Fundy Model Forest

~Partners in Sustainability~

Report Title: Developing Remote Sensing Tools for Monitoring Indicators of Sustainability – A Test Case on Crown Land

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The Fundy Model Forest…
…Partners in Sustainability

"The Fundy Model Forest (FMF) is a partnership of 38 organizations that are promoting sustainable forest management practices in the Acadian Forest region."

Atlantic Society of Fish and Wildlife Biologists
Canadian Institute of Forestry
Canadian Forest Service
City of Moncton
Conservation Council of New Brunswick
Fisheries and Oceans Canada
Indian and Northern Affairs Canada
Eel Ground First Nation
Elgin Eco Association
Elmhurst Outdoors
Environment Canada
Fawcett Lumber Company
Fundy Environmental Action Group
Fundy National Park
Greater Fundy Ecosystem Research Group
INFOR, Inc.
J.D. Irving, Limited
KC Irving Chair for Sustainable Development
Maritime College of Forest Technology
NB Department of the Environment and Local Government
NB Department of Natural Resources
NB Federation of Naturalists
New Brunswick Federation of Woodlot Owners
NB Premier's Round Table on the Environment & Economy
New Brunswick School District 2
New Brunswick School District 6
Nova Forest Alliance
Petitcodiac Sportsman's Club
Red Bank First Nation
Remsoft Inc.
Southern New Brunswick Wood Cooperative Limited
Sussex and District Chamber of Commerce
Sussex Fish and Game Association
Town of Sussex
Université de Moncton
University of NB, Fredericton - Faculty of Forestry
University of NB - Saint John Campus
Village of Petitcodiac
Washademoak Environmentalists

Natural Resources Canada Ressources naturelles Canada

Canada

Developing Remote Sensing Tools for Monitoring Indicators of Sustainability – A Test Case on Crown Land

Report prepared for Fundy Model Forest,
New Brunswick Dept of Natural Resources,

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APPENDICES

1.INTRODUCTION

This project was undertaken for the New Brunswick Department of Natural Resources and Energy in partnership with the Fundy Model Forest, Canadian Forestry Service, and Parks Canada to demonstrate the utility of Landsat satellite data for effective monitoring of forest harvest on an annual or biannual basis. The temporal duration of this analysis spans from 12 September 1999 to 6 September 2000, dates determined by the imagery acquired for change detection processing.

This analysis will

make use of methodology previously tested by Franklin for the Fundy Model Forest in Southern New Brunswick. This involves the use of Tasseled Cap vegetation indices as the base upon which forest cover change is identified through image subtraction. This change is then classified based on sample data generated by provincial crown updates. The current provincial data is updated on an annual basis for crown land only through the manual interpretation of cut photos. These are flown ?

1.1 Objectives

The project objective is to map areas of forest extraction occurring during this time period and classify according to the harvest treatment taking into account the degree and type of vegetation removed. This procedure will be applied to all land jurisdictions.

Determine spectral signitures for softwood, mixed wood, hardwood undergoing the various harvest treatments currently in use across the province.

Provide methodology that can be replicated by provincial personnel for future monitoring and inventory updates.

One of the goals for this project was to create a replicable methodology for change detection.

This research grant will support the study of changes on crown land using a satellite based methodology which utilizes brightness/greenness/wetness indices derived from Landsat Thematic data in 1999 and 2000. Earlier applications of these methods were able to provide accuracy in clearcut and partial cut change detection approaching 75% overall, and provided evidence to suggest that annual updates to the GIS database were possible using this methodology. Image analysis activities were designed to further the technology to quantify detectable clearcut and partial harvest conditions.

The most important aspects of change on crown land are related to forest management treatments and large-area, synoptic reporting mechanism to detect change and analyze patterns in the GIS. This study will use imagery from 1999 and 2000 for an area of crown land outside the FMF.

Each image will be transformed on a pixel-by-pixel basis using tasseled cap wetness/greenness/brightness transformation. A 1999-2000 difference image will be created from the wetness index. The resulting difference image will then be classified using supervised classification techniques and employing forest and cloud masks which will be created from the existing forest inventory and the imagery, respectively, in order to confine processing to forested cover areas only.

DNR is interested in deriving 9 classes of harvest with these project methods: 3 levels of severity classified by softwood, mixed wood and hardwood forest types. The ultimate goal is to assess the utility of using the harvest training class data to allow for a more concrete examination of threshold definitions in the data thereby facilitating the development of a methodology that can be replicated in future annual harvest update work using satellite imagery.
Some method of atmospheric correction/radiometric correction will be considered on this project in order to create a methodology that allows for automation Steve Franklin will be consulted for expert advice in this area.

The second aspect of the work will focus on accuracy assessment using the GIS as an ancillary data set. The third aspect of the test case study is a ground truthing exercise to ensure the accuracy assessment as well. What is needed now is the development of specific monitoring tools based on a comprehensive study of thresholds in change detection that the brightness/greenness/wetness method provides in the annual detection of changes by satellites

To develop indicators of sustainable forest management and to measure, monitor and report performance: This project will provide the tools required to detect changes annually or biannually across the entire landbase and to summarize those changes as they relate to the existing GIS database

Establish a research strategy to support sound forest ecosystem management: FMF has taken the lead in the development and application of modern remote sensing methods in forest management issues such as partial change detection and classification of ecological units. This project furthers the research tools and applications. Applications of these research tools by a Fundy Model Forest Partner (ie. NBDNRE) will further strengthen linkages to local and regional levels (NB crown land) where issues of Sustainable Forest Management (SFM) are being dealt with.

1.2 Study area

The selection of a study area was carried out by DNR personnel. This process was driven by a requirement for representation of both crown land and private holdings as well as the availability of information on recent harvest for use as pseudo field truth. The chosen area, depicted in Figure?, was defined in the New Brunswick provincial standard projection and datum, Double Stereographic NAD83. This geography and geometry is determined by a scale factor of 0.999912, a true origin of –66.5 W 46.5 N, a false origin of 2500000 7500000 and the WGS 84 ellipsoid. The geometric coordinates provided by DNR for corner bounds were;

Upper left: 2,530,479.42400 7,544,543.21800
Lower right: 2,600,695.47700 7,445,254.81400

located in the Northwest quadrant of the Landsat scene, this area of approximately 6971 hectares represents a sizeable portion of the interior of southeastern New Brunswick. It spans from the upper limits of Grand Lake north to just below Chatham and from the community of Doaktown east to ????? The land cover is predominantly forest, approximately 4788 hectares, but is also characterized by extensive wetlands. The natural landscape is significantly impacted by anthropogenic activity related to forestry and agriculture.

1.3 Data

1.3.1 Satellite Imagery

The imagery used in this analysis consisted of two Landsat satellite scenes acquired at track 9 frame 28. Landsat 5 Thematic Mapper (TM) sensor captured the earliest date of imagery, 12 September 1999. The most recent image, 6 September 2000, was captured by the Landsat 7 Enhanced Thematic Mapper (ETM). Both scenes were purchased from a Canadian distributor, Radarsat International. The contact information is provided below.

Radarsat International
www.rsi.ca
Tel: (604) 244 - 0400
Fax: (604) 244 - 0404

The following list provides specifications for ordering Landsat imagery. Inquiry into image quality with regards to cloud cover, haze and sensor aberrations is also recommended.

Specifications for ordering a Landsat Scene	
Satellite	Landsat 7 is the newest
Sensor	ETM is the Landsat 7 sensor
Scene date	6 September 2000
Bands	all bands
Track / frame (also referred to as path and row)	track 9 frame 28
Processing level	systematic path oriented image

Scene size	full scene
Media format	HDF for Landsat 7, on CD

1.3.2 Geographic Information System Vector Data

A digital file of line features from the NB forest inventory was provided by DNR in .shp format for the study area extent. This supplied the georeferenced road and stream features that would be used to rectify the image data. A selection of mature forest stands from the forest inventory was supplied as a digital vector file, funatype.e00, for use in training land cover classification. Digital .e00 files of harvest updates from the 1999-operating year on crown land within the study area were also made available for use in simulating field truth information for the final classification of forest harvest.

1.4 Software

1.4.1 Image Processing

The image processing software used in this project is known commercially as EASI PACE version 7.0 Image Processing Kit. It is distributed by the PCI Geomatics group located at 50 West Wilmot Street, Richmond Hill, Ontario, Canada.

1.4.2 Geographic Information System

All spatial analysis required in this project was performed with PCI Geomatics' SPANS version 7.1. This included import of ESRI format input files, such as the forest inventory and all vector information, and the export of final data products.

1.5 Project Flow Diagram

2. IMAGE PREPROCESSING

2.1 Geometric Correction

Two empty georeferenced .pix files were created in the image processing software according to the geographic specifications provided by DNR New Brunswick for the project study area. This resulted in raster files that were 2341 pixels by 3310 lines. The lower right coordinates were adjusted as follows
to accommodate a 30 metre ground resolution per pixel.

Easting: from 2600695.47700 to 2600709.4
Northing: from 7445254.81400 to 7445243.2

The 1999 image was corrected to a 0.43 pixel RMS error based on 35 GCPs collected from the georeferenced road and stream vector data supplied by DNR.

The 2000 image was corrected to the geometrically corrected 1999 image with 32 GCPs collected for a 0.50 pixel RMS error.

2.2 Atmospheric correction

Once the image data was georeferenced it was investigated for atmospheric correction. Atmospheric correction involves removing the scattered component from the scene radiance. Both the 1999 and the 2000 scene were carefully selected for minimum cloud content and haze. After the geometric correction, histograms were generated for each band in both image dates to determine the amount of haze removal necessary. Figures ? and ? provide these graphic depictions of data distribution and illustrate the offset from zero attributed to haze. Text versions of histograms with statistics are provided in Appendix?.

