A Comparison Between Two Satellite-Based Land Cover Classification Programs For a Boreal Forest Region in Northwest Alberta, Canada

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Abstract - **Two independent, satellite-based land cover classification programs are being undertaken in Alberta, Canada. Multitemporal data from the Advanced Very High Resolution Radiometer (AVHRR) sensor is being used to develop a land cover map of Canada. Landsat Thematic Mapper (Landsat TM) data is also being employed to develop a land cover classification program for the Province of Alberta, as part of the Earth Observation Pilot Projects Program (EOP3) of the Long Term Space Plan (LTSP). The purpose of this study is to determine to what extent the land cover maps derived from AVHRR and Landsat TM data were similar for a 14,000 km^2 pilot project area in the Caribou Mountains, Alberta. A 2-Stage class aggregation process was devised to reconcile the differences between the two land cover classification legends after which the representativeness of the AVHRR land cover distribution was also determined. The percentage of the study area classified between the AVHRR and EOP3 land cover maps were similar for seven of nine aggregated classes that included four forest land cover classes, undifferentiated wetland, black spruce bog, and water. Differences in classified area for burns and clearcuts were attributed to spectral confusion with coniferous classes, and the effects of the AVHRR 1-km cell size relative to the sizes of clearcuts, respectively. Consistent with previous studies, AVHRR classifications tended to overestimate the dominant land cover classes and underestimate the extent of the less common classes.**

I. INTRODUCTION

Canada's forests cover 45 percent of its total landbase of which approximately half are considered capable of growing merchantable tree species (Natural Resources Canada 1997). Canada's landbase accounts for 10 percent of the world's forest land and almost 20 percent of global trade in forest products (Canadian Council of Forest Ministers 1996). Increasing demands, however, are being placed on Canada's forests for meeting multiple resource needs, and our decisions toward sustainable development could impact global economic, social and environmental systems (Canadian Council of Forest Ministers 1996). Canada has therefore made a commitment to ensuring the sustainability of its forests, but this can only be achieved if the extent of its national forest resource can be mapped and quantified (Penner 1995).

A land cover map of Canada has been produced from a classification of Advanced Very High Resolution Radiometer (AVHRR) data undertaken as part of the Northern BIOsphere and Modeling Experiment (NBIOME) by the Canada Centre for Remote Sensing (CCRS) and the Canadian Forest Service (CFS) (Beaubien et al. 1997; Cihlar and Beaubien 1997; Cihlar et al. 1997a). The objective of this work was to generate an up-to-date, spatially consistent land cover map of the landbase of Canada for subsequent use by users interested in environmental information at national and regional scales. The initial map (version 1) was distributed to provincial forest agencies in late 1997 for evaluation and assessment prior to modification and release of the final map. Work reported in this paper is part of the assessment that was carried out in Alberta.

Parallel to the mapping of Canada with AVHRR data, higher resolution Landsat Thematic Mapper (TM) data was employed to develop a land cover classification program for the Province of Alberta by GAIA Consultants Inc., and Geomatics International, Inc. This program was developed under a pilot project co-funded by Alberta Environmental Protection and CCRS, as part of the Earth Observation Pilot Projects Program (EOP3) of the Long Term Space Plan (LTSP). The objective of the EOP3 project was to produce a province-wide, multi-user, image-based ground cover classification system that would be appropriate for resource overviews and operational applications from medium to small scales. The EOP3 project is consistent with the objectives of Alberta Environmental Protection to acquire information that ensures Alberta's renewable resources are being managed in a sustainable manner, and to explore methods of achieving environmental protection and resource management goals.

The CCRS had recently requested regional assistance to review the Alberta coverage within the AVHRR land cover map of Canada. In response to this request, the objective of this study was to conduct a descriptive analysis of the extent that land cover maps derived from AVHRR and Landsat TM data were similar. A secondary objective was to devise an aggregation process to reconcile the differences between the AVHRR land cover legend with the higher resolution EOP3 legend, and to report on the representativeness of the AVHRR land cover distribution.

