THE FEASIBILITY OF USING LANDSAT THEMATIC MAPPER DATA FOR FINE SCALE VEGETATION CLASSIFICATION IN SOUTHERN ONTARIO

BY

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ABSTRACT

An analysis was performed using LANDSAT Thematic Mapper digtital imagery to determine the feasibility of fine scale vegetation classification in southern Ontario.

MICROPIPS, an image processing program, was used to analyse the Thematic Mapper data, based on spectral response patterns of different land cover types. Final classified images were compared with vegetation classifications as determined by the Royal Botanical Gardens, in Hamilton, Ontario.

It was concluded, that it was possible to classify land cover types using MICROPIPS, but only at a general level. Thus, it was not feasible to classify vegetation on a fine scale.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1 Purpose of the Study

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. In many respects, remote sensing can be thought of as a reading process. Through the use of various sensors, data are remotely collected so that they may be analyzed to obtain information about the objects, areas, or phenomena that is under investigation.

For several decades, remotely sensed data have been used to study various aspects of the enviroment. Initially aerial photography was used, but with the advent of satellite technology, remote sensing from space has become the primary method employed by the remote senser.

Probably no combination of two technologies has generated more interest and application over a wider range of disciplines than the merger of remote sensing and space technology. Although many aspects of the process are still in the infancy stage, satellite remote sensing has become part of the day to day routine of those involved in earth resource management. All of this has happened in a very short period of time and the status of remote sensing from space continues to change as new/or improved spacecraft are put into orbit (Lillesand and Kiefer, 1979). Since remote sensing from space is such a valuable tool in the area of earth resource management, it is thus also a valuable tool for the mapping of land cover/use.

It is the aim of this thesis to address the mapping of landcover using remote sensing. More specifically this thesis will be concerned with the feasibility of using LANDSAT Thematic Mapper (TM) data and digital processing of these data in order to produce a fine scale vegetation classification for the lands of the Royal Botanical Gardens, Hamilton, Ontario. The final product obtained from the image processing will then be compared to a detailed botanical survey and airphoto classification produced by the Royal Botanical Gardens. From this comparison it will be possible to determine the feasibility of using LANDSAT-TM data for detailed classification of mixed deciduous vegetation in southern Ontario.

1.2 Study Area

The area chosen for the study is the lands belonging to the Royal Botanical Gardens in Hamilton, Ontario (Figure 1.1-1.4). The lands include both well drained uplands and marshy lowlands. The uplands are divided into three separate regions, these being, Rock Chapel, Berry Property, and Hendrie Valley. The marshy lowlands area is comprised of the north and south shores of Cootes Paradise Marsh.

Rock Chapel is approximately 72 ha in area and is located on and below the Niagara Escarpment. This region is comprised of 3 adjacent lots. The main lot is separated from the southernmost "L" shaped lot by a hydro cut, and from the northern most lot by Borer's Glen. Approximately half of the land on top of the