While methods of atmospheric correction were investigated with these images, it was felt that neither image contained a sufficient amount of to prohibit to the change detection methods to follow. With this acknowledged, the correction was carried out for the purpose of documenting methodology. Through this process it was discovered that there was essentially no difference between the tasseled cap output derived from corrected data and that achieved with the original bands. This suggests that the tasseled cap transformation itself has the effect of reducing the influence of haze on image information content. However, if the quality of scene data necessitates atmospheric correction, the dark object subtract procedure is recommended as a simple solution.

This correction a simple process of histogram adjustment. An area expected to contain the minimum digital number (DN) value, such as a deep clear lake is masked. Beneath this mask, inspection of histograms for all bands reveals the offset, most prominent in visible bands, attributable to atmospheric scattering. Reflection from water in the NIR band should be zero. This is observed in the histogram for band 4. for each visible band the minimum value was used to estimate the shift required. In the case of the 1999 image, visible bands were adjusted by subtracting the shift from all data values t achieve a minimum value closer to zero as follows.

Band1 – 55
Band2 – 15
Band3 – 12

3. CHANGE DETECTION METHODS

3.1 Tasseled Cap Transformation

Tasseled cap indices are generated from the original bands by a mathematical transformation designed to reduce the redundancy in the data. The resulting output are 32-bit real channels that individually describe differing dimensions of landscape reflectance. These channels can be scaled to 8-bit data without losing the information content necessary for further processing. Previous studies by Franklin involving change detection utilizing tasseled cap data has indicated that the wetness index provides the best indication of vegetation removal. It is this band that is investigated for thresholds related to the severity of harvest activity. (i.e. clear cuts vs. selective cuts) However, each of the 3 indices are important in the distinction between softwood and hardwood species.

T.C. = A1*(TM1) + A2*(TM2) + A3*(TM3) + A4*(TM4) + A5*(TM5) + A7*(TM7)

	A1	A2	A3	A4	A5	A6
Brightness	0.3037	0.2793	0.4743	0.5585	0.5082	0.1863
Greenness	-0.2848	-0.2435	-0.5436	0.7243	0.084	-0.18
Wetness	0.1509	0.1973	0.3279	0.3406	-0.7112	-0.4572

3.2 Regression Analysis

Not necessary for this project due to the near anniversary dates. If the is some seasonal variation in sun illumination and environmental conditions it may be necessary. Advisable to regress the Landsat image data bands themselves rather than the tasseled cap output. If performing a time series analysis one image should serve as the basis for all other images to be regressed.

This is performed with the a series of steps. The first is to generate regression equations by assessing scatterplots of each data band with the corresponding band of the other image date.

Tasseled Cap Difference Means		
	Original	Regress only
B	-13.478	1.663
G	3.7	-1.139
W	0.837	0.439

3.3 Image Subtraction

Image subtraction provides a quantitative measure of the disagreement or change between the two dates. This change was identified for all three tasseld cap indices. The resulting “difference”images contain data that is organized according to the degree and direction of change resulting in a normal distribution. To facilitate visual interpretation and continued processing the calculations were carried out so that the change condition of interest, vegetation loss, is represented by positive numeric values. In a histogram representation of the data, the more extreme the change is found at the far tails. Where there is no change between dates values would approximate zero and center about the mean, as this would be the most prevalent scenario. Where there are negative values is indicative of the reverse change condition, vegetation regeneration. Since the objective of this exercise is to map vegetation loss only attention was focussed on the positive side of the histogram. Since only forest change is of interest in this study a means was required to isolate forest change from all other land cover change. Most notable for this confusion are clouds and cloud shadows as well as pre-existing harvest areas and agriculture. A general land cover classification was completed on the 1999 tasseled cap indices. The initial goal was just to discriminate between forest and other cover types. This allowed for confusion amongst forest types of softwood, mixed wood and hardwood.

Perform image subtraction for all 3 indices
Histograms were generated for the three tasseled cap difference images for use in statistical analysis.

Once difference data is produced it can be investigated for variance in the change by means of thresholding. This essentially involves identifying breakpoints in the data distribution that relate to different conditions on the ground. Through interpretation of RGB difference imagery and interpretation skills one can simply query the image data to uncover data values corresponding to certain harvest conditions and then through a trial and error thresholds observe the results for the best capture of harvest features. These thresholds are usually quite effective for a coarse distinction. If field truth information is available, bitmap masks can be traced for each harvest scenario and used to observe data characteristics. Both methods were implemented in this project as pseudo field truth information was provided. This process accomplished the first component of our harvest classification, resulting in two image masks; severe harvest and partial harvest that would be implemented in the final forest type classification of harvest.

3.4 Image masks

3.4.1 Cloud and cloud shadow mask

11568 hectares

No cloud mask

3.4.2 Land Cover Classification of 12 September 1999, Landsat TM

Import vectors for samples or trace graphics masks for training area pixels
Run supervised classification for7 classes using 3 1999 TC indices.
Forest mask
Filter speckle

FOREST TYPE		
Softwood	Mixed Wood	Hardwood
PINE	SPTH	IHTH
SPBF	THBF	TOHW
	THSP	
* FUNA codes of selected forest polygons from NB Forest Inventory		

```
MLR     Maximum Likelihood Report

 _________Areas________  ____Percent Pixels Classified by
Code______


 Code Name     Pixels      1     2     3     4     5     6
7
 --------------------  ------------------------------------
-------

    1 mixcover  26143   64.2  13.4  21.7   0.1   0.5   0.0
0.0
    2 hrdcover  18184   20.9  76.9   0.2   2.0   0.0   0.0
0.0
    3 sftcover  38196   10.8   0.2  87.4   0.1   1.6   0.0
0.0
    4 agrcover   5757    0.1   2.0   0.0  94.6   3.3   0.0
0.0
    5 baresoil   6656    0.7   0.1   0.2   4.8  94.1   0.1
0.0
    6 turbwat    5623    0.0   0.0   0.0   0.0   0.7  95.3
3.9
    7 deepwat    6968    0.0   0.0   0.0   0.0   0.0   1.1
98.8

 Average accuracy  =  87.34%
 Overall accuracy  =  81.94%
```

4. FOREST HARVEST CLASSIFICATION

4.1 Training Data

The first step in this process was to collect training areas for each of the desired classes of harvest. DNR provided digital vector files of 1999 forest harvest updates for Crown lands within the study area. These files provided spatial information on the location and extent of harvest activities during the 1999-operating year, spanning from March 1999 to March 2000. In addition, the “treatment” field in these data sets provided qualitative information on the harvest method employed for each cut. Due to the limited detail on amount of vegetation extracted in this pseudo field information it was felt that the preferred nine harvest classes would be unobtainable. Therefore, the data were organized into just two severity classes according to the scheme shown below.

Harvest Severity	**Treatment Code**
Severe	CC, RC
Moderate	PC, CT, SC, IT, SH, CL, ST, TI

In order to impart information on the forest species extracted in these harvest areas an overlay was performed with a softwood-mixed wood-hardwood (S-M-H) layer derived from the funatype.e00. These data were used previously to train for forest in the 1999 land cover classification. Refer to table ? in this report for the reclassification scheme.

4.3 Forest Harvest Determination by Modeling Thresholds

For the sake of comparison, and as an attempt at some measure of verification, another method was employed to derive these final results which utilized spatial modeling. Once again, this method did not make use of the 1999 update layers. A Spatial overlay was performed with the S-M-H forest type layer and each of the severity layers resulting in a combination of these two data sources that rendered the 6 harvest classes sought after.

figure

It should be noted that this method still requires comprehensive field truth information as it relies heavily on the accuracy of the 1999 land cover classification. In this case, the use of FUNA codes from the NB forest inventory accomplished adequate definition of spectral signatures to distinguish forest from other cover types. While good spectral separation was achieved between the hardwood and softwood categories, there was considerable confusion with mixed wood. Time constraints did not allow for attempts at refinement of these spectral signatures. It is expected, however, that complete spectral separation in forest types would be difficult with the training data that was available.

4.2 Supervised Classification

The training vectors, described above, were imported into the image processing system to guide the necessary graphics editing performed to create a mask of training pixels. This mask was used to generate spectral signatures of tasseled cap difference data for each of the six classes. These are provided in Appendix ?. This calculation of separability measures yields values in the range of 0, when there is complete overlap between two signatures and 2, when there is complete separation. These were computed, producing the following matrix.

	28	29	30	31	32
29	0.49811				
30	0.91815	0.16349			
31	0.37420	0.73129	0.89474		
32	0.61763	0.60960	0.60544	0.15692	
33	1.07417	0.89817	0.76411	0.35201	

Matrix Legend:

28 – Softwood Severe
29 – Mixed Wood Severe
30 – Hardwood Severe
31 – Softwood Partial

This matrix reveals significant overlap in all classes, suggesting that this training data alone would not achieve a reliable classification. To verify this, these signatures were used in the application of a maximum likelihood classifier the tasseled cap difference data. The full classification report is provided in Appendix ?. The confusion matrix, shown below, reports extensive omission and commission errors for all classes and a low overall accuracy.

Maximum Likelihood Report

Areas			Percent Pixels Classified by Code					
Code	Name	Pixels	101	102	103	201	202	203
101	sftclrta	2545	61.3	10.3	2.9	17.3	2.0	6.2
102	mixclrta	917	13.3	34.1	26.0	12.3	2.7	11.6
103	hrdclrta	528	4.4	13.1	44.5	11.2	1.5	25.4
201	sftprtta	1330	19.4	5.6	2.1	35.0	3.2	34.7
202	mixprtta	575	9.0	6.3	3.8	22.3	3.7	55.0
203	hrdprtta	176	2.3	6.3	4.5	15.9	2.3	68.8

Average accuracy = 41.22%
Overall accuracy = 44.74%

These results confirmed that the 1999 update information was inadequate as a source of field truth information to achieve the six classes of harvest by way of the preferred methodology. At this point, it was considered appropriate to employ wetness change thresholds to determine the two classes of severity. It was also decided that the 1999 tasseled cap indices would be added to the difference data as additional image data input to the classification of forest type.