II. METHODS

A. *Study Area*

The study area is located in the Caribou Mountains in northwestern Alberta and is approximately 14,000 km^2 in size. It is bounded by 59.42° North Latitude and 116.59° West Longitude on the northwest, to 58.42° North Latitude and 114.51° West Longitude on the southeast. The area is part of the Boreal Forest Natural Region and is primarily in the Sub-Arctic sub-region (Achuff 1994). Surficial deposits are primarily till or organic peat, and discontinuous permafrost is common (Achuff 1994). This area is also part of the Hay River and Lower Foothills Sections of the Boreal Forest Region (B.18b and B.19a, Rowe 1972). Vegetation consists primarily of open and closed stands of black spruce (*Picea mariana* [Mill.] B.S.P.) on poorly drained sites. Very small amounts of balsam poplar (*Populus balsamifera* L.) may also be found in wetter areas. Also in this region are mixtures of trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* [Moench] Voss), and stands of balsam fir (*Abies balsamea* [L.]) that exist in over mature white spruce stands. A few isolated patches of white birch (*Betula papyrifera* Marsh.) and jack pine (*Pinus banksiana* Lamb.) are also found on drier sites.

B. *AVHRR Land Cover Classification*

NOAA-14 AVHRR satellite data were processed for April 11 through October 31, 1995, by the Manitoba Centre for Remote Sensing (MCRS). Only afternoon passes were used by MCRS for the generation of the initial 10-day composite data with a pixel size of 1 km. Further processing of these composites and the extraction of land cover information was performed using techniques described elsewhere (Cihlar et al. 1997b). Mean AVHRR pixel values for channels 1, 2, and the Normalized Difference Vegetation Index were computed for the 1995 growing season as the average values for a composite period multiplied by the number of growing season days in that period (Cihlar et al. 1997a). These mean AVHRR values were subsequently used in the classification method. Twenty-three land cover classes were identified using the Enhancement-Classification Method (ECM) (Beaubien et al. 1997, Cihlar et al. 1997a). The ECM uses a visual identification of important cover classes in contrast-enhanced images, and then subsequently labels these cover classes with the help of ancillary information such as Landsat TM images and personal knowledge of the land cover distribution of the area. The land cover classes are described in Cihlar and Beaubien (1997), and are consistent with the International Geosphere-Biosphere Programme (IGBP) classification scheme (Belward 1991) but classes were hierarchically subdivided to accommodate the greater detail available in the processed data.

C. *EOP3 Land Cover Classification*

Ground cover classes for the EOP3 project were to encompass key, representative landscapes and vegetation communities throughout the province of Alberta by selecting sample sites from each of Alberta's six major natural regions. The resultant classification (Fig. 1) was intended to facilitate ready updating and modelling of ground cover in a GIS database. Alberta Environmental Protection, GAIA Consultants Inc., and Geomatics International Inc. jointly developed a hierarchical land cover classification legend (GAIA Consultants Inc. and Geomatics International Inc. 1998). The Landsat TM scene used for the northwest study area was imaged for Track 46, Frame 19, Quad 2 on September 1, 1994. The image was geometrically corrected to 1:50,000 scale NTS maps, with an overall RMS error of 17.91 m. Field data for 136 sites collected by Geomatics International and Alberta Environmental Protection from October 1996, and August 1997, served as ground truth information for the image classification exercise. The full TM quarter scene was initially stratified, using ISODATA clustering of TM bands 3, 4, and 5, into four strata: 1) Forest, 2) Burns, 3) Wetland, and 4) Water Bodies. Masks were generated for each of these four strata, from which an image classification was performed.