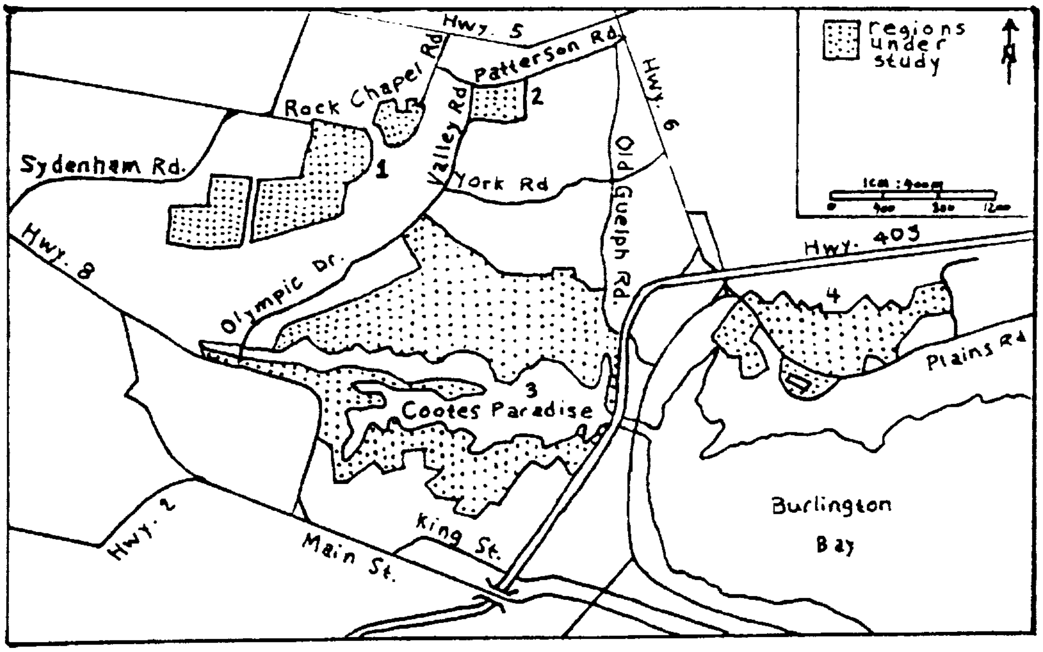


Figure 1.1: Study area. Lands of the R.B.G. 1-Rock Chapel, 2-Berry Property, 3-north and south shore of Cootes Paradise, 4-Hendrie Valley (R.B.G. trail guide, 1986).

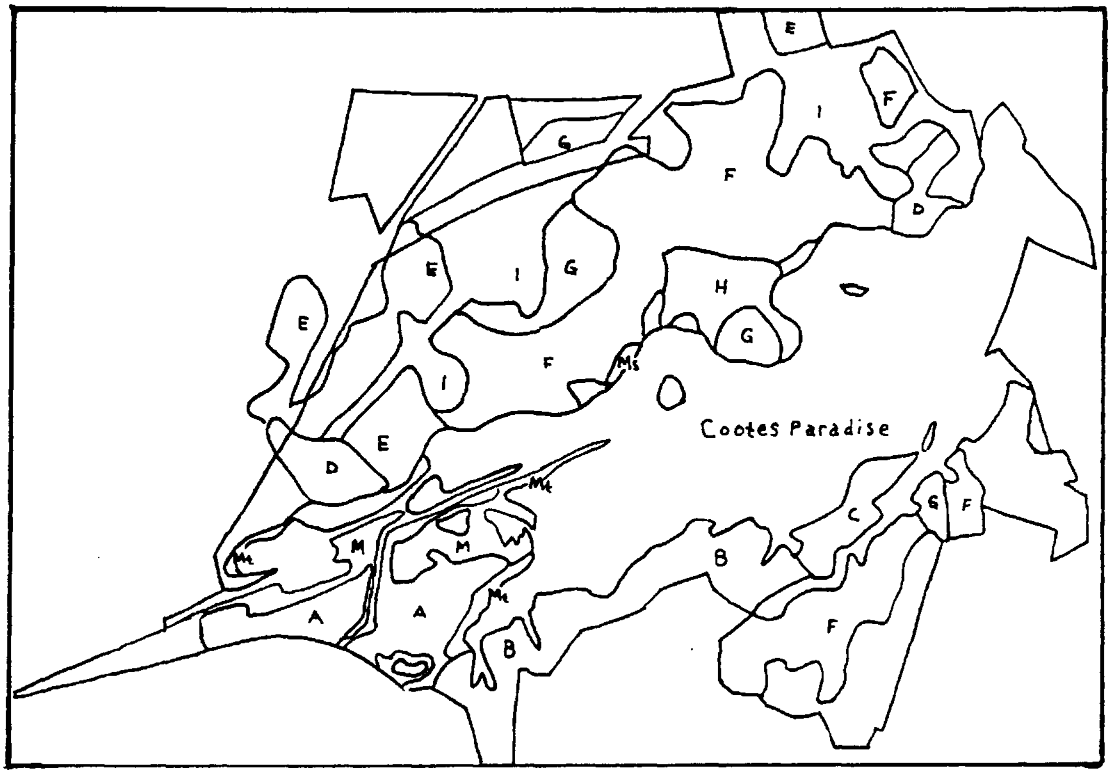


Figure 1.2: Vegetation zones - Cootes Paradise, (R.B.G. vegetation zone map, 1986).

