbs, and grasses, although less common and of smaller percentages. This class is characterized by topographic depressions with impeded drainage, standing water, and saturated soils and includes low-centered polygons with standing water in centers, or sedges interspersed with numerous ponds. Emergent and aquatic species may also be present along lake margins and in shallow ponds and lake shelves. Rims of low-centered polygons typically include mosses (*Sphagnum* sp.), lichens, heaths, and prostrate shrubs (*Salix* sp. and *Betula* sp.).

### Moist Meadow Tundra

This class is dominated by the sedge family (*Carex* sp. and *Eriophorum* sp.) with various grasses, forbs, mosses, and low-lying shrubs. Moist meadow communities commonly consist of a continuous mat of sedges with moss and lichen understory. Associated genera include *Cassiope* sp., *Ledum* sp., *Vaccinium* sp., and *Potentilla* sp. This community is found in drained lake basins, along flood plains, within low-centered polygons, troughs of high-centered polygons, and along drainage channels (fig. 4).

### Moist Meadow-Tussock Tundra Complex

Within the Arctic Coastal Plain province, this community consists of a mosaic of high-centered polygons with tussock tundra centers and meadow troughs, as well as low-centered polygons with a major component of tussock tundra along the wide rims. This class occurs where either tussock tundra or meadow communities occupy less than two-thirds of an acre (approximate resolution size of a Landsat pixel). Vegetation typically includes tussock-forming sedges (*Eriophorum vaginatum*) and meadow communities dominated by herbaceous sedges interspersed with various forbs, grasses, heaths, and mosses.

The moist meadow-tussock complex within the eolian area mapped by Williams and others (1977), specifically the region east of Meade River and south of Teshekpuk Lake within the Arctic Coastal Plain province, consists of widely spaced, decumbent tussocks with a major component of lichen, heath, and *Dryas* species.

Figure 4.--Wet Meadow Tundra and Moist Meadow Tundra communities.

Within the Arctic Foothills and Brooks Range provinces, this class includes tussock tundra interlaced with drainages supporting sedges and grasses. Along some ridges in the southwestern portion of the reserve this class represents Dryas-covered solifluction lobes.

### Moist Tussock Tundra

Eriophorum vaginatum is the primary tussock forming species. Tussock tundra is common throughout the Arctic Foothills and may be found on well-drained sites in all areas of the NPRA. Cottongrass tussock are the dominant landscape elements, while moss is the common understory. Lichen, heath, forbs, and prostrate shrubs are also present in varying density. Tussock tundra communities are found on high-centered polygons, primary surfaces, sloping stream channels, and the rims of low-centered polygons (fig. 5).

### Riparian Shrubland

This class consists of willow (Salix sp.) and alder (Alnus sp.) thickets ranging from 0.5 to 2 meters in height along the major flood plains. The riparian shrubland category was identified using high-altitude color infrared photographs acquired by NASA in the summer of 1977. Riparian shrubland was included by reidentifying spectral classes within the flood plains of the Colville River, the Kokolik River, the Utukok River, and associated tributaries.

### Dry Mat and Cushion Tundra

This class is comprised of Dryas sp., heath, and lichen species found at higher elevations on rubble slopes, solifluction lobes, fellfields, and alluvial fans. The vegetation is generally low growing, and mat-like with the dominant species being Dryas sp. in the foothills and mountains, while lichen and heath associations are found mainly on marine beach strands and stabilized sand dunes. Bare rock and soil may cover up to 30 percent of this unit (fig. 6).

### Barrens

Barrens include any area with less than 30 percent vegetated cover and include bedrock exposures along rivers, cliffs, talus slopes, and other accumulations of rock in the Brooks Range, gravel and sand flood plains along all major rivers, and sand dunes. Along the coast, barrens consist of tidal flats, beaches, and spits.

### Deep Water

This class encompasses the waters of the Arctic Ocean and lakes with basins deeper than one meter with low sediment load.