ISODATA clustering proceeded separately under the Forest mask using TM Bands 3, 4, and 5, and under the Wetland mask using TM Bands 2, 3, and 4. Previous work by Geomatics International has suggested TM bands 3, 4 and 5 work well for boreal forest cover types, TM bands 2, 3 and 4 are best to differentiate wetlands, and TM bands 4, 5 and 7 separate wetlands from burns. Using known cover types at a select number of ground truth sites, clusters were aggregated

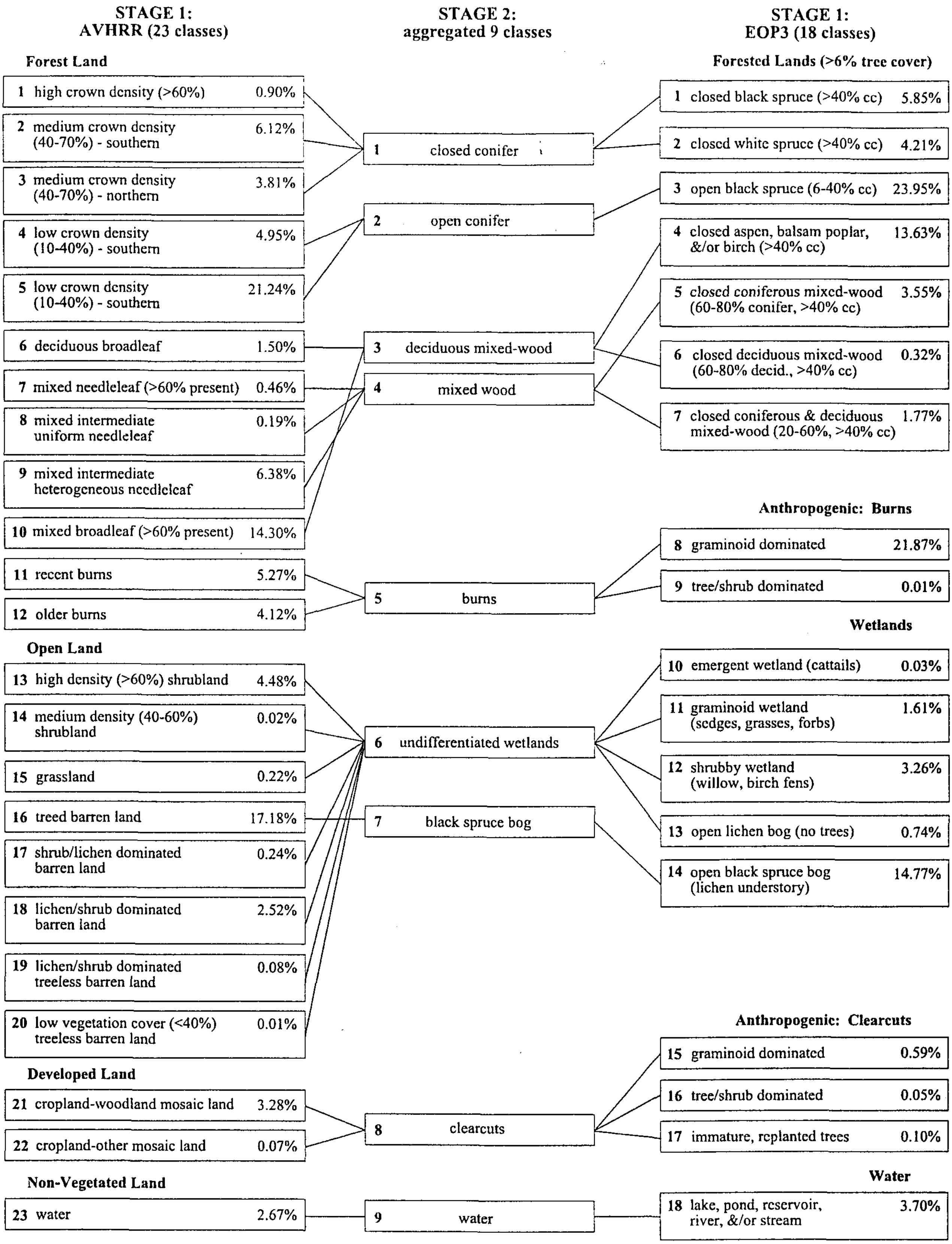

Fig. 1. 2-Stage class aggregation process.
Note: For Stage 1, the numbers on the right side of each box refer to the percent by area of each class in the study area.

