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Ducks Unlimited, Inc.

Gulkana Earth Cover Classification

Mission Statement

The Bureau of Land Management (BLM) sustains the health, diversity and productivity of the public lands for the use and enjoyment of present and future generations.

Partners

The Department of the Interior, Bureau of Land Management and Ducks Unlimited, Inc. completed this project under a cooperative agreement.

Cover

The cover photo shows the Gakona Glacier. It depicts the remoteness of the area and the need to use helicopters for data collection.

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Abstract

The Bureau of Land Management (BLM) – Alaska and Ducks Unlimited, Inc. (DU) have been cooperatively mapping wetlands and associated uplands in Alaska using remote sensing and GIS technologies since 1988. The goal of this project was to continue the mapping effort by mapping the Gulkana River Watershed and associated uplands. Three Landsat TM satellite scenes (Path 66, 67 and 68, Row 16 acquired 9/16/95, 3/30/89, and 7/14/93 respectively) were used to classify the project area into 30 earth cover categories. An unsupervised clustering technique was used to determine the location of field sites and a custom field data collection form and digital database were used to record field information. A helicopter was utilized to gain access to field sites throughout the project area. Global positioning system (GPS) technology was used both to navigate to pre-selected sites and record locations of new sites selected in the field. Data were collected on 412 field sites during an 11 day field season from 7/7/97 through 7/18/97. Approximately 25% (102) of these field sites were set aside for accuracy assessment. A modified supervised/unsupervised classification technique was performed to classify the satellite imagery. The classification scheme for the earth cover inventory was based on Viereck *et al.* (1992) and revised through a series of meetings coordinated by the BLM – Alaska and DU. The overall accuracy of the major categories was 85%.

Introduction

The Bureau of Land Management (BLM) – Alaska and Ducks Unlimited, Inc. (DU) began cooperatively mapping wetlands and associated uplands in Alaska using remote sensing and geographic information system (GIS) technologies in 1988 (Ritter *et al.* 1989). Early mapping projects focused exclusively on wetlands (Ritter *et al.* 1989) but it was apparent that mapping the entire landscape was more cost effective and ultimately more useful to land managers. The BLM is creating a satellite-based, earth cover inventory of all BLM managed lands in Alaska. Many other agencies in Alaska (e.g., National Park Service, U.S. Fish and Wildlife Service, U.S. Forest Service, Alaska Department of Natural Resources, Alaska Department of Fish and Game) are also using similar techniques, and cooperating on these mapping projects. This earth cover mapping effort provides an inventory of Alaska's land base that can be used for regional management of land and wildlife. Earth cover databases allow researchers, biologists, and managers to define and map crucial areas for wildlife; perform analysis of related habitats; detect changes in the landscape; plot movement patterns for large ungulates; generate risk assessments for proposed projects; and provide baseline data to which wildlife and sociological data can be related.

Landsat Thematic Mapper (TM) satellite imagery was chosen as the primary source for the BLM/DU earth cover mapping effort. Satellite imagery offers a number of advantages for region-wide projects. TM data is cost effective, processed using automated mapping techniques, and collected on a cyclical basis, providing a standardized data source for future database updates or change detection studies (Kempka *et al.* 1993). In addition, TM imagery includes a mid-infrared band, which is sensitive to both vegetation and soil moisture content and is useful in identifying earth cover types. When combined with other GIS data sets, (e.g., elevation, slope, aspect, shaded relief, and hydrology), Landsat TM data produces highly accurate classifications with a moderately detailed classification scheme.

The Gulkana River Watershed Earth Cover Mapping project area contains highly diverse landscapes and is deemed important for its wildlife and recreational values. The project area extends from the Gakona and Gulkana glaciers in the north, to the confluence of the Copper, Gakona, and Gulkana Rivers in the south, to the foothills of the Talkeetna Mountains in the west. Two other earth cover mapping projects are adjacent, the Tanana Flats to the north (mapping completed 1997) and the Tiekel River Watershed to the south (mapping completed 1999). The combined area of these three projects totals 19.2 million acres and stretches from Fairbanks to Thompson Pass. The project area is relatively roaded and supports high recreational use, particularly in the vicinity of Tangle Lakes and Lake Louise. The project area includes important caribou (*Rangifer tarandus*) calving grounds and supports an abundant tundra swan (*Cygnus columbianus*) population. The earth cover data will aid in the critical process of resource planning in this valuable and diverse area.

Project Objective

The objective of this project was to develop a baseline earth cover inventory using Landsat TM imagery for the Gulkana River Watershed and associated areas. More specifically, this project purchased, classified, field verified, and produced high quality, high resolution digital and hard copy resource base maps. The result of this project was an integrated GIS database that can be used for improved natural resources planning.

Project Area

The Gulkana River Watershed mapping project (Figure 1) consisted of 8.4 million acres centered roughly on Lake Louise and bisected by the Trans-Alaska pipeline. The Glenn and Richardson highways run through the eastern half of the project, near the confluence of the Gakona, Gulkana and Copper Rivers. This area experienced relatively high recreational use because of its accessibility. The Gulkana project was located between the Tanana Flats project (completed in 1997) to the north and the Tiekel Watershed project (completed in 1999) to the south, and thus formed an important link in the Alaska earth cover mapping effort. It included portions of the following USGS 1:250,000 scale quadrangles: Gulkana, Talkeetna Mountains, Healy and Mt. Hayes. The town of Glennallen fell just outside the southern boundary of the project.

This project area encompassed a wide variety of environments ranging from glaciated mountains to lowland black spruce (*Picea mariana*) muskeg. Non-forested uplands form important caribou habitat, the higher elevations were home to Dall sheep (*Ovis dalli*), while moose (*Alces alces*) and bear (*Ursus* spp.) abounded throughout most of the project area. Innumerable small lakes and ponds supported the pond lilies and other aquatic vegetation that make up an important summer food source for breeding tundra swans.

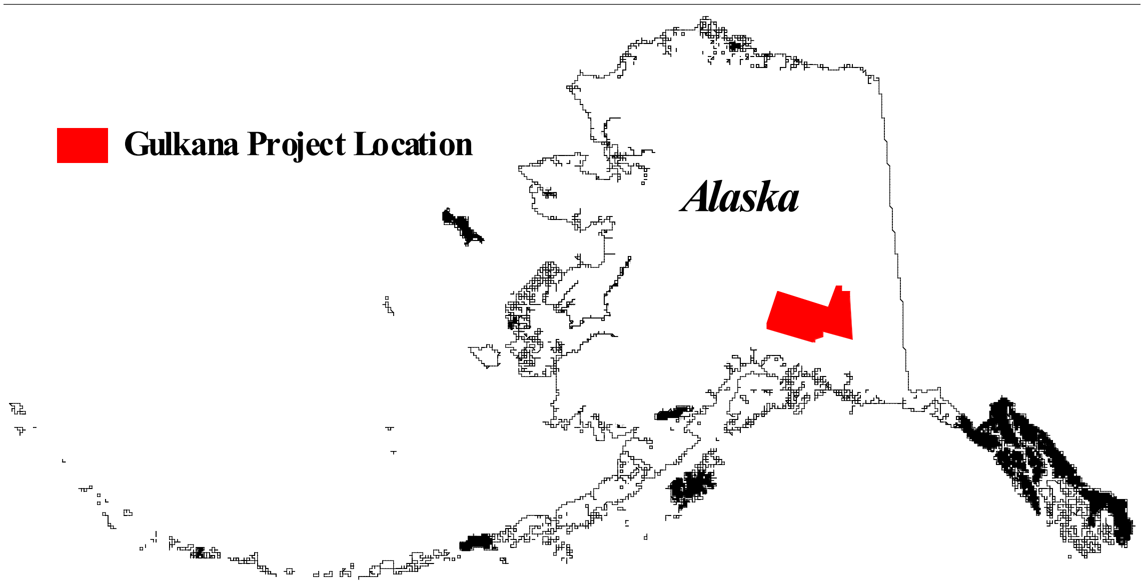


Figure 1. Gulkana Earth Cover Project Area

Data Acquisition

Three Landsat TM scenes were purchased to cover the project area. Due to the scarcity of cloud free summer images the scenes purchased were from different years and seasons; the first was acquired in summer, the second in early fall, and the third in late winter (Figure 2). Two of the images were primarily used to create the classification, Path 68 Row 16 (summer) and Path 66 Row 16 (fall). The third image, Path 67 Row 16 (late winter) was useful only for distinguishing forested areas from non-forested areas because of its pervasive snow cover. The original intent was to use the Landsat TM scene from Path 67 Row 16, but the only image available in this path was snow covered. Therefore, the project area was classified using two images on adjacent paths, 68 and 66. The scenes were purchased from EROS Data Center in Albers Equal Area projection and were terrain corrected by EROS.

Field data was collected over an 11-day period from 7-18 July 1997. The ancillary data used in this project included: 1:60,000 aerial photographs (color infrared transparencies from 1980, 1981, 1982, 1984, and 1986; color infrared prints from 1984 and 1987) on loan from BLM State Office and USGS 1:250,000 scale Digital Elevation Models (DEM). In addition, landcover survey data from the 1980 ASVT Phase I, Denali, Alaska (Krebs 1980) project was used to supplement current field data.

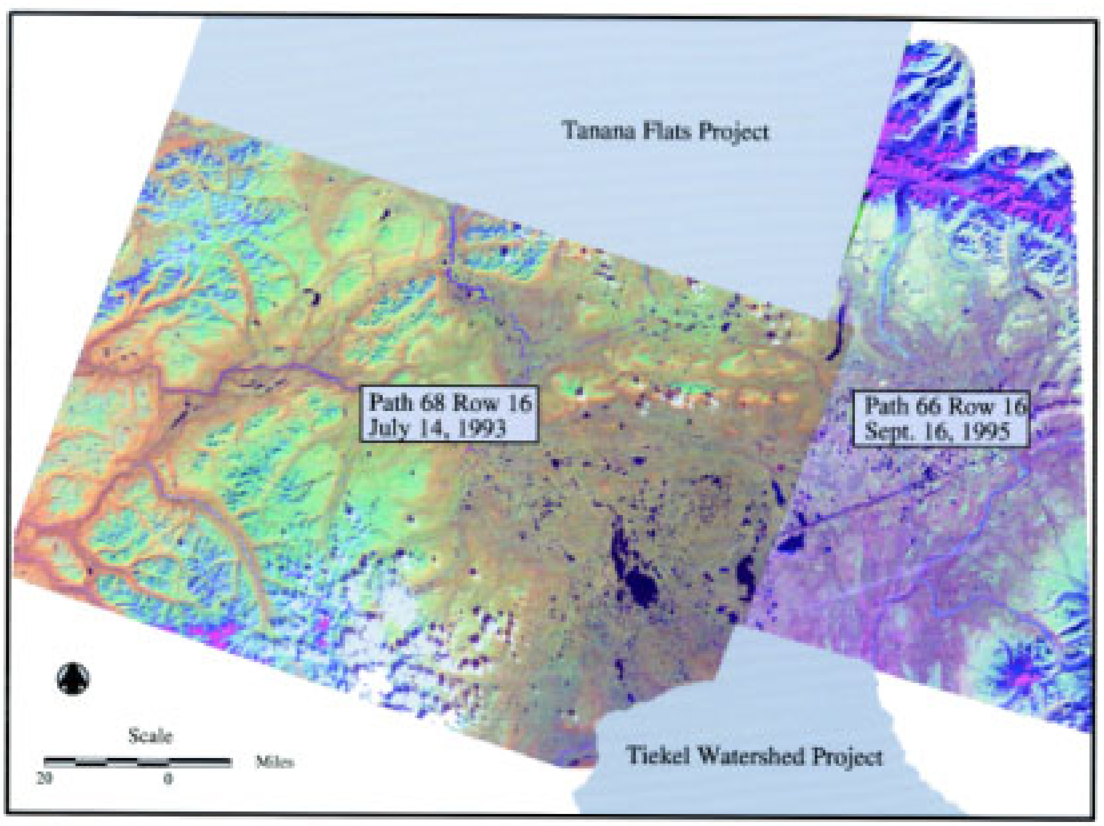


Figure 2. Satellite Imagery Used for Gulkana Earth Cover Project.

Methods

Classification Scheme

The classification system categorized the features to be mapped. The system was derived from the anticipated uses of the map information and the features of the earth that could be discerned by TM data. The classification system had two critical components: (1) a set of labels (e.g., forest, shrub, water); and (2) a set of rules, or a system for assigning labels. The set of rules for assigning labels was mutually exclusive and totally exhaustive (Congalton 1991). Any given area fell into only one category and every area was to be included in the classification.

Until recently, the BLM/DU classification systems were project specific. As projects expanded in size and as other cooperators began mapping and sharing data across Alaska, the necessity for a standardized classification system became apparent. At the BLM Earth Cover Workshop in Anchorage on 3-6 March 1997, a classification system based on the existing Alaska Vegetation Classification (Viereck *et al.* 1992) (Table 1) was designed to address this need. The goal of this meeting was to (1) develop an earth cover classification system for the state of Alaska that can be used in large regional mapping efforts, and (2) build consensus for the system among multiple land management agencies. The classification system has been slightly improved since this meeting.

The classification scheme consisted of 10 major categories and 27 subcategories. A classification decision tree and written description (Appendices A and B) was developed in order to clarify the classification. Though based largely on Level III of the Viereck *et al.* (1992) classification, some classes have been modified, added or omitted for the Earth Cover Mapping projects: e.g., rock, water, ice, cloud and shadow classes were added. Other classes that could not reliably be discerned from satellite imagery had to be collapsed, such as open and closed low shrub classes, or dryas, ericaceous, willow, and dwarf shrub classes. Because of the importance of lichen for site characterization and wildlife, and because the presence of lichen can be detected by satellite imagery, shrub and forested classes with and without a component of lichen were distinguished. A few classes from Level IV of the Viereck *et al.* (1992) classification were also mapped because of their identifiable satellite signature and their importance for wildlife management. These Level IV classes included tussock tundra, low shrub tussock tundra and low shrub willow/alder.

