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Comparisons of Digital Terrain Data for Wetland Inventory on Two Alaskan Army Bases

Rae A. Melloh, Charles H. Racine, Steven W. Sprecher,
Nancy H. Greeley, and Patricia B. Weyrick

November 1999

Abstract: The nation's military installations encompass undeveloped lands that have become increasingly important as wildlife habitats. Resource managers of the installations need wetland inventories to improve stewardship of these lands. Digital geographic data are readily available to land managers. The use of these data to inventory wetlands has not been demonstrated. As part of a project to integrate wetlands into the ITAM (Integrated Training Area Management) program for managing Army lands, wetland inventory methods using existing digital geographic information for two terrains on Army installations in Alaska were explored: (1) glacial moraine depressions and estuarine marsh on Fort Richardson, and (2) discontinuous permafrost and taiga forest on Fort Wainwright's Yukon Command training site. Our results show that (1) existing geographic data used to infer wetland locations (Landsat Thematic Mapper [TM], National Wetland Inventory [NWI] maps, and hydric soil maps) only partly agree, and (2) optimum Landsat TM band combinations for wetland inventory vary on a site-specific basis. Landsat TM classifications (unsupervised) of Fort Richardson wetlands compared reasonably well (0.73 Kappa Index of Agreement [KIA]) with the NWI map as long as the band combinations included at least one visible and the near-infrared wavelength band (e.g., bands 3, 4, and 5 or bands 2, 3, and 4). The Fort Richardson hydric soils map indicates more extensive wetlands than indicated by the NWI (0.64 KIA). The Landsat TM classification could be made to agree fairly well with the NWI map (0.73 KIA). At Fort Wainwright, use of the thermal wavelength band (6, 4, and 2 composite) improved Landsat TM classification agreement with the NWI (0.67 KIA) because of warmer apparent brightness temperatures of lowland wetland sites compared to upland forested sites. Topographic position in the taiga forest plays a strong role in determining soil moisture, dominant vegetation, and whether or not the site is underlain by permafrost; therefore, a wet terrain map derived from a digital elevation model agreed nearly as well to the NWI map (0.64 KIA) as did the Landsat TM classification (0.67 KIA). Existing geographic information can serve as an initial wetland map. However, accurate wetland maps will require field mapping.

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PREFACE

This report was prepared by Rae A. Melloh, Research Physical Scientist, Geological Sciences Division, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Engineer Research and Development Center (ERDC), Hanover, New Hampshire; Dr. Charles H. Racine, Ecologist, Geological Sciences Division, CRREL; Dr. Steven W. Sprecher, Soil Scientist, Wetlands Branch, Ecological Research Division, Environmental Laboratory, ERDC, Vicksburg, Mississippi; Nancy H. Greeley, Physical Scientist, Information Systems Branch, Technical Resources Center, CRREL; and Patricia B. Weyrick, Physical Science Technician, Geochemical Sciences Division, CRREL. Funding for this work was provided by the Strategic Environmental Research and Development Program / Integrated Training Area Management Wetland Integration Project through WES funding document number W 81 EW F-4-M102 and CRREL appropriation number 2142040 08 8150 P612784 19129.

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Comparisons of Digital Terrain Data for Wetland Inventory on Two Alaskan Army Bases

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INTRODUCTION

Background

The need to delineate and inventory wetlands has increased in recent years both for the scientific community and for resource management at national and local levels. Current scientific focus on wetland mapping includes an effort to estimate natural sources and sinks for atmospheric constituents that regulate climate (Matthews and Fung 1987, Chappellaz et al. 1993). Resource managers of the nation's military installations need wetland inventories to improve stewardship of these largely undeveloped lands. At the community level, conservation commissions may take on the task of wetland inventory and designate prime areas to be protected from development (Ammann et al. 1986, Ammann and Stone 1991). The need for methods to inventory wetlands thus spans global to local scales.

Three criteria for wetland delineation are hydrophytic vegetation, hydric soils, and hydrologic state. Wetland inventories may utilize combinations of available geographic data, including hydric soils maps, National Wetland Inventory (NWI) maps, digital elevation, and satellite imagery. Current technology allows the various sources to be combined into georeferenced digital data sets; however, the use and reliability of the combined products for wetland inventory is not clear.

A low rate of agreement was found between NWI maps and hydric soils maps during a recent study of seven military installations.* NWI maps are interpreted from aerial photographs and are based largely on wetland vegetation as it appears on color-infrared photography. Soils maps are drawn in the field on aerial photographs from point soil investigations that are extrapolated by interpretation of land form, especially the slope of the land. Hydric and subhydric soil categories may have inclusions of nonhydric soils, while nonhydric soil categories may have inclusions of hydric soils.

The Wetland Subcommittee of the Federal Geographic Data Committee (FGDC) concluded that the synergistic effects of combining Landsat Thematic Mapper (TM) and NWI digital data would have greater value than using either data source alone (FGDC 1992). The FGDC reported that conventional aerial photography techniques, such as those used in the NWI program (by the Fish and Wildlife Service), are more accurate than Landsat TM classification for mapping the areal extent and classification detail. The subcommittee also asserts that the combination of the more accurate NWI maps and the repetition of Landsat TM coverage provide the potential for both accurate and synoptic data sets.

Objectives

As part of a project to integrate wetlands into the ITAM (Integrated Training Area Management) program for managing Army lands, this study explored wetland inventory methods for two terrains on Army installations in Alaska: (1) glacial moraine depressions and estuarine marsh on Fort Richardson, and (2) discontinuous permafrost and taiga forest on Fort Wainwright's Yukon Command training site. The focus of our work with these terrain types was to (1) determine which Landsat TM band combinations provide classification maps of wetlands that compare best with NWI maps, (2) derive and evaluate a procedure for wetland mapping in the taiga forest, based solely on digital elevation data, and (3) quantify and discuss reasons

* Personal communication, D. Tazik, CERL, Champaign, Illinois, 1998.

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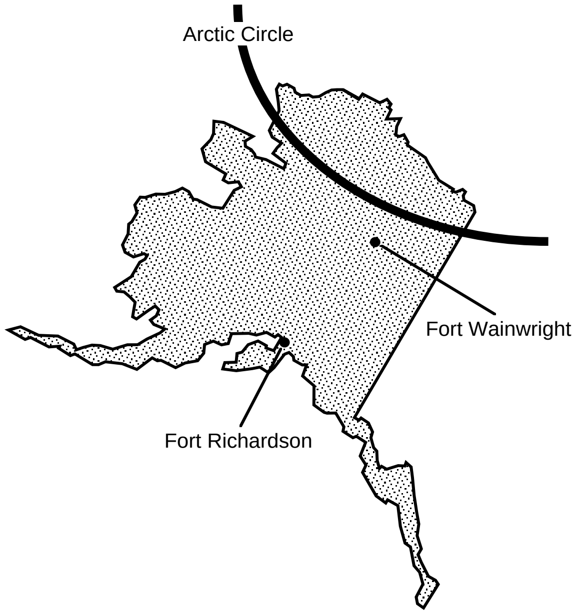

Figure 1. Fort Richardson and Fort Wainwright, Alaska.

for the disagreement between the various wetland maps (hydric soils, NWI, Landsat TM classifications, and wet terrain).

Sites on Fort Richardson and Fort Wainwright, Alaska (Fig. 1), were chosen based on availability of digitized spatial data and prior knowledge of the wetlands derived from ongoing research projects at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire (Racine et al. 1992, Racine et al. 1993). Although representative of Alaskan terrain, the two military bases are environmentally quite different: (1) Fort Richardson is glaciated and Fort Wainwright is not, and (2) there is discontinuous permafrost control on soil moisture and vegetation at Fort Wainwright but not at Fort Richardson. One area on each base was selected for analysis: Fort Richardson's glaciated coastal plain and Fort Wainwright's mountains. Fort Richardson's coastal plain, including an estuarine salt marsh, is located along the south side of Knik Arm in upper Cook Inlet. On Fort Wainwright, the Yukon Command training area in the foothills of the Yukon/Tanana Upland serves as an example of wetlands in mountainous, discontinuous permafrost terrain.

DATA COMPILATION AND PRE-PROCESSING METHODS

National Wetland Inventory classifications

NWI maps are prepared by the U.S. Department of the Interior Fish and Wildlife Service (FWS) using the classification system of Cowardin et al. (1979) for distinguishing wetland types. The classification hierarchy includes five major systems: marine, estuarine, riverine, lacustrine, and palustrine (App. A). The systems are divided into subsystems, such as estuarine subtidal. Subsystems are divided into classes, e.g., estuarine intertidal emergent. The designations are based on photo interpretation of vegetation cover as distinguishable on high altitude color-infrared aerial photography (normally at a scale of 1:60,000) and with limited field verification.

NWI maps for our two sites were available on Mylar sheets and were purchased from the U.S. Geological Survey, Earth Science Information Center, in Anchorage, Alaska. Digital data were not available for these map sheets, so sections of the Yukon Command training area at Fort Wainwright and the coastal plain and estuarine marsh of Fort Richardson were digitized.

Landsat TM wetland classification

Landsat TM classification maps were generated and their agreement with NWI was evaluated in an attempt to identify the pertinent spectral band combinations for automated wetland classification. The software package IDRISI was used for image processing; it is a low-cost, easy-to-use, yet powerful tool for manipulating digital data, and is available to resource managers using WINDOWS or MS-DOS. IDRISI is licensed and supported by the IDRISI Project, Clark University Graduate School of Geography, in Worcester, Massachusetts (Eastman 1992).

Landsat-5, TM seven-band data sets were obtained on 22 June 1991 for Fort Wainwright, and on 16 September 1986 for Fort Richardson. TM bands 1, 2, and 3 correspond to visible blue, green, and red wavelengths; band 4 is reflected near-infrared (near-IR); bands 5 and 7 are reflected middle IR wavelengths; and band 6 is emitted thermal radiation. The images were rectified to a Universal Transverse Mercator (UTM) projection using from 6 to 16 ground control points, and first-order (linear), nearest neighbor resampling. The nearest neighbor resampling technique was used so that the original data values would be maintained. The root-mean-square-error (RMSE) for each resampled image was less than one pixel (± 30 m).