into the various classes present. By visually comparing the satellite image composite with the field data, areas that appeared misclassified were further resolved by ISODATA clustering using masks of each individual class. Scrub wetlands were a major source of conflict with Burns due to their similar reflectance values in all 6 Landsat TM bands. The occurrences of burn pixels within wetland areas were errors of commission. A mask of Wetland areas was created, then ISODATA clustering was completed under this mask with TM Bands 4, 5, and 7. The spectral clusters created were subsequently assigned its correct class value.

Subsequent to the second field trip in August 1997, the Wetland classes were refined using the new wetland ground truth data. Wetlands were also extracted from the closed hardwood class and the Burn class using TM Bands 2, 3, and 4. Clearcuts, both recent and regenerating, required manual editing because they were misclassified as wetlands. The PCI Imageworks[1] program was used to manually edit clearcuts that were easily recognized on the Landsat TM image based on their shape and pattern. The final classification consisted of 18 classes that were filtered to a minimum polygon size of 2 ha, the nominal minimum size of polygons used in Alberta Vegetation Inventory maps. (Note that while only 18 classes occurred in the study area, a total of 64 classes have been defined for the province as a whole.) Due to field logistics and expense it was not possible to obtain an independent data set for accuracy assessment. All available ground truth sites were therefore used for accuracy assessment, of which an overall accuracy of 91.2% was attained based on a diagonal sum over the total (124/136). User's accuracy per class ranged from 0% to 100%, with an average of 79%.

D. *Land Cover Class Aggregation*

The two land cover classification datasets were spatially registered into a single PCI database after being projected in Arc/Info to the same geographic coordinate system (Universal Transverse Mercator, Zone 11) and NAD83 datum. Registration was performed by determining the pixel and line number for the AVHRR image that was closest to the upper left corner of the TM image. The appropriate number of AVHRR pixels was then extracted to fill the study area database. The registration of the AVHRR image was determined by counting the number of TM pixels between the upper left corner of the TM image and the closest corner of the AVHRR image. The registration was within ±15 TM pixels (~ 375 m) in the east-west direction, and within ±2 TM pixels (50 m) in the north-south direction.

The two image channels containing the classified datasets were compared using PCI program MLR (PCI 1995) to produce a confusion matrix. The initial confusion matrix consisted of the original land cover classes and numerical codes assigned to each of the classifications. A preliminary assessment was conducted to determine how the land cover classes were associated to each other. The next step, and a very important one, was the reconciliation of the two very different classification legends. This was addressed by devising a 2-Stage aggregation process, which first involved reducing the initial larger number of AVHRR classes. The second Stage involved reducing the number of EOP3 classes to the same number of reduced AVHRR classes to facilitate comparisons in a new confusion matrix. The decision rules used during the reconciliation of the two classification legends were based upon the hierarchical structure of the land cover definitions, and the relative proportions or frequency of occurrence in the study area (Fig. 1). If a land cover class occurred in less than 1% of the study area, it was merged with the closest logical class in its hierarchical category level. Similar to Cihlar et al. (1997a), AVHRR classes were aggregated and ordered to correspond as closely as possible to the EOP3 classes, and assigned the corresponding TM class number.

III. RESULTS OF CLASS AGGREGATION

Aggregation of land cover classes from Stage 1 to Stage 2 was necessary to align the AVHRR land cover map to the EOP3 legend (Fig. 1). The class aggregation process required interpretation of the differences in the class descriptions, tempered with knowledge of the land cover distribution in the study area. This process is valuable because it is sometimes difficult to assign ecologically meaningful information to the AVHRR classes from classifications of higher resolution data due to the mixed nature of the pixels (Iverson et al. 1989). Refinement of this process could lead to future exercises that use higher resolution land cover classifications from Landsat data to validate or enhance the AVHRR land cover classification similar to that undertaken by Cihlar et al. (1997a).