A - Floodplain forest
B - Uplands forest; mixed deciduous woods
C - Sassafrass forest
D - Moist woods
E - Reforestation
F - Mature mixed forest
G - Secondary succession; hawthorn and shrub
H - Deciduous forest
I - Mown grass or weed field
M - Marsh
Ms- Marsh; sagitteria dominant
Mt- Marsh; typha dominant

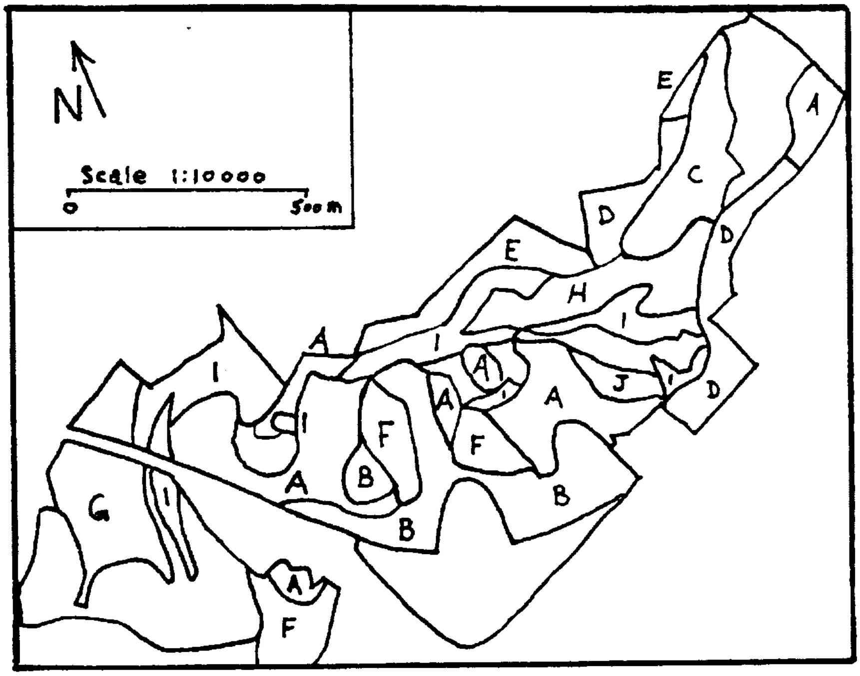


Figure 1.3: Vegetation zones - Hendrie Valley, (R.B.G. vegetation zone map, 1986).

A - Mixed deciduous forest
B - Mown field
C - Flood plain meadow
D - Maple woods
E - Cleared forest
F - Moist, open woods
G - Cleared areas
H - Floodplain forest
I - Marsh
J - Swampy woods

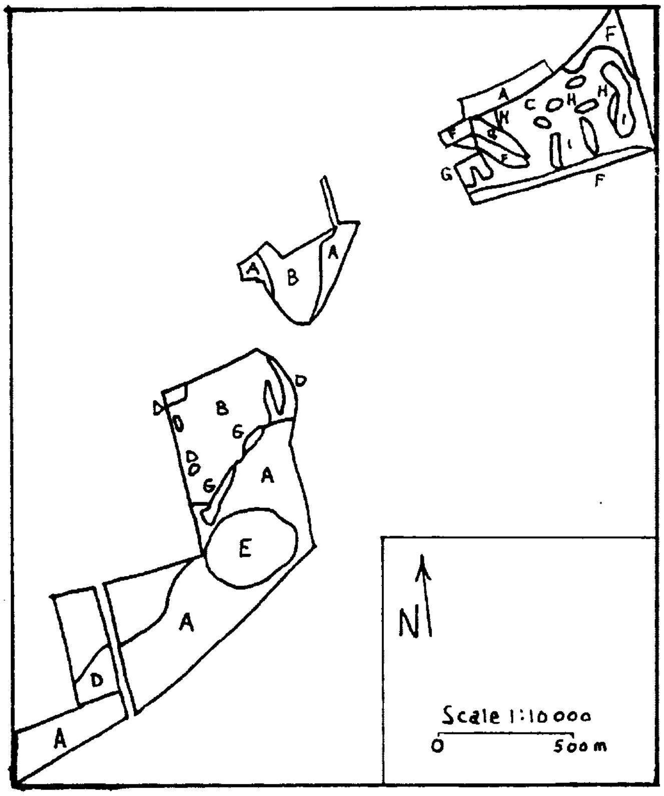


Figure 1.4: Vegetation zones - Rock Chapel and Berry Property, (R.B.G. vegetation zone map, 1986).