Composite images were generated using three data layers consisting of either the Landsat TM bands or band transformations. The approach was to try combinations we judged to be good candidates for discriminating wetlands from uplands based on previous studies (Crist and Cicone 1984;

Jensen 1986; FGDC 1992). The combinations tried for Fort Richardson (Table 1) and Fort Wainwright (Table 2) were similar. Band transformations included (1) tasseled-cap, (2) principal component, and (3) normalized difference vegetation index (NDVI).

The tasseled-cap approach transforms the six bands of reflected data into three dimensions: brightness, greenness, and wetness, and is described by Crist and Cicone (1984). Brightness, greenness, and wetness three-component images have been used to enhance separation between urban, water, and wetland classes (Jensen 1986). The greenness dimension contrasts visible bands with near-IR bands and thus is a good vegetation indicator, because reflection from vegetation is low in the visible and high in the near-IR wavelengths. The brightness component is composed of weighted sums of visible band data and is a bare soil indicator; the pixel values decrease as soil moisture increases. The wetness component contrasts middle-IR reflectance with visible and near-IR reflectance (Crist and Cicone 1984). The wetness image provides subtle information about the moisture status of a wetland environment where increasing moisture is seen as increasing pixel value (Jensen 1986).

The principal components transformation reduces the dimensionality of multiband TM data by finding the between-band correlations and mathematically transforming the data into new uncorrelated images (Jensen 1986). In this way six or seven bands of TM data can be reduced to three dimensions with little loss of information. Principal components transformations were used in three instances: (1) all seven bands (TM1 through TM7) were reduced to three bands (P71, P72, and P73; Table 1), (2) the six reflective bands were reduced to two bands (P61 and P62, Table 2), and (3) the three visible bands were reduced to one band (PV, Table 2).

Table 1. Fort Richardson, Alaska: Band combinations and error statistics (NWI classes vs. wetlands classified from Landsat).

Composition of 3-layer composites			*Error of ommission (%)*	*Error of commission (%)*	*Overall agreement (%)*	*KIA*
a. Coastal plain and estuarine marsh unseparated						
P71	P72	P73	66	6	90	0.44
Wet	Green	Bright	68	3	90	0.43
TM2	TM3	TM4	61	24	88	0.42
TM2	TM4	TM6	68	12	89	0.39
TM3	TM4	TM7	79	6	88	0.29
TM2	TM4	TM5	80	6	88	0.27
TM3	TM4	TM5	82	6	88	0.25
TM4	TM5	TM7	95	4	86	0.07
b. Coastal plain section						
Wet	Green	Bright (#1)	78	6	93	0.32
TM3	NDVI	TM7	80	2	93	0.31
TM3	NDVI	Wet	80	3	93	0.30
TM2	TM4	TM5	81	2	93	0.29
TM2	TM4	TM6	81	5	93	0.28
TM3	TM4	TM5	83	1	93	0.28
TM3	TM4	TM7	83	1	93	0.27
TM2	NDVI	Wet	85	1	93	0.24
TM2	TM3	TM4	86	2	93	0.23
P71	P72	P73	90	1	93	0.17
TM4	TM5	TM7	93	4	92	0.12
TM3	TM4	TM5 (a)	83	1	93	0.28
TM3	TM4	TM5 (b)	54	67	90	0.38
TM3	TM4	TM5 (c)	47	94	89	0.37
c. Estuarine marsh section						
TM2	TM3	TM4 (#2)	3	7	92	0.54
TM3	TM4	TM5	1	9	91	0.44
TM2	TM4	TM6	2	9	90	0.43
TM2	TM4	TM5	3	9	90	0.41
TM3	TM4	TM7	2	9	90	0.41
P71	P72	P73	0	13	88	0.04
TM4	TM5	TM7	0	14	88	0.03
Wet	Green	Bright	0	14	88	—
DEM	<10M		0	14	88	—
d. Recombined coastal plain and estuarine marsh						
#1 and #2, from above			35	7	93	0.72
#1 and #2, +mixed class*			23	54	87	0.59
TM3	TM4	TM5 (a)	36	6	93	0.72
TM3	TM4	TM5 (b)	24	35	90	0.67
TM3	TM4	TM5 (c)	21	46	89	0.64
TM3	TM4	TM5 (mode)	25	18	93	0.73

* See text for explanation.

The NDVI transformation is an indicator of photosynthetic biomass and is derived from TM bands 4 and 3 (near-IR and red, respectively) as the ratio of their difference divided by their sum:

$$\mathrm{NDVI} = \frac{(\mathrm{IR} - \mathrm{red})}{(\mathrm{IR} + \mathrm{red})}.$$

The NDVI method again takes advantage of the fact that vegetation reflectivity is high in near-IR wavelengths and relatively low in the visible (Kauth and Thomas 1976).

The ability to duplicate the NWI using Landsat TM data was assessed. An unsupervised clustering algorithm was used to separate each of the

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three-dimensional composite images into 30 or more spectral classes. The clustering routine in IDRISI is a histogram peak technique in three dimensions (Eastman 1992). The class maps derived from automated classification were digitally compared with the NWI maps. Classes whose pixels fell predominantly in NWI upland or wetland were assigned to that category in a two-class wetland / upland map (TM-wetland). Once classes were assigned to wetland or non-wetland status, errors of omission, commission, and overall Kappa coefficients (Congalton 1991) were computed (App. B) to assess the TM-wetland and NWI reference map agreement. Separating the data into more than 30 classes was found not to significantly improve the agreement.

Table 2. Fort Wainwright, Alaska: Band combinations and error statistics (NWI classes vs. wetlands classified from Landsat).

Composition of 3-layer composites (%)			*Error of omission (%)*	*Error of commission (%)*	*Overall agreement (%)*	*KIA*
TM2	TM4	TM6	25	19	86	0.67
TM7	NDVI	TM6	23	22	86	0.67
PV	TM4	TM6	23	24	85	0.65
TM2	NDVI	TM6	27	21	84	0.64
Elev	Slope	Aspect	29	21	84	0.64
P71	P72	P73	17	29	83	0.63
TM2	TM3	TM4	28	24	83	0.61
P61	P62	TM6	37	16	83	0.59
TM2	TM4	TM5	36	20	82	0.57
PV	TM4	TM5	21	41	80	0.56
TM2	TM4	TM7	41	16	81	0.55
Wet	Green	Bright	30	34	79	0.53

Digital elevation model wet terrain classification

A digital elevation model (DEM) was used to identify wet terrain units for the mountain and valley topography of Fort Wainwright. The DEM was acquired from the U.S. Geological Survey, EROS Data Center, in Sioux Falls, South Dakota. Slope and aspect data layers were computed from the digital elevation data. The elevations were divided into fifteen 40-m increments between 160 and 760 m. The slopes were divided into six steepness classes (0–1%, 1–3%, 3–7%, 7–12%, 12–20%, and 20–35%). The aspects were divided into nine directions (N, NE, E, SE, S, SW, W, NW, and flat areas). The slope, aspect, and elevation layers were then composited using the IDRISI software. The composite image was clustered into terrain classes. Wet terrain was identified by digital comparison of the terrain classes with the NWI map.

The Fort Richardson site was divided into estuarine and palustrine systems using a DEM as a mask, where areas below 10-m elevation were primarily estuarine and areas above were palustrine wetlands. This eliminated misclassification between the two.

Hydric soils wetland maps

Digital maps of Fort Richardson soils were provided from the existing ITAMS database by the Construction Engineering Research Laboratory (CERL) in Champaign, Illinois. Comparable soils maps were not available for the Fort Wainwright sites; a photo-interpretive soils map at 1:250,000 scale (Alaska Department of Natural Resources 1982) was too coarse to compare with the NWI maps or the DEM, and was not digitized for overlay.

Digital map comparisons

The NWI, soils, and TM-wetland maps were compared by digitally counting pixels that agreed or disagreed and computing the error statistics (App. B). Methods of evaluating errors of commission, omission, overall accuracy, and individual class accuracy are described in Jensen (1986). Accuracy assessment techniques for satellite-derived landcover data, including the Kappa Index of Agreement (KIA) used here, are reviewed by Congalton (1991). We used NWI maps as the reference image when comparing NWI wetlands with Landsat TM classifications, hydric soils data, and wet terrain. There are currently no field-mapped wetland "knowns" available for the sites; thus our comparisons establish agreement rather than accuracy. Images are compared by cross-tabulations in which the categories of one image are compared with those of a second image, on a pixel-by-pixel basis.

PART 1. FORT RICHARDSON

Site description

The training lands of Fort Richardson are located on the south side of Knik Arm in upper Cook Inlet and include both coastal plain wetlands and an estuarine marsh. Small bogs, marshes, swamps, ponds, and lakes dot the coastal plain where poorly drained soils occur in shallow depressions in glacial moraines and terraces. The wet areas are commonly underlain by firm or compact glacial till. Other wetlands occur in swales, drainageways,

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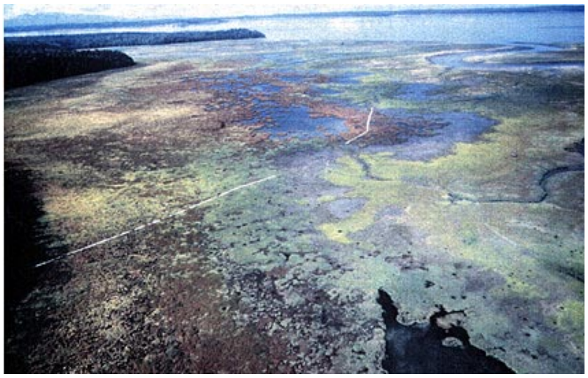

Figure 2. Fort Richardson, Alaska: Eagle River Flats, an estuarine marsh.

and on slopes affected by seepage (USDA 1979). In some instances very poorly drained peat has accumulated in low-lying areas and broad depressions. Eagle River Flats, an 826-ha estuarine salt marsh at the mouth of the Eagle River (Fig. 2), includes vegetated and unvegetated mudflats and various types of marshes, meadows, semipermanent ponds, and permanent ponds, arranged in zones determined by sedimentation rates and frequency of tidal flooding (Racine et al. 1993). This coastal marsh borders Cook Inlet where tides reach 11 m.