In a similar project, conducted for the Fundy Model Forest, it was found that wetness change (difference) in forest cover accurately depicted forest harvest. Partial harvest could be distinguished from clear cuts by stratifying the wetness difference image. Between 1 standard deviation and 4 standard deviations from the mean, change in wetness was significant but not indicative of complete vegetation removal interpreted a spatial harvest. Image data beyond 4 standard deviations could be accepted as severe harvest (i.e. clear cuts). Statistics from new signatures generated from the 1999 brightness, greenness and wetness as well as the three tasseled cap difference data channels verified that these thresholds were sound. The separability measures computed for these signatures show improvement in spectral definitions but still not optimal separation for producing a classification with acceptable accuracy.

Severe Harvest Matrix:

	10	11
11	0.98922	
12	1.62838	

Legend:

10 – Softwood Severe
11 – Mixed Wood Severe

Partial Harvest Matrix:

	7	8
8	1.26654	
9	1.24277	

Legend:

31 – Softwood Partial
32 – Mixed Wood Partial

Despite the poor spectral separability, the two harvest severity masks were utilized in separate processing steps to classify harvest by forest type. As expected, this method yielded better results than the first attempt at a supervised classification. The two confusion matrices resulting from this method are still characterized by errors yet both levels of harvest severity show substantial improvement in overall accuracy.

Severe Harvest Classification

Areas			Percent Pixels Classified by Code		
Code	Name	Pixels	101	102	103
101	sftclrta	4202	87.2	11.6	1.2
102	mixclrta	1176	16.9	65.3	17.8
103	hrdclrta	407	5.9	11.3	82.8

Average accuracy = 78.43%
Overall accuracy = 82.42%

Partial Harvest Classification

Areas			Percent Pixels Classified by Code		
Code	Name	Pixels	201	202	203
201	sftprtta	1540	88.4	4.9	6.6
202	mixprtta	435	8.5	54.0	37.5
203	hrdprtta	137	14.6	27.0	58.4

Average accuracy = 66.95%
Overall accuracy = 79.40%

Comparatively, good accuracy was achieved for the softwood class. This is thought to be attributable to the relative number of training pixels available foe softwood forest versus the mixed & hardwood.

5. RESULTS & CONCLUSIONS

5.1 Forest Harvest Results

5.1.1 Supervised Classification

These results indicate that overall, ? hectares of the 478818 hectares of forest cover in this study area was harvested between 12 September 1999 and 6 September 2000. This is approximately 3% of all forested land. There was more partial harvesting, 84.0603 sq km, in this time frame than clear cutting, 53.7759 sq km. However, it should be noted that the partial harvesting class includes thinning. Most severe harvest was of softwood. Most partial harvest was on mixed wood stands. Hardwood was the least harvested in both severity classes.

HARVEST CATEGORIES	Area(%)	Area(sq km)
softwood clearcut	22.35	26.591
mixed wood clearcut	13.45	16.001
hardwood clearcut	6.93	8.238
softwood partial cut	21.6	25.699
mixed wood partial cut	22.98	27.331
hardwood partial cut	12.69	15.09
Total	**100**	**118.95**

5.1.2 Spatial Overlay Modeling

HARVEST CATEGORIES	Area(%)	Area(sq km)
softwood clear cut	20.24	24.071
mixed wood clear cut	17.22	20.484
hardwood clear cut	5.27	6.275
softwood partial cut	15.55	18.502
mixed wood partial cut	21.54	25.619
hardwood partial cut	20.18	24
Total	**100**	**118.95**

The breakdown of these two levels of harvesting into the S_M_H forest type harvested was computed by two methods. Table ? provides the results achieved by supervised classification.

5.1.3 Comparison of methods

Both methods show the highest percentage of forest extraction occurred as partial harvest in mixed wood forests. There is also agreement for the lowest harvest result as the severe hardwood class. These results may not be surprising to anyone familiar with forestry operations in the Acadian forest. However, they do give credibility to the results of this analysis, which are otherwise somewhat unreliable due to insufficient field truth information. It is important to remember that neither one of these methods were achieved to an acceptable level of confidence as both are inherently dependent on accurate and sufficient training data. Table ? is provided as tool for interpreting these differences and perhaps arriving at reasonable estimates for each class.

HARVEST CATEGORIES	softwood clear cut	mixed wood clear cut	hardwood clear cut	softwood partial cut	mixed wood partial cut	hardwood partial cut	Total Area (sq km)	Total %
softwood	23.42	0.621	0.03	0	0	0	**24.071**	
clear cut	19.69	0.52	0.03	0	0	0		**20.24**
mixed wood	3.154	13.913	3.417	0	0	0	**20.484**	
clear cut	2.65	11.7	2.87	0	0	0		**17.22**
hardwood	0.017	1.467	4.791	0	0	0	**6.275**	
clear cut	0.01	1.23	4.03	0	0	0		**5.27**
softwood	0	0	0	17.756	0.613	0.132	**18.502**	
partial cut	0	0	0	14.93	0.52	0.11		**15.55**
mixed wood partial cut	0	0	0	7.274	8.852	9.492	**25.619**	
partial cut	0	0	0	6.12	7.44	7.98		**21.54**
hardwood partial cut	0	0	0	0.668	17.866	5.466	**24.000**	
partial cut	0	0	0	0.56	15.02	4.6		**20.18**
Total Area (sq km)	**26.591**	**16.001**	**8.238**	**25.699**	**27.331**	**15.09**	**118.95**	
%	**22.35**	**13.45**	**6.93**	**21.6**	**22.98**	**12.69**		**100**

The decrease in softwood harvest is higher from the supervised classification results to the overlay results in both severity levels may be explained by the higher proportion of mixed wood in the1999 land cover classification then is represented in the NB forest inventory. Likewise the substantial difference in results of the two methods for the hardwood partial class is most likely attributable to the very small number of training pixels achievable for this class with the update layers provided.

5.2 Conclusions

5.2.1 Classifying Severity of Harvest

Thresholds for 3 levels of harvest severity were attempted in this analysis. While ideally this process would be based on the incorporation of detailed field truth information, this project relied on training data provided in the form of digital harvest update layer with treatment codes to classify harvest based on the volume of forest of vegetation extraction. Using treatment codes as an indicator of harvest severity was effective for a distinction between full (severe) harvest and partial (moderate) harvest.

To achieve the distinction of a light harvest class, more detailed field truth information must be collected. This would include a breakdown of species composition before and after harvest (preferably under-story and over-story) as well as a measure of the volume of vegetation removed and the method by which it was extracted. This would allow us to better evaluate how certain harvesting activities reflect spectrally in the imagery. This gives us a means to classify harvest training samples in a manner that is more compatible for detecting and correlating levels of change in the difference image data. For example clear-cuts with legacy patches, should they be considered severe or moderate harvest? A shelterwood cut might be classified at all 3 levels depending on the stage. Thinning may remove a considerable amount of vegetation.

Severe harvest is easily observed in various composites of the original image bands and thus is also very obvious in the tasseled cap indices. RGB change images provides a wonderful tool for visual interpretation of degrees of vegetation extraction in recent harvest versus preexisting harvest and levels of regeneration distinct from undisturbed forest cover. The index difference image data is easy to threshold as the severe harvest data (extreme change or difference) lies in the extreme positive tail of a normally distributed data set. The threshold can be nicely defined in the wetness index difference data at 4 standard deviations, in the positive direction, from the mean. While there can be some confusion with extreme change in other cover types this is easily remedied by applying image masks generated from the land cover classification to restrict the processing to forest cover only. There is very little speckle noise captured at this threshold.

The partial cuts, or moderate level of harvest severity, are somewhat less distinct in both, the original image data as well as the tasseled cap indices. Their ease of detection depends on the nature of the harvest method (strip cut size and direction, selective cut volume, shelterwood cut stage) as well as the type of vegetation harvested. RGB change imagery does reveal slight change as lighter tones however these are sometimes very subtle and can be missed or misinterpreted. Recognition elements of shape, pattern and association can be useful for manual interpretation but these do not lend themselves well to automation. The index difference image can be stratified based on lesser degrees of change but thresholds are difficult to correlate with particular treatment codes and thus this source of training is ineffective for stratification of this class of harvest into light versus moderate harvest making field truth . (Franklin’s training data included a measure of basal area reduction) a critical component of this exercise. The wetness difference threshold for partial harvest generally lies at 1 standard deviation, in the positive direction, from the mean. This usually capture a significant amount of speckle noise and confusion related to change in other cover types.

Accurate training data is also crucial to reducing change confusion that can not be dealt with effectively by way of image masks. With the current information, the definition of a partial harvest threshold becomes an exercise in compromise between complete capture of harvest and exclusion of speckle. Some investigation was carried out to devise a method to eliminate speckle through the use of threshold masks of brightness and greenness difference data.

5.2.2 Classifying Forest Type

Since the FUNA codes in the update training layers are based on vegetation remaining after harvest the land cover classification of 99 tasseled cap data was used as the main source of information on the forest type harvested in 2000. This classification was achieved by using FUNA codes in the NB forest inventory to derive accurate training information. Was this effective in lieu of field truth?