A - Mixed deciduous forest
B - Mown field
C - Old field succession - Hawthorn
D - Cut-over woods, planted woods
E - Cleared sugarbush
F - Forest and Hawthorn transition
G - Old field succession
H - Wet meadow
I - Hawthorn thickets

escarpment is used for agriculture, and about 1/4 of the rest is mown fields. The main vegetation zones here are, mown fields, mixed deciduous forest, with Quercus rubra (red oak), Quercus alba (white oak), Betula papyrifera (white birch), Prunus serotina (Black cherry), Pinus strobus (white pine), and Acer saccharum (sugar maple) being the most common, cut over woods, and cleared sugarbush (R.B.G. report,1986).

Berry property is a former pasture that is bounded by hardwood forest/mixed deciduous forest, (Solidago species, Geum canadense, Rubus occidentalis, Pyrus malus, Fraxinus pennsylvanica (red ash) and F. americana (white ash), Ulmus americana (american elm) and U. rubra (red elm), and Juglans nigra (black walnut) present) to the north and west. Farmland borders the property to the east and south. The property is transversed by two ravines that are lined with Hawthorn thickets (Crataegus species). The majority of the area is in some stage of old field succession with grasses being the dominant plant along with Hawthorn thickets. There is also a transition zone between the deciduous forest border and the former pasture area(R.B.G. report,1986).

Hendrie Valley is approximately 80 ha in area and has a great diversity of habitats. Deciduous forest, almost exclusively Acer saccharum, occupies the majority of the valley slopes. With Pinus strobus, Tsuga canadensis (eastern hemloch), Prunus serotina, and Corylus cornuta frequently present. As well, Quercus rubra is dominant on the steepest slopes. In the lowlands and around ravines the dominant vegetation is moist open woods, where Acer negundo (manitoba maple) and Fraxinus (ash) species are dominant. There is a heterogenous tract of swampy woods along the southwest edge of South Pasture swamp, where Lythrum salicaria represents approximately 50 % of the cover, and the valley floor consists of marsh and floodplain. The floodplain is subdivided into two separate zones, floodplain meadow in the eastern end of the valley, and, in the central region, it is floodplain forest. Acer negundo, Fraxinus species, Ulmus americana and U. rubra, Juglans nigra and J. cinerea (white walnut), and Populus deltoides (eastern cottonwood popular) comprise the forest (R.B.G. report,1986).

As mentioned above, Cootes Paradise Marsh is divided into two separate zones, the north and south shores. These regions together cover a total area of nearly 800 ha of forest, field and marsh. The different vegetation zones found within these two regions are, floodplain forest (Salix (willow) species, Acer negundo dominant), mixed deciduous forest (Quercus rubra and Q. alba, Prunus serotina, Acer saccharium present), sassafrass forest (Sassafrass albidium), moist woods, reforestation, mature mixed forest, secondary succession (hawthorne-Crataegus species and shrub), mown grass (weed field), and marsh (R.B.G. report,1986).

1.3 Data Acquisition and Interpretation Characteristics of Remote Sensing

The detection of electromagnetic energy is the essential process involved in the application of remote sensing. The detection can be performed either photographically or electronically. Photographic systems offer many advantages: they are relatively simple and inexpensive and provide a high degree of spatial detail and geometric integrity. Electronic sensors generate an electric signal that corresponds to the energy variations in the original scene. Although considerably more complex and expensive than photographic systems, electronic sensors offer the advantages of a broader spectral range of sensitivity, improved calibration potential, and the ability to electronically transmit data (Lillesand and Kiefer,1979).

In remote sensing, the term image is used for any pictorial representation of image data, whereas, photograph refers to images that were detected as well as recorded on film. Thus all photographs are images because the term image relates to any pictorial product. Not all images, however, are photographs.