National Wetland Inventory description

Eagle River Flats, an estuarine system, accounts for 55% of the wetlands in the study area (Fig. 3, Table 3). The remaining 45% are on the coastal plain, where palustrine systems are dominant (38%), and lacustrine and riverine systems make up 5 and 2%, respectively.

Table 3. Fort Richardson, Alaska: NWI system.

NWI system	*Hectares*	*Wetland (%)*
Estuarine	832	54
Lacustrine	84	5
Palustrine	590	38
Riverine	38	3
Total wetland	1544 (17%)	
Total upland	7745 (83%)	
Total	9289	

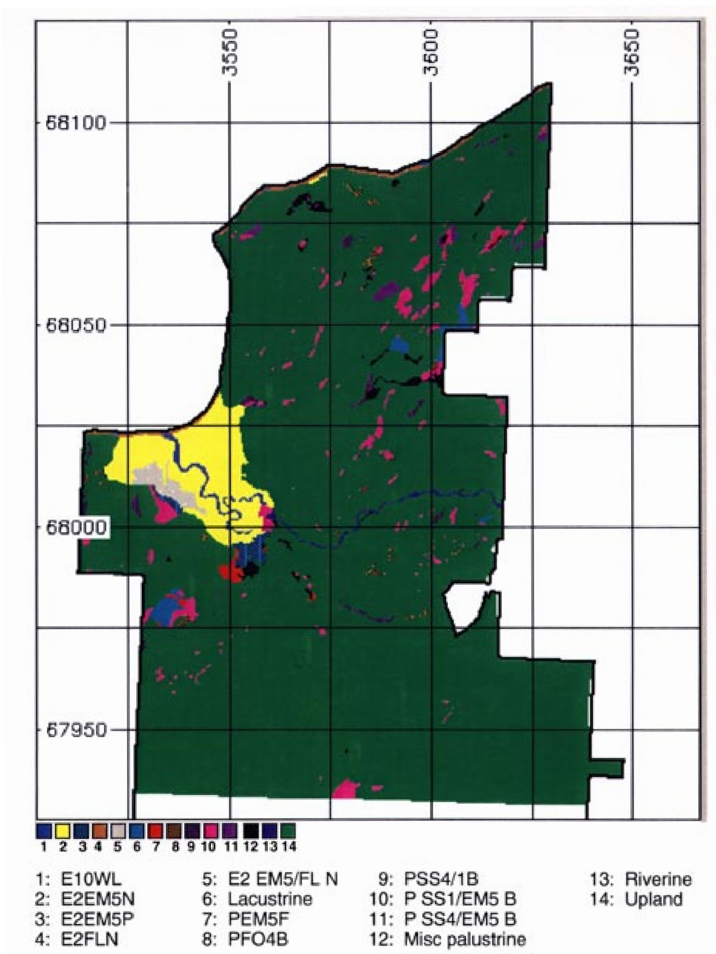

Figure 3. Fort Richardson, Alaska: NWI wetlands.

Methods and results

Hydric soils

Soils on Fort Richardson were broken into hydric (Table 4) and nonhydric categories (Fig. 4) using the Soil Conservation Service's listing of hydric soils of the United States (USDA 1987) and screening for additional hydric soils in the Anchorage Area Soil Survey (USDA 1979). The only addition to the national list was the Cryaquent mapping unit, which is locally described as "consisting of poorly drained sandy, silty, and clayey stratified sediments deposited on low-lying coastal plains, and where most of the areas are inundated periodically by tidal water." This soil type underlies much of Eagle River Flats but also occurs on the coastal plain and is not assigned to a specific soil series. Hydric soils cover 21% of the study area above UTM 67,975 north.

Deriving Landsat TM wetland maps

Composite images were generated for eight Landsat TM band combinations (Table 1a) encompassing both the estuarine marsh and coastal plain. Overall agreement with NWI maps ranged from 86 to 90%; however, between 61 and 95% of the wetlands were omitted from these initial classification maps. The KIAs were low, ranging

Table 4. Fort Richardson, Alaska: Hydric soils.

Soil series		*Slope (%)*
CmA	Clam Gulch silt loam	0–3
CmB		3–7
CmC		7–12
CmD		12–20
CmE		20–30
Cn	Cryaquents, loamy	
DoA	Doroshin peat	0–3
DoB		3–7
DoC		7–12
DoD		12–20
JaA	Jacobsen very stony silt loam	0–3
JaB		3–7
KaA	Kalifonsky silt loam	0–3
KaB		3–7
Mr	Moose River silt loam	
Rw	Riverwash	
Sa	Salamatof peat	
SmA	Slikok mucky silt loam	0–3
SmB		3–7
SmC		7–12
SpA	Spenard silt loam	0–3
SpB	Spenard silt loam	3–7
St	Starichkof peat	
ToA	Torpedo Lake gravelly sandy loam	0–3
ToB		3–7
ToC		7–12
ToD		12–20

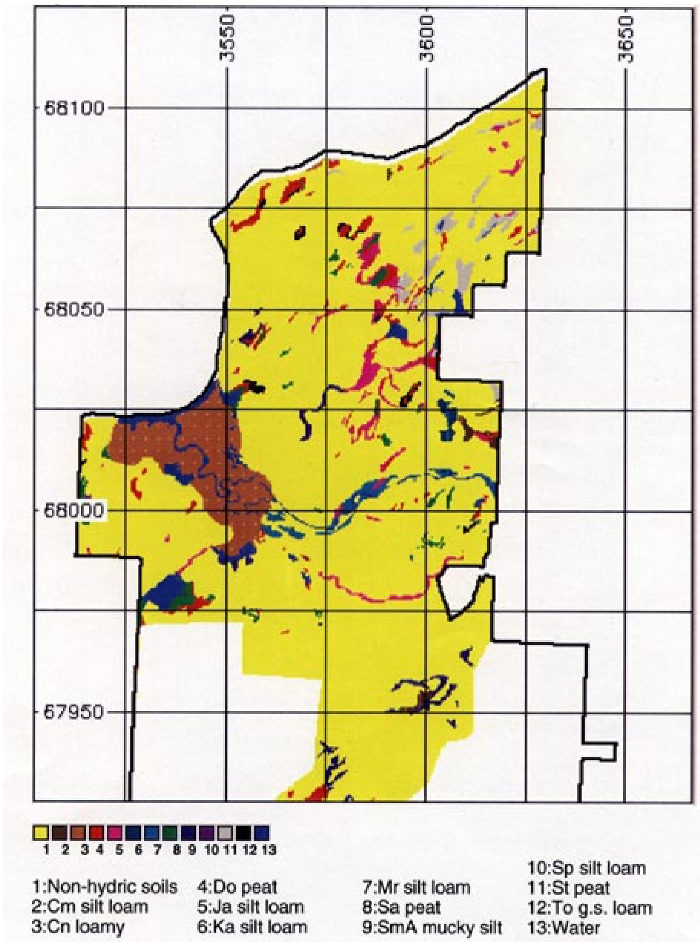

Figure 4. Fort Richardson, Alaska: Hydric soils.

from 0.07 to 0.44, reflecting the high omission error. The best performing composites were the principle component and tasseled-cap transformations; however, a few of the other band combinations also performed well (Table 1a).

The study area was then separated into the lower estuarine marsh and higher coastal plain using the 10-m elevation as a boundary between the two. The separation was accomplished using a DEM as a mask. Classifications were run separately on eleven combinations of the coastal plain (Table 1b) and eight combinations of the estuarine marsh (Table 1c). The separate classifications were ultimately reunited to give the final classification map (Table 1d).

Overall agreement of the coastal plain section alone ranged between 92 and 93% (Table 1b); however, the KIAs were between 0.12 and 0.32, reflecting omission errors in the 93 to 78% range. The composites providing the best matched classifications were those that included the tasseled-cap or NDVI transformations, though a number of band combinations agreed nearly as well. The principle components composite approach did not compare well, nor did band combinations that excluded visible wavelength information.

The class maps for the estuarine marsh section alone had overall agreements between 88 and 92% and KIAs from 0.03 to 0.51 (Table 1c). Non-agreement in this section was due to misclassifying upland areas around the edge of the marsh as wetland (commission). The best composites were those that combined visible and near-IR bands.

Adding the error matrices of the best agreeing classifications of the estuarine marsh (TM234 composite) and coastal plain (tasseled-cap composite) resulted in a KIA of 0.72 (Table 1d). The higher KIA compared to the two sections alone is due to a reduction in the combined omission error when the estuarine and coastal plain wetland areas are added together. It is interesting to note that the separate classifications were not improved, but the overall error statistics did improve. The omission error attributable to not finding palustrine wetlands (omission) remained large (35%) while commission error was relatively low (7%).