5. 3 Deliverables

Data Catalogue

Data Type	File Name	Format	Size	Description of Contents
Raster		PIX		Corrected subset of DNR extent includes all 7 bands of 1999 scene and tasseled cap indices.
		PIX		Corrected subset of DNR extent includes all 7 bands of 2000 scene and tasseled cap indices.
		PIX		Tasseled cap indices of each date, difference images, image masks and classification results.
Vector		E00		
		E00		
		E00		

6. RECOMMENDATIONS

These results clearly indicated that the amount of training data was inadequate for an acceptable accuracy.
The shortage of hardwood samples was particularly problematic. One other issue to note was the source of training data. One should keep in mind that even a small amount of incorrectly classified pixels in the training data can sufficiently confuse the classifier. Even though the quality of the forest inventory is considered adequate for most spatial analysis conducted in a GIS. For this process to yield truly reliable results field work should be conducted and carried out with the aim of this process in mind This means that detailed information that is applicable regardless of the level of harvest severity. Severe harvest is a case to itself. Essentially all the information required here is species composition and density of a block prior to harvest, method of harvest employed, species identification and density of any remaining vegetation

Recommend that steps be taken to produce a detailed land cover classification for the entire province of New Brunswick that agrees highly with the information gleaned from the traditional air photo methodology. This data product could be used a baseline for biological diversity monitoring including future harvest updates as well as change detection focused on other components of the natural landscape such as wetlands. This classification exercise would provide valuable insight to spectral definitions of forest communities with variations in species composition and maturity. It would also create the necessary data base and field truth information to investigate the utility of high resolution sensors for honing these signatures. This research may lead to the fine scale definition of spectral signatures that may then be utilized for calculating rates of change in back casting projects to then compute projections for future forest conditions.

-APPENDIX A-

Georeferencing Reports

DNR_12Sept1999.pix

```
  1:GEOref    Type:150 [Georeferencing        ]   Last Update: 11:14 16Feb2001
    Contents: Master Georeferencing Segment for File

Georeference Units             :    SG          E012
Projection                     :    Stereographic
Datum - Ellipsoid              :    WGS 84 (GPS)

Upper Left  Corner             :         2530479.424 E         7544543.218 N
Upper Right Corner             :         2600709.424 E         7544543.218 N
Image Centre                   :         2565594.424 E         7494893.218 N
Lower Left  Corner             :         2530479.424 E         7445243.218 N
Lower Right Corner             :         2600709.424 E         7445243.218 N

Pixel Size                     :              30.000 E              30.000 N

Upper Left  Corner             :     66d05'55.81" W  Lon   46d53'59.59" N  Lat
Upper Right Corner             :     65d10'28.64" W  Lon   46d53'34.66" N  Lat
Image Centre                   :     65d38'37.63" W  Lon   46d27'03.16" N  Lat
Lower Left  Corner             :     66d06'19.31" W  Lon   46d00'24.77" N  Lat
Lower Right Corner             :     65d11'46.25" W  Lon   46d00'00.43" N  Lat

True origin            :    66d30'00.0000"W 46d30'00.0000"N
False: Easting/Northing:       2500000.00      7500000.00
```

DNR_6Sept2000.pix

```
  1:GEOref    Type:150 [Georeferencing        ]   Last Update: 11:17 16Feb2001
    Contents: Master Georeferencing Segment for File

Georeference Units             :    SG          E012
Projection                     :    Stereographic
Datum - Ellipsoid              :    WGS 84 (GPS)

Upper Left  Corner             :         2530479.424 E         7544543.218 N
Upper Right Corner             :         2600709.424 E         7544543.218 N
Image Centre                   :         2565594.424 E         7494893.218 N
Lower Left  Corner             :         2530479.424 E         7445243.218 N
Lower Right Corner             :         2600709.424 E         7445243.218 N

Pixel Size                     :              30.000 E              30.000 N

Upper Left  Corner             :     66d05'55.81" W  Lon   46d53'59.59" N  Lat
Upper Right Corner             :     65d10'28.64" W  Lon   46d53'34.66" N  Lat
Image Centre                   :     65d38'37.63" W  Lon   46d27'03.16" N  Lat
Lower Left  Corner             :     66d06'19.31" W  Lon   46d00'24.77" N  Lat
Lower Right Corner             :     65d11'46.25" W  Lon   46d00'00.43" N  Lat

True origin            :    66d30'00.0000"W 46d30'00.0000"N
False: Easting/Northing:       2500000.00      7500000.00
```

-APPENDIX A-

Georeferencing Reports

DNR_harvest99-00.pix

```
   1:GEOref    Type:150 [Georeferencing        ]   Last Update: 15:54 05Apr2001
     Contents: Master Georeferencing Segment for File

 Georeference Units             :    SG          E012
 Projection                     :    Stereographic
 Datum - Ellipsoid              :    WGS 84 (GPS)

 Upper Left  Corner             :         2530479.424 E         7544543.218 N
 Upper Right Corner             :         2600709.424 E         7544543.218 N
 Image Centre                   :         2565594.424 E         7494893.218 N
 Lower Left  Corner             :         2530479.424 E         7445243.218 N
 Lower Right Corner             :         2600709.424 E         7445243.218 N

 Pixel Size                     :              30.000 E              30.000 N

 Upper Left  Corner             :     66d05'55.81" W  Lon   46d53'59.59" N  Lat
 Upper Right Corner             :     65d10'28.64" W  Lon   46d53'34.66" N  Lat
 Image Centre                   :     65d38'37.63" W  Lon   46d27'03.16" N  Lat
 Lower Left  Corner             :     66d06'19.31" W  Lon   46d00'24.77" N  Lat
 Lower Right Corner             :     65d11'46.25" W  Lon   46d00'00.43" N  Lat

 True origin            :    66d30'00.0000"W 46d30'00.0000"N
 False: Easting/Northing:       2500000.00      7500000.00
```

-APPENDIX B-

Channel Descriptor Listings

DNR_12Sept1999.pix

```
   1 [ 8U] gcpwork:Registration Channel=1,
file=D:\pci_v70\user\DNR_1
   2 [ 8U] gcpwork:Registration Channel=2,
file=D:\pci_v70\user\DNR_1
   3 [ 8U] gcpwork:Registration Channel=3,
file=D:\pci_v70\user\DNR_1
   4 [ 8U] gcpwork:Registration Channel=4,
file=D:\pci_v70\user\DNR_1
   5 [ 8U] gcpwork:Registration Channel=5,
file=D:\pci_v70\user\DNR_1
   6 [ 8U] gcpwork:Registration Channel=6,
file=D:\pci_v70\user\DNR_1
   7 [32R] RTR:Brightness
(0.30*C1+0.28*C2+0.47*C3+0.56*C4+0.51*C5
   8 [32R] RTR:Greenness (-0.28*C1-0.24*C2-
0.54*C3+0.72*C4+0.08*C
   9 [32R] RTR:Wetness (0.15*C1+0.20*C2+0.33*C3+0.34*C4-
0.71*C5
```

DNR_6Sept2000.pix

```
   1 [ 8U] gcpwork:Registration Channel=1,
file=D:\pci_v70\user\DNR_6
   2 [ 8U] gcpwork:Registration Channel=2,
file=D:\pci_v70\user\DNR_6
   3 [ 8U] gcpwork:Registration Channel=3,
file=D:\pci_v70\user\DNR_6
   4 [ 8U] gcpwork:Registration Channel=4,
file=D:\pci_v70\user\DNR_6
   5 [ 8U] gcpwork:Registration Channel=5,
file=D:\pci_v70\user\DNR_6
```

```
   6 [ 8U] gcpwork:Registration Channel=6,
file=D:\pci_v70\user\DNR_6
   7 [32R] RTR:Brightness
(0.30*C1+0.28*C2+0.47*C3+0.56*C4+0.51*C5
   8 [32R] RTR:Greenness (-0.28*C1-0.24*C2-
0.54*C3+0.72*C4+0.08*C
   9 [32R] RTR:Wetness (0.15*C1+0.20*C2+0.33*C3+0.34*C4-
0.71*C5
```

-APPENDIX B-

Channel Descriptor Listings

DNR_harvest99-00.pix

```
   1 [ 8U] mask of valid image data overlap
   2 [ 8U] cloud & cloud shadow mask for 1999 & 2000
   3 [ 8U] 1999 brightness index, original output of
tasseled cap
   4 [ 8U] 1999 greenness index, original output of
tasseled cap
   5 [ 8U] 1999 wetness index, original output of tasseled
cap
   6 [ 8U] 2000 brightness index
   7 [ 8U] 2000 greenness index
   8 [ 8U] 2000 wetness index
   9 [ 8U] 1999 brightness index, regressed to 2000
brightness
  10 [ 8U] 1999 greenness index, regressed to 2000
greenness
  11 [ 8U] 1999 wetness index, regressed to 2000 wetness
  12 [16S] brightness difference: 2000 - 1999
  13 [16S] greenness difference: 1999 - 2000
  14 [16S] wetness difference: 1999 - 2000
  15 [ 8U] 1999 land cover classification of tasseled cap
indices
  16 [ 8U] land cover training areas encoded for confusion
matrix
  17 [ 8U] mask to eliminate cloud from 1999 land cover
classification
  18 [ 8U] filtered 1999 land cover classification
  19 [ 8U] forest cover mask from 1999 land cover
classification
  20 [ 8U] partial change, 1SD threshold of wetness
difference
  21 [ 8U] severe change, 4SD threshold of wetness
difference
  22 [ 8U] MODEL: partial change in forest cover only
  23 [ 8U] MODEL: severe change in forest cover only
  24 [ 8U] filtered partial forest change mask
  25 [ 8U] filtered severe forest change mask
  26 [ 8U] MLC: partial harvest classification by forest
type
```

```
  27 [ 8U] MLC: severe harvest classification by forest
type
  28 [ 8U] partial harvest training areas encoded for
matrix
  29 [ 8U] severe harvest training areas encoded for matrix
  30 [ 8U] MODEL: partial harvest classification by forest
type
  31 [ 8U] MODEL: severe harvest classification by forest
type
```

-APPENDIX C-

Database Segment Listings

DNR_12Sept1999.pix

```
1:GEOref   Type:150 [Georeferencing        ]   Last Update: 11:14 16Feb2001
  Contents: Master Georeferencing Segment for File

2:DNRlines Type:116 [Vectors/Polygons      ]   Last Update: 11:25 16Feb2001
  Contents: line features for DNR study area in DS NAD83
```

DNR_6Sept2000.pix

```
1:GEOref   Type:150 [Georeferencing        ]   Last Update: 11:17 16Feb2001
  Contents: Master Georeferencing Segment for File
```