The original AVHRR classification of the study area consisted of 23 land cover types that included forest land (10 classes plus 2 burn classes), open land (8 classes), developed land (2 classes) and water (1 class). These 23 land cover types were subsequently reduced to 9 during the aggregation process (Fig. 1). The original 10 forest land classes were combined based on similarity of description and their relative size in the study area into 4 classes that comprised closed conifer, open conifer, deciduous mixed-wood and mixed wood (Fig. 1). The first 5 forest classes were combined based on crown closure into open and closed conifer. This stratification is in recognition that species composition (ie. conifer) and crown closure are among the

[1] The mention of trade names is for information only and does not imply endorsement by the authors.

important parameters that affect spectral responses of forest canopies (Guyot et al. 1989). The deciduous broadleaf forest class was combined with the mixed broadleaf forest class into a deciduous mixed-wood class because the class definitions suggest that these two categories often identify the same class (Cihlar and Beaubien 1997). Recent burns and older burns were combined into a single burn category because only one burn class was apparent from the EOP3 classification (Fig. 1). The open land category was reduced to 2 classes: undifferentiated wetlands consisting of shrubland, grassland, and several classes of barren land; and treed barren land that was relabelled as black spruce bog (Fig. 1). There were 2 classes of developed land that by description, have evidence of anthropogenic activity (Cihlar and Beaubien 1997). Thus, they were combined to form a single developed land class that was associated with the clearcut category in the EOP3 classified image. The water class was not merged with any other category.

The EOP3 classification of the study area resulted in 18 classes that occurred in four major categories comprising anthropogenic (5 classes), forested lands (7 classes), wetland (5 classes), and water (1 class) (Fig. 1). The anthropogenic category consisted of 3 clearcut and 2 burn classes of which several occupied less than 1% of the study area. These classes were combined in Stage 2 into 2 anthropogenic classes comprising one clearcut and one burn class. The forested lands category was reduced from 7 classes to 4 classes that consisted of closed conifer, open conifer, deciduous mixed-wood and mixed wood. Several wetland classes were also combined due in part to their similar descriptions and because there were no corresponding wetland classes in the AVHRR land cover map. The 6 wetland classes were reduced to 3 consisting of undifferentiated wetland, black spruce bog and water (Fig. 1). This aggregation exercise reduced the original 18 classes in Stage 1 to 9 classes in Stage 2.

IV. DISCUSSION

Table 1 shows the results of a pixel-by-pixel comparison of the two maps. Considering only the diagonal entries, it is evident that direct correspondence (ie., pixel belonging to the same cover type on both classifications) ranged widely (1.3 – 66.7%) and was generally low. This is a consequence of the different spatial resolution of the two maps. Thus, while large contiguous patches of a single cover type are likely to have close correspondence on the two maps, the correspondence will be low where cover types are intermixed over short distances. A definitive solution to this problem requires higher resolution input data. The launch of MODIS in 1998 and similar sensors in the future will make important advances in this direction.

Comparing the percentage of each cover type identified by each method is more meaningful than a per-pixel comparison. For 7 of the 9 aggregated land cover classes, the percentages over the 14,000 km^2 study were remarkably

Table 1
CONFUSION MATRIX FOR RESULTS OF STAGE 2 OF AGGREGATION PROCESS
Note: Values in confusion matrix represent percent of pixels classified by code.