Comparison of the Landsat TM wetland classes with the NWI map indicated that some of the

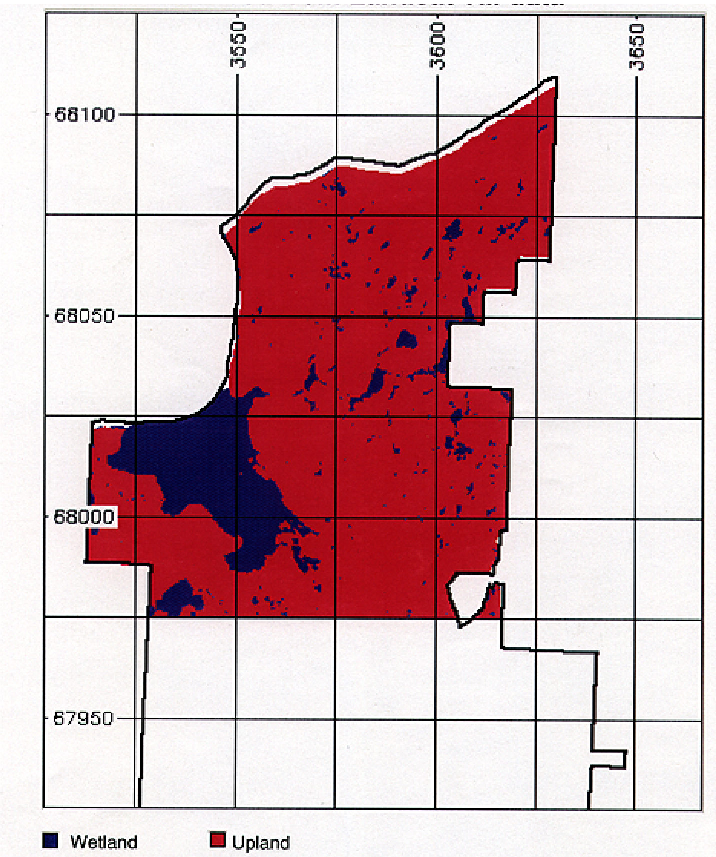

Figure 5. Fort Richardson, Alaska: Wetlands derived from Landsat TM data.

Landsat TM classes were assigned to upland though they had nearly as much wetland as upland. An attempt was made to subdivide the mixed wetland / upland classes into subclasses that might break more meaningfully between wetland and upland. The result of this "clusterbusting" attempt was not successful: the resulting subclasses were also mixed, and predominantly upland.

A somewhat improved balance of commission and omission errors could be obtained using a variation of the TM345 composite image (Table 1b). This composite had performed relatively well on both the estuarine and coastal sections. First, spectral classes that were not predominantly wetland but contained greater than 40% wetland were classed as wetland (TM345b, Table 1b). This reduced the omission error on the coastal plain section from 83% to 54%, and though the commission error increased substantially, the KIA improved from 0.28 to 0.38. In a second trial we added mixed classes with greater than 20% wetland. This resulted in an omission error of 47%, and though the commission error increased to 94%, the KIA dropped only slightly, to 0.37.

Adding the three TM345 versions of the coastal plain classification to the estuarine section classification (also TM345) resulted in combined KIAs ranging from 0.64 to 0.72 (Table 1d). The image with the KIA of 0.67 included the best balance of error in the palustrine, so we chose this one to finalize. The two-class wetland / upland map was passed through a modal filter, which eliminated isolated pixels. The filtering increased omission slightly from 24 to 25%, but improved commission from 35 to 18%. The final class map (Fig. 5) had an overall accuracy of 93% and KIA of 0.73. The overall percentage of wetland pixels correctly found on the Fort Richardson site was 75%, while upland pixels were correctly found 96% of the time.

Comparison of Landsat TM and NWI wetland maps

A cross-tabulation image (Fig. 6) of the NWI and best agreeing Landsat TM wetlands map shows areas of (1) upland agreement, (2) NWI upland but Landsat TM wetland (commission),

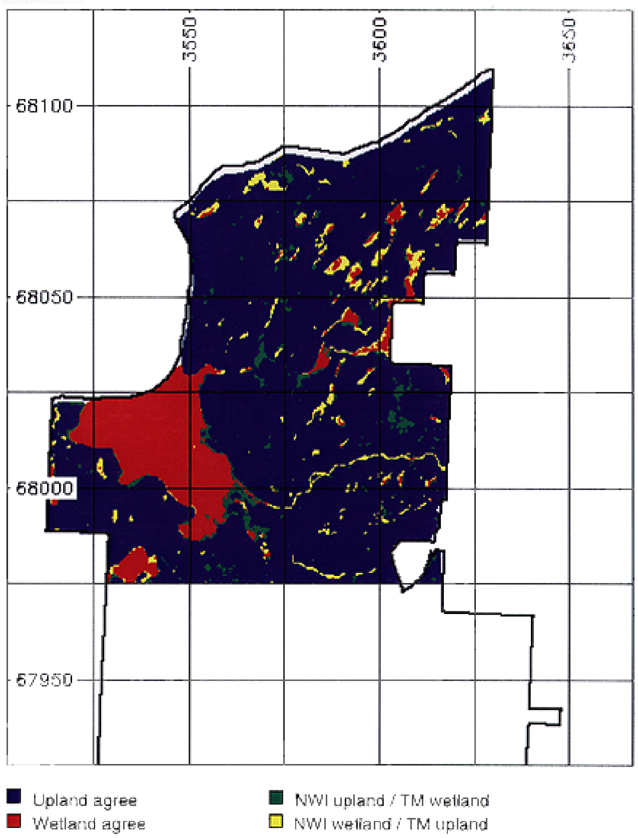

Figure 6. Fort Richardson, Alaska: NWI wetland and Landsat TM data comparison.

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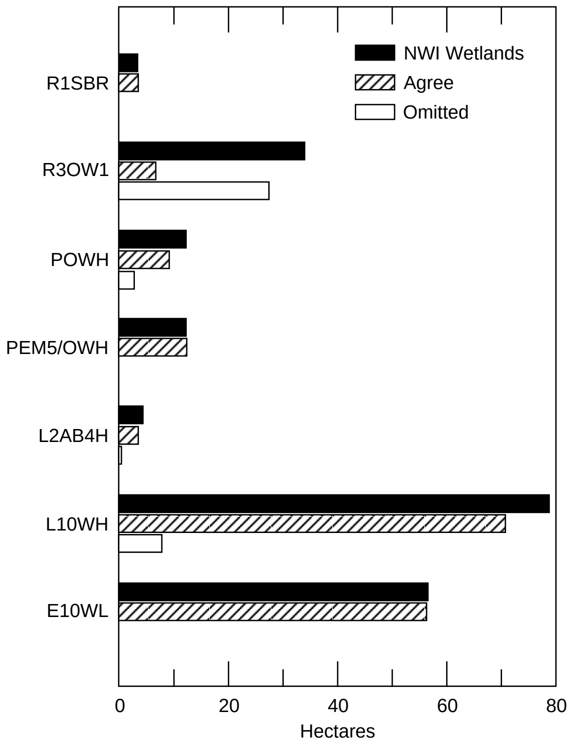

Figure 7. Fort Richardson, Alaska: Open water classification accuracy.

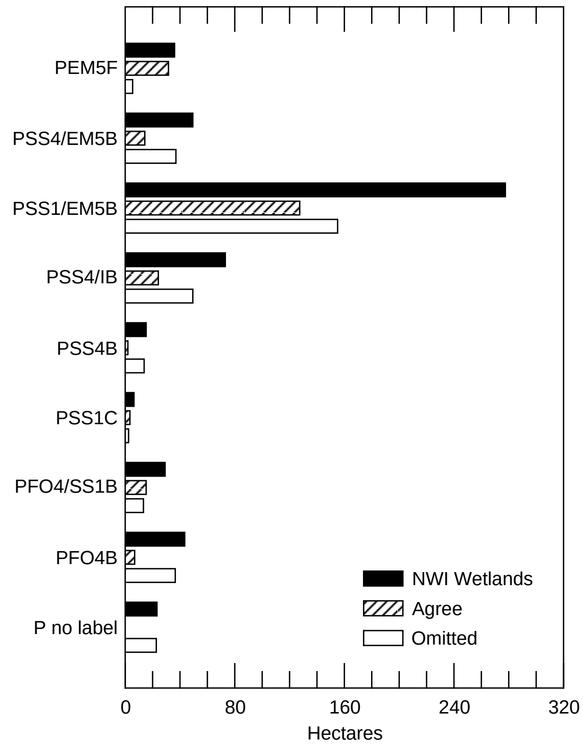

Figure 9. Fort Richardson, Alaska: Palustrine system classification accuracy.

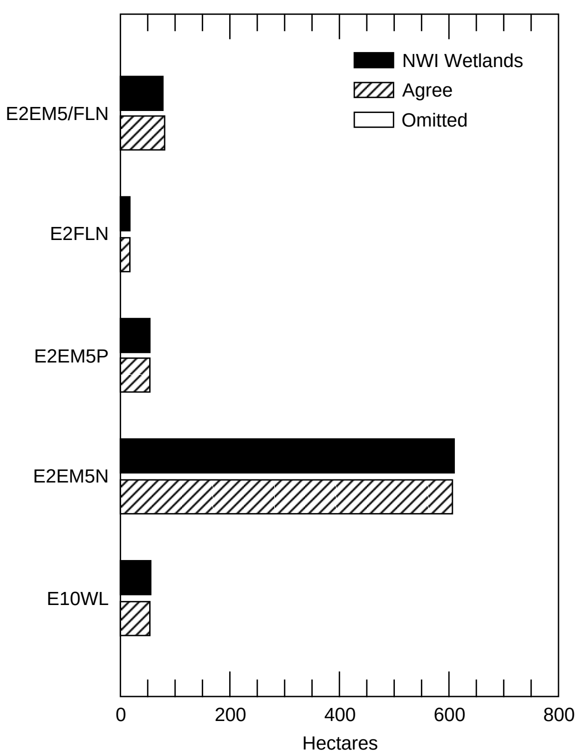

Figure 8. Fort Richardson, Alaska: Estuarine system classification accuracy.

(3) NWI wetland but Landsat TM upland (omission), and (4) wetland agreement. Classification was successful for open water and emergent classes included in the palustrine, riverine, lacustrine, and estuarine systems (Fig. 7). The only poorly classified open water was Eagle River, a small stream not readily observable at a 30-m pixel scale. The estuarine system was almost perfectly identified (Fig. 8). The errors in classification occurred almost exclusively in the palustrine system, forested, scrub-shrub, and emergent classes and in the deciduous and evergreen subclasses (Fig. 9). The numerous small wetlands tended to be mixed in classes that were predominantly disturbed upland (lawns, excavations, and clearings), resulting in less than 50% of the predominant palustrine class (PSS1/EM5B) being identified. Mixed upland and wetland classes remained mixed when clusterbusting techniques were tried.