DNR_harvest99-00.pix

```
 1:GEOref   Type:150 [Georeferencing        ]   Last Update: 15:54 05Apr2001
              Contents: Master Georeferencing Segment for File

 2:partharv Type:101 [Bitmap                ]   Last Update: 14:28 29Mar2001
            Contents: partial wetness change in forest cover, 1SD

 3:sevharv  Type:101 [Bitmap                ]   Last Update: 14:28 29Mar2001
             Contents: severe wetness change in forest cover, 4SD

 4:cldmask  Type:101 [Bitmap                ]   Last Update: 14:29 29Mar2001
          Contents: graphics mask traced on 1999 shadow & 2000 cloud

 5:partmlc  Type:171 [Pseudo-Colour Table   ]   Last Update: 16:19 05Apr2001
   Contents: partial harvest classification of TCdifference images &99 BGW

 6:sevmlc   Type:171 [Pseudo-Colour Table   ]   Last Update: 16:12 05Apr2001
  Contents: severe harvest classification of  TC difference images & 99 BGW

 7:sftprtta Type:121 [Signatures            ]   Last Update: 14:35 29Mar2001
             Contents: softwood partial harvest TC dif & TC 1999

 8:mixprtta Type:121 [Signatures            ]   Last Update: 14:35 29Mar2001
            Contents: mixed wood partial harvest TC dif & TC 1999

 9:hrdprtta Type:121 [Signatures            ]   Last Update: 14:35 29Mar2001
             Contents: hardwood partial harvestTC dif & TC 1999

10:sftclrta Type:121 [Signatures            ]   Last Update: 14:36 29Mar2001
                Contents: softwood clear cut TC dif & TC 1999

11:mixclrta Type:121 [Signatures            ]   Last Update: 14:36 29Mar2001
               Contents: mixed wood clear cut TC dif & TC 1999

12:hrdclrta Type:121 [Signatures            ]   Last Update: 14:36 29Mar2001
                Contents: hardwood clear cut TC dif & TC 1999

13:mixcover Type:121 [Signatures            ]   Last Update: 14:32 29Mar2001
                Contents: mixed wood land cover training areas

14:hrdcover Type:121 [Signatures            ]   Last Update: 12:45 29Mar2001
                 Contents: hardwood land cover training areas

15:hrdcover Type:101 [Bitmap                ]   Last Update: 17:48 26Mar2001
                 Contents: hardwood land cover training areas
```

```
16:sftcover Type:101 [Bitmap                ]   Last Update: 18:02 26Mar2001
                 Contents: softwood land cover training areas

17:agrcover Type:101 [Bitmap                ]   Last Update: 16:45 22Mar2001
                Contents: agriculture land cover training ares

18:baresoil Type:101 [Bitmap                ]   Last Update: 16:32 22Mar2001
                 Contents: bare soil land cover training ares

19:turbwat  Type:101 [Bitmap                ]   Last Update: 16:34 22Mar2001
               Contents: turbid water land cover training areas

20:deepwat  Type:101 [Bitmap                ]   Last Update: 16:34 22Mar2001
                 Contents: deepwater land cover training areas

21:sftclrta Type:101 [Bitmap                ]   Last Update: 15:44 27Mar2001
                  Contents: softwood clear cut training areas

22:sftprtta Type:101 [Bitmap                ]   Last Update: 16:30 27Mar2001
               Contents: softwood partial harvest training areas

23:mixclrta Type:101 [Bitmap                ]   Last Update: 16:31 27Mar2001
                 Contents: mixed wood clear cut training areas

24:mixprtta Type:101 [Bitmap                ]   Last Update: 16:37 27Mar2001
              Contents: mixed wood partial harvest training areas

25:hrdclrta Type:101 [Bitmap                ]   Last Update: 16:08 27Mar2001
                  Contents: hardwood clear cut training areas

26:hrdprtta Type:101 [Bitmap                ]   Last Update: 16:43 27Mar2001
               Contents: hardwood partial harvest training areas

28:sftclrta Type:121 [Signatures            ]   Last Update: 14:36 29Mar2001
                   Contents: softwood clear cut TC dif only

29:mixclrta Type:121 [Signatures            ]   Last Update: 14:36 29Mar2001
                  Contents: mixed wood clear cut TC dif only

30:hrdclrta Type:121 [Signatures            ]   Last Update: 14:37 29Mar2001
                   Contents: hardwood clear cut TC dif only

31:sftprtta Type:121 [Signatures            ]   Last Update: 14:38 29Mar2001
                 Contents: softwood partial harvestTC dif only

32:mixprtta Type:121 [Signatures            ]   Last Update: 14:38 29Mar2001
                Contents: mixed wood partial harvestTC dif only

33:hrdprtta Type:121 [Signatures            ]   Last Update: 14:38 29Mar2001
                 Contents: hardwood partial harvestTC dif only

34:99 landc Type:171 [Pseudo-Colour Table   ]   Last Update: 16:03 05Apr2001
        Contents: land cover classification of 1999 tasseled cap indices

36:mixcover Type:121 [Signatures            ]   Last Update: 17:05 22Mar2001
                Contents: mixed wood land cover training areas

37:hrdcover Type:121 [Signatures            ]   Last Update: 17:05 22Mar2001
                 Contents: hardwood land cover training areas

38:sftcover Type:121 [Signatures            ]   Last Update: 17:06 22Mar2001
                 Contents: softwood land cover training areas

39:agrcover Type:121 [Signatures            ]   Last Update: 17:06 22Mar2001
                Contents: agriculture land cover training ares

40:baresoil Type:121 [Signatures            ]   Last Update: 17:06 22Mar2001
                 Contents: bare soil land cover training ares

41:turbwat  Type:121 [Signatures            ]   Last Update: 17:06 22Mar2001
               Contents: turbid water land cover training areas
```

```
42:deepwat  Type:121 [Signatures            ]   Last Update: 17:07 22Mar2001
                 Contents: deepwater land cover training areas

43:wetSD+.5 Type:101 [Bitmap                ]   Last Update: 16:01 22Mar2001
                                   Contents:

45:sftpart  Type:101 [Bitmap                ]   Last Update: 16:36 29Mar2001
                                   Contents:

46:classmsk Type:101 [Bitmap                ]   Last Update: 14:53 23Mar2001
                                   Contents:

47:mixpart  Type:101 [Bitmap                ]   Last Update: 16:37 29Mar2001
                                   Contents:

48:hrdpart  Type:101 [Bitmap                ]   Last Update: 16:37 29Mar2001
                                   Contents:

49:sftsev   Type:101 [Bitmap                ]   Last Update: 16:38 29Mar2001
                                   Contents:

50:mixed_wd Type:116 [Vectors/Polygons      ]   Last Update: 11:48 26Mar2001
            Contents: mixed wood vectors from funa = SPTH,THBF,THSP

51:hard_wd  Type:116 [Vectors/Polygons      ]   Last Update: 11:48 26Mar2001
               Contents: hardwood vectors from funa = IHTH,TOHW

52:soft_wd  Type:116 [Vectors/Polygons      ]   Last Update: 11:48 26Mar2001
             Contents: softwood vectors from funa= SPBF & > .35km

53:mixsev   Type:101 [Bitmap                ]   Last Update: 16:38 29Mar2001
                                   Contents:

54:hrdthin  Type:116 [Vectors/Polygons      ]   Last Update: 14:59 27Mar2001
                                   Contents:

55:hrdpart  Type:116 [Vectors/Polygons      ]   Last Update: 15:21 27Mar2001
                                   Contents:

56:hrdclear Type:116 [Vectors/Polygons      ]   Last Update: 15:22 27Mar2001
                                   Contents:

57:mixthin  Type:116 [Vectors/Polygons      ]   Last Update: 15:22 27Mar2001
                                   Contents:

58:mixpart  Type:116 [Vectors/Polygons      ]   Last Update: 15:22 27Mar2001
                                   Contents:

59:mixclear Type:116 [Vectors/Polygons      ]   Last Update: 15:23 27Mar2001
                                   Contents:

60:partmod  Type:171 [Pseudo-Colour Table   ]   Last Update: 16:20 05Apr2001
           Contents: partial harvest classification by spatial model

61:hrdsev   Type:101 [Bitmap                ]   Last Update: 16:39 29Mar2001
                                   Contents:

62:mixpart2 Type:101 [Bitmap                ]   Last Update: 16:40 29Mar2001
                                   Contents:

63:hrdpart2 Type:101 [Bitmap                ]   Last Update: 16:40 29Mar2001
                                   Contents:

64:sftpart2 Type:101 [Bitmap                ]   Last Update: 16:40 29Mar2001
                                   Contents:

65:sftsev2  Type:101 [Bitmap                ]   Last Update: 16:41 29Mar2001
                                   Contents:

66:sftthin  Type:116 [Vectors/Polygons      ]   Last Update: 15:23 27Mar2001
```

```
                                   Contents:

67:sftpart  Type:116 [Vectors/Polygons      ]   Last Update: 15:23 27Mar2001
                                   Contents:

68:sftclear Type:116 [Vectors/Polygons      ]   Last Update: 15:24 27Mar2001
                                   Contents:

69:hrdsev2  Type:101 [Bitmap                ]   Last Update: 16:42 29Mar2001
                                   Contents:

70:mixsev2  Type:101 [Bitmap                ]   Last Update: 16:42 29Mar2001
                                   Contents:

71:mixcover Type:101 [Bitmap                ]   Last Update: 15:49 05Apr2001
                Contents: mixed wood land cover training areas

72:sevmod   Type:171 [Pseudo-Colour Table   ]   Last Update: 16:19 05Apr2001
     Contents: severe harvest classification by spatial model -APPENDIX D-
```