Image Preprocessing

Each image was examined for quality and consistency. Each band was examined visually and statistically by reviewing histograms. Combinations of bands were displayed to check for band to band registration and for clouds, shadows, and haze. Positional accuracy was checked by

Table 1. Classification scheme developed at the BLM Earth Cover Workshop

Level II	Level III	Level IV
1.0 Forest	1.1 Closed Needleleaf	
	1.2 Open Needleleaf	1.21Open Needleleaf Lichen
	1.3 Woodland Needleleaf	1.31 Woodland Needleleaf Lichen
	1.4 Closed Deciduous	1.41 Closed Paper Birch
		1.42 Closed Aspen
		1.43 Closed Balsam Poplar/Cottonwood
		1.44 Closed Mixed Deciduous
	1.5 Open Deciduous	1.51 Open Paper Birch
		1.52 Open Aspen
		1.53 Open Balsam Poplar/Cottonwood
		1.54 Open Mixed Deciduous
	1.6 Closed Mixed Needleleaf/Deciduous	
	1.7 Open Mixed Needleleaf/Deciduous	
2.0 Shrub	2.1 Tall Shrub	
	2.2 Low Shrub	2.21 Low Shrub Willow/Alder
		2.22 Low Shrub Tussock Tundra
		2.23 Low Shrub Lichen
		2.24 Low Shrub Other
	2.3 Dwarf Shrub	2.31 Dwarf Shrub Lichen
		2.32 Dwarf Shrub Other
3.0 Herbaceous	3.1 Bryoid	3.11 Lichen
		3.12 Moss
	3.2 Wet Herbaceous	3.21Wet Graminoid
		3.22 Wet Forb
	3.3 Mesic/Dry Herbaceous	3.31 Tussock Tundra
		3.32 Mesic/Dry Sedge Meadow
		3.33 Mesic/Dry Grass Meadow
		3.34 Mesic/Dry Graminoid
		3.35 Mesic/Dry Forb
4.0 Aquatic Vegetation	4.1 Aquatic Bed	
	4.2 Emergent Vegetation	
5.0 Water	5.1 Snow	
	5.2 Ice	
	5.3 Clear Water	
	5.4 Turbid Water	
6.0 Barren	6.1 Sparsely Vegetated	
	6.2 Rock/Gravel	
	6.3 Mud/Silt/Sand	
7.0 Urban		
8.0 Agriculture		
9.0 Cloud/Shadow	9.1 Cloud	
	9.2 Shadow	
10.0 Other		

comparing the image to available ancillary data such as adjacent imagery, hydrography, or digital elevation models (DEMs).

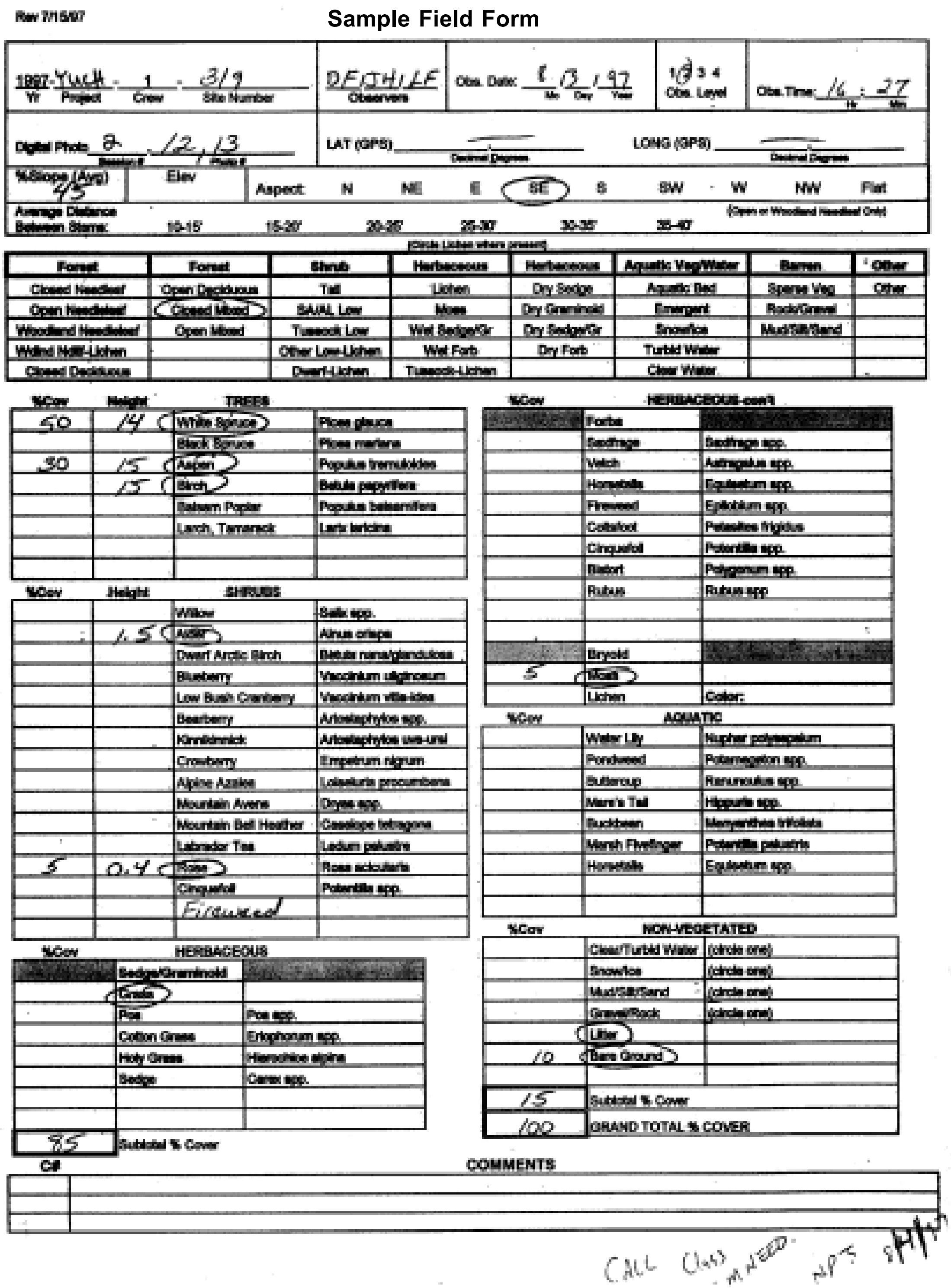
To optimize helicopter efficiency, field sites were identified and plotted on field maps before fieldwork began. Sufficient samplesfor each mapped class were selected to span the variation of spectral responses within that class throughout the entire image. For example, a shrub class in the southern part of an image may have a different spectral response than the same shrub class in the northern part of that image. Many factors contribute to such variation, including aspect, terrain shadow, or small differences in soil moisture. In addition, each earth cover type encompassed a variety of subtypes; e.g., the open needleleaf class included forested areas with 25%-60% crown closure, trees of varying height, and a diverse understory composition.

An unsupervised classification was used to identify spectrally unique areas within the study area. The image analyst individually selected training sites from these spectrally unique areas. Whenever possible, training sites were grouped in clusters to reduce the amount of travel time between sites. The image analyst also to placed training sites near landmarks that were easily recognizable in the field, such as lakes or streams. A tally of the estimated number of field sites per class was kept until all of the target map classes were adequately sampled throughout the project area. The coordinates of the center points of the field sites were then uploaded into a Y-code Rockwell Precision Lightweight GPL receiver (PLGR) for navigational purposes. Training sites were overlain with the satellite imagery and plotted at 1 inch = 1 mile scale. These field maps were used for recording field notes, placing additional field sample sites, and navigating to field sites.

Field Verification

The purpose of field data collection was to assess, measure, and document the on-the-ground vegetation variation within the project area. This variation was correlated with the spectral variation in the satellite imagery during the image classification process. Low-level helicopter surveys were a very effective method of field data collection since a much broader area was covered with an orthogonal view from above, similar to a satellite sensor. In addition, aerial surveys were often the only alternative in Alaska due to the large amount of roadless areas.

To obtain a reliable and consistent field sample, a custom field data collection form (Kempka *et al.*, 1994) was developed and used to record field information (Figure 3). A five-person helicopter crew performed the field assessment. Each crew consisted of a pilot, biologist, recorder, navigator, and alternate. The navigator operated the GPS equipment and interpreted the satellite image derived field maps to guide the biologist to the pre-defined field site. It was valuable for the image processor to gain first-hand knowledge of the project area, therefore the image processor also fulfilled the role of the navigator. The biologist identified plant species, estimated the percent cover of each cover type, determined the overall earth cover class, and photographed the site. The recorder wrote species percentages and other data on the field form and generally assisted the biologist. The alternate was responsible for crew check-ins, data entry, and


Rev 7/15/97

Sample Field Form

1997-Yuch - 1 - 3/9 (Yr, Project, Crew, Site Number)	DF/JH/LF (Observers)	Obs. Date: 8/13/97 (Mo, Day, Year)	1 2 3 4 (Obs. Level)	Obs. Time: 16 : 27 (Hr, Min)
Digital Photo: 2 / 12, 13 (Session #, Photo #)	LAT (GPS) (Decimal Degrees)		LONG (GPS) (Decimal Degrees)	

%Slope (Avg): 4/5 — Elev — Aspect: N NE E SE S SW W NW Flat

Average Distance Between Stems: 10-15' 15-20' 20-25' 25-30' 30-35' 35-40' (Open or Woodland Needleaf Only)

(Circle Lichen where present)

Forest	Forest	Shrub	Herbaceous	Herbaceous	Aquatic Veg/Water	Barren	Other
Closed Needleaf	Open Deciduous	Tall	Lichen	Dry Sedge	Aquatic Bed	Sparse Veg	Other
Open Needleleaf	Closed Mixed	SA/AL Low	Moss	Dry Graminoid	Emergent	Rock/Gravel	
Woodland Needleleaf	Open Mixed	Tussock Low	Wet Sedge/Gr	Dry Sedge/Gr	Snowice	Mud/Silt/Sand	
Wdlnd Ndlf-Lichen		Other Low-Lichen	Wet Forb	Dry Forb	Turbid Water		
Closed Deciduous		Dwarf-Lichen	Tussock-Lichen		Clear Water		

TREES

%Cov	Height	TREES	
50	14	White Spruce	Picea glauca
		Black Spruce	Picea mariana
30	15	Aspen	Populus tremuloides
	15	Birch	Betula papyrifera
		Balsam Poplar	Populus balsamifera
		Larch, Tamarack	Larix laricina

SHRUBS

%Cov	Height	SHRUBS	
		Willow	Salix spp.
	1.5	Alder	Alnus crispa
		Dwarf Arctic Birch	Betula nana/glandulosa
		Blueberry	Vaccinium uliginosum
		Low Bush Cranberry	Vaccinium vitis-idea
		Bearberry	Artostaphylos spp.
		Kinnikinnick	Artostaphylos uva-ursi
		Crowberry	Empetrum nigrum
		Alpine Azalea	Loiseluria procumbens
		Mountain Avens	Dryas spp.
		Mountain Bell Heather	Cassiope tetragona
		Labrador Tea	Ledum palustre
5	0.4	Rose	Rosa acicularis
		Cinquefoil	Potentilla spp.
		Fireweed	

HERBACEOUS

%Cov	HERBACEOUS	
	Sedge/Graminoid	
	Grass	
	Poa	Poa spp.
	Cotton Grass	Eriophorum spp.
	Holy Grass	Hierochloe alpina
	Sedge	Carex spp.
85	Subtotal % Cover	

HERBACEOUS-con't

%Cov	HERBACEOUS-con't	
	Forbs	
	Saxifrage	Saxifrage spp.
	Vetch	Astragalus spp.
	Horsetails	Equisetum spp.
	Fireweed	Epilobium spp.
	Coltsfoot	Petasites frigidus
	Cinquefoil	Potentilla spp.
	Bistort	Polygonum spp.
	Rubus	Rubus spp
	Bryoid	
5	Moss	
	Lichen	Color:

AQUATIC

%Cov	AQUATIC	
	Water Lily	Nuphar polysepalum
	Pondweed	Potamegeton spp.
	Buttercup	Ranunculus spp.
	Mare's Tail	Hippuris spp.
	Buckbean	Menyanthes trifoliata
	Marsh Fivefinger	Potentilla palustris
	Horsetails	Equisetum spp.

NON-VEGETATED

%Cov	NON-VEGETATED	
	Clear/Turbid Water	(circle one)
	Snow/Ice	(circle one)
	Mud/Silt/Sand	(circle one)
	Gravel/Rock	(circle one)
	Litter	
10	Bare Ground	
15	Subtotal % Cover	
100	GRAND TOTAL % COVER	

COMMENTS

C#	COMMENTS

CALL Class mixed. NPS 8/1/97

Figure 3. Custom Field Data Collection Form.

substitution in case of sickness. The majority of sites were observed without landing the helicopter. Ground verification was performed when identification of dominant vegetation was uncertain.

These DU/BLM procedures for collecting field data have evolved into a very efficient and effective means of data collection. The navigator used a GPS unit to locate the site and verified the location on the field map.As the helicopter approached the site at about 300 meters above ground level the navigator described the site and the biologist took a picture with a digital camera. The pilot then descended to approximately 5-10 meters above the vegetation and laterally moved across the site while the biologist called out the vegetation to the recorder. The biologist took another picture with the digital camera for a close-up view of the site. The pilot then ascended to approximately 100 meters so that the biologist could estimate the percentages of each species to the recorder. The navigator then directed the pilot to the next site. On average, it took approximately 6-10 minutes to collect all of the information for one site.