### Shallow and Sedimented Water

Shallow lake shelves, turbid lakes, deltaic plumes, and rivers and lakes with high sediment loads comprise this class. Emergent and aquatic vegetation may also be present along lake shelves.

Figure 5.--Moist Meadow-Tussock Tundra Complex and Moist Tussock Tundra communities.

Figure 6.--Riparian Shrubland and Dry Mat and Cushion Tundra communities.

## Ice and Snow

Depending on the satellite overpass date ice and snow occur in the Arctic Ocean and at high elevations in the Brooks Range. The presence of ice in lakes generally indicates deep water lakes.

## Comparison with USGS Classification System

In order to maintain consistency, the NPRA land cover classes follow the classification system being used in the USGS land use and land cover mapping program (Anderson and others, 1976). However, in order to optimize the multispectral data and fulfill NPRA study requirements, Level II categories were modified. The NPRA project was the first attempt by USGS researchers to determine the applicability of the USGS land use and land cover classification system to Arctic Alaska. Table 2 shows the relation of that system with the final NPRA classification scheme.

Table 2.--U.S. Geological Survey Land Use and Land Cover Classification--comparison of the system with the NPRA classification system.

| USGS Land Use and Land Cover Classification System | | NPRA Classification Scheme |
|---|---|---|
| Level I | Level II | |
| Tundra | Shrub and Brush Tundra | Riparian Shrubland |
| | Herbaceous Tundra | Moist Meadow Tundra |
| | Herbaceous Tundra | Moist Tussock Tundra |
| | Bare Ground Tundra | Dry Mat and Cushion Tundra |
| | Wet Tundra | Wet Meadow Tundra |
| | Mixed Tundra | Moist Meadow-Tussock Tundra Complex |
| Water | Lakes, Streams, Bays | Deep Water<br>Shallow and Sedimented Water |
| Barren | Bare Exposed Rock | Barrens |
| Snow and Ice | | Ice and Snow |

Level I categories of the USGS land use and land cover classification system are applicable to generalized NPRA classes. The NPRA deep and shallow/sediment water classes are equivalent to Level III categories within a combined lakes and stream class of the USGS land use and land cover classification system. The Herbaceous Tundra class encompasses two distinct plant communities; Moist Tussock Tundra and Moist Meadow Tundra as determined in the NPRA project. For the purpose of the NPRA study, this third level was necessary and obtainable using Landsat digital data.

## Evaluation of Classification

U.S. Geological Survey researchers sought further verification of Landsat derived spectral classes. With funding from the USGS, the Institute of Arctic and Alpine Research delineated spectral classes for

Landsat scene 2902-21175 (Komarkova and Webber, 1978), which were then compared with units mapped in the field at Atkasook during the previous two summers. Results of the comparison indicated a high correspondence between spectral classes and vegetation units mapped at Atkasook.

The evaluation provided valuable information for spectral class identification and clearly defined problem classes. The Atkasook base map covers less than one percent of a full Landsat frame, and therefore, the results cannot be confidently extrapolated to the full frame. However, the comparison clearly establishes the need of ground truth information for identification of classes, as well as for verification of classification accuracy. Land cover mapping with Landsat digital data in isolated regions, in conjunction with a number of intensely studied areas eases fieldwork requirements and increases reliability of the class assignments.

A preliminary color display of the entire NPRA classification was photographically mosaicked at the scale of 1:500,000 for review by Department of the Interior personnel studying the region. A number of problems were evident. Mountain shadows were misclassified as water, Riparian shrubs were not mapped, and poor class identification was evident in the Barrow area.

Two approaches were used to resolve classification problems. The first approach was supervised "reclustering" to refine spectral clusters. The availability of high-resolution aerial photographs provided the necessary ground truth information for a modification of the unsupervised cluster statistics. Homogeneous land cover types were extracted from the MSS data and clustered to obtain new statistical means. The new cluster statistics, obtained from either of the above mentioned techniques, replaced the problem clusters (cluster statistics) in the original statistics files. The statistics file was again examined to identify potential conflicts between different land cover categories. High variances and low separability are undesirable and clusters with spectral overlaps were deleted or pooled. These modified statistics were transferred to the IBM 360/67, punched, and the entire scene was reclassified on the CDC 7600. Classification results were again evaluated in each case and showed noticeable improvement.