-Appendix D-

Ground Control Point Segment Report

DNR_12Sept1999_raw.pix

```
    Set 2 Units:LONG/LAT    E012  Set 1 Units:PIXEL          Number GCPs:  35

GCP's are ordered from worst to best residuals.
  GCP        Set 2 GCP's           Set 1 GCP's          Residual     Distance
  No. ----(SG          E012)---  ------(PIXEL)----  --- -------(PIXEL)--------
   22(   2570599.9,   7519737.1)(  2027.3,   734.9)(   -0.06,    0.64)    0.65
    2(   2538351.0,   7451473.3)(  1400.0,  3172.0)(   -0.12,   -0.61)    0.62
   16(   2534731.2,   7488496.0)(  1049.1,  1983.8)(    0.04,    0.60)    0.61
   36(   2535485.3,   7479148.7)(  1132.0,  2285.0)(   -0.40,    0.45)    0.60
   15(   2596830.3,   7458875.2)(  3268.0,  2562.0)(   -0.52,    0.29)    0.59
   35(   2585539.5,   7456109.1)(  2915.9,  2722.9)(   -0.25,   -0.52)    0.58
   20(   2568088.8,   7464286.5)(  2293.0,  2566.0)(   -0.42,    0.36)    0.55
   29(   2583713.6,   7513884.0)(  2493.9,   842.9)(    0.39,   -0.36)    0.53
   28(   2530903.1,   7518557.5)(   734.7,  1022.6)(   -0.21,   -0.47)    0.51
   19(   2569960.9,   7492511.6)(  2177.0,  1630.0)(   -0.40,    0.30)    0.50
   18(   2546947.4,   7474532.7)(  1537.0,  2363.0)(    0.24,   -0.43)    0.49
    1(   2548436.7,   7449047.5)(  1746.0,  3188.5)(    0.46,    0.06)    0.46
   31(   2580144.3,   7474525.0)(  2623.9,  2154.1)(    0.08,   -0.42)    0.43
   13(   2598909.2,   7532006.7)(  2876.9,   154.1)(   -0.39,   -0.11)    0.41
   37(   2551385.8,   7463057.9)(  1754.4,  2711.4)(    0.28,    0.28)    0.40
   38(   2593691.7,   7506950.5)(  2863.9,  1007.1)(    0.10,   -0.38)    0.39
   17(   2532788.8,   7500720.4)(   908.9,  1594.9)(    0.30,   -0.26)    0.39
   23(   2567407.7,   7505287.6)(  2014.0,  1227.5)(    0.38,    0.02)    0.38
   32(   2554140.9,   7483097.0)(  1718.5,  2038.0)(   -0.03,    0.37)    0.37
    9(   2551608.9,   7511980.2)(  1453.9,  1108.1)(   -0.27,    0.13)    0.30
   14(   2568515.6,   7539276.5)(  1836.4,   108.0)(    0.01,    0.30)    0.30
    7(   2590806.0,   7521089.0)(  2680.5,   563.0)(   -0.10,    0.28)    0.29
    5(   2557078.3,   7454672.2)(  1993.0,  2950.0)(   -0.24,    0.14)    0.28
   10(   2599203.2,   7482841.1)(  3196.0,  1762.0)(    0.25,   -0.12)    0.28
    6(   2592869.2,   7498384.8)(  2891.0,  1293.0)(    0.27,   -0.05)    0.27
   33(   2559627.1,   7526125.9)(  1627.9,   594.0)(   -0.01,   -0.27)    0.27
   21(   2586047.3,   7488436.8)(  2730.0,  1662.0)(    0.18,    0.18)    0.25
   11(   2596848.7,   7446339.3)(  3348.1,  2972.0)(    0.21,   -0.11)    0.24
   24(   2541168.9,   7501400.8)(  1179.0,  1520.0)(    0.20,   -0.10)    0.22
   12(   2551369.4,   7541925.4)(  1258.1,   129.0)(   -0.20,   -0.02)    0.20
    3(   2551069.2,   7492355.5)(  1560.0,  1754.0)(    0.18,    0.08)    0.20
    4(   2535429.8,   7538969.2)(   755.0,   326.0)(    0.07,   -0.18)    0.20
   26(   2535222.4,   7468312.2)(  1191.7,  2640.9)(   -0.18,   -0.03)    0.18
   27(   2544018.2,   7536293.1)(  1053.0,   359.6)(    0.08,   -0.12)    0.15
   34(   2599610.3,   7466935.0)(  3309.1,  2280.4)(    0.10,    0.10)    0.14

Residual Plot (PIXEL)                          RMS=(    0.27,    0.33)    0.43
 +-------------------+-------------------+
 |                   |                   |
 |                   |                   |
 |                   |                   |
 |                 22|                   |
 |                   16                  |
 |           36      |                   |
 |         1519    32|   37              |
 |                   | 21                |
 |              95   |343    1           |
 +--------------12---+----623------------+
 |           13      |2710               |
 |                  334  17              |
 |                   |38   29            |
 |              28   31 18               |
 |             35  2 |                   |
 |                   |                   |
 |                   |                   |
 |                   |                   |
 |                   |                   |
 +-------------------+-------------------+
```

-Appendix D-

Ground Control Point Segment Report

DNR_6Sept2000_utm.pix

```
    Set 2 Units:LONG/LAT    E012  Set 1 Units:PIXEL          Number GCPs:  32

GCP's are ordered from worst to best residuals.
  GCP        Set 2 GCP's            Set 1 GCP's          Residual      Distance
  No. ----(SG          E012)---  ------(PIXEL)----  --- -------(PIXEL)--------
   26(   2561424.9,   7479846.8)(  2736.4,  3106.5)(   -0.09,    0.67)    0.68
   29(   2593241.3,   7522975.1)(  4084.2,  1438.8)(   -0.58,    0.33)    0.66
   11(   2570018.0,   7536953.7)(  3181.0,   838.0)(   -0.44,   -0.48)    0.65
    4(   2534973.8,   7510311.3)(  1732.8,  1841.1)(   -0.64,   -0.03)    0.64
   20(   2575747.5,   7498195.1)(  3340.9,  2397.8)(   -0.62,   -0.06)    0.62
    8(   2535427.1,   7538965.6)(  1803.0,   697.0)(    0.47,    0.40)    0.62
   22(   2551867.5,   7468645.1)(  2334.9,  3537.1)(    0.31,    0.49)    0.58
    1(   2594152.5,   7511458.8)(  4100.4,  1899.9)(   -0.29,   -0.49)    0.56
   30(   2591304.0,   7503068.7)(  3972.5,  2230.5)(    0.52,   -0.21)    0.56
   25(   2551072.5,   7492360.1)(  2344.5,  2587.5)(   -0.49,    0.26)    0.55
   19(   2572278.8,   7512306.3)(  3228.5,  1827.5)(    0.51,   -0.16)    0.54
   23(   2546769.9,   7475183.7)(  2143.0,  3266.0)(    0.51,   -0.14)    0.53
    7(   2532639.0,   7447852.7)(  1529.0,  4333.0)(   -0.15,   -0.50)    0.52
    6(   2595048.8,   7446010.1)(  4020.4,  4518.6)(    0.18,    0.48)    0.51
   14(   2584683.8,   7458171.3)(  3627.9,  4013.9)(    0.33,    0.38)    0.51
   21(   2581072.5,   7483836.3)(  3528.4,  2981.4)(   -0.43,    0.16)    0.46
   27(   2569044.0,   7488937.7)(  3057.5,  2755.6)(    0.27,   -0.37)    0.46
   16(   2555287.5,   7516855.1)(  2556.8,  1616.1)(   -0.16,    0.42)    0.45
    5(   2596796.3,   7490316.3)(  4168.4,  2750.4)(   -0.39,    0.22)    0.45
   31(   2553669.0,   7452203.7)(  2377.0,  4197.0)(   -0.43,    0.03)    0.43
   32(   2557974.9,   7530203.7)(  2688.5,  1087.0)(    0.36,    0.10)    0.37
   13(   2597501.3,   7465525.1)(  4153.1,  3742.1)(    0.11,   -0.34)    0.36
    2(   2556558.8,   7542643.8)(  2653.9,   587.2)(    0.33,    0.10)    0.35
   24(   2555977.1,   7502424.6)(  2559.0,  2194.0)(    0.12,    0.32)    0.34
   15(   2558591.3,   7461021.3)(  2589.9,  3852.9)(    0.12,   -0.32)    0.34
   12(   2577836.3,   7527636.3)(  3477.5,  1224.5)(    0.15,   -0.28)    0.32
    9(   2598052.1,   7535468.7)(  4299.5,   947.5)(    0.28,   -0.14)    0.31
   17(   2533087.5,   7490035.1)(  1621.9,  2647.9)(   -0.10,   -0.26)    0.28
   18(   2577534.0,   7469107.7)(  3361.5,  3563.5)(    0.18,   -0.19)    0.26
    3(   2531006.3,   7466601.3)(  1497.3,  3580.9)(    0.09,   -0.24)    0.26
   10(   2564347.5,   7449145.1)(  2798.8,  4338.1)(    0.04,   -0.13)    0.14
   28(   2540538.8,   7523192.6)(  1978.7,  1336.1)(   -0.08,   -0.04)    0.09

Residual Plot (PIXEL)                                 RMS=(    0.37,    0.33)    0.50
 +-------------------+-------------------+
 |                   |                   |
 |                   |                   |
 |                   |                   |
 |                26 |                   |
 |                   |                   |
 |               16  |  6 22 8           |
 |        29         |24  14             |
 |         25 5      |                   |
 |          21       |    32             |
 +-------4--31-----28+-------------------+
 |       20          10   9  19          |
 |                17 | 18    30          |
 |                   |13 27              |
 |          11  1 7  |                   |
 |                   |                   |
 |                   |                   |
 |                   |                   |
 |                   |                   |
 |                   |                   |
 +-------------------+-------------------+
```