Comparison of Landsat TM wetland and hydric soil maps

A comparison of the Landsat TM wetland map with the hydric soils map resulted in a KIA of 0.59. Wetland extent based on soil type was greater than that based on the Landsat TM. Only 326 hectares of nonhydric soils were committed with Landsat

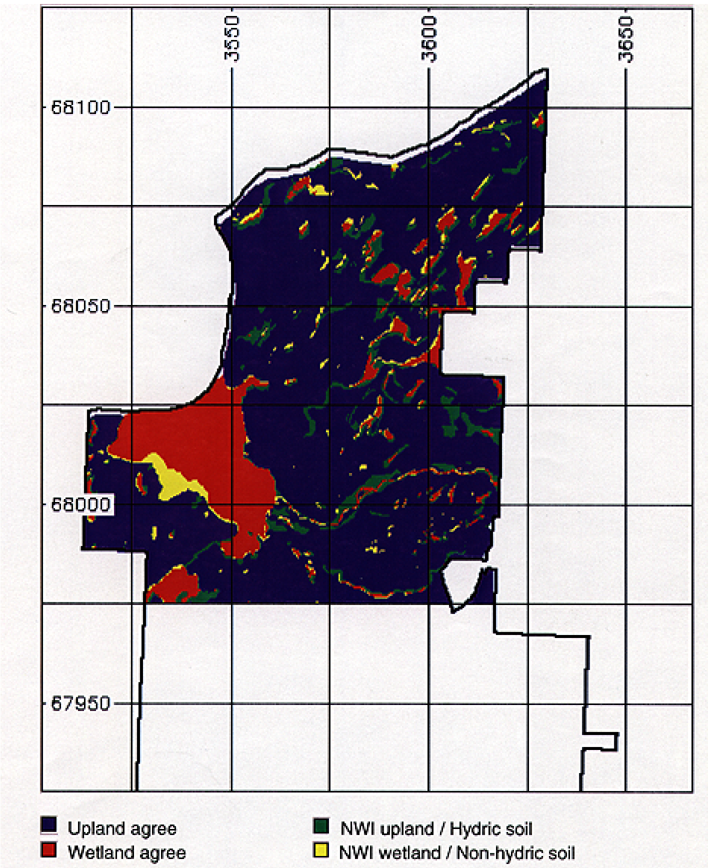

Figure 10. Fort Richardson, Alaska: NWI wetland and hydric soils data comparison.

TM wetlands. The nonhydric soil series most often erroneously included was the Purches; 98 out of 698 hectares of this nonhydric soil series coincided with Landsat TM wetlands. The Kasilof silt loams were the next often included; 57 out of 629 hectares of this nonhydric soil series coincided with TM-wetlands. The hydric soil areas omitted from TM-wetlands were more numerous (827 hectares); the only categories covered well were the Cryaquent map unit, which underlies the estuarine marsh (642 out of 645 hectares) and water that is spectrally distinct (270 out of 305 hectares).

Comparison of NWI and hydric soils maps

A comparison of the soils and NWI data (Fig. 10) resulted in a KIA of 0.64 and an overall accuracy of 89%. The 36% omission error is largely attributable to less extensive NWI wetland areas (1544 hectares) than hydric soils (2251 hectares). The greatest mismatches (Fig. 11) were for Jacobsen silt loams (JaA, JaB) and Doroshin peats (DoA, DoB, DoC). Of these wet soils, 74% of the 243 hectares of Jacobsen and 69% of the 214 hectares of the Doroshin were not designated as NWI wetland.

There were also NWI wetlands that occurred in areas mapped as nonhydric soils. The error of commission was 16% and due almost entirely to the Purches soils (PuA, PuB), in which 18% of the 698 hectares coincided with NWI wetlands. The Purches soils are moderately well drained to somewhat poorly drained soils (USDA 1979), and may have inclusions of hydric soils.

PART 2. FORT WAINWRIGHT

Site description

The Yukon Command training area rises from the northern extent of the Tanana River Valley into the foothills of the Yukon-Tanana Upland. This site lies within the discontinuous permafrost region and the taiga forest. Permafrost is defined as a thickness of soil, bedrock, or other surface material that has been colder than 0°C for two or more years. The site is characterized by mountainous upland benches that rise 500 to 600 meters above the valley floors. In this terrain and climate, topographic position plays a strong role in determining the dominant vegetation and whether the site is underlain by permafrost. North-facing slopes and low-gradient

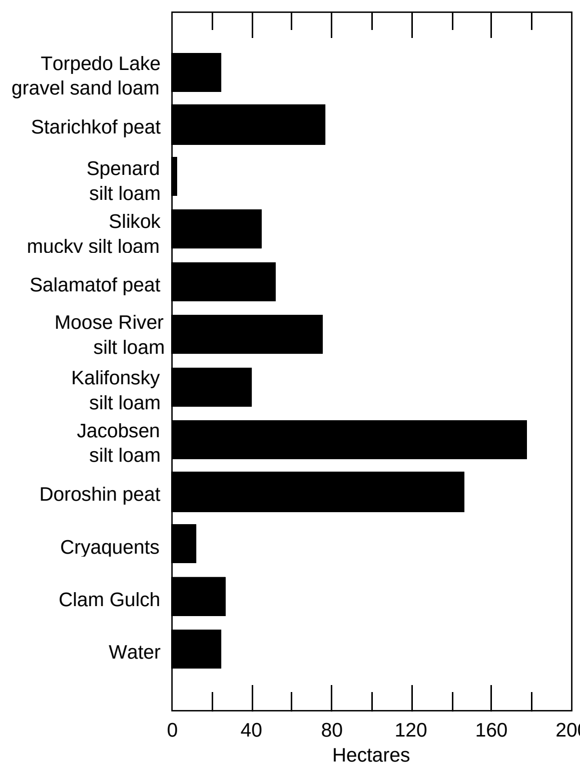

Figure 11. Fort Richardson, Alaska: Hydric soils not included in NWI wetlands.

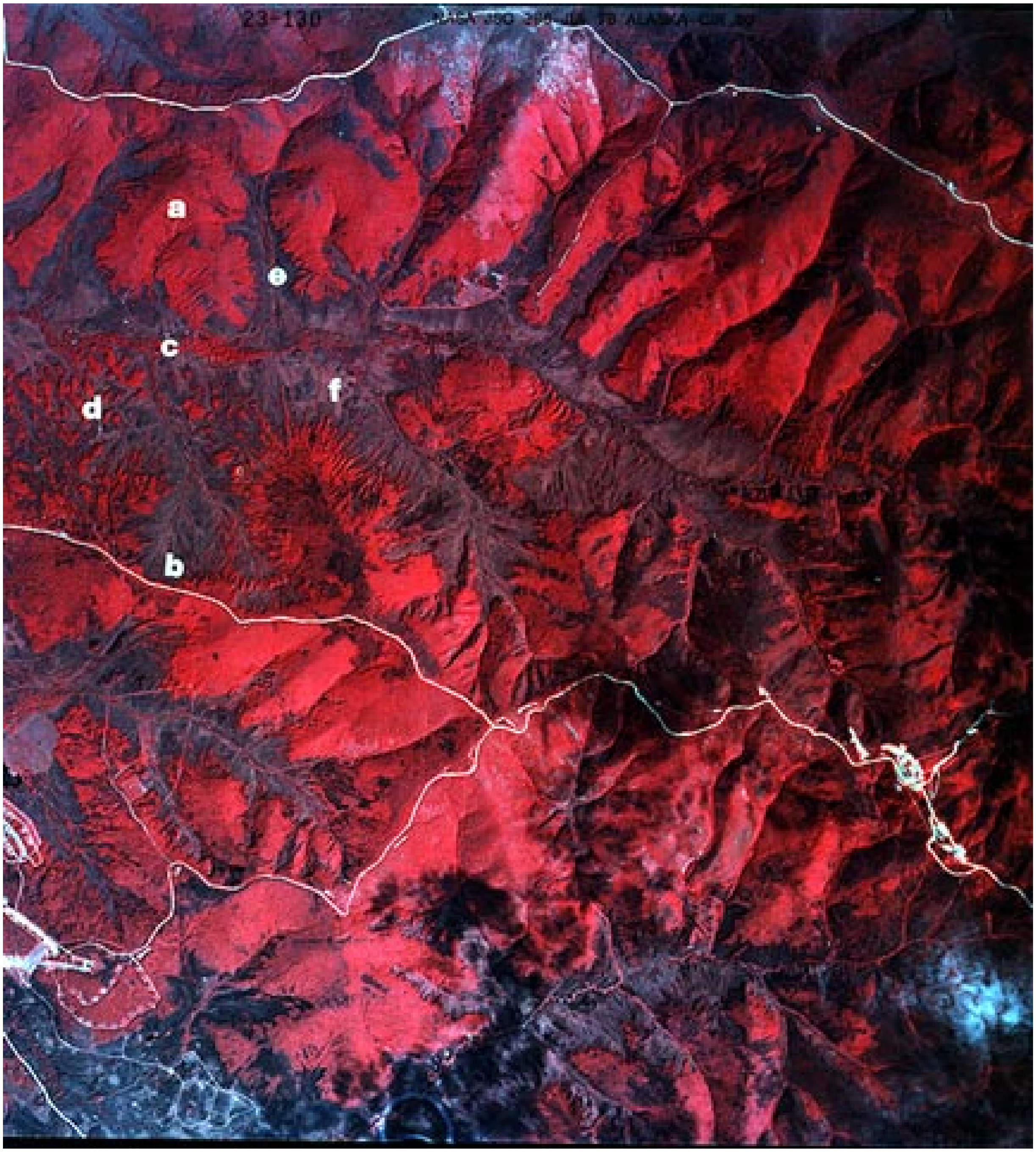

Figure 12. Fort Wainwright, Alaska: Color-infrared aerial photograph of Moose River, July 1978. a) upland deciduous forest in better-drained position at higher elevation, b) wetland on north-facing slope, c) upland deciduous trees along Moose Creek, d) upland deciduous forest islands within wetlands, e) needle-leaved evergreen scrub-shrub wetland in tributary valley, and f) mixed deciduous and evergreen needle-leaved scrub-shrub in the main Moose River valley.

sites are usually underlain by permafrost. The presence of permafrost promotes poor drainage and palustrine wetland development.