	AVHRR	1. Closed conifer	2. Open conifer	3. Deciduous mixed-wood	4. Mixed wood	5. Burns	6. Undifferentiated wetlands	7. Black spruce bog	8. Clearcuts	9. Water
EOP3	% of study area	10.82	26.19	15.81	7.03	9.39	7.57	17.18	3.34	2.67
1. Closed conifer	10.06	14.5	16.4	9.5	19.0	32.5	2.0	3.8	0.3	2.1
2. Open conifer	23.96	12.2	32.1	3.7	3.0	16.4	7.9	22.3	0.4	2.0
3. Deciduous mixed-wood	13.95	0.7	1.1	66.7	11.4	0.3	2.3	1.1	16.3	0.1
4. Mixed wood	5.32	5.4	6.4	37.9	34.8	3.6	4.1	5.1	2.4	0.4
5. Burns	21.87	18.7	51.4	0.0	0.1	1.3	4.7	22.6	0.0	1.3
6. Undifferentiated wetlands	5.64	2.6	9.1	35.7	8.2	4.7	15.4	10.9	12.6	0.7
7. Black spruce bog	14.77	8.8	25.0	2.2	1.4	8.1	17.8	34.6	0.4	1.8
8. Clearcuts	0.73	7.5	9.4	27.1	33.1	7.1	7.1	3.4	4.9	0.5
9. Water	3.70	12.8	22.6	2.9	1.1	4.8	9.4	9.3	0.4	36.6

similar between the AVHRR and EOP3 classifications, especially when the differences in spatial resolution are considered (Table 1). These 7 land cover classes included the 4 forest land cover classes, undifferentiated wetland, black spruce bog and water. For closed conifer, open conifer, deciduous mixed-wood and mixed wood, the percent coverages from the AVHRR map were 11%, 26%, 16%, and 7%, respectively. These values compared favourably for the same classes on the EOP3 map, which were 10%, 24%, 14%, and 5%, respectively. AVHRR vs. EOP3 values were similar for the other classes of undifferentiated wetland (8% vs. 6%), black spruce bog (17% vs. 15%) and water (3% vs. 4%) (Table 1). Some of the differences in the mixed-wood forest land classes were attributed to differences in their definitions. AVHRR forest land classes for conifer and deciduous are defined by percent crown closure, whereas the mixed-wood classes are defined by percent of numbers of trees present (Cihlar and Beaubien 1997). In the EOP3 system, however, all forested lands are defined as having either open (6% – 40%) or closed (> 40%) crown closure (GAIA Consultant Inc. and Geomatics International Inc. 1998). Differences in these definitions explains why mixed broadleaf forest was combined with the deciduous broadleaf forest rather than with the mixed-wood forest class.

Another difference in the two land cover legends was the definitions of barren land. The AVHRR legend defined barren land as land that contained less than 10% of trees with low shrubs, lichen, herbaceous vegetation cover, bare soil, rock or small water bodies (Cihlar and Beaubien 1997). The EOP3 legend defined barren land as vegetation cover of less than 6%, with subtypes that were not characterized by vegetation but described as rock, talus, avalanche chutes, and exposed soil (GAIA Consultants Inc. and Geomatics International Inc. 1998).

In the AVHRR map, the percentage of the study area corresponding to the more dominant classes was generally larger than the EOP3 classification (Table 1). The water class was also the smallest class and was underestimated (2.67%) when compared to the EOP3 class for water (3.7%). These observations appear consistent with Penner (1995) and Cihlar et al. (1997a), who reported that as a result of the larger pixel sizes, the AVHRR-derived classification tended to overestimate the dominant classes and underestimate the extent of the less common classes.

The only classes where the percentage occurrence in the study area was quite different between AVHRR and EOP3 were burns and clearcuts. The percentage of burned area for AVHRR was considerably smaller (9.39%) than that estimated from EOP3 (21.87%) (Table 1). Areas that are burned have relatively low vegetation reflectance similar to that for conifer stands. Thus, areas classified as burns on the EOP3 map corresponded mostly to the conifer and black spruce bog classes on the AVHRR land cover map. There were also four recent E-class fires, defined as those greater than 200 ha, during 1993 and 1994[1]. It is possible that the charred areas would resemble the reflectance response of areas containing predominately conifer and black spruce bog.