Field Data Analysis

The collected field information was entered into a digital database using a custom data entry application (DUFF), designed jointly by the BLM and DU and programmed by GeoNorth. The relational database was powered by SQL Anywhere while the user interface was programmed in Visual Basic. The user interface was organized similarly to the field form to facilitate data entry (Figure 4). The application utilized pull down menus to minimize keystrokes and checked for data integrity to minimize data entry errors. The database program also calculated an overall class name for each site based on the recorded species and its cover percentage. Digital images from each site were stored in the database and accessible from within the user interface. The number of field sites per earth cover class was tracked daily to ensure that adequate samples were being obtained within each class.

Every image was unique and presented special problems in the classification process. The approach used in this project (Figure 5) has been proven successful over many years. The image processor was actively involved in the field data collection and had first hand knowledge of every training site. The image processor's site-specific experience and knowledge in combination with high quality ancillary data overcame image problems to produce a high quality, useful product.

Erdas Imagine (vers. 8.3) was used to perform the classification. Arc/Info (vers. 7.2.1) was utilized to manage the field site polygons. Various word processing and data analysis software were also used during the image classification including Microsoft Word, Excel, and Access.

Classification

Generation of New Bands

The Landsat TM imagery contained 7 bands of data: 3 visible bands, 1 near-infrared band, 2 mid-infrared bands, and 1 thermal band. One new band, the NDVI, was generated for this project. The NDVI was highly correlated with the 4/3 ratio, a band ratio that typically reduces the effect of shadows in the

Sample Field Site – Closed Mixed Needleleaf/Deciduous

High site photo

Low site photo

DUFF INTERFACE

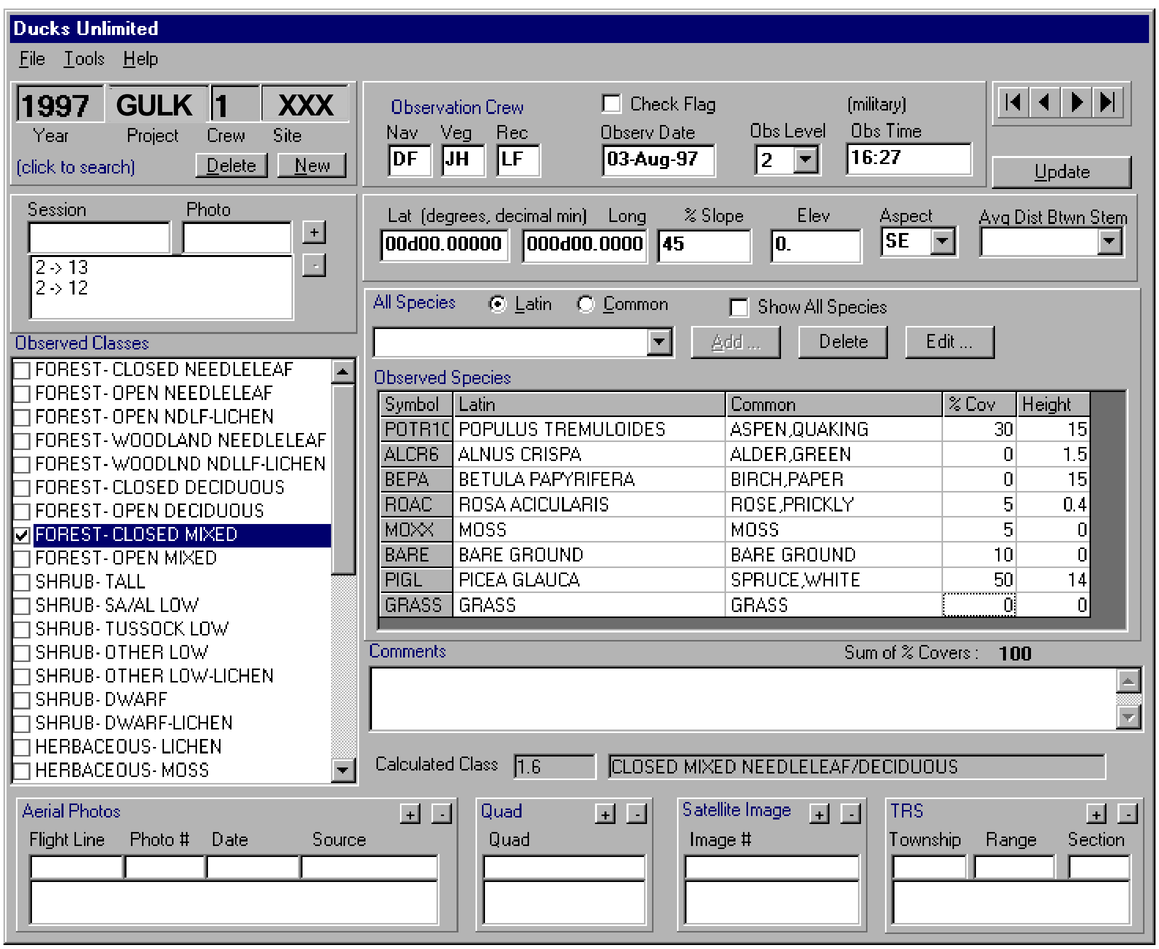


Figure 4. The Customized Database and User Interface for Field Data Entry (DUFF).

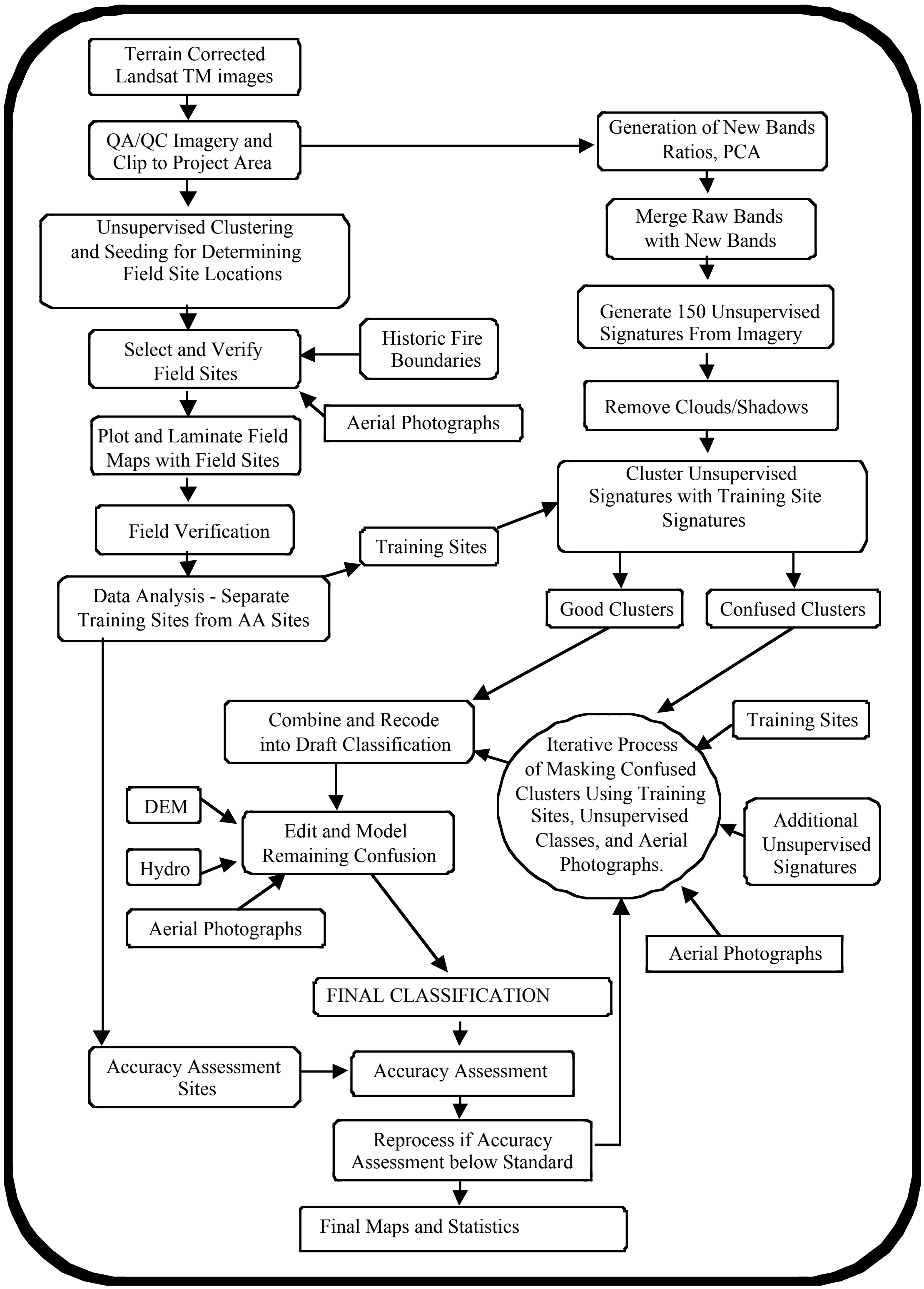


Figure 5. The Image Processing Flow Diagram.

image and enhances the differences between vegetation types (Kempka *et al.* 1995, Congalton *et al.* 1993). The NDVI had been correlated with various forest and crop canopy characteristics such as biomass and leaf area index. This NDVI band replaced thermal band (band 6) to retain a 7-band image for classification.

Removal of Clouds and Shadows

Clouds and cloud shadows were removed from the image before field sites were selected. This process eliminated any confusion between clouds, cloud shadows, and other vegetation types. They were removed using an unsupervised classification and manual on-screen editing. Clouds were separated from shadows and classes were recoded to their respective class number. The cloud/shadow layer is then combined with the rest of the classified image during the last step in the classification process.

Seeding Process

Spectral signatures for the field sites to be used as training areas were extracted from the imagery using a "seeding" process in Erdas Imagine. A pixel within each training area was chosen as a "seed" and adjoining pixels were evaluated for inclusion in each training site using a threshold value based on a spectral Euclidean distance. The standard deviations of the seeded areas were kept close to or below 3 and all seeded areas were required to be over 15 pixels (approximately 3.75 acres) in size. Along with the field training areas, additional "seeds" were generated for clear water, turbid water, and snow classes. These classes were easily recognizable on the imagery and aerial photography. The output of the seeding process in Imagine was a signature file that contained all of the statistics for the training areas. The signature file was then used in the modified supervised/unsupervised classification.

Generation of Unsupervised Signatures

An unsupervised classification was generated using the six raw bands and the NDVI ratio. One hundred and fifty signatures were derived from the unsupervised classification using the ISODATA program in Imagine. The output of this process was a signature file similar to that of the seeding process but containing the 150 unsupervised signatures. A maximum likelihood classification of the 150 unsupervised signatures was generated using the supervised classification program in Imagine.

Modified Supervised/Unsupervised Classification

A modified supervised/unsupervised classification approach (Chuvieco and Congalton, 1988) was used for the classification. This approach uses a statistical program to group the spectrally unique signatures from the unsupervised classification with the signatures of the supervised training areas. In this way, the spectrally unique areas were labeled according to the supervised training areas. This classification approach provided three major benefits: (1) it aided in the labeling of the unsupervised classes by grouping them with known supervised training sites; (2) it helped to identify classes that possessed no spectral uniqueness (i.e., training sites that were spectrally inseparable); and (3) it identified areas of spectral reflectance present in the imagery that had not been represented by a training site. This approach was an iterative process because all of the supervised signatures do not cluster perfectly with the unsupervised signatures the first time. The unsupervised signatures that matched well with the supervised signatures were inspected, labeled with the appropriate class label, and removed from the classification process. The remaining confused clusters were grouped into general categories (e.g., forest, shrub, non-vegetation) and the process was repeated. This process was continued until all of the spectral classes were adequately matched and labeled, or until the remaining confused classes were spectrally inseparable. Throughout this iterative process, interim checks of classification accuracy were performed by intersecting the classified image with a coverage of the training sites to determine if the training sites were being accurately labeled by the classification. Areas with incorrectly classified training sites were run through further iterations of the supervised/unsupervised classification and further refined. The iterative process of interim accuracy assessments and refining classifications was terminated when the accuracy assessments indicated no improvements between one iteration and the next.

Editing and Modeling

Models that incorporated ancillary data sets such as elevation, slope, aspect, shaded relief, or hydrography helped to separate confused classes. For instance, terrain shadow/water confusion was easily corrected by creating a model using a shaded relief layer derived from DEMs.

For this project, the final steps of the classification process were to model the confused classes remaining after the iterative supervised/unsupervised classification process and to make final edits in areas that still had classification errors. Editing of classification errors was a process of comparing the classified image to the raw satelite image, aerial photography, and notes on field maps to identify errors remaining in the classification. These errors were then corrected by manually changing the class value for the pixels that were classified in error to their correct class value.

Accuracy Assessment

There were two primary motivations for accuracy assessment: (1) to understand the errors in the map (so they can be corrected), and (2) to provide an overall assessment of the reliability of the map (Gopal and Woodcock, 1992). Factors affecting accuracy included the number and location of test samples and the sampling scheme employed. Congalton (1991) suggested that 50 samples be selected for each map category as a rule of thumb. This value has been empirically derived over many projects. A second method of determining sample size includes using the multinomial distribution and specifying a given confidence in the estimate (Tortora 1978). The results of this calculation tend to favorably agree with Congalton's rule of thumb. Once a sample size is determined, it must be allocated among the categories in the map. A strictly proportional allocation is possible. However, the smaller categories in areal extent will have only a few samples that may severely hamper future analysis. The other extreme is to force a given number of samples from each category. Depending on the extent of each category, this approach can significantly bias the results. Finally, a sampling scheme must be selected. A purely random approach has excellent statistical properties, but is practically difficult and expensive to apply. A purely systematic approach is easy to apply, but could result in sampling from only limited areas of the map.