Black spruce can tolerate a wide range of moisture conditions and is the species most commonly associated with treed wetlands in interior Alaska. Stands of black spruce become more open over very poorly drained sites (Aber and Melillo 1991). Although black spruce is a tree species, its height is greatly reduced on cold, wet permafrost sites to less than 2-m height; in the NWI system, trees less than 6 m tall are placed in the scrub-shrub class (Cowardin et al. 1979). Treeless bogs occupy the wettest sites and are sometimes surrounded by black spruce.

Generally, well-drained, south-facing slopes and sediments beneath large streams are free of permafrost (Brown and Kreig 1983). The deciduous species quaking aspen and paper birch may dominate ridge tops and south-facing slopes where soils are well-drained and microclimate is warmer (Aber and Melillo 1991). On deeper mid-slope soils the forest may transition to white spruce (Aber and Melillo 1991), a species that usually indicates lack of permafrost or a seasonally thawed layer (active layer) more than 1 m thick (Brown and Kreig 1983). Vegetation patterns in interior Alaska also depend on fire history. Aspen and birch invade areas where the forest floor has been entirely consumed by fire, whereas spruce forest replaces itself where the forest floor is left intact (Van Cleve et al. 1983).

The Yukon Command training site follows these topo-vegetation generalities. Deciduous trees, appearing as bright red on the summer color-IR aerial photograph (Fig. 12a), occupy better-drained positions higher up on both north-facing and south-facing slopes. Colder north-facing slopes have a mixture of deciduous and evergreen forest; along Moose Creek black spruce bogs occur at higher elevations on north-facing slopes (Fig. 12b) than on south-facing slopes. Deciduous trees follow the lower Moose Creek channel where permafrost may be locally absent (Fig. 12c); these floodplain areas are designated non-wetland on NWI maps. Upland islands of “red” non-wetland deciduous forest occur in better drained soils on slight topographic rises (Fig. 12d). Needle-leaved evergreen (black spruce) scrub-shrub wetlands (PSS4B, Fig. 13) dominate the Moose River tributary valleys (Fig. 12e). Pink tones on the color-IR aerial photograph within the main valley (Fig. 12f) indicate open stands on wetter soils where the understory includes decid-

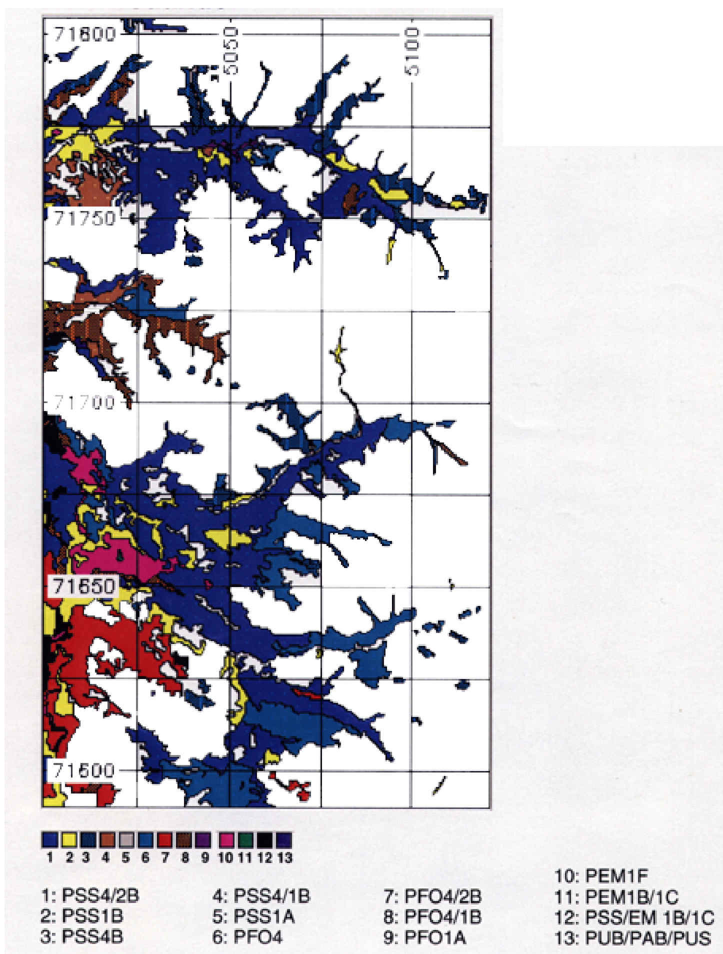

Figure 13. Fort Wainwright, Alaska: NWI wetlands.

Figure 14. Fort Wainwright, Alaska: Moose River tributary (photograph taken from helicopter, 31 May 1994).

Figure 15. Fort Wainwright, Alaska: Close-up of Moose River tributary (photograph taken from helicopter, 31 May 1994).

uous shrubs or grass-like emergents. The pink-toned areas lie within the NWI designation of needle-leaved evergreen (black spruce) and deciduous (such as tamarack) scrub-shrub wetlands (PSS4/2B).

Vegetation cover in a Moose River tributary (Fig. 12e) viewed from a helicopter (Fig. 14) was a lighter-green deciduous forest higher on the slope and a darker-green black spruce scrub-shrub on lower slopes and valleys (PSS4B). The light-toned central zone along the tributary (Fig. 15) is designated as broad-leaved deciduous scrub-shrub (PSS1A).

National Wetland Inventory description

Wetlands on the Yukon Command training area (Fig. 13) are almost entirely of the palustrine system. Scrub-shrub is the dominant class at 64% and forested is 31.2% (Table 5). At the subclass level, mixed evergreen and deciduous, needle-leaved scrub-shrub (PSS4/2B) is the dominant cover type (42%). Needle-leaved evergreen forest is the second largest map category (15.8%), making up 50% of the forested wetlands (PFO).

Methods and results

Deriving Landsat TM wetland maps and comparing with NWI

Eleven different band or band transformation combinations (Table 2) were tried in the classification of the Yukon Command training area. The

Table 5. Fort Wainwright, Alaska: NWI classes within the palustrine system.

NWI class	*Map key*	*Description*	*Percent*
Scrub-shrub	(1)	needle-leaved deciduous/evergreen	42.1
	(2)	broad-leaved deciduous	9.7
	(3)	needle-leaved evergreen	8.2
	(4)	needle-leaved evergreen/broad-leaved deciduous	3.2
	(5)	broad-leaved deciduous	0.4
Forested	(6)	needle-leaved evergreen	15.8
	(7)	needle-leaved evergreen/deciduous	8.6
	(8)	needle-leaved evergreen/broad-leaved deciduous	6.6
	(9)	mixed needle-leaved/deciduous and evergreen	0.2
Emergent	(10)	broad-leaved deciduous	3.5
	(11)	broad-leaved deciduous	0
Scrub-shrub/emergent	(12)	broad-leaved deciduous	1.4
Other	(13)	aquatic bed, /unconsolidated bottom /unconsolidated shore	0.2
Total		25,925 hectares	
Wetland		33%	
Upland		67%	

combinations that agreed well with the NWI (KIA = 0.67) included the emitted thermal wavelength band (TM6). The thermal wavelength image (TM6) is a measure of brightness temperature (T_B), which is a function of the surface temperature (T_S) and emissivity (e) of the landcover:

$$T_B = e\, T_S.$$

Brightness temperatures in this summer (22 June) morning image were warmer in the lowland scrub-shrub wetlands and colder in the upland deciduous forest. Brightness temperature changes were especially distinct where steep north-facing slopes adjoined gently sloping wetland areas. Deciduous forests on south-facing slopes were also "colder" than adjacent lowlands, though the thermal gradient appeared less abrupt there. Factors affecting the summer morning thermal image may be (1) a decrease in temperature with elevation, (2) topographic control of sun exposure causing higher surface temperatures in the extensive lowland and open stands of evergreen scrub-shrub (short black spruce), and (3) different canopy emissivities of the open evergreen scrub-shrub and closed stands of upland deciduous forest.

A cross-tabulation image comparing the NWI-wetland and TM-wetlands (Fig. 16) shows areas of (1) upland agreement, (2) NWI-upland but TM-wetland (commission), (3) NWI-wetland but TM-upland (omission), and (4) wetland agreement. The predominant cover type, palustrine scrub-shrub mixed deciduous and needle-leaved evergreen (PSS4/2B), was readily identified (Fig. 17). The "B" in the identifier (PSS4/2B) is a water regime modifier indicating saturated soils (App. A). Forested wetlands (PFO) were less successfully separated into wetland and upland (Fig. 17).

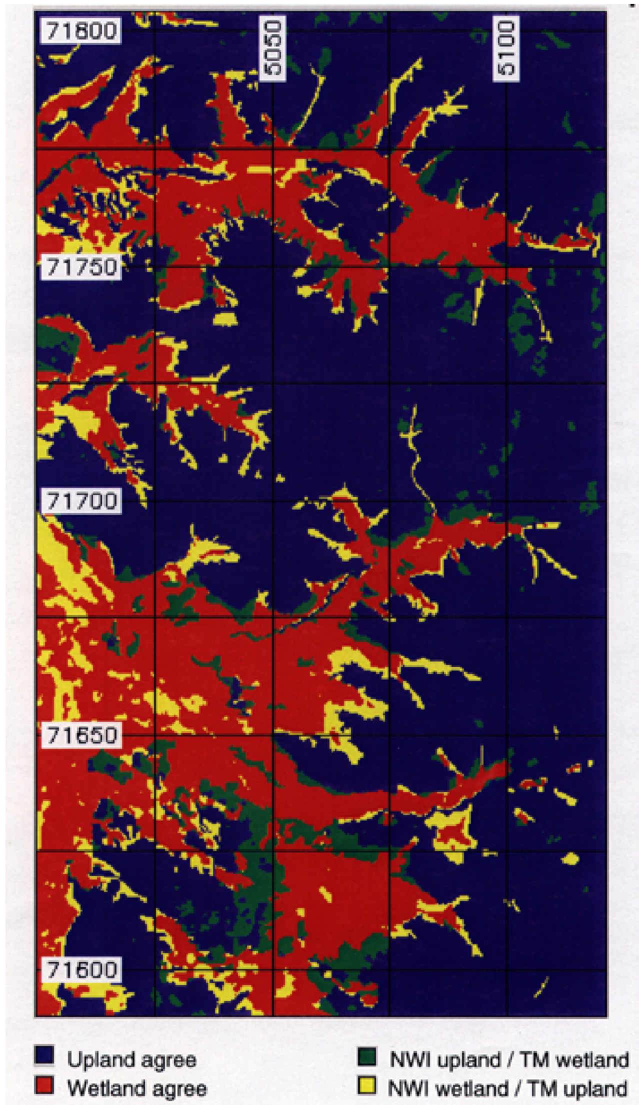

Figure 16. Fort Wainwright, Alaska: NWI wetland and Landsat TM data comparison.