Data interpretation of remote sensing can involve analysis of pictorial (image) and/or digital data. Visual interpretation has long been the basic method of remote sensing. Visual techniques make use of the brain's ability to qualitatively evaluate spatial patterns in a scene. Visual intrepretation techniques have certain disadvantages, however, in that they require extensive training and are labour intensive. In addition, spectral characteristics are not always fully evaluated in visual interpretation efforts. In applications where spectral patterns are highly informative, it is therefore preferable to analyze digital rather than pictorial data (Sabins,1978).

The basic character of digital image data is actually composed of a two-dimensional array of discrete picture elements or pixels. The intensity of each pixel corresponds to the "brightness" or radiance measured electronically over the ground area corresponding to each pixel. Within each pixel there is a digital number which corresponds to the average radiance measured within the corresponding pixel. These values are simply positive intergers that result from quantizing the original electrical signal from the sensor into positive integer values using a process called analog-to-digital signal conversion. Usually, the digital numbers constituting a digital image are recorded over such numerical ranges as, 0 to 63, 0 to 127, 0 to 255, 0 to 511, or 0 to 1023. These ranges represent the set of integers that can be recorded using 6,7,8,9,10-bit binary computer coding scales, respectively. In such numerical formats, the image data can easily analyzed with the use of a computer (Sabins,1978).

The use of computer assisted analysis techniques allows the spectral patterns in remote sensing data to be more fuuly examined. It also permits the data analysis process to be largely automated, providing cost advantages over visual interpretation techniques. However, computers are somewhat limited in their ability to evaluate spatial patterns. Therefore, visual and numerical techniques are complementary in nature, and consideration must be given to which approach best suits the particular application (Lillesand and Kiefer,1979).

1.4 Orbital and Sensor Characteristics of Landsat TM

LANDSAT-4 and -5 were launched into repetitive, circular, sun-synchronous, near-polar orbits at an altitude of 705 km. The lower orbits, as compared to the first generation Landsat missions, 1-2-3, were chosen to aid in the improvement of the ground resolution of the sensors aboard. The orbits have an inclination angle of 98.2 degrees (8.2 degrees from normal) with respect to the equator. The satellite crosses the equator on the north-south portion of each orbit at 9:45 A.M. local sun time. Each orbit takes approximately 99 minutes, with just over 14.5 orbits being completed in one day. Due to the earth's rotation, there is approximately 2752 km distance between ground tracks for consecutive orbits, at the equator. Thus this orbit results in a 16 day repeat cycle for each satellite, as well the time interval between adjacent coverage tracks of the same satellite is 7 days (Harris,1987).

The TM is a highly advanced multispectral scanner incorporating a number of spectral, radiometric, and geometric design improvements relative to earlier types of scanners, such the LANDSAT Multi-Spectral Scanner (MSS), also available on LANDSAT-4 and-5. TM was designed specifically for classification of land-cover types, particularly vegetation discrimination. The spectral bands sense in a range from 0.45 um to 12.5 um wavelength and were chosen to take advantage of distinctive characteristics of the of the spectral response of vegetation (Table 1.1). Also, each TM image covers a ground area of 185 x 185 km.

The improvements incorporated in TM over the MSS are, an increase in the number of spectral bands, from 4 to 7 (a blue visible light band and an additional infrared band now included), and an improvement in spatial resolution, from 79m x 79m to 30m x

TABLE 1.1 Thematic Mapper Spectral Bands

Band	Wavelength (μm)	Nominal spectral location	Principal applications
1	0.45–0.52	Blue	Designed for water body penetration, making it useful for coastal water mapping. Also useful for soil/vegetation discrimination, forest type mapping, and cultural feature identification.
2	0.52–0.60	Green	Designed to measure green reflectance peak of vegetation (Figure 1.10) for vegetation discrimination and vigor assessment. Also useful for cultural feature identification.
3	0.63–0.69	Red	Designed to sense in a chlorophyll absorption region (Figure 1.10) aiding in plant species differentiation. Also useful for cultural feature identification.
4	0.76–0.90	Near-infrared	Useful for determining vegetation types, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination.
5	1.55–1.75	Mid-infrared	Indicative of vegetation moisture content and soil moisture. Also useful for differentiation of snow from clouds.
6[a]	10.4–12.5	Thermal infrared	Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping applications.
7[a]	2.08–2.35	Mid-infrared	Useful for discrimination of mineral and rock types. Also sensitive to vegetation moisture content.