However, in some areas problems were still evident. Each class or group of classes with similar spectral responses should represent a specific land cover. Problems arise when two land cover types have similar reflectance values, that is, one spectral class encompasses two distinct land cover types. Stratification techniques were utilized to resolve this type of misclassification when it occurs in geographically distinct regions. Boundaries were delineated and digitized from topographic maps encompassing areas of misclassified pixels. Misclassified spectral classes were isolated within these polygons. A mask containing the pixel boundaries of these polygons was created and transferred to the IBM 360. With the mask registered to the classified data, spectral classes with specified polygons were assigned to a new category. For example, deep water and steep north-facing slopes with shadows were spectrally very similar. Interpretation of aerial photography revealed the presence of barren slopes in shadow. To eliminate this water/shadow confusion, the north-facing slope was delineated and all water classes which occurred within the digitized polygon were changed to the class--Barrens. Stratification of the north-facing slope shadows and riverine willow cleared up two major problems of concern to BLM personnel.

Color infrared photographs acquired during the summer of 1977 by NASA aircraft (WB-57) provided excellent source materials for the assignment of spectral classes to land cover categories. With photographs as source materials, identification of the cover type associated with a spectral class was more reliable and conflicts between classes could be resolved.

Classification discordancies between frames was expected considering the numerous Landsat passes that have been used: pass dates range from early July to late August for years the 1975, 1976, and 1977. Spectral variation from scene to scene was due to varying climatic conditions over the growing season and from year to year. Recorded precipitation and temperatures for 1975 were consistent with the 30-year norm (NOAA, 1977); however, the 1976 and 1977 growing season had abnormally high temperatures and low precipitation, indicating a regional drought.

### 1978 Field Season

In the summer of 1978, portions of the NPRA were again visited by USGS researchers. Three major objectives were accomplished during the field season: (1) the revised digital classification was checked to verify accuracy and to locate problem areas where further refinement was needed, (2) the validity of land cover classes and class descriptions were checked, and (3) increased confidence was gained in the photointerpretation of color infrared photographs acquired in 1977. The field data were utilized for final improvements of the classification and for decisions regarding final scene mosaicking.

Two USGS geographers accompanied members of the USGS Branch of Alaskan Geology who were mapping NPRA surficial deposits. One group worked out of the Naval Arctic Research Laboratory (NARL) at Barrow, covering the northwestern portion of the Reserve from Icy Cape to Topagoruk River, while the other (based at Camp Driftwood on the Utukok River) worked in the western Arctic Foothills and the Brooks Range. The long helicopter traverses and numerous stops necessary for the geologic mapping effort were extremely beneficial to the acquisition of land cover data.

## OUTPUT PRODUCT GENERATION

### Geographic Registration to Map Base

Each of the ten Landsat scenes analyzed were registered to the Universal Transverse Mercator projection. A digitizer was used through EDITOR to create pairs of corresponding points consisting of specific latitude and longitude as digitized from maps, and row and column coordinates in the rotated, skew-corrected classified data. For each scene, approximately 30 control points, primarily water features, were found on alpha-numeric line printer maps of the Landsat data and the appropriate 1:63,360- or 1:250,000-scale USGS topographic quadrangles. These coordinate pairs were analyzed in EDITOR to produce second-order polynomial which served as a calibration file between map latitude/longitude and image coordinates (Gaydos and Newland, 1978). Depending on the scale of available maps (1:250,000 in much of the NPRA) and the degree of change in water boundaries between the maps and the more recent Landsat imagery, these calibration files can locate exact map coordinates to within 1 to 5 pixels.