Deriving wet terrain maps and comparing with NWI

The influence of slope, aspect, and elevation on wetland location is further shown by the wet terrain classification derived from these three physical data layers. The elevation / slope / aspect composite was clustered into 53 classes, eight of which were found to be predominantly wetland when compared to the NWI (Table 6). The cross-tabulation image comparing the NWI wetland and wet terrain map comparison is shown in Figure 18. The KIA (0.64) for the wet terrain classification matched the NWI nearly as well as the Landsat TM wetlands map. The error of omission of NWI-wetlands from the wet terrain units was 20.5%, and commission of NWI-upland within the wet

Table 6. Fort Wainwright, Alaska: Wet terrain units.

Unit no.	Direction	Elevation (m)	Slope (%)	Percent agreement with NWI	Percent area
1	SW,W	160–320	1–7	70.2	22
2	NW	160–320	1–7	66.9	19
3	flat	160–240	0–1	85.7	16
4	N	160–240	0–3	77.1	13
5	S,W	160–240	0–1	84.2	12
6	E,SE,S	160–320	1–7	56.2	11
7	NE	160–320	1–3	64.9	6
8	E	160–240	0–1	72.0	1

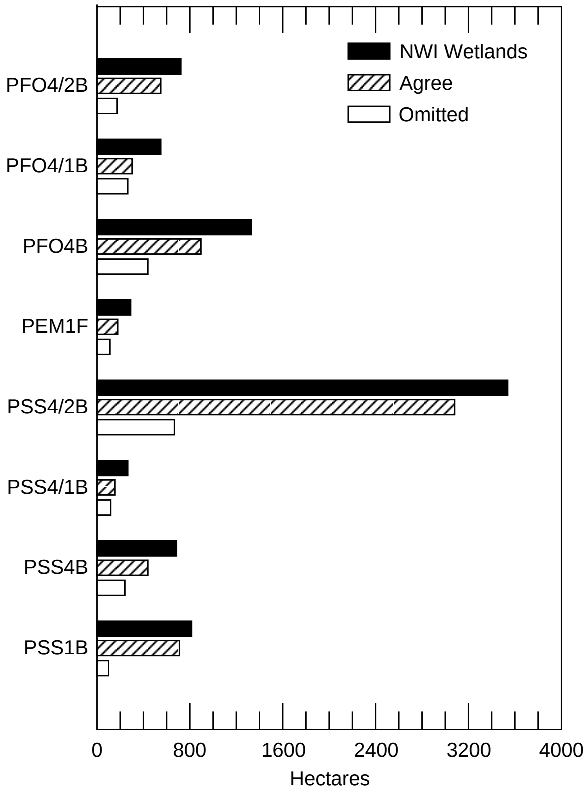

Figure 17. Fort Wainwright, Alaska: Palustrine system classification accuracy.

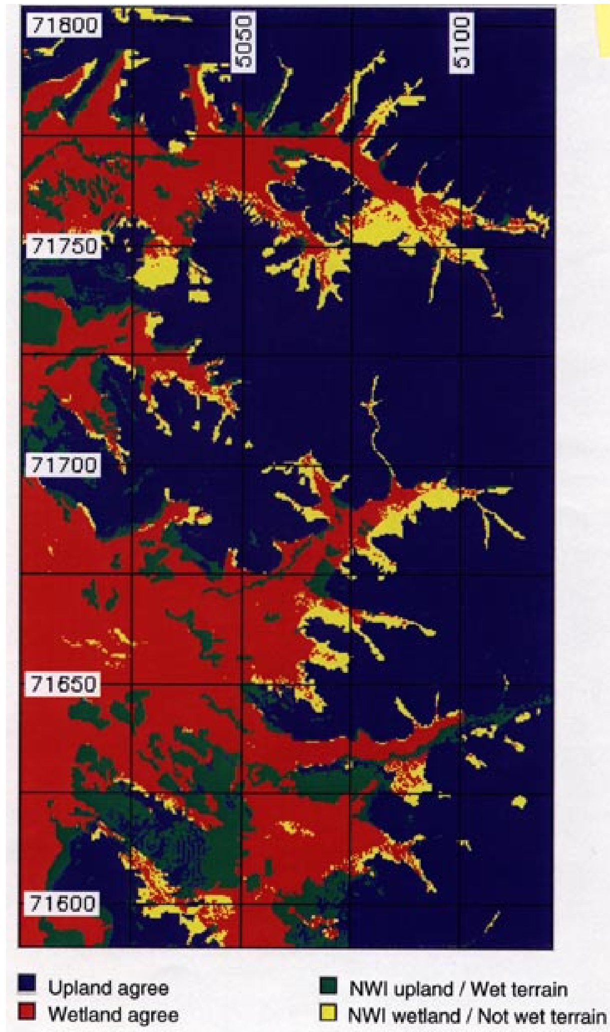

Figure 18. Fort Wainwright, Alaska: NWI wetland and wet terrain comparison.

terrain units was 28.75%. The wet terrain map missed wetlands at higher elevations and slopes, especially north-facing slopes, and included upland at low elevation and low slopes.

Table 7. Soils, NWI, TM-wetland, and wet terrain comparisons.

Fort Richardson			*Fort Wainwright*		
Comparisons		*KIA*	*Comparisons*		*KIA*
TM-wetland	NWI	0.73	TM-wetland	NWI	0.67
Hydric soils	NWI	0.64	Wet terrain	NWI	0.64
TM-wetland	Hydric soils	0.59			

SUMMARY

Based on comparisons (Table 7) of hydric soils, NWI, Landsat TM, and wet terrain maps, we can draw some inferences about methods for wetland resource mapping using exiting geographic data for the two sites.

Site-specific Landsat TM band preferences

The estuarine marsh could be classified based on elevation alone. A composite of TM bands 3, 4, and 5 (red, near-IR, and middle-IR, respectively) worked well overall on Fort Richardson, though palustrine scrub-shrub and forested wetlands on the coastal plain were not well discriminated. A composite of TM bands 2, 3, and 4 (green, red, and near-IR, respectively) worked best in the estuarine marsh section.

In the mountain and valley terrain of Fort Wainwright, we found that use of the thermal band (TM6) was the key to improved classification results, and a composite of TM bands 6, 4, and 2 was the most useful for wetland mapping. The thermal band (TM6) was useful because topographic position, which influences sun exposure and brightness temperature, also influences soil moisture, tree species, and vegetative vigor in the discontinuous permafrost / taiga forest. Topographic control on sun exposure, a decrease in temperature with elevation, and higher thermal emission from warmer open stand lowlands compared to closed-stand deciduous forest are factors that may influence the thermal band brightness temperatures. The near-IR band (TM4) was useful for discriminating upland from wetland, especially on south-facing slopes where deciduous forests reflected more in the near-IR.

Palustrine scrub-shrub wetlands were mapped with more success on Fort Wainwright than on Fort Richardson. Possible explanations include seasonal differences in image dates, and the distribution of wetlands. There were seasonal differences in the deciduous canopies: the Fort Wainwright image was acquired in summer (22 June 1991) and the Fort Richardson image was acquired in the early fall (16 September 1986). The distribution of the wetlands of the two sites differs. The scrub-shrub wetlands on Fort Wainwright are extensive contiguous black spruce lowlands surrounded by extensive contiguous areas of upland deciduous forest. The thermal-IR band (TM6), though useful in the mountain and valley terrain of Fort Wainwright, provided little advantage on the flatter coastal plain of Fort Richardson. At Fort Richardson, the evergreen and deciduous scrub-shrub wetlands are less extensive, occurring as small inclusions in depressions on glacial moraines or borders of lakes and ponds, and were not assigned a unique spectral signature by the methods employed here. The agreement of the classifications presented here represent levels that might be exceeded by more intensive, supervised classification techniques. Supervised approaches allow the analyst more control in defining boundaries between spectral classes. The supervised approach requires more a-priori ground truth than was available for this project.

Though Landsat TM classifications will not delineate wetland systems on the installations with a high degree of accuracy, such classifications will provide valuable information to plan and carry out field mapping. At Fort Richardson, for example, estuarine, riverine, and lacustrine systems are readily mapped using TM and should require limited field verification. More field effort would be required to accurately map the coastal plain palustrine scrub-shrub and forested wetlands.

Omission and commission errors are inherent in Landsat TM wetland mapping because spectral signatures of wetland and upland vegetation are not always separable. The reliability of Landsat TM classifications can, however, be statistically assessed. In this report we did not attempt to classify specific vegetation or wetlands types; a supervised approach would be recommended for that task. Other potential improvements in classification accuracy might involve integration of imagery from more than one season, or of finer spatial resolution (i.e., SPOT).

Use of hydric soils maps

On Fort Richardson, wetland delineation based on NWI maps was less extensive than wetland distribution based on the hydric soils map. One reason for this is that hydric soil units have upland inclusions. Also, NWI wetland maps are based on interpretation of vegetation cover on high-altitude color-IR photography, thus hydric soils would be missed where overlying vegetation indicators are not distinct.