Alaska Perspective

Obtaining adequate reference data for performing an accuracy assessment can be extremely expensive in remote areas. Aircraft is the only means of transportation throughout most of Alaska. Aerial photographs are available for most of Alaska, but most are at a scale that makes it difficult if not impossible to distinguish some vegetation classes. Ideally, fieldwork would be performed during one summer, the classification would be performed during the winter, and the reference data would be collected the next summer. This procedure would allow a stratified random sample of the classification and ensure adequate sampling of all the classes. Unfortunately, this methodology is not typically feasible due to the cost of obtaining the field data in Alaska.

In this project, the fieldwork for obtaining the training sites for classifying the imagery and the reference data for the accuracy assessment was accomplished at the same time. Special care was taken during the preprocessing stage and in the field to make sure adequate samples were obtained. However, funding limitations did not allow for the number of samples suggested for each class (n=50) for the accuracy assessment. Some earth cover classes were naturally limited in size and distribution, so that a statistically valid accuracy assessment sample could not be obtained without additional field time. For classes with low sample sizes few, if any, field sites were withheld for the accuracy assessment. This does not indicate that the classification for these types is inaccurate but rather that no statistically valid conclusions can be made about the accuracy of these classes. However, withholding even a small percentage of sites for the accuracy assessment provided some confidence in the classification and guided the image processor and end user in identifying areas of confusion in the classification.

Selection of Accuracy Assessment Sites

Approximately 25-30% of the collected field sites were set aside for use in the assessment of map accuracy while the remainder were utilized in the classification process. Unfortunately, given time and budget constraints it was not always possible to obtain enough sites per class to perform both the classification and a statistically valid accuracy assessment. A minimum of 15 sites in an individual class (5 for accuracy assessment, 10 for image processing training sites) were required before any attempt was made to assess the accuracy of that class. Classes with less than 15 field sites were still classified. However, these classes were collapsed into the next, more general hierarchical class when accuracy assessment was performed. Accuracy assessment sites were selected randomly across the project area to reduce bias.

Error Matrix

The standard method for assessing the accuracy of a map was to build an error matrix, also known as a confusion matrix, or contingency table. The error matrix compares the reference data (field site or photo interpreted site) with the classification. The matrix was designed as a square array of numbers set out in rows and columns that expressed the number of sites assigned to a particular category in the reference data relative to the number of sites assigned to a particular category in the classification. The columns represented the reference data while the rows indicated the classification (Lillesand and Kiefer, 1994). An error matrix was an effective way to represent accuracy in that the individual accuracy of each category was plainly described along with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the classification. A commission error occurred when an area was included in a category it did not belong. An omission error was excluding that area from the category in which it did belong. Every error was an omission from the correct category and a commission to a wrong category. Note that the error matrix and accuracy assessment was based on the assumption that the reference data was 100% correct. This assumption was not always true, especially when the reference data was derived from aerial photographs.

In addition to clearly showing errors of omission and commission, the error matrix was used to compute overall accuracy, producer's accuracy, and user's accuracy (Story and Congalton 1986). Overall accuracy was allocated as the sum of the major diagonal (i.e., the correctly classified samples) divided by the total number of samples in the error matrix. This value is the most commonly reported accuracy assessment statistic. Producer's and user's accuracies are ways of representing individual category accuracy instead of just the overall classification accuracy.

Kappa Analysis

A Kappa analysis was performed on the error matrix as a further measure of accuracy (Congalton 1991). Cohen's coefficient of agreement (Kappa) was calculated as a measure of overall agreement in the error matrix after chance agreement was removed from consideration. In other words, Kappa provided a better measure of agreement by adjusting the overall accuracy for chance agreement or that agreement that might be contributed solely by chance matching of the two maps. The result of the Kappa analysis was the KHAT statistic. Landis and Koch (1977) characterized the possible ranges for KHAT into three groupings: a value greater then 0.80 (i.e., 80%) represented strong agreement; a value between 0.40 and 0.80 represented moderate agreement; and a value below 0.40 represented poor agreement.

In addition to calculating KHAT, confidence intervals were calculated using the approximate large sample variance. The large sample variance was used to test if the agreement between the classification and reference data was significantly different from zero or a random classification with the Z statistic. The Z statistic in the Kappa analysis was used to test if a classification was significantly different from another classification. A Z statistic of ≤ 1.98 indicated that the classification was not significantly different from a random classification at the 99% confidence level.

Accuracy Assessment Software

In order to automate the accuracy assessment process, a program was developed in Visual Basic to format the data, calculate the statistics for each individual accuracy assessment polygon, flag mixed sites, and generate the error matrix and statistics. The program generated a listing of accuracy assessment sites along with the assigned class value for both the reference data and classification. Additional information generated included a table of the percentage and number of pixels by class that fell within each accuracy assessment site. The table was used to analyze mixed classes and to clear up any confusion between the accuracy assessment site and the classification. The table also helped to identify any non-map errors in the accuracy assessment such as registration problems and labeling errors.

The accuracy assessment program also calculated an error matrix and Kappa statistics for the classification. The program generated the error matrix based on the reference value and the classification value that was created in the previous step. The error matrix was then used to compute the Kappa statistics. The error matrix and Kappa statistics were used to report the final accuracy of the classification.

Results

Field Verification

The field crew for the Gulkana project (Table 2) was the first to use the DUFF data entry software, the digital cameras, and the PLGR GPS unit on a DU/BLM mapping project. This was also the first project to implement the classification scheme developed at the March, 1997, meeting. Minor revisions, improvements, and complications resulted. For example, due to a bug in the DUFF program, no data entry could be performed in the field (this problem was repaired before the next field crew was deployed). Prior to this field season, only one photograph was taken per site, but because the digital cameras were capable of storing over 80 images, the policy of taking both a high and a low shot was established. Finally, minor changes were made to the classification decision tree based on the field observations of the crew.

Field data was collected on a total of 412 field sites (Figure 6) during the 11-day field season from 7-18 July 1997. An average of 40 sites per day were collected, with no weather days and two half-day breaks. Daily flight time did not exceed 6 hours. Approximately 25% (n=102) of these sites were reserved for accuracy assessment. The proportions of sites per class (Table 3) largely reflects the proportion of corresponding earth cover types within the project area, though proportionally more sites were collected for classes that were difficult to map, such as wet graminoid meadows. All plant species recorded during the field data collection and their overall percentages of cover are listed in Appendix C.

A Bell Jet Ranger helicopter was used to gain access to the field sites. The field camp and main fuel depot were based out of the privately owned Tangle Lakes Lodge. Flight following was carried out by the alternate via radio. It was often necessary to transport a portable antenna to various parts of the project area to maintain radio contact. Contact was made every 30 minutes as specified by the Office of Aircraft Services.

Mapped versus Sampled Boundary

The preliminary project boundary was based on the full Landsat TM scene from Path 67 Row 16. Because this image was not available, the project was mapped using images from two adjacent paths. As a result, the area covered by the imagery was expanded considerably, though the time budgeted for field data collection had not changed. The decision was made to map the additional area even though it could not be sampled within the allotted time. Therefore, although the project area extended westward to the Talkeetna Mountains (Figure 6), the area actually sampled was determined by management priorities as outlined by BLM biologists. Clearly, no accuracy assessment could be calculated for areas that were not sampled. However, the mapped areas outside the sampled area have been verified with the available aerial photography.

Classification

The four most extensive classes within the final classification were: open needleleaf, low

Table 2. List of field data collection participants.

Participant	Role	Agency
Jim Sisk	Biologist/Vegetation Expert	BLM Northern District
Scott Guyer	Recorder/Vegetation Expert	BLM State Office
Mike Sondergaard	Recorder/Alternate	BLM Glennallen
Mike Coffeen	Project Logistics Manager/Alt.	BLM Glennallen
Alex Morton	Navigator/Image Processor	DU Western Reg. Office

Table 3. Field sites per mapped class.

Class Name	Total Field Sites per Class	Sites Witheld for Accuracy Assesement
OPEN NEEDLELEAF	60	25
LOW SHRUB OTHER	55	19
TALL SHRUB	44	15
WET GRAMINOID	31	7
WOODLAND NEEDLELEAF	23	6
DWARF SHRUB OTHER	21	5
ROCK/GRAVEL	17	6
LOW SHRUB LICHEN	13	5
LOW SHRUB WILLOW/ALDER	12	5
LOW SHRUB TUSSOCK TUNDRA	12	0
CLOSED MIXED DECIDUOUS	12	5
CLOSED ASPEN	12	2
CLOSED NEEDLELEAF	11	0
CLOSED MIXED NEEDLELEAF/DECIDUOUS	11	0
AQUATIC BED	11	0
MESIC/DRY GRAMINOID	9	0
OPEN MIXED NEEDLELEAF/DECIDUOUS	8	0
EMERGENT VEGETATION	8	0
WOODLAND NEEDLELEAF LICHEN	7	0
NON-VEGETATED SOIL	7	2
TUSSOCK TUNDRA	6	0
SPARSE VEGETATION	6	0
OPEN NEEDLELEAF LICHEN	3	0
DWARF SHRUB LICHEN	3	0
OTHER	2	0
OPEN POPLAR	2	0
CLOSED POPLAR	2	0
CLOSED BIRCH	2	0
OPEN MIXED DECIDUOUS	1	0
MOSS	1	0
TOTAL	**412**	**102**

Figure 6. Field Site Distribution.

shrub, woodland needleleaf, and dwarf shrub. Large expanses of spruce muskeg interspersed with low shrub were typical of the project area. Uplands were characterized by dwarf shrub, low shrub, and dry graminoid cover types. Other large classes include tall shrub, commonly found on steep slopes and in riparian corridors, and water reflecting the large number of lakes and rivers both large and small within the project area (Table 4, Figure 7). Stands of closed canopy deciduous trees were found on steep, well drained slopes, or on alluvial deposits near major rivers. Extensive stands of deciduous trees were found south of the confluence of the Copper and Gulkana rivers. Closed canopy needleleaf and closed canopy mixed needleleaf/deciduous stands also appeared to be constrained by soil conditions and were found only near major river drainages. Open deciduous stands were rare, occurring mainly in areas that had been recently burned or otherwise disturbed. The aquatic bed cover type, composed primarily of floating pond lilies, was relatively abundant in this project area, particularly in the vicinity of Fish Lake. Rock and sparse vegetation cover types were found mostly at the highest elevations, along ridgetops and in glaciated areas. The mapped area contained a larger proportion of higher elevation areas than the sampled area and this was reflected in the higher percentage of rock and sparse vegetation classes. Rock also appeared as gravel beds in riparian corridors along with non-vegetated soil, or mud. Most of the snow and ice was found in the Gakona

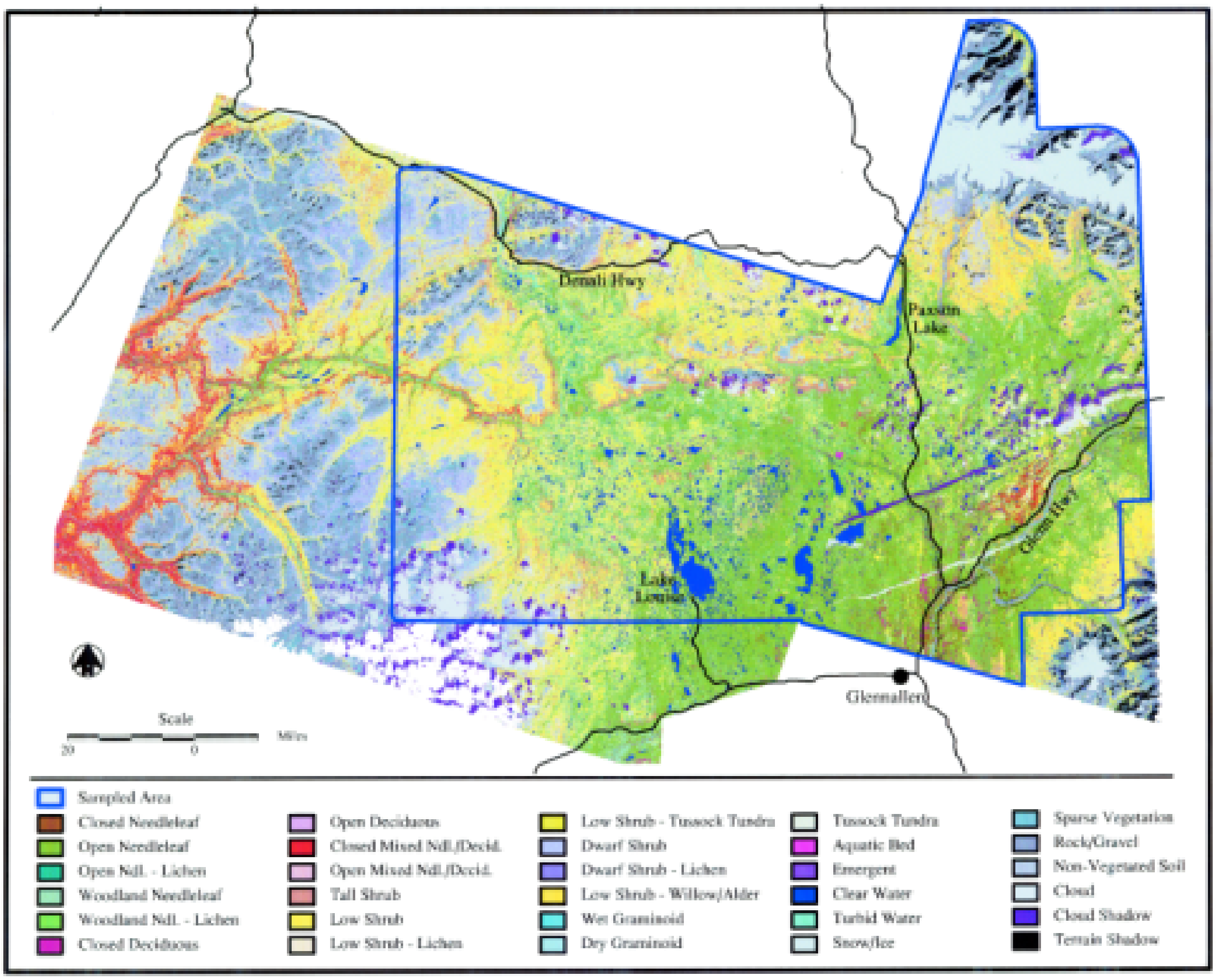


Figure 7. Gulkana Earth Cover Project Final Classified Map.

and Canwell glaciers on Mount Kimball and Mount Drum. Clouds were present in the imagery over parts of the Talkeetna Mountains and the Alphabet Hills and also over lower elevation areas like the Chistochina River drainage. A jet trail cloud and accompanying shadow were clearly visible extending from Ewan Lake to the Copper River.