[a] Bands 6 and 7 are out of wavelength sequence because band 7 was added to the TM late in the original system design process.

(from Lillesand and Kiefer, 1979, p. 567)

30m, except for the thermal band (band 6), which has a resolution of 125m x 125m. Also, there was an increase in the number of dectectors to record data, from six in each of the previous four bands used to 16 for all non-thermal bands and four detectors for the thermal band, thus a total of 100 detectors (Harris,1987). Therefore, the result is an overall improvement in image interpretation and classification.

1.5 Previous Studies Using LANDSAT TM Data For Vegetation Classification

The LANDSAT Multispectral Scanner (MSS) has proved to be useful for land-cover classification, although it suffers from many first-generation disadvantages. The second-generation LANDSAT Thematic Mapper (TM) was designed specifically to categorize land-cover types, incorprating the improved Thematic Mapper characteristics; these being (1) increased 30 m spatial resolution, (2) higher radiometric resolution and (3) several spectral bands featuring better placement in the spectrum and inclusion of the middle and thermal infrared regions (Salomonson et al. 1980). There has been detailed studies of LANDSAT-4 TM data undertaken by a number of authors. For example, effects of the various TM improvements on classification accuracy have been investigated by Williams et al. (1984), Toll (1984), Irons et al. (1985) and Toll (1985). These studies revealed that the improved spatial and radiometric characteristics of the Thematic Mapper increased the classification accuracy, but that the improved spatial resolution decreased the classification accuracy and that this had the largest effect. Anuta et al. (1984) also studied the dimensionality of the Thematic Mapper data using principal compoment analysis and showed that the spectral separability of Thematic Mapper was twice as high as that of Multispectral data.

There has been much research done on simulated Thematic Mapper data which concluded that the Thematic Mapper bands will offer significant improvements over the Multispectral Scanner in the classification accuracy of vegetative-cover types. Those who support this conclusion are, Dottavio and Williams (1982), Teillet et al. (1981), and Spanner et al. (1984).

The LANDSAT TM sensor is well suited for vegetation monitoring, as shown by Tucker (1978) and Salomonson et al. (1980). Spectral bands were specifically selected that are sensitive to chlorphyll and other leaf pigment absorption (visible reflectance, bands 1,2 and 3), green biomass (near-infrared reflectance, band 4), leaf and soil water content (mid-infrared reflectance, bands 5 and 7), and surface temperature (thermal emissivity, band 6).

Much ongoing research is concerned with the application of LANDSAT TM for fine scale landscape classification. Many researchers have used LANDSAT data in mapping natural resources (forests) and landscape classification (Franklin 1986, Ioka and Koda 1986). Many investigations using Thematic Mapper data in forested and other vegetated areas have examined the dimensionality of the spectral data and sought the best subset of bands or band transforms for discriminating cover types (Anuta et al. 1984, Berstein et al. 1984, Crist and Cicone 1984, Nelson et al. 1984, Toll 1984, 1985, and Spanner et al. 1984). The optimum choice of bands for discriminating coniferous vegetation is data dependent; in some cases band 4 was found to be important (Spanner et al. 1984, Benson and DeGloria 1985), while others in the mid-infrared ranges (bands 5 and 7) or the thermal range (band 6) were found to be more important (Nelson et al. 1984, DeGloria 1984).

The above mentioned studies were aimed at classifying or identifying discrete objects (forest stands) larger than a pixel, at some implicit categoric resolution. Investigations of the relationship of forest cover or density to reflectance and of the reflectance characteristics of other types of vegetation with incomplete canopy closure (Robinove et al. 1981) indicate that when vegeatative cover is incomplete, the strongest spectral signal is the soil or understory brightness, modified by the amount of canopy covering it.

Thus, there is a lot of ongoing research as to the applicability of Thematic Mapper data in the area of land use/cover mapping, and from