There was poor correspondence for clearcuts between AVHRR and EOP3. This is probably due to the size of the individual clearcut areas, and the resolution of the two sensors. At a Landsat TM pixel size of 25 m, there are 1600 TM pixels in 1 AVHRR pixel. Although clearcuts ranged from less than 50 Landsat TM pixels to 2500 Landsat TM pixels, the majority was less than 1 AVHRR pixel in size. Clearcuts in the study area were clearly visible on the Landsat TM image as alternate patch cut or strip cut patterns that were manually identified and edited during the EOP3 classification process. An incorrect assumption could have been made during class generalization (Fig. 1) that clearcuts occurred within developed land because the category was anthropogenic. Further investigations would be necessary to mitigate the classification differences for the burn and clearcut categories, but it is unlikely that these differences could be completely removed under conditions represented in this study.

Another factor which should be considered is that the EOP3 classification was undertaken with a single date Landsat TM image, while the AVHRR classification was derived using a series of 10-day composites acquired throughout the growing season. The phenology of vegetation at time of imaging will influence the distribution of land cover types that can be mapped. Considering the effects of vegetative phenology is particularly important when comparisons to other image classifications are to be undertaken, or, when contiguous scenes are necessary to classify large areas.

V. CONCLUSIONS

This study was undertaken for a single Natural Region within Alberta. Further work is needed to compare the consistency and differences between the AVHRR and EOP3 land cover classifications over areas that represent the other major Natural Regions of Alberta. AVHRR classes consist of mixed pixels at the Landsat TM scale, and were often described by more than one EOP3 class. Despite the differences in spatial resolution, the aggregated 9-class AVHRR and EOP3 maps were remarkably similar for all classes except clearcut and burns. The AVHRR classes showed better correspondence for the larger classes, but under represented small classes present in small patches. Adjustments for regional differences in land cover are

[1] Personal communications. L. Lyseng, Alberta Environmental Protection, March 23, 1998.

desirable, and can be invaluable for incorporating local knowledge about vegetation associations and land cover distributions into AVHRR classifications. Further work is being undertaken by CCRS and CFS to develop methods for quantifying the sub-pixel composition of AVHRR classes which will help to improve their accuracy in future land cover mapping.

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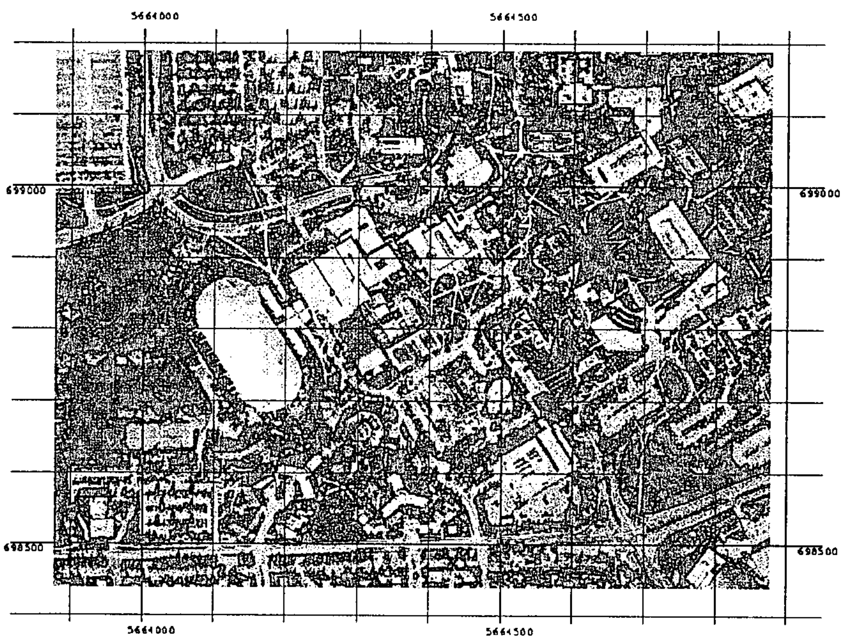

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