Modeling

Modeling was performed using a shaded relief image and an elevation zone image derived from USGS DEM at 1:250,000 scale. The shaded relief image was created in Erdas Imagine using the solar azimuth and solar elevation listed in the header file for the TM image. The DEM was often used to help separate spectrally confused classes like terrain shadow and deep water. Elevation images were also used to model cover types that were slope, aspect or elevation limited.

Modeling was primarily used to identify misclassified areas. Since water, wet graminoid, closed canopy forest and shadow have similar spectral signatures these classes

Table 4. Acreage of earth cover classes within the project area.

CLASS NUMBER	CLASS NAME	MAPPED ACRES	MAPPED PERCENT	SAMPLED ACRES	SAMPLED PERCENT
1	Closed Needleleaf	25,909.02	0.31%	22,739.89	0.44%
2	Open Needleleaf	1,592,169.62	19.02%	1,332,068.21	25.53%
3	Open Ndl. - Lichen	47,046.33	0.56%	40,573.08	0.78%
4	Woodland Needleleaf	884,326.36	10.56%	698,472.20	13.39%
5	Woodland Ndl. - Lichen	32,823.28	0.39%	23,437.54	0.45%
10	Closed Deciduous	66,795.00	0.80%	31,373.93	0.60%
13	Open Deciduous	1,011.90	0.01%	584.68	0.01%
16	Closed Mixed Ndl./Decid.	135,460.57	1.62%	17,156.66	0.33%
17	Open Mixed Ndl./Decid.	10,898.47	0.13%	9,255.86	0.18%
20	Tall Shrub	323,292.94	3.86%	215,752.28	4.14%
21	Low Shrub	1,535,524.05	18.34%	1,068,100.25	20.47%
22	Low Shrub - Lichen	243,510.74	2.91%	153,350.25	2.94%
23	Low Shrub - Tussock Tundra	25,514.27	0.30%	25,411.08	0.49%
24	Dwarf Shrub	818,392.69	9.78%	327,734.84	6.28%
25	Dwarf Shrub - Lichen	101,212.85	1.21%	35,891.88	0.69%
26	Low Shrub - Willow/Alder	176,994.62	2.11%	72,893.07	1.40%
32	Wet Graminoid	33,106.83	0.40%	29,732.88	0.57%
43	Dry Graminoid	176,727.74	2.11%	65,540.47	1.26%
50	Tussock Tundra	5,704.88	0.07%	5,695.31	0.11%
60	Aquatic Bed	12,539.74	0.15%	12,042.02	0.23%
61	Emergent	3,706.21	0.04%	3,527.85	0.07%
70	Clear Water	192,442.62	2.30%	161,021.76	3.09%
71	Turbid Water	58,807.47	0.70%	43,570.07	0.84%
72	Snow/Ice	273,551.85	3.27%	206,558.92	3.96%
80	Sparse Vegetation	335,126.14	4.00%	99,429.25	1.91%
81	Rock/Gravel	686,687.26	8.20%	229,256.78	4.39%
82	Non-Vegetated Soil	20,780.81	0.25%	12,920.04	0.25%
92	Cloud	288,032.22	3.44%	115,607.59	2.22%
93	Cloud Shadow	151,839.52	1.81%	91,407.90	1.75%
94	Terrain Shadow	111,731.92	1.33%	66,142.27	1.27%
Total		**8,371,667.92**	**100**	**5,217,248.81**	**100**

were often confused. Water obviously did not occur on a slope, but terrain shadows did,so a slope based model was used to search out shadowed areas that had been misclassed as water or wet graminoid. Tussock tundra signatures were confused with dwarf shrub, but unlike dwarf shrub, tussock tundra will not occur at higher elevations or on steep slopes. Closed canopy needleleaf was found only at lower elevations within the project area, so modeling was also used to check for
cloud or terrain shadow that had been misclassed as forest.

Editing

Editing was performed on all classes to various extents depending on how well the iterative classification process worked for each. The edits were verified with field sites, aerial photography and field notes wherever possible. Some editing centered around ecological differences across the project area. For example, a single signature classified low shrub near Dickey Lake and dwarf shrub on the Alphabet Hills. Editing in this case consisted of correctly labeling and separating classes along ecological boundaries. Because the project area was relatively diverse, this kind of editing was often necessary.

Another kind of editing was needed to classify areas that fell in the middle of the gradient between one class and another, e.g., between woodland and shrub. A woodland area of 10-15% trees was easily confused with a shrub area of 5-10% trees. Similarly, low shrub areas at a height of 1 meter were confused with tall shrub areas of only 1.5 meters in height. These transitional areas and signatures had to be examined and a classification decision made based on the available data.

In some cases, a single pixel fell across two cover types, as when a pixel fell across the edge between a lake and the forested land surrounding it. These half-water, half-land signatures were often confused with emergent and closed deciduous signatures. Editing was done to separate legitimate emergent, deciduous or mixed forest pixels based on aerial photography, field notes and topography. The remaining mixed pixels were blended into surrounding areas with a limited majority scan algorithm.

The portions of the Path 66 Row 16 image that contained haze required a great deal of editing. An open needleleaf spectral signature under haze tended to be misclassified as a slightly more reflective class, like woodland needleleaf or shrub. Shrub pixels under haze likewise tended to be confused with a more reflective class, like dwarf shrub. Since the thickness of the haze varied across the affected region, global changes could not be applied to misclassified areas. Therefore, the image had to be extensively edited based on aerial photography and field notes.

The wet graminoid and emergent classes were also heavily edited based on aerial photography and field notes. These cover types commonly required extra editing because they were generally both limited in extent and highly variable. Emergent vegetation typically occurred in narrow strips, often only a few pixels wide, making it very difficult to obtain reliable ground samples. Wet graminoid sites were more extensive and common, but they were highly variable with respect to spectral reflectance. Small differences in soil moisture content, density of vegetation, and the proportion of senescent plants drastically affected the reflectance values. Standing water created a very dark signature, while senescent plants created a very bright signature. Dense, lush graminoid vegetation that completely obscured the presence of water created a third signature, often confused with other leafy cover types, like tall shrub.

Accuracy Assessment

Some earth cover classes were inadequately represented in the field data available for training and accuracy assessment, either because of their scarcity within the project area, e.g., tussock tundra and closed needleleaf, or because they were difficult to reach, e.g., high elevation graminoid meadows. Classes with an inadequate sample size were collapsed into the next hierarchical cover type for accuracy assessment of the classification. This grouping resulted in 8 accuracy assessment classes. Low shrub lichen, low shrub willow/alder and low shrub tussock tundra were grouped into a general Low Shrub class for accuracy assessment. Species specific closed deciduous subclasses were grouped into Closed Mixed Deciduous. Rock/gravel, non-vegetated soil and sparse vegetation were grouped into Barren. The overall accuracy of the grouped classes was 85% (Table 5). A more complete error matrix presenting the Kappa statistic as well as user's and producer's accuracy for each class is given in Appendix D.

Overall Accuracy Assessment

The accuracy of open needleleaf was relatively high (92%), a direct result of being the most extensive cover type. Woodland needleleaf producer's accuracy was the lowest of all the grouped classes (67%) but its user's accuracy remained high (80%). This indicated that where an area was classified as woodland it had a high probability of being woodland, while there was some lower chance that areas classified as shrub or open needleleaf might actually contain woodland. The woodland class was the most difficult class to map due to its high diversity of possible components. For example, a woodland site could include 40% graminoid cover and just 10% trees, or it could contain 20% trees and 50% shrubs. In some cases, cover types other than trees dominated the signature of woodland sites, whereas in other cases, spruce trees dominated. In addition, the haze covering large portions of the scene from Path 66 Row 16 tended to further obscure the difference between open needleleaf, woodland needleleaf and low shrub.

The user's accuracy was particularly high for closed deciduous classes (100%). Generally, the closed deciduous classes have a distinctive signature and will rarely be confused with classes other than tall shrub. Tall shrub (80-86%), low shrub (83%) and dwarf shrub (100-63%) accuracy was satisfactory, especially since the sites that were misclassified fell into other shrub categories. Wet graminoid accuracy was particularly high in the user's category,

Table 5. The accuracy assessment error matrix.

	Open Ndlf	Wdld Ndfl	Cld Decid	Tall Shrb	Low Shrb	Dwf Shrb	Wet Grmd	Barren	Total	User's
Open Ndlf	23	1	1				1		26	88.5%
Wdld Ndlf	1	4							5	80.0%
Cld Decid			6						6	100%
Cld Mix	1								1	0%
Tall Shrb				12	2				14	85.7%
Low Shrb		1		3	24		1		29	82.8%
Dwf Shrb					3	5			8	62.5%
Wet Grmd							5		5	100%
Barren								8	8	100%
Total	25	6	7	15	29	5	7	8	102	
Producer's	92%	66.7%	85.7%	80%	82.8%	100%	71.4%	100%		85.3%

indicating that areas classed as wet graminoid had a high likelihood of actually containing wet graminoid. The difference between user's (100%) and producer's (71%) accuracy for wet graminoid reflected the extensive editing done for this class. Rock and soil classes tend to be confused with sparse vegetation, but were otherwise easily distinguishable; thus the accuracy for barren classes was very high (100%).

Discussion

While the accuracy assessment performed in this project was not a robust test of the classification, it gives the user some confidence while using the classification. It provided enough detail for the end user to determine where discrepancies in the classification may cause a problem while using the data. It is also important to note the variations in the dates of the imagery, aerial photographs, and field data. For this project, the imagery was from different years and seasons; 16 September 1995 and 14 July 1993. The aerial photographs spanned a seven year period from 1980-87, and the field data was collected in July 1997. Differences due to environmental changes from the different sources may have affected the accuracy assessment.

A major assumption of quantitative accuracy assessments is that the label from the reference information represents the "true" label of the site and that all differences between the remotely sensed map classification and the reference data are due to classification and/or delineation error (Congalton and Green 1993). Unfortunately, error matrices can be inadequate indicators of map error because they are often confused by non-map error differences. Some of the non-map errors that can cause confusion are: (1) registration differences between the reference data and the remotely sensed map classification, (2) digitizing errors, (3) data entry errors, (4) changes in land cover between the date of the remotely sensed data and the date of the reference data, (5) mistakes in interpretation of reference data, and (6) variation in classification and delineation of the reference data due to inconsistencies in human interpretation of vegetation.

Final Products

The project final product included a digital classification, map, and database of 30 earth cover classes within the Gulkana River Watershed project area. The digital map was delivered in ArcInfo Grid and Erdas Imagine format. The unclassified Landsat TM images used to create the cover map were also delivered. The field site database, a species list and earth cover acreage tables were stored as digital tables in Microsoft Excel and Access format. Digital photos of the field sites are stored as jpeg's. Plots of the entire project area at 1:250,000 scale, and selected 1:63,360 scale quadrangles were also produced. All of the delivered datasets were loaded into ArcView projects for display purposes.

Summary

The Bureau of Land Management (BLM) – Alaska and Ducks Unlimited, Inc. (DU) have been cooperatively mapping wetlands and associated uplands in Alaska using remote sensing and GIS technologies since 1988. This project continued with the mapping effort for the Gulkana River Watershed project using Landsat TM satellite scenes, Path 68 Row 16 and Path 66, Row 16 acquired 14 July 1993, and 16 September 1995. The project area was classified into 30 earth cover categories with an overall accuracy of 85%. The digital database and map of the classification were the primary products of this project along with hard copy maps of the classification, a complete field database including digital site photos, and an ArcView project.

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Appendices

Appendix A. Alaska Earth Cover Classification Class Descriptions

1.0 Forest

Needleleaf and Deciduous Trees-
The needleleaf species generally found were white spruce (*Picea glauca*) and black spruce (*P. mariana*). White spruce tended to occur on warmer sites with better drainage, while black spruce dominated poorly drained sites, and was more common in the interior of Alaska. The needleleaf classes included both white and black spruce.

The deciduous tree species generally found were paper birch (*Betula papyrifera*), aspen (*Populus tremuloides*) and cottonwood (*P. balsamifera* and *P. trichocarpa*). Black cottonwoods (*P. trichocarpa*) were generally found only in river valleys and on alluvial flats. Under some conditions willow (*Salix* spp.) and alder *(Alnus rubra)* formed a significant part of the tree canopy. Deciduous stands were found in major river valleys, on alluvial flats, surrounding lakes, or most commonly, on the steep slopes of small hills. Mixed deciduous/coniferous stands were present in the same areas as pure deciduous stands. While needleleaf stands were extremely extensive, deciduous and mixed deciduous/coniferous stands were generally limited in size. The only exception to this rule was near major rivers, where relatively extensive stands of pure deciduous trees occur on floodplains and in ancient oxbows.

1.1 Closed Needleleaf

At least 60% of the cover was trees, and ≥75% of the trees were needleleaf trees. Closed needleleaf sites were rare because even where stem densities were high, the crown closure remained low. Generally, closed needleleaf sites were found only along major rivers.

1.2 Open Needleleaf

From 25-59% of the cover was trees, and ≥75% of the trees were needleleaf. This class was very common throughout the interior of Alaska. A wide variety of understory plant groups were present, including low and tall shrubs, forbs, grasses, sedges, horsetails, mosses and lichens.