-Appendix E-

Histogramming Database Image Reports: Original Bands

```
DNR_12Sept1999.pix

    1 [ 8U] Band 1 of DNR_12Sept1999.pix

 1073440+             *
       |             *
       |             *
       |             *
 805080+             *
       |             **
       |             **
       |            ***
 536720+            ***
       |            ***
       |            ***
       |            ***
 268360+            ***
       |            ****
       |            ****
       |000000000001****6210000000000000000000000000000000000000000000
      0+--------+-------+-------+-------+-------+-------+-------+-------+
      10      42      74     106     138     170     202     234     266

 Number of pixels plotted:   7554738    Cell width: 4
 Mean:  65.320  Median:  64 Mode:  63 Standard Dev:   6.646 Min:  10  Max: 255

2 [ 8U] Band 2 of DNR_12Sept1999.pix

 1934880+  *
       |  *
       |  *
       |  *
1451160+ **
       | **
       | **
       | **
 967440+ **
       | **
       | **
       | **
 483720+ **
       | ***
       | ***
       |2***3000000000000000000000000000000000000000               0
      0+--------+-------+-------+-------+-------+-------+-------+-------+
      15      47      79     111     143     175     207     239     271

 Number of pixels plotted:   7554738    Cell width: 4
 Mean:  24.073  Median:  23 Mode:  23 Standard Dev:   3.395 Min:  15  Max: 254

3 [ 8U] Band 3 of DNR_12Sept1999.pix

 1349760+    *
       |    *
       |    *
       |    *
1012320+    *
       |    *
       |    **
       |    **
 674880+    **
       |    **
       |    **
       |    ***
 337440+    ***
       |    ***
       |    ****
       |0002****63100000000000000000000000000000000000000000000000000000
      0+--------+-------+-------+-------+-------+-------+-------+-------+
       0      32      64      96     128     160     192     224     256

 Number of pixels plotted:   7554738    Cell width: 4
 Mean:  22.197  Median:  21 Mode:  19 Standard Dev:   6.400 Min:   0  Max: 255
```

-Appendix E-

Histogramming Database Image Reports: Original Bands

```
   4 [ 8U] Band 3 of DNR_12Sept1999.pix

 237600+                **
      |                ***
      |               ****
      |               ****
178200+              ******
      |              ******
      |             *******
      |            ********
118800+            *********
      |           **********
      |           **********
      |           ***********
 59400+          ************
      |          *************
      |          **************
      |0*6221123***************731100000000000000000000000000         0
     0+--------+-------+-------+-------+-------+-------+-------+-------+
      0      32      64      96     128     160     192     224     256

Number of pixels plotted:   7554738    Cell width: 4
Mean:  64.994  Median:  66 Mode:  69 Standard Dev:  14.150 Min:   0  Max: 255
```

```
   5 [ 8U] Band 5 of DNR_12Sept1999.pix

 232000+         **
      |        ****
      |        ****
      |        *****
174000+        *****
      |       *******
      |       *******
      |       ********
116000+       *********
      |       **********
      |       **********
      |       ***********
 58000+       ************
      |      **************
      |      ****************
      |6*3223*****************85311000000000000000000000000000000000000
     0+--------+-------+-------+-------+-------+-------+-------+-------+
      0      32      64      96     128     160     192     224     256

Number of pixels plotted:   7554738    Cell width: 4
Mean:  48.964  Median:  46 Mode:  40 Standard Dev:  16.324 Min:   0  Max: 255
```

```
   6 [ 8U] Band 7 of DNR_12Sept1999.pix

 728480+   *
      |   *
      |  **
      |  **
546360+  **
      |  **
      |  ***
      |  ***
364240+  ***
      |  ***
      |  ***
      |  ****
182120+  *****
      |  *****
      |  ******
      |49******96321000000000000000000000000000000000000000   0      00
     0+--------+-------+-------+-------+-------+-------+-------+-------+
      1      33      65      97     129     161     193     225     257

Number of pixels plotted:   7554738    Cell width: 4
Mean:  18.169  Median:  16 Mode:  13 Standard Dev:   8.133 Min:   1  Max: 255
```

-Appendix E-

Histogramming Database Image Reports: Original Bands

```
DNR_6Sept2000.pix
    1 [ 8U] Band 1 of DNR_6Sept2000.pix

  1581600+    *
         |   *
         |   *
         |  **
  1186200+  **
         |  **
         |  **
         |  **
   790800+  **
         |  **
         |  **
         |  ***
   395400+  ***
         |  ***
         |  ***
         |04****5210000000000000000000000000000000000000000000000 0000
        0+--------+-------+-------+-------+-------+-------+-------+-------+
        47      71      95     119     143     167     191     215     239

 Number of pixels plotted:   7554738    Cell width: 3
 Mean:  57.179  Median:  56 Mode:  56 Standard Dev:   3.430 Min:  47  Max: 227

    2 [ 8U] Band 2 of DNR_6Sept2000.pix

  1177760+    *
         |   *
         |   *
         |   *
   883320+   **
         |   **
         |   **
         |   **
   588880+   **
         |   **
         |   **
         |   **
   294440+   ***
         |   ***
         |  *****
         |01*****410000000000000000000000000000000 00   00
        0+--------+-------+-------+-------+-------+-------+-------+
        25      57      89     121     153     185     217     249

 Number of pixels plotted:   7554738    Cell width: 4
 Mean:  41.552  Median:  40 Mode:  39 Standard Dev:   4.421 Min:  25  Max: 218

    3 [ 8U] MOSAIC  Channel 3 from DNR_6Sept2000.pix

  1237920+    *
         |   *
         |   *
         |  **
   928440+  **
         |  **
         |  **
         |  **
   618960+  **
         |  **
         |  **
         |  **
   309480+  ***
         |  ***
         |  ****
         |01*****63210000000000000000000000000000000000000000 00 0
        0+--------+-------+-------+-------+-------+-------+-------+-------+
        15      47      79     111     143     175     207     239     271

 Number of pixels plotted:   7554738    Cell width: 4
 Mean:  30.394  Median:  28 Mode:  27 Standard Dev:   6.786 Min:  15  Max: 240
```

-Appendix E-

Histogramming Database Image Reports: Original Bands

```
    4 [ 8U] Band 4 of DNR_6Sept2000.pix

  225920+                      ***
        |                    ****
        |                   ******
        |                  *******
  169440+                  ********
        |                 *********
        |                ***********
        |               ************
  112960+               ************
        |               *************
        |              **************
        |              ***************
   56480+             ****************
        |             *****************
        |  *         *******************
        |0**1000001114*******************5210000000000000000
       0+--------+-------+-------+-------+-------+-------+-------+
        4      28      52      76     100     124     148     172

Number of pixels plotted:   7554738    Cell width: 3
Mean:  70.433  Median:  71 Mode:  74 Standard Dev:  13.847 Min:   4  Max: 158
```

```
   5 [ 8U] Band 5 of DNR_6Sept2000.pix

  231680+          **
        |        ****
        |        ****
        |        *****
  173760+        *****
        |        ******
        |        *******
        |       ********
  115840+       *********
        |       *********
        |       **********
        |       ***********
   57920+       ************
        |       *************
        |  *    ****************
        |01*2001*****************8642211000000000000000000000000 0  0
       0+--------+-------+-------+-------+-------+-------+-------+-------+
        0      32      64      96     128     160     192     224     256

Number of pixels plotted:   7554738    Cell width: 4
Mean:  53.761  Median:  51 Mode:  42 Standard Dev:  16.056 Min:   0  Max: 236
```

```
   6 [ 8U] Band 7 of DNR_6Sept2000.pix

  564800+      *
        |     *
        |     **
        |     **
  423600+     **
        |    ***
        |    ***
        |    ****
  282400+    ****
        |    ****
        |    ****
        |    *****
  141200+    *****
        |    ******
        |    *******
        |0256********854321100000000000000000000000000000 00   00
       0+--------+-------+-------+-------+-------+-------+-------+
        0      32      64      96     128     160     192     224

Number of pixels plotted:   7554738    Cell width: 4
Mean:  27.325  Median:  25 Mode:  22 Standard Dev:   9.795 Min:   0  Max: 221
```

-Appendix F-

Histogramming Database Image Reports: Tasseled Cap Indices

-Appendix G-

Histogramming Database Image Reports: Tasseled Cap Difference Images

```
DNR_harvest99-00.pix

   29 [16S] MODEL   Source= TC_subtract_model.txt

 5220480 +                                *
         |                                *
         |                                *
         |                                *
 3915360 +                                *
         |                                *
         |                                *
         |                                *
 2610240 +                                *
         |                                *
         |                                *
         |                                *
 1305120 +                               **
         |                               **
         |                               ***
         |0000000000000000000000000000001***411000000000000000000000000
       0 +---------------+---------------+---------------+---------------+
      -225            -113              -1             111             223

 Number of pixels plotted:   7555833   Cell width:    7.0000
 Minimum value in data:      -225  Pixels less than histogram min:         0
 Maximum value in data:       199  Pixels more than histogram max:         0
 For all data: Mean:        1.663  Standard Deviation:                 7.260
```

```
30 [16S] MODEL   Source= TC_subtract_model.txt

 3641760 +                          *
         |                         *
         |                         *
         |                         *
 2731320 +                         *
         |                         *
         |                         *
         |                         **
 1820880 +                         **
         |                         **
         |                         **
         |                         **
  910440 +                        ***
         |                        ***
         |                        ***
         |000000000000000000000128****421000000000000000000000 0000
       0 +---------------+---------------+---------------+---------------+
      -155             -59              37             133             229

 Number of pixels plotted:   7555833   Cell width:    6.0000
 Minimum value in data:      -155  Pixels less than histogram min:         0
 Maximum value in data:       182  Pixels more than histogram max:         0
 For all data: Mean:       -1.139  Standard Deviation:                 7.557
```

```
   31 [16S] MODEL   Source= TC_subtract_model.txt

 3056160 +                       *
         |                      *
         |                      *
         |                      *
 2292120 +                      *
         |                      *
         |                      **
         |                      **
 1528080 +                      **
         |                      **
         |                     ***
         |                     ***
  764040 +                     ***
         |                     ****
         |                     ****
         |000000000000000000013******5211000000000000000000 0        0
       0 +---------------+---------------+---------------+---------------+
      -114             -34              46             126             206

 Number of pixels plotted:   7555833   Cell width:    5.0000
 Minimum value in data:      -114  Pixels less than histogram min:         0
 Maximum value in data:       186  Pixels more than histogram max:         0
 For all data: Mean:        0.439  Standard Deviation:                 9.135
```