Use of NWI maps

The Fish and Wildlife Service prepares NWI maps with the specific intent of mapping wetlands. Some inherent difficulties are 1) vegetation can be interpreted on the color-IR photographs; however, wetlands are defined as areas of both hydric soils and hydrophytic vegetation, 2) surface vegetation in wetlands may not be distinguishable from non-wetland vegetation on the color-IR photographs, 3) the surface vegetation may be an indeterminate indicator of underlying saturated soils, but both criteria are needed, and (4) in interior Alaska, disturbance of wetlands by fire may temporarily convert the vegetation to upland types.

Use of derived wet terrain maps

Terrain mapping using DEMs is a good tool for understanding topographic controls on vegetation, permafrost, and wetland location in mountain and valley, discontinuous permafrost taiga forest regions. At Fort Wainwright, wet terrain units were almost as successful at matching NWI wetlands as the best TM classification. The success of wet terrain mapping in the mountain and valley terrain of Fort Wainwright may be attributed to the location of wetlands in low topographic positions and on flat or gentle slopes. Wet terrain mapping combined with Landsat TM classification would likely provide even better results.

CONCLUSIONS

Our conclusions address (1) band combinations that provide the best Landsat TM-derived classification maps of wetlands vegetation at the sites studied, (2) the success of a wet terrain classification procedure to map wetlands, and (3) insight into the use of available digital data to inventory wetlands on military installations in Alaska.

Landsat TM-derived classifications of wetlands in glacial moraine depressions and the estuarine marsh of Fort Richardson, Alaska, compared reasonably well with the National Wetland Inventory as long as the band combinations included at least one visible and the near-infrared band. Eleven three-band combinations were tried, including principal components, tasseled-cap, and a normalized difference vegetation index (NDVI).

The Yukon Command training site at Fort Wainwright lies within the unglaciated discontinuous permafrost region and taiga forest of interior Alaska where topographic position plays a strong role in determining soil moisture, dominant vegetation, and whether or not the site is underlain by permafrost. Eleven different three-band or band transformations were tried in Landsat TM classification of the wetlands. Use of the thermal wavelength band of the Landsat TM significantly improved classifications because apparent brightness temperatures of lowland wetland sites were warmer than upland forested sites.

The unsupervised classification approach allowed an expedient survey of a large number of band combinations to identify the most useful band composites. The accuracy of the classifications presented here represent levels that may be exceeded by supervised classification techniques. The supervised approach requires more a-priori ground truth than was available at the initiation of this project, but was substantially assembled as part of this project.

Wet terrain units were derived for the mountain and valley terrain of Fort Wainwright by manipulating slope, elevation, and aspect data into combinations most likely to produce wetlands. The procedure identified eight distinct wet terrain units that together agreed nearly as well as the satellite data classifications when compared with the National Wetland Inventory (NWI).

None of the existing geographic information sources alone, or in combination, inventory the installation wetlands with unquestionable accuracy. The way to obtain highly accurate maps is to combine existing map data with accurate verification and mapping in the field. If possible, available digital data should be assembled prior to field wetland delineation and used as a basis for planning field mapping.

Once an installation's wetlands are accurately mapped, they can be digitized and georeferenced with Landsat TM data. Changes noted on imagery acquired on subsequent dates may then provide the resource manager with information on seasonal or year-to-year variability in vegetative vigor or moisture status of the known wetlands. Major physical alterations and disturbances of wetlands resulting from training activities could also be monitored with Landsat TM data. This synergism could provide both an accurate and synoptic tool for wetland stewardship.

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APPENDIX A: CLASSIFICATION HIERARCHY OF THE NATIONAL WETLAND INVENTORY
(From Cowardin et al. 1979.)

This classification hierarchy of wetlands and deepwater habitats shows systems, subsystems, and classes. The palustrine system does not include deepwater habitats.

WETLANDS AND DEEPWATER HABITATS

System — Subsystem — Class

- Marine
  - Subtidal
    - Rock bottom
    - Unconsolidated bottom
    - Aquatic bed
    - Reef
  - Intertidal
    - Aquatic bed
    - Reef
    - Rocky shore
    - Unconsolidated shore
- Estuarine
  - Subtidal
    - Rock bottom
    - Unconsolidated bottom
    - Aquatic bed
    - Reef
  - Intertidal
    - Aquatic bed
    - Reef
    - Streambed
    - Rocky shore
    - Unconsolidated shore
    - Emergent wetland
    - Scrub-shrub wetland
    - Forested wetland
- Riverine
  - Tidal
    - Rock bottom
    - Unconsolidated bottom
    - Aquatic bed
    - Rocky shore
    - Unconsolidated shore
    - Emergent wetland
  - Lower perennial
    - Rock bottom
    - Unconsolidated bottom
    - Aquatic bed
    - Rocky shore
    - Unconsolidated shore
    - Emergent wetland
  - Upper perennial
    - Rock bottom
    - Unconsolidated bottom
    - Aquatic bed
    - Rocky shore
    - Unconsolidated shore
  - Intermittent
    - Streambed
- Lacustrine
  - Limnetic
    - Rock bottom
    - Unconsolidated bottom
    - Aquatic bed
  - Littoral
    - Rock bottom
    - Unconsolidated bottom
    - Aquatic bed
    - Rocky shore
    - Unconsolidated shore
    - Emergent wetland
- Palustrine
  - Rock bottom
  - Unconsolidated bottom
  - Aquatic bed
  - Unconsolidated shore
  - Moss-lichen wetland
  - Emergent wetland
  - Scrub-shrub wetland
  - Forested wetland

APPENDIX B: ERROR ANALYSES

Table B1. Cross-tabulation of TM246 class map and NWI reference map pixels.

TM	*Upland*		*Wetland*		
class	*Committed*	*Agreed*	*Omitted*	*Agreed*	*Total*
1		16,834	1,585		18,419
2		17,945	347		18,292
3		16,004	1,615		17,619
4		17,112	91		17,203
5		12,002	3,804		15,806
6	6,922			9,570	16,492
7		12,000	4,707		16,707
8	1,691			12,212	13,903
9		15,169	214		15,383
10	3,392			11,829	15,221
11		10,987	899		11,886
12		9,138	4,189		13,327
13	2,401			10,589	12,990
14	1,882			9,166	11,048
15		7,214	998		8,212
16		7,192	142		7,334
17	8,959		13		8,972
18		3,031		6,277	9,308
19		5,317	299		5,616
20	647			7,093	7,740
21		7,746	60		7,806
22	228			5,417	5,645
23		2,659	1,332		3,991
24	783			1,187	1,970
25		1,517	132		1,649
26		1,511	26		1,537
27		1,179	52		1,231
28		889	390		1,279
29		581	198		779
30		482	205		687
	20,977	172,437	21,298	73,340	
Total	193,414		94,638		288,052

1. Each TM class is assigned to Wetland or Upland based on whether it agrees predominantly with the NWI reference map wetland or upland pixels.
2. Pixels that lie in the nondominant category are assigned to omit and commit columns as appropriate.
3. The total of each column is tabulated and the error matrix (Fig. B1) is filled in.

ERROR MATRIX

		TM interpretation		
		Upland	Wetland	Total
NWI	Upland	172,437	20,977	193,414
	Wetland	21,298	73,340	94,638
	Total	193,735	94,317	288,052

OF GENERIC FORM

A	B	C
D	E	F
G	H	I

Computations:

% Omission of wetland	D/F	= 21,298/94,638	=	22.5%
% Commission of upland	B/F	= 20,977/94,638	=	22.2%
% Wetland accuracy	E/F	= 73,340/94,638	=	77.5%
% Upland accuracy	A/C	= 172,437/193,414	=	89.2%
% Overall accuracy	(A+E)/I	= (172,437 + 73,340)/288,052	=	85.3%

Kappa Index of Agreement:

$$KIA = \frac{I(A+E) - [(G*C)+(H*F)]}{I^2 - [(G*C)+(H*F)]} = 0.667.$$

Figure B1. Computation of error matrix statistics.

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14. ABSTRACT
The nation's military installations encompass undeveloped lands that have become increasingly important as wildlife habitats. Resource managers of the installations need wetland inventories to improve stewardship of these lands. Digital geographic data are readily available to land managers. The use of these data to inventory wetlands has not been demonstrated. As part of a project to integrate wetlands into the ITAM (Integrated Training Area Management) program for managing Army lands, wetland inventory methods using existing digital geographic information for two terrains on Army installations in Alaska were explored: (1) glacial moraine depressions and estuarine marsh on Fort Richardson, and (2) discontinuous permafrost and taiga forest on Fort Wainwright's Yukon Command training site. Our results show that (1) existing geographic data used to infer wetland locations (Landsat Thematic Mapper [TM], National Wetland Inventory [NWI] maps, and hydric soil maps) only partly agree, and (2) optimum Landsat TM band combinations for wetland inventory vary on a site-specific basis. Landsat TM classifications (unsupervised) of Fort Richardson wetlands compared reasonably well (0.73 Kappa Index of Agreement [KIA]) with the NWI map as long as the band combinations included at least one visible and the near-infrared wavelength band (e.g., bands 3, 4, and 5 or bands 2, 3, and 4). The Fort Richardson hydric soils map indicates more extensive wetlands than indicated by the NWI (0.64 KIA). The Landsat TM classification could be made to agree fairly

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13. ABSTRACT (cont'd)

well with the NWI map (0.73 KIA). At Fort Wainwright, use of the thermal wavelength band (6, 4, and 2 composite) improved Landsat TM classification agreement with the NWI (0.67 KIA) because of warmer apparent brightness temperatures of lowland wetland sites compared to upland forested sites. Topographic position in the taiga forest plays a strong role in determining soil moisture, dominant vegetation, and whether or not the site is underlain by permafrost; therefore, a wet terrain map derived from a digital elevation model agreed nearly as well to the NWI map (0.64 KIA) as did the Landsat TM classification (0.67 KIA). Existing geographic information can serve as an initial wetland map. However, accurate wetland maps will require field mapping.

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