1.21 Open Needleleaf Lichen

From 25-59% of the cover was trees, ≥75% of the trees were needleleaf, and ≥ 20% of the understory was lichen.

1.3 Woodland Needleleaf

From 10-24% of the cover was trees, and ≥75% of the trees were needleleaf. Woodland understory was extremely varied and included most of the shrub, herbaceous, or graminoid types present in the study area.

1.31 Woodland Needleleaf Lichen

From 10-24% of the cover was trees, ≥75% of the trees were needleleaf, and ≥ 20% of the understory was lichen. The lichen often occurred in small round patches between trees. Within the study area, this class was generally found along ridgetops or on riparian benches.

1.4 Closed Deciduous (Mixed Deciduous Species 1.45)

At least 60% of the cover was trees, and ≥75% of the trees were deciduous. Occurred in stands of limited size, generally on the floodplains of major rivers, but occasionally on hillsides, riparian gravel bars, or bordering small lakes. This class included paper birch, aspen, or cottonwood.

1.41 Closed Birch
At least 60% of the cover was trees, ≥75% of the trees were deciduous, and ≥75% of the deciduous trees were paper birch (*Betula Papyrifera)*. This class was very rare.

1.42 Closed Aspen
At least 60% of the cover was trees, ≥75% of the trees were deciduous, and ≥75% of the deciduous trees were aspen. Stands of pure aspen occurred, but were generally no larger than a few acres. They were found on steep slopes, with particular soil conditions, and on river floodplains.

1.43 Closed Poplar
At least 60% of the cover was trees, ≥75% of the trees were deciduous, and ≥75% of the deciduous trees were cottonwood. Stands of pure cottonwood were occasionally found on riparian gravel bars.

1.5 Open Deciduous (Mixed Deciduous Species 1.54)
From 25-59% of the cover was trees, and ≥75% of the trees were deciduous. There was generally a needleleaf component to this class though it was less than 25%. This was a relatively uncommon class.

1.51 Open Birch
From 25-59% of the cover was trees, ≥75% of the trees were deciduous, and ≥75% of the deciduous trees were paper birch. This class was very rare. No examples of this class were found in the study area.

1.52 Open Aspen
From 25-59% of the cover was trees, ≥75% of the trees were deciduous, and ≥75% of the deciduous trees were aspen.

1.53 Open Cottonwood
From 25-59% of the cover was trees, ≥75% of the trees were deciduous, and ≥75% of the deciduous trees were cottonwood.

1.6 Closed Mixed Needleleaf/Deciduous
At least 60% of the cover was trees, but neither needleleaf nor deciduous trees made up ≥75% of the tree cover. This class was uncommon and found mainly along the meanders of major rivers.

1.7 Open Mixed Needleleaf/Deciduous
From 25-59% of the cover was trees, but neither needleleaf nor deciduous trees made up ≥75% of the tree cover. This class occurred in regenerating burns, on hill slopes, or bordering lakes.

2.0 Shrub
The tall and low shrub classes were dominated by willow species, dwarf birch (*Betula nana* and *B. glandulosa*) and *Vaccinium* species, with alder being somewhat less common. However, the proportions of willow to birch and the relative heights of the shrub species varied widely, which created difficulties in determining whether a site was made up of tall or low shrub. As a result, the height of the shrub species making up the largest proportion of the site dictated whether the site was called a low or tall shrub. The shrub heights were averaged within a genus, as in the case of a site with both tall and low willow shrubs. Dwarf shrub was usually composed of dwarf ericaceous shrubs and *Dryas* species, but often included a variety

of forbs and graminoids. The species composition of this class varied widely from site to site and included rare plant species. It is nearly always found on hill tops or mountain plateaus, and may have included some rock.

2.1 Tall Shrub
Shrubs made up 40-100% of the cover and shrub height was ≥1.3 meters. This class generally had a major willow component that was mixed with dwarf birch and/or alder, but could also have been dominated by nearly pure stands of alder. It was found most often in wet drainages, at the head of streams, or on slopes.

2.21 Willow/Alder Low Shrub
Shrubs made up 40-100% of the cover, shrub height was .25-1.3 meters, and ≥75% of the shrub cover was willow and/or alder.

2.22 Other Low Shrub/Tussock Tundra
Shrubs made up 40-100% of the cover, shrub height was .25-1.3 meters, and ≥35% of the cover was made up of tussock forming cotton grass *(Eriophorum vaginatum*). This class was found in extensive patches in flat, poorly drained areas. It was generally made up of cotton grass, ericaceous shrubs, willow and/or alder shrubs, other graminoids, and an occasional black spruce.

2.23 Other Low Shrub/Lichen
Shrubs made up 40-100% of the cover, shrub height was .25-1.3 meters, and ≥20% of the cover was made up of lichen. This class was found at mid-high elevations. The shrub species in this class were nearly always dwarf birch.

2.24 Other Low Shrub
Shrubs made up 40-100% of the cover, shrub height was .25-1.3 meters. This was the most common low shrub class. It was generally composed of dwarf birch, willow species, *Vaccinium* species, and ledum species.

2.31 Dwarf Shrub/Lichen
Shrubs made up 40-100% of the cover, shrub height was ≤.25 meters, and ≥20% of the cover was made up of lichen. This class was generally made up of dwarf ericaceous shrubs and *Dryas* species, but often included a variety of forbs and graminoids. It was nearly always found at higher elevations on hilltops, mountain slopes and plateaus. This class may be more open than the Other Dwarf Shrub class.

2.31 Other Dwarf Shrub
Shrubs made up 40-100% of the cover, the shrub height is ≤.25 meters. This class was generally made up of dwarf ericaceous shrubs and *Dryas* species, but often included a variety of forbs and graminoids, and some rock. It was nearly always found at higher elevations on hilltops, mountain slopes, and plateaus.

3.0 <u>Herbaceous</u>
The classes in this category included bryoids, forbs, and graminoids. Bryoids and forbs were present as a component of most of the other classes but rarely appeared in pure stands. Graminoids such as *Carex* spp., *Eriophorum* spp., or bluejoint grass (*Calamagrostis canadensis*) may have dominated a community.

3.11 Lichen
Composed of ≥40% herbaceous species, ≤25% water, and ≥ 60% lichen species.

3.12 Moss
Composed of ≥40% herbaceous species, ≤25% water, and ≥60% moss species.

3.21 Wet Graminoid
Composed of ≥40% herbaceous species, ≤25% water, and where ≥60% of the herbaceous cover was graminoid, and ≥20% of the graminoid cover was made up of *Carex aquatilis*. This class represented wet or seasonally flooded sites. It was often present in stands too small to be mapped at the current scale.

3.31 Tussock Tundra
Composed of ≥40% herbaceous species, ≤25% water, where ≥50% of the herbaceous cover was graminoid, and ≥35% of the graminoid cover was made up of tussock forming cotton grass. Tussock tundra often included ericaceous shrubs, willow and/or alder shrubs, forbs, bryoids, and other graminoids, and was usually found at lower elevations in flat, poorly drained areas.

3.311 Tussock Tundra/Lichen
Composed of ≥40% herbaceous species, ≤25% water, where ≥50% of the herbaceous cover was graminoid, and ≥20% of the cover was lichen, and ≥35% of the graminoid cover was made up of tussock forming cotton grass. Tussock tundra often included ericaceous shrubs, willow and/or alder shrubs, forbs and other graminoids, and was usually found at lower elevations in flat, poorly drained areas. This class included a major component of lichen.

3.34 Mesic/Dry Graminoid
Composed of ≥40% herbaceous species, ≤5% water, with ≥50% graminoids excluding tussock forming cotton grass and *Carex aquatilis*. This class was not common and was found generally only at high elevations.

3.35 Mesic/Dry Forb
Composed of ≥40% herbaceous species, ≤5% water, with <50% graminiods. Regenerating burn areas dominated by fireweed *(Epilobium angustifolium)* fell into the mesic/dry forb category. However, forb communities without significant graminoid or shrub components were generally rare in the interior of Alaska.

4.0 <u>Aquatic Vegetation</u>
The aquatic vegetation was divided into aquatic bed and emergent classes. The aquatic bed class was dominated by plants with leaves that float on the water surface, generally pond lilies (*Nuphar polysepalum*). The emergent vegetation class was composed of species that were partially submerged in the water, and included freshwater herbs such as horsetails (*Equisetum* spp.), marestail (*Hippuris* spp.), and buckbean (*Menyanthes trifoliata*).

4.1 Aquatic Bed
Aquatic vegetation made up ≥20% of the cover, and ≥20% of the vegetation was composed of plants with floating leaves. This class was generally dominated by pond lilies.

4.2 Emergent Vegetation
Aquatic vegetation made up ≥20% of the cover, and ≥20% of the vegetation was composed of plants other than pond lilies. Generally included freshwater herbs such as horsetails, marestail, or buckbean.

5.1 Clear Water
Composed of ≥80% clear water.

5.2 Turbid Water
Composed of ≥80% turbid water.

6.0 Barren
This class included sparsely vegetated sites, e.g., abandoned gravel pits or riparian gravel bars, along with non-vegetated sites, e.g., barren mountaintops or glacial till.

6.1 Sparse Vegetation
At least 50% of the area was barren, but vegetation made up ≥20% of the cover. This class was often found on riparian gravel bars, on rocky or very steep slopes and in abandoned gravel pits. The plant species were generally herbs, graminoids, and bryoids.

6.2 Rock/Gravel
At least 50% of the area was barren, ≥50% of the cover was composed of rock and/or gravel, and vegetation made up less than 20% of the cover. This class was most often made up of mountaintops or glaciers.

6.3 Non-vegetated Soil
At least 50% of the area was barren, ≥50% of the cover was composed of mud, silt or sand, and vegetation made up less than 20% of the cover. This type was generally along shorelines or rivers.

7.0 Urban
At least 50% of the area was urban. This class was not found in the study area.

8.0 Agriculture
At least 50% of the area was agriculture. This class was not found in the study area.

9.0 Cloud/Shadow
At least 50% of the cover was cloud or shadow.

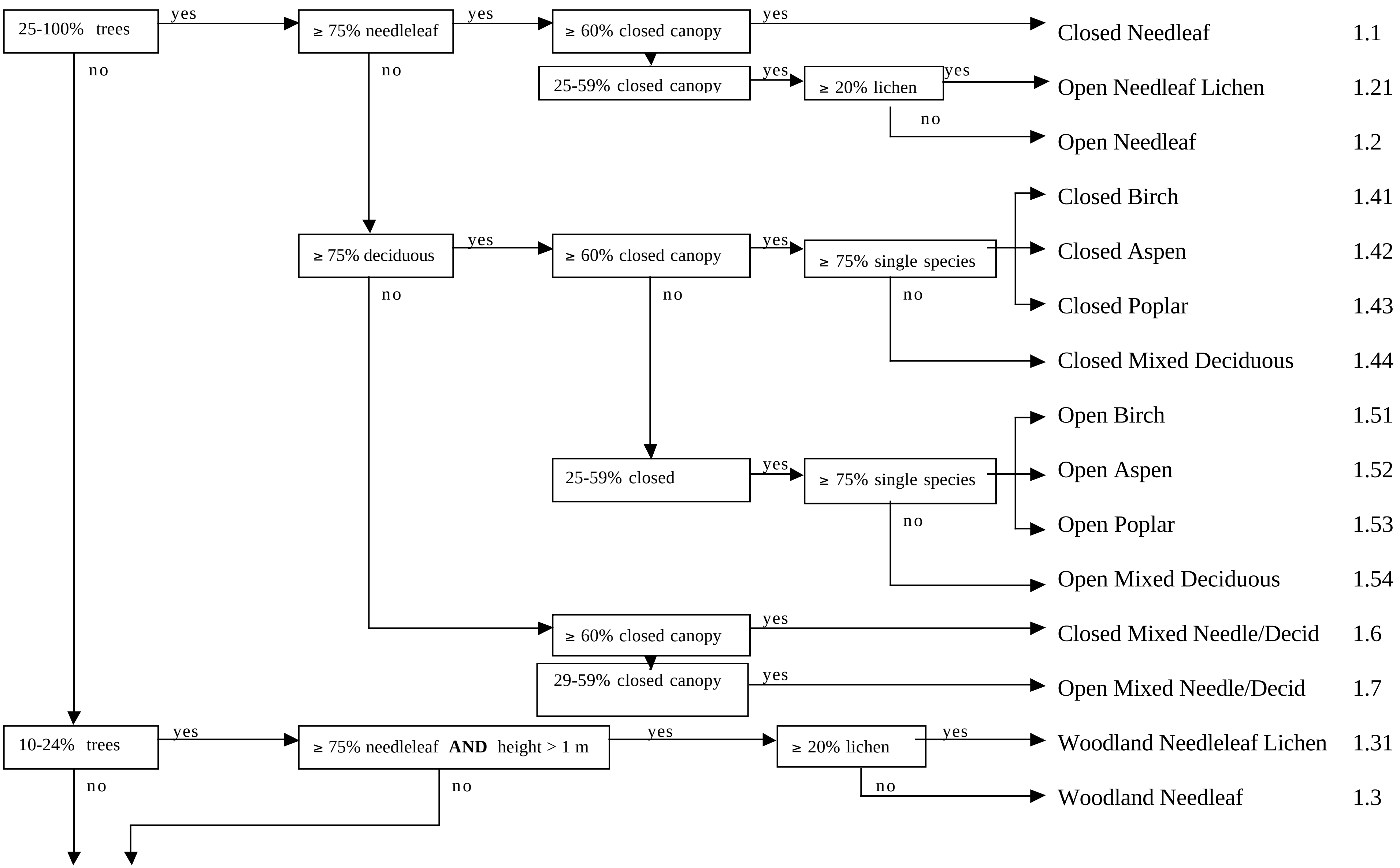
9.1 Cloud
At least 50% of the cover was made up of clouds.