-Appendix F-

Classifier Signature Reports: Land Cover classification of 1999 Tasseled Cap Indices

```
39:agrcover  Type:121 [Signatures            ]   Last Update: 17:06 22Mar2001
   Contents: agriculture land cover training ares
   Sample size:   5760    Encoding:   4    Threshold:   3.00    Bias:    1.00

  Channel          Mean    Deviation    Lo-Limit    Up-limit

   3        53.036285     5.242147       3.000       3.000
   4       185.562332    19.227818       3.000       3.000
   5       138.923431    12.807653       3.000       3.000


Class Correlation Matrix:

           3        4        5
   +---------------------------
  3|  1.00000
  4|  0.70593  1.00000
  5|  0.11404  0.69953  1.00000


Class Covariance Matrix:

           3        4        5
   +---------------------------
  3|   27.480
  4|   71.155  369.709
  5|    7.656  172.269  164.036


Determinant of Covariance Matrix:  0.18655176E+06

Inverse Covariance Matrix:

           3        4        5
   +---------------------------
  3|  0.16601
  4| -0.05550  0.02385
  5|  0.05053 -0.02246  0.02732


Triangular Inv-Covar. Matrix:

           3        4        5
   +---------------------------
  3|  0.40744
  4| -0.13621  0.07278
  5|  0.12403 -0.07643  0.07808
```

-Appendix D-

Classifier Signature Reports: Land Cover classification of 1999 Tasseled Cap Indices

```
  40:baresoil  Type:121 [Signatures            ]   Last Update: 17:06 22Mar2001
     Contents: bare soil land cover training ares
     Sample size:   6670    Encoding:   5    Threshold:   3.00    Bias:    1.00

  Channel          Mean    Deviation    Lo-Limit    Up-limit

     3        45.253075    10.139336       3.000       3.000
     4       123.828339    14.881523       3.000       3.000
     5       144.288605    18.330252       3.000       3.000


Class Correlation Matrix:

           3        4        5
   +---------------------------
  3|  1.00000
  4| -0.18954  1.00000
  5| -0.76854  0.00779  1.00000



Class Covariance Matrix:

           3        4        5
   +---------------------------
  3|  102.806
  4|  -28.600  221.460
  5| -142.839    2.126  335.998



Determinant of Covariance Matrix:  0.28734664E+07

Inverse Covariance Matrix:

           3        4        5
   +---------------------------
  3| 0.025894
  4| 0.003239 0.004921
  5| 0.010988 0.001346 0.007639



Triangular Inv-Covar. Matrix:

           3        4        5
   +---------------------------
  3|  0.16092
  4|  0.02013  0.06720
  5|  0.06828 -0.00043  0.05455
```

-Appendix D-

Classifier Signature Reports: Land Cover classification of 1999 Tasseled Cap Indices

```
  42:deepwat   Type:121 [Signatures            ]   Last Update: 17:07 22Mar2001
     Contents: deepwater land cover training areas
     Sample size:   6968    Encoding:   7    Threshold:   3.00    Bias:    1.00

  Channel          Mean    Deviation    Lo-Limit    Up-limit

     3         2.638203     0.879746       3.000       3.000
     4       124.358353     1.803420       3.000       3.000
     5       187.213974     1.989062       3.000       3.000

Class Correlation Matrix:

           3        4        5
   +---------------------------
  3|  1.00000
  4| -0.28137  1.00000
  5|  0.08451 -0.46250  1.00000


Class Covariance Matrix:

           3        4        5
   +---------------------------
  3|  0.77395
  4| -0.44641  3.25232
  5|  0.14788 -1.65906  3.95637


Determinant of Covariance Matrix:  0.71879651E+01

Inverse Covariance Matrix:

           3        4        5
   +---------------------------
  3|  1.40720
  4|  0.21158  0.42295
  5|  0.03612  0.16945  0.32246


Triangular Inv-Covar. Matrix:

           3        4        5
   +---------------------------
  3|  1.18626
  4|  0.17836  0.62541
  5|  0.03045  0.26226  0.50275
```

-Appendix D-

Classifier Signature Reports: Land Cover classification of 1999 Tasseled Cap Indices

```
  14:hrdcover  Type:121 [Signatures            ]   Last Update: 12:22 29Mar2001
     Contents: hardwood land cover training areas
     Sample size:  18212    Encoding:   1    Threshold:   3.00    Bias:    1.00

  Channel          Mean    Deviation    Lo-Limit    Up-limit

     3       39.735229     6.104134       3.000       3.000
     4      191.239731    10.246643       3.000       3.000
     5      170.194870     5.984970       3.000       3.000

Class Correlation Matrix:

           3        4        5
   +---------------------------
  3|  1.00000
  4|  0.93353  1.00000
  5| -0.72972 -0.53853  1.00000


Class Covariance Matrix:

           3        4        5
   +---------------------------
  3|   37.260
  4|   58.390  104.994
  5|  -26.659  -33.026   35.820


Determinant of Covariance Matrix:  0.55662954E+04

Inverse Covariance Matrix:

           3        4        5
   +---------------------------
  3|  0.47970
  4| -0.21757  0.11210
  5|  0.15642 -0.05858  0.09033


Triangular Inv-Covar. Matrix:

           3        4        5
   +---------------------------
  3|  0.69261
  4| -0.31414  0.11582
  5|  0.22584  0.10679  0.16709
```

-Appendix D-

Classifier Signature Reports: Land Cover classification of 1999 Tasseled Cap Indices

```
  13:mixcover  Type:121 [Signatures            ]   Last Update: 13:12 29Mar2001
     Contents:
     Sample size:  26147    Encoding:   1    Threshold:   3.00    Bias:    1.00

  Channel          Mean    Deviation    Lo-Limit    Up-limit

     3        29.329828     5.102774       3.000       3.000
     4       174.069763     9.861753       3.000       3.000
     5       177.397949     4.765413       3.000       3.000

Class Correlation Matrix:

           3        4        5
   +---------------------------
  3|  1.00000
  4|  0.92585  1.00000
  5| -0.49402 -0.23563  1.00000


Class Covariance Matrix:

           3        4        5
   +---------------------------
  3|  26.0383
  4|  46.5907  97.2542
  5| -12.0129 -11.0733  22.7092


Determinant of Covariance Matrix:  0.33801826E+04

Inverse Covariance Matrix:

           3        4        5
   +---------------------------
  3|  0.61711
  4| -0.27366  0.13224
  5|  0.19300 -0.08028  0.10699


Triangular Inv-Covar. Matrix:

           3        4        5
   +---------------------------
  3|  0.78556
  4| -0.34836  0.10434
  5|  0.24569  0.05088  0.20985
```

-Appendix D-

Classifier Signature Reports: Land Cover classification of 1999 Tasseled Cap Indices

```
  44:sftcover  Type:121 [Signatures            ]   Last Update: 12:23 29Mar2001
     Contents: softwood land cover training areas
     Sample size:  38327    Encoding:   1    Threshold:   3.00    Bias:    1.00

  Channel          Mean    Deviation    Lo-Limit    Up-limit

     3        23.112036     2.893609       3.000       3.000
     4       159.573624     5.625027       3.000       3.000
     5       177.509979     4.214417       3.000       3.000


Class Correlation Matrix:

           3        4        5
   +---------------------------
  3|  1.00000
  4|  0.75777  1.00000
  5| -0.36661  0.13529  1.00000



Class Covariance Matrix:

           3        4        5
   +---------------------------
  3|   8.3730
  4|  12.3339  31.6409
  5|  -4.4707   3.2072  17.7613



Determinant of Covariance Matrix:  0.93130631E+03

Inverse Covariance Matrix:

           3        4        5
   +---------------------------
  3|  0.59239
  4| -0.25062  0.13822
  5|  0.19437 -0.08804  0.12113



Triangular Inv-Covar. Matrix:

           3        4        5
   +---------------------------
  3|  0.76967
  4| -0.32562  0.17943
  5|  0.25253 -0.03240  0.23728
```

-Appendix D-

Classifier Signature Reports: Land Cover classification of 1999 Tasseled Cap Indices

```
  41:turbwat   Type:121 [Signatures            ]   Last Update: 17:06 22Mar2001
     Contents: turbid water land cover training areas
     Sample size:   5626    Encoding:   6    Threshold:   3.00    Bias:    1.00

  Channel          Mean    Deviation    Lo-Limit    Up-limit

     3         5.793281     1.808391       3.000       3.000
     4       118.662285     2.886597       3.000       3.000
     5       192.574829     2.489973       3.000       3.000


Class Correlation Matrix:

           3        4        5
   +---------------------------
  3|  1.00000
  4|  0.23141  1.00000
  5| -0.16668 -0.64467  1.00000



Class Covariance Matrix:

           3        4        5
   +---------------------------
  3|  3.27028
  4|  1.20800  8.33244
  5| -0.75053 -4.63363  6.19996



Determinant of Covariance Matrix:  0.93391715E+02

Inverse Covariance Matrix:

           3        4        5
   +---------------------------
  3|  0.32327
  4| -0.04296  0.21107
  5|  0.00703  0.15255  0.27615



Triangular Inv-Covar. Matrix:

           3        4        5
   +---------------------------
  3|  0.56856
  4| -0.07556  0.45317
  5|  0.01236  0.33868  0.40161
```

-**Appendix E-**

Classifier Signature Reports: Land Cover classification of 1999 Tasseled Cap Indices