These calibration files were used with the skew-corrected data to register digitized points and lines to the Landsat data. Calibration files were input to a program on TENEX which creates a parameter file to be used on the IBM 360/67 at Ames to reformat the Landsat data into precision corrected pixels of any size. For the NPRA classification, 50-$m^2$ pixels were chosen for ease of displaying the data on a film recorder.

Each scene was geometrically corrected relative to the central meridian of the UTM zone within which it fell. Therefore, all scenes within the same zone were corrected relative to each other. This feature enables the digital mosaicking of adjacent scenes.

## Digital Mosaicking

USGS plans to produce an Alaskan series of land cover maps at a scale of 1:250,000 derived from Landsat digital data. Eight to ten quadrangles are to be made from the existing ten scenes already processed for the NPRA map. Utilizing VICAR (Video Image Communication and Retrieval) software developed at the Jet Propulsion Laboratory in California, portions of two or more scenes will be mosaicked digitally to form a single map image covering a 1° x 3° quadrangle. One of the quadrangles in the NPRA (Barrow) will be produced from only one Landsat scene. More commonly, however, portions of two and in some cases three or four different scenes will be used to create these 1° x 3° quadrangles. The VICAR software, implemented on the IBM 360/67 at Ames, allows mosaicking of irregularly shaped areas.

The analyst can choose those portions of each scene that best represent the landscape for a particular area rather than being limited to the relatively simple mosaicking of rectangular sections. These irregular portions of the scenes can be delineated on maps, digitized, and mosaicked to form new images eliminating scene overlaps. Each scene is referenced to a new output image by finding control points within areas of scene overlap. A new image produced from irregular portions of several images can be digitally created. This new image will be precision corrected to UTM with a 50-$m^2$ pixels size. Mosaicked data will be read from digital tape to a laser writing device to produce color separates which will then be used to print the maps.

## Acreage Summaries

One of the inherent advantages of classified Landsat data is that it is already in digital form, and can be queried as a data base. Through programs in EDITOR, the user may obtain acreage totals by spectral class (land cover category) for any area within the NPRA. Summaries by drainage basin, physiographic region, test site, or user-specified area can be extracted from the data. In this way, land cover summaries were generated for a caribou calving area for researchers with the Wildlife Research Unit of the University of Alaska.

Aggregations by cover type and physiographic province were produced from the first version of the NPRA map. The boundaries of the Arctic Coastal Plain, Arctic Foothills, and Brook Range were digitized from 1:250,000-scale quadrangles. Masks were created to overlay the province boundaries onto the digital data and totals by land cover were obtained for each province in the NPRA. These totals were made available to USGS and BLM scientists studying the region.

Summaries will also be produced by township. Researchers at the Center for Advanced Computation digitized townships from 1:63,360-scale USGS quadrangles, and the masks generated were referenced to the precision corrected scenes of the map. Totals by land cover were obtained by township and by 1:250,000-scale quadrangle. These will be published as part of the Alaska series of land cover maps, and will be printed along with the 1:250,000-scale maps.

## RECOMMENDATIONS AND RESEARCH APPLICATIONS

The NPRA project was the first attempt by USGS analysts to perform image processing utilizing pattern recognition techniques with multiple Landsat scenes. The spectral variability from scene to scene in overlapping areas was unavoidable due to the variety of pass dates. Differing climatic conditions, changes in soil moisture, and phenology between Landsat pass dates led to changes in spectral reflectance values in overlapping areas. Considering the complexity of the three physiographic provinces and variety of scene dates, certain preprocessing techniques, if utilized, might have reduced spectral confusion between land cover categories. However, the successful application of these techniques requires the use of Landsat scenes which have close overflight dates and reflect similar phenological stages. This would have been possible with NPRA scenes from the same or adjacent orbital paths. Normalization of the data, radiometric correction to adjust for sensor anomalies, removal of atmospheric haze, and linear contrast stretching of the multiple scanner (MSS) data could have enhanced digital image processing of the NPRA classification. Mosaicking of the MSS data prior to classification could have reduced the amount of time and effort expended on stratification. Image processing of the mosaicked MSS data would have provided the basis for clustering and classification within physiographic provinces (Newland, Peterson and Norman, 1980). Stratification of the MSS data within provinces decreases spectral variability related to landscape complexity, thereby reducing the number of image processing tasks and increasing the overall efficiency of the analysis. Utilization of the above mentioned preprocessing techniques when possible, would greatly facilitate image processing and post processing tasks when classifying extensive regions of high landscape complexity.