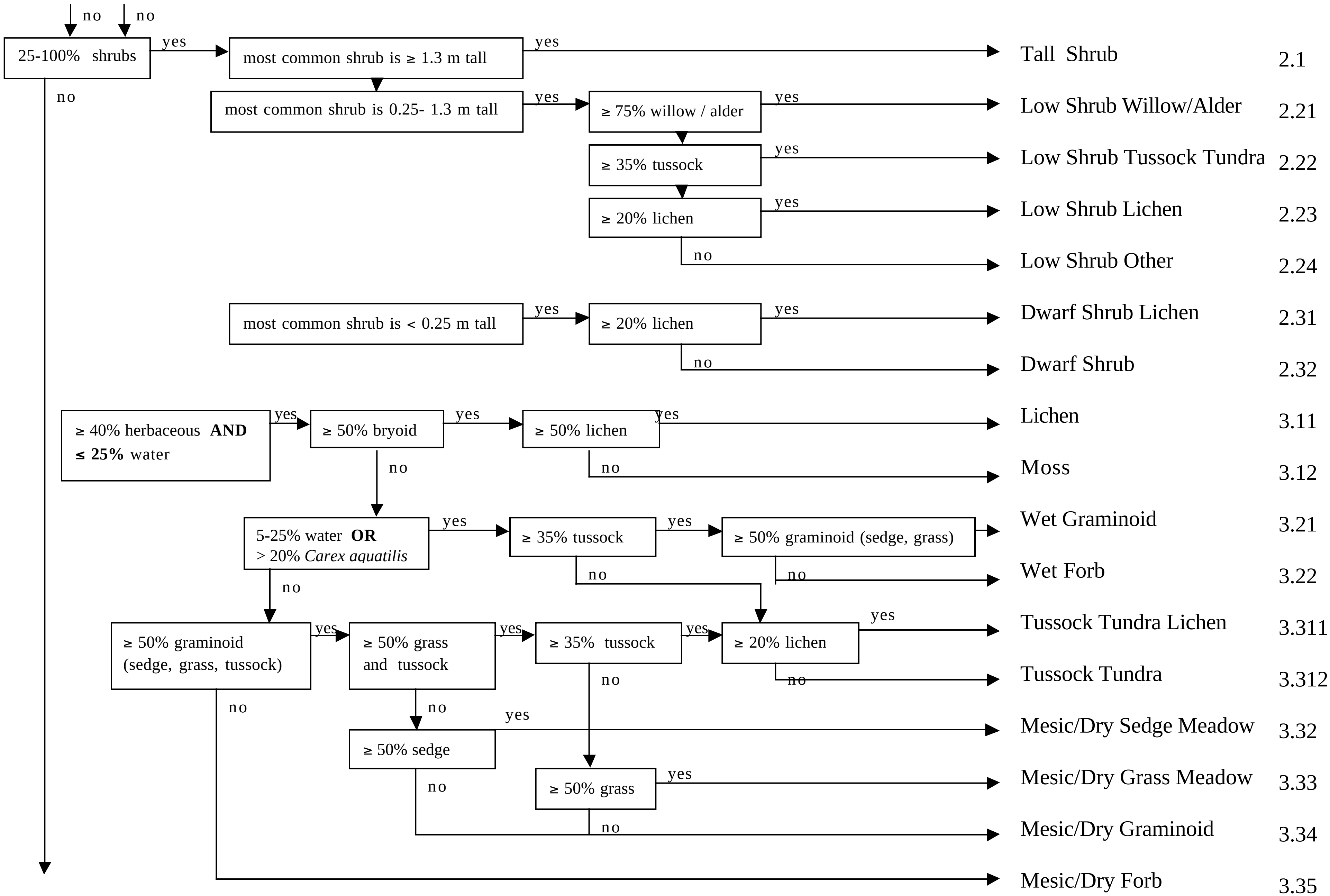
9.2 Cloud Shadow
At least 50% of the cover was made up of clouds shadows.

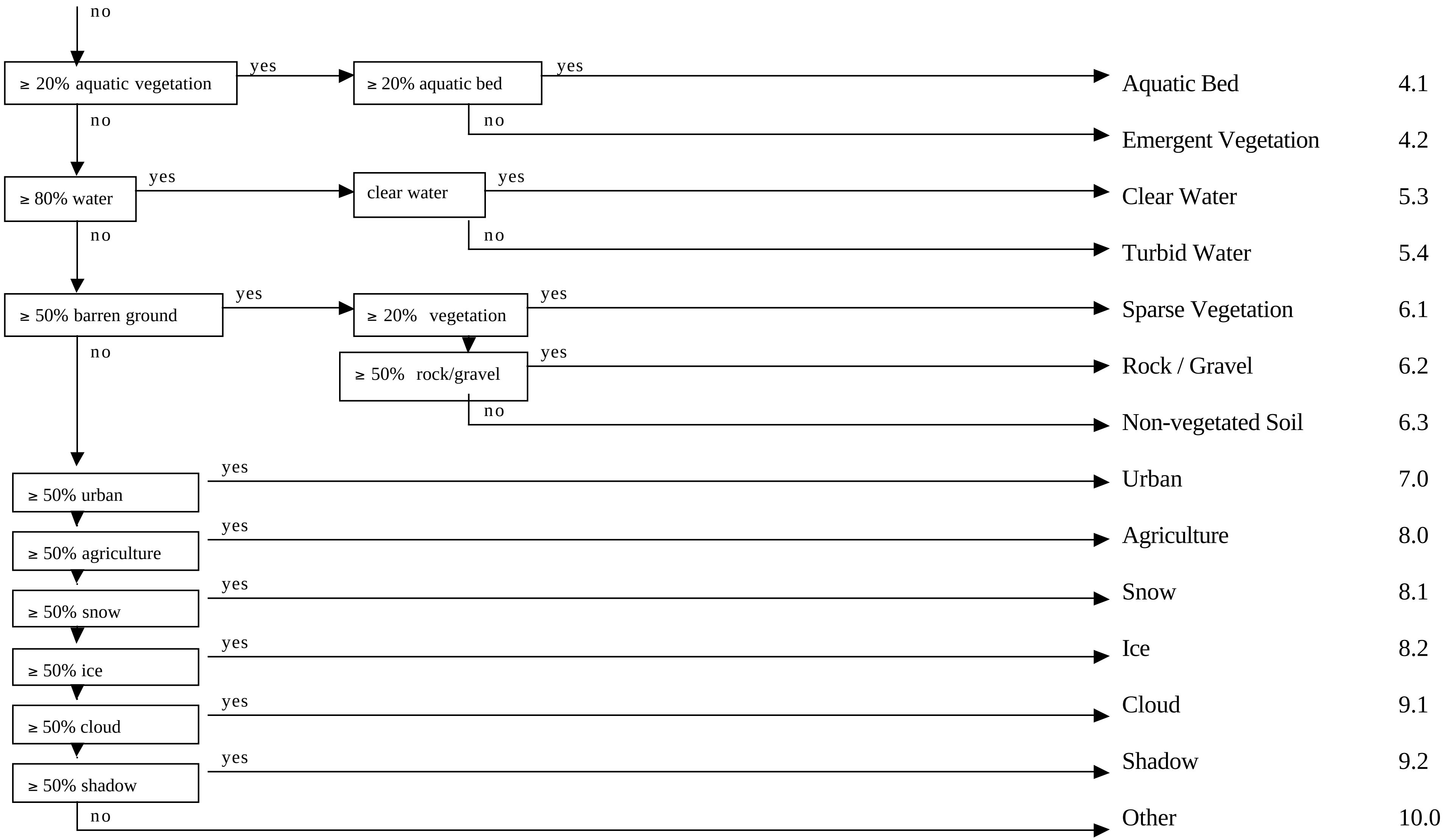
9.3 Terrain Shadow
At least 50% of the cover was made up of terrain shadows.

10.0 Other
Sites that did not fall into any other category were assigned to Other. For example, sites containing 25%-80% water, <25% shrub and <20% aquatic vegetation were classed as Other. Sites classed as Other may have also included extensive areas of vegetative litter, such as downed wood.

Appendix B. Earth Cover Classification Decision Tree




no
no
25-100% shrubs
yes
no
most common shrub is ≥ 1.3 m tall
yes
Tall Shrub
2.1
most common shrub is 0.25- 1.3 m tall
yes
≥ 75% willow / alder
yes
Low Shrub Willow/Alder
2.21
≥ 35% tussock
yes
Low Shrub Tussock Tundra
2.22
≥ 20% lichen
yes
Low Shrub Lichen
2.23
no
Low Shrub Other
2.24
most common shrub is < 0.25 m tall
yes
≥ 20% lichen
yes
Dwarf Shrub Lichen
2.31
no
Dwarf Shrub
2.32
≥ 40% herbaceous AND
≤ 25% water
yes
≥ 50% bryoid
yes
≥ 50% lichen
yes
Lichen
3.11
no
no
Moss
3.12
5-25% water OR
> 20% Carex aquatilis
yes
≥ 35% tussock
yes
≥ 50% graminoid (sedge, grass)
Wet Graminoid
3.21
no
no
Wet Forb
3.22
no
≥ 50% graminoid
(sedge, grass, tussock)
yes
≥ 50% grass
and tussock
yes
≥ 35% tussock
yes
≥ 20% lichen
yes
Tussock Tundra Lichen
3.311
no
no
Tussock Tundra
3.312
no
no
yes
≥ 50% sedge
Mesic/Dry Sedge Meadow
3.32
≥ 50% grass
yes
Mesic/Dry Grass Meadow
3.33
no
no
Mesic/Dry Graminoid
3.34
Mesic/Dry Forb
3.35


no
≥ 20% aquatic vegetation
yes
≥ 20% aquatic bed
yes
Aquatic Bed 4.1
no
Emergent Vegetation 4.2
no
≥ 80% water
yes
clear water
yes
Clear Water 5.3
no
Turbid Water 5.4
no
≥ 50% barren ground
yes
≥ 20% vegetation
yes
Sparse Vegetation 6.1
≥ 50% rock/gravel
yes
Rock / Gravel 6.2
no
Non-vegetated Soil 6.3
no
≥ 50% urban
yes
Urban 7.0
≥ 50% agriculture
yes
Agriculture 8.0
≥ 50% snow
yes
Snow 8.1
≥ 50% ice
yes
Ice 8.2
≥ 50% cloud
yes
Cloud 9.1
≥ 50% shadow
yes
Shadow 9.2
no
Other 10.0

Appendix C. Plant Species and Cover Type List.

Symbol	Percent Cover	Family	Genus and Species	Common
SAX_	14.00%	SALICACEAE	SALIX SPP	WILLOW
BEGL	12.86%	BETULACEAE	BETULA GLANDULOSA	BIRCH,TUNDRA DWARF
CAAQ	6.72%	CYPERACEAE	CAREX AQUATILIS	SEDGE,WATER
CAXX	5.91%	CYPERACEAE	CAREX SPP	SEDGE SPP
MOXX	5.74%		MOSS SPP	MOSS SPP
LITT	5.58%		LITTER	LITTER
GRAV	4.35%		GRAVEL	GRAVEL
CLWA	4.07%		CLEAR WATER	CLEAR WATER
LIXX	3.68%		LICHEN SPP	LICHEN SPP
PIMA	9.32%	PINACEAE	PICEA MARIANA	SPRUCE,BLACK
POTR10	3.31%	SALICACEAE	POPULUS TREMULA	ASPEN,QUAKING
ALCR6	3.17%	BETULACEAE	ALNUS CRISPA	ALDER,GREEN
LEGR	2.79%	ERICACEAE	LEDUM GROENLANDICUM	LABRADOR-TEA,GREENLAND
ROCK	2.48%		ROCK	ROCK
PIGL	2.30%	PINACEAE	PICEA GLAUCA	SPRUCE,WHITE
ERXX	2.27%	CYPERACEAE	ERIOPHORUM SPP	COTTON-GRASS
GRS	1.75%		GRASS SPP	GRASS
CACA4	1.68%	POACEAE	CALAMAGROSTIS CANADENSIS	REEDGRASS,BLUE-JOINT
BRGR	1.64%		BARE GROUND	BARE GROUND
ALRU2	1.62%	BETULACEAE	ALNUS RUBRA	ALDER,RED
VAMI	1.56%	ERICACEAE	VACCINIUM MICROCARPUS	BLUEBERRY
ERVA4	1.54%	CYPERACEAE	ERIOPHORUM VAGINATUM	COTTON-GRASS,TUSSOCK
EMNI	1.23%	EMPETRACEAE	EMPETRUM NIGRUM	CROWBERRY,BLACK
DRXX	1.13%	ROSACEAE	DRYAS SPP	MOUNTAIN-AVENS
BEPA	0.97%	BETULACEAE	BETULA PAPYRIFERA	BIRCH,PAPER
POBA2	0.97%	SALICACEAE	POPULUS BALSAMIFERA	POPLAR,BALSAM
SATRE	0.91%	SALICACEAE	SALIX SPP TREE	WILLOW,TREE
NUPO	0.90%	NYMPHAEACEAE	NUPHAR POLYSEPALUM	WATER LILY
EQXX	0.89%	EQUISETACEAE	EQUISETUM SPP	HORSETAILS SPP
PESA5	0.76%	ASTERACEAE	PETASITES SAGITTATUS	COLTSFOOT,ARROW-LEAF
SADW1	0.65%	SALICACEAE	SALIX SPP DWARF	WILLOW DWARF
SILT	0.62%		SILT	SILT
SAND	0.58%		SAND	SAND
MUDX	0.56%		MUD	MUD
CATE11	0.55%	ERICACEAE	CASSIOPE TETRAGONA	BELL-HEATHER,ARCTIC
EQFL	0.53%	EQUISETACEAE	EQUISETUM FLUVIATILE	HORSETAIL,WATER
POTR12	0.48%	SALICACEAE	POPULUS TRICHOCARPA	BLACK COTTONWOOD
POFR4	0.34%	ROSACEAE	POTENTILLA FRUTICOSA	CINQUEFOIL,SHRUBBY
VAUL	0.32%	ERICACEAE	VACCINIUM ULIGINOSUM	BLUEBERRY,BOG
METR3	0.30%	MENYANTHACEAE	MENYANTHES TRIFOLIATA	BUCKBEAN
MYGA	0.28%	MYRICACEAE	MYRICA GALE	SWEETGALE
GRXX	0.26%		GRAMINOID SPP	GRAMINOID SPP
HEAL	0.19%	FABACEAE	HEDYSARUM ALPINUM	SWEETVETCH,ALPINE
COCA13	0.18%	CORNACEAE	CORNUS CANADENSIS	BUNCHBERRY,CANADA
EPAN2	0.15%	ONAGRACEAE	EPILOBIUM ANGUSTIFOLIUM	FIREWEED
JUAL2	0.14%	JUNCACEAE	JUNCUS ALBESCENS	RUSH,NORTHERN WHITE
POPA14	0.12%	ROSACEAE	POTENTILLA PALUSTRIS	CINQUEFOIL,MARSH

Symbol	Percent Cover	Family	Genus and Species	Common
SHCA	0.12%	ELAEAGNACEAE	SHEPHERDIA CANADENSIS	BUFFALO-BERRY,CANADA
EQPA	0.11%	EQUISETACEAE	EQUISETUM PALUSTRE	HORSETAIL,MARSH
POXX1	0.11%	POTAMOGETONACEA	POTAMEGETON SPP	PONDWEED SPP
BENA	0.10%	BETULACEAE	BETULA NANA	BIRCH,SWAMP
JUHO2	0.10%	CUPRESSACEAE	JUNIPERUS HORIZONTALIS	JUNIPER,CREEPING
RUCH	0.08%	ROSACEAE	RUBUS CHAMAEMORUS	CLOUDBERRY
CHCA2	0.07%	ERICACEAE	CHAMAEDAPHNE CALYCULATA	LEATHERLEAF
NULU	0.06%	NYMPHAEACEAE	NUPHAR LUTEUM	COW-LILY,YELLOW
NYTE	0.06%	NYMPHAEACEAE	NYMPHAEA TETRAGONA	WATER-LILY,PYGMY
SACA14	0.06%	ROSACEAE	SANGUISORBA CANADENSIS	BURNET,CANADA
SASP2	0.06%	SALICACEAE	SALIX SPHENOPHYLLA	WILLOW,WEDGE-LEAF
TUWA	0.06%		TURBID WATER	TURBID WATER
SPBE	0.04%	ROSACEAE	SPIRAEA BEAUVERDIANA	SPIRAEA,BEAUVERED
EPXX	0.03%	ONAGRACEAE	EPILOBIUM SPP	FIREWEED SPP
HELA4	0.03%	APIACEAE	HERACLEUM LANATUM	COW-PARSNIP
LUNO	0.03%	FABACEAE	LUPINUS NOOTKATENSIS	LUPINE,NOOTKA
LUPO2	0.03%	FABACEAE	LUPINUS POLYPHYLLUS	LUPINE,LARGE-LEAVED
PEFR5	0.03%	ASTERACEAE	PETASITES FRIGIDUS	COLTSFOOT,ARCTIC SWEET
SAEX2	0.03%	SAXIFRAGACEAE	SAXIFRAGA EXILIS	SAXIFRAGE
ANGE2	0.01%	APIACEAE	ANGELICA GENUFLEXA	ANGELICA,KNEELING
ARCA13	0.01%	ASTERACEAE	ARTEMISIA CANA	SAGEBRUSH,SILVER
BORI	0.01%	SAXIFRAGACEAE	BOYKINIA RICHARDSONII	BOYKINIA
DEGL3	0.01%	RANUNCULACEAE	DELPHINIUM GLAUCUM	LARKSPUR,TOWER
DIXX	0.01%	DIAPENSIACEAE	DIAPENSIA SPP	DIAPENSIA SPP
EQAR	0.01%	EQUISETACEAE	EQUISETUM ARVENSE	HORSETAIL,FIELD
LEDE5	0.01%	ERICACEAE	LEDUM DECUMBENS	LABRADOR-TEA,NARROW-LEAF
PELA	0.01%	SCROPHULARIACEAE	PEDICULARIS LABRADORICA	LOUSEWORT,LABRADOR
POAL8	0.01%	POTAMOGETONACEAE	POTAMOGETON ALPINUS	PONDWEED,ALPINE
RAXX	0.01%	RANUNCULACEAE	RANUNCULUS SPP	CROWFOOT/BUTTERCUP
RONU	0.01%	ROSACEAE	ROSA NUTKANA	ROSE,NOOTKA
SEVU	0.01%	ASTERACEAE	SENECIO VULGARIS	GROUNDSEL,COMMON
VAVI	0.01%	ERICACEAE	VACCINIUM VITIS-IDAEA	CRANBERRY,MOUNTAIN
ACDE2	0.00%	RANUNCULACEAE	ACONITUM DELPHINIFOLIUM	MONKSHOOD,LARKSPUR-LEAF
ALGE2	0.00%	POACEAE	ALOPECURUS GENICULATUS	FOXTAIL,MEADOW
ANPO	0.00%	ERICACEAE	ANDROMEDA POLIFOLIA	ROSEMARY,BOG
ARBI2	0.00%	ASTERACEAE	ARTEMISIA BIENNIS	WORMWOOD,BIENNIAL
ARLA2	0.00%	POACEAE	ARCTAGROSTIS LATIFOLIA	ARCTIC-BENTGRASS
ARLE3	0.00%	COMPOSITAE	ARNICA LESSINGII	ARNICA,ALPINE
ARST6	0.00%	ASTERACEAE	ARTEMISIA STELLERANA	SAGEBRUSH,HOARY
ARUV	0.00%	ERICACEAE	ARCTOSTAPHYLOS UVA-URSI	BEARBERRY
ARXX	0.00%	COMPOSITAE	ARNICA SPP	ARNICA SPP
ASSI	0.00%	ASTERACEAE	ASTER SIBIRICUS	ASTER,SIBERIAN
ASXX	0.00%	FABACEAE	ASTRAGALUS SPP	VETCH
ASYU	0.00%	ASTERACEAE	ASTER YUKONENSIS	ASTER,YUKON
ATDI	0.00%	ASPLENIACEAE	ATHYRIUM DISTENTIFOLIUM	FERN,ALPINE LADY
BLSP	0.00%	BLECHNACEAE	BLECHNUM SPICANT	FERN,DEER
CARO2	0.00%	CAMPANULACEAE	CAMPANULA ROTUNDIFOLIA	BELLFLOWER,SCOTCH
CAUN4	0.00%	SCROPHULARIACEAE	CASTILLEJA UNALASCHCENSIS	INDIAN-PAINTBRUSH,ALASKA
CIDO	0.00%	APIACEAE	CICUTA DOUGLASII	WATER-HEMLOCK,WESTERN

Symbol	Percent Cover	Family	Genus and Species	Common
CIMA	0.00%	APIACEAE	CICUTA MACKENZIANA	WATER-HEMLOCK,MACKENZIE
COST4	0.00%	CORNACEAE	CORNUS STOLONIFERA	DOGWOOD,RED-OSIER
COSU4	0.00%	CORNACEAE	CORNUS SUECICA	DOGWOOD,SWEDISH DWARF
DRDR	0.00%	ROSACEAE	DRYAS DRUMMONDII	MOUNTAIN-AVENS,YELLOW
ELMA5	0.00%	CYPERACEAE	ELEOCHARIS MACROSTACHYA	SPIKERUSH,CREEPING
EQPR	0.00%	EQUISETACEAE	EQUISETUM PRATENSE	HORSETAIL,MEADOW
GAAP2	0.00%	RUBIACEAE	GALIUM APARINE	BEDSTRAW,CATCHWEED
HITE	0.00%	HIPPURIDACEAE	HIPPURIS TETRAPHYLLA	MARE'S-TAIL,FOUR-LEAF
HIVU2	0.00%	HIPPURIDACEAE	HIPPURIS VULGARIS	MARE'S-TAIL,COMMON
JUAR2	0.00%	JUNCACEAE	JUNCUS ARCTICUS	RUSH,ARCTIC
JUCO	0.00%	CUPRESSACEAE	JUNIPERUS COMUNIS	JUNIPER,COMMON
LYAL3	0.00%	LYCOPODIACEAE	LYCOPODIUM ALPINUM	CLUBMOSS,ALPINE
MEMA3	0.00%	BORAGINACEAE	MERTENSIA MARITIMA	OYSTERLEAF
MEPA	0.00%	BORAGINACEAE	MERTENSIA PANICULATA	BLUEBELLS,TALL
MYSC	0.00%	BORAGINACEAE	MYOSOTIS SCORPIOIDES	FORGET-ME-NOT,TRUE
PAFI3	0.00%	SAXIFRAGACEAE	PARNASSIA FIMBRIATA	GRASS-OF-PARNASSUS
PAWA	0.00%	PAPAVERACEAE	PAPAVER WALPOLEI	POPPY,WALPOLE'S
PEPA31	0.00%	ASTERACEAE	PETASITES PALMATUS	COLTSFOOT,SWEET
POAL11	0.00%	POLYGONACEAE	POLYGONUM ALPINUM	SMARTWEED,ALPINE
POAL5	0.00%	POLYGONACEAE	POLYGONUM ALASKANUM	RHUBARB,ALASKA WILD
POAN5	0.00%	ROSACEAE	POTENTILLA ANSERINA	SILVERWEED
POBI5	0.00%	POLYGONACEAE	POLYGONUM BISTORTA	BISTORT,MEADOW
POHY4	0.00%	ROSACEAE	POTENTILLA HYPARCTICA	CINQUEFOIL,ARCTIC
POXX	0.00%	POACEAE	POA SPP	POA SPP
PUKA	0.00%	POACEAE	PUCCINELLIA KAMTSCHATICA	GRASS,ALASKA ALKALI
RAGE	0.00%	RANUNCULACEAE	RANUNCULUS GELIDUS	BUTTER-CUP,ARCTIC
RANI	0.00%	RANUNCULACEAE	RANUNCULUS NIVALIS	BUTTER-CUP,SNOWY
ROAC	0.00%	ROSACEAE	ROSA ACICULARIS	ROSE,PRICKLY
SAXX	0.00%	SAXIFRAGACEAE	SAXIFRAGA SPP	SAXIFRAGE SPP
SEAT2	0.00%	ASTERACEAE	SENECIO ATROPURPUREUS	GROUNDSEL,ARCTIC
SECY	0.00%	ASTERACEAE	SENECIO CYMBALARIOIDES	GROUNDSEL,CLEFT-LEAF
SEER2	0.00%	ASTERACEAE	SENECIO EREMOPHILUS	GROUNDSEL,DESERT
SELU	0.00%	ASTERACEAE	SENECIO LUGENS	GROUNDSEL,BLACK-TIP
SEPA4	0.00%	ASTERACEAE	SENECIO PAUCIFLORUS	GROUNDSEL,FEW-FLOWER
SEPA5	0.00%	ASTERACEAE	SENECIO PAUPERCULUS	GROUNDSEL,BALSAM
SEPS	0.00%	ASTERACEAE	SENECIO PSEUDOARNICA	GROUNDSEL,SEABEACH
SIAC	0.00%	CARYOPHYLLACEAE	SILENE ACAULIS	CAMPION,MOSS
SOCA6	0.00%	ASTERACEAE	SOLIDAGO CANADENSIS	GOLDEN-ROD,CANADA
VAOX	0.00%	ERICACEAE	VACCINIUM OXYCOCCOS	CRANBERRY,SMALL

Appendix D. Gulkana River Watershed Accuracy Assessment Error Matrix

	Opn Ndlf	Wdld Ndlf	Cld Decid	Tall Shrb	Low Shrb	Dwf Shrb	Wet Grmd	Barren	**TOTAL**	**USER'S**	**LOW L**	**UPPER L**	**KAPPA**	**VARIANCE**
Opn Ndlf	**23**	1	1				1		**26**	**88.46**	**75.41**	**100**	**0.8472**	
Wdld Ndlf	**1**	4							**5**	**80**	**40.94**	**100**	**0.7875**	
Cld Decid			**6**						**6**	**100**	**96.67**	**100**	**1**	
Cld Mix	**1**								**1**	**0**	**0**	**20**	**0**	
Tall Shrb				**12**	2				**14**	**85.71**	**65.95**	**100**	**0.8325**	
Low Shrb		**1**		3	**24**		1		**29**	**82.76**	**68.32**	**97.2**	**0.7591**	
Dwf Shrb					3	**5**			**8**	**62.5**	**26.45**	**98.55**	**0.6057**	
Wet Grmd							**5**		**5**	**100**	**96**	**100**	**1**	
Barren								**8**	**8**	**100**	**97.5**	**100**	**1**	
TOTAL	**25**	**6**	**7**	**15**	**29**	**5**	**7**	**8**	**102**					
PRODUCER'S	**92**	**66.67**	**85.71**	**80**	**82.76**	**100**	**71.43**	**100**		**85.29**				
LOW L	**80.57**	**25.62**	**56.93**	—	**58.42**	**68.32**	**96**	**35.11**	**97.5**		**77.93**			
UPPER L	**100**	**100**	**100**	—	**100**	**97.2**	**100**	**100**	**100**			**92.65**		
KAPPA	**0.8472**	**0.7875**	**1**	**0**	**0.8325**	**0.7591**	**0.6057**	**1**	**1**				**0.8198**	
VARIANCE														**0.0018**

Appendix E. Contact Information

The following additional data is available:

ARC/INFO coverages
Final map classification in ERDAS Imagine format
Final map compositions in Imagine 8.2 format
Raw Landsat TM and DEM imagery
Field database files and FoxPro data entry program
ARC/INFO coverage of aerial photograph flight lines

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