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[3/] Beginning in 1980, standard processing of Landsat MSS data at the EROS Data Center (EDC) includes radiometric correction, geometric correction, and haze removal with an optional linear contrast stretch.

To estimate the quantitative validity of classification results, an accuracy verification is necessary. Currently an accuracy verification of the NPRA classification is being considered for selected quadrangles. Land cover categories would be verified by interpretation of CIR photographs referenced to sample plots.

The use of Landsat digital data has tremendous potential as a base for regional landscape studies. Statistical summaries of the extent of plant communities of the present landscape provide a quantitative base for inferences regarding historic changes on the land. Succession of plant communities in response to modification of the land by thaw lake processes has been documented with U-2 photography and Landsat digital data (Morrissey, 1979). On the Arctic Coastal Plain, the author found that areas modified by thaw lake processes support mainly meadow communities, or are presently covered with water, while primary surfaces (areas failing to show evidence of thaw lake activity) are usually colonized by Moist Meadow-Tussock Tundra Complexes and tussock tundra communities mapped using Landsat digital data.

Comparison of the final classification with topographic maps documents a high correlation with water bodies, drainage patterns, extent and distribution of wetlands, and topographic features such as drained lake beds, ancient beach strands, and primary surfaces. Used in conjunction, these two complementary data bases (Landsat data and topographic maps) reveal insight in the interaction of terrain elements which together comprise the landscape.

Within the NPRA, 97,000 square kilometers have been mapped by cover type and provide a data base for decisions concerning water and land resource management by State, local, and federal agencies. However, maximum utilization of the NPRA land cover classification requires further knowledge through additional research into the relationships, and inferences which can be drawn, of the interaction of terrain elements and land cover. Research possibilities and applications using the NPRA classification as a data base are numerous: (1) the use of statistical summaries of surface water area in calculating water volume on the Arctic Coastal Plain; (2) determination of the extent and distribution of wetlands; (3) feasibility of using the land cover classification as a base for delineation of wetlands to fulfill requirements for the National Wetlands Inventory; (4) integration of the classification with other ancillary data into a geographic information system for habitat assessment; (5) use of multi-stage sampling as a means for maximizing the information gathering potential of the classification; (6) documentation of changes in surface water levels of thaw lakes by comparing the classification with USGS topographic maps; (7) utilization of the classification to calculate ground ice content for the Arctic Coastal Plain based on ground ice measurements by Hussey and Michelson (1966); (8) production of a major soils map by correlating land cover categories or spectral classes with major soil types (i.e., Tedrow, 1977; Everett, 1975); (9) selection of road routes based on land cover classes; and (10) determination of general land use suitability for development of natural resources. Utilization of the NPRA classification by private and public agencies will demonstrate the utility of Landsat digital data as a base for resource decisions.

## CONCLUSIONS

The North Slope is ideally suited for mapping land cover with Landsat digital data. Landsat data provide an effective means for producing land cover maps in remote regions with a high level of detail. The classification scheme devised for the NPRA mapping effort was based on plant communities optimally delineated with multispectral data. The land cover classes include Deep Water, Shallow and Sedimented Water, Wet Meadow, Moist Meadow, Moist Meadow-Tussock Complex, Moist Tussock, Dry Mat and Cushion, Barrens, Riparian Shrubland, and Ice and Snow.

Landsat digital data provide an attractive alternative to traditional photointerpretation methods in land use and land cover mapping projects. Although additional research is required for maximum utilization of the NPRA classification, the availability of that data base will furnish federal and local agencies with current land cover information necessary for decisions concerning the management of land and water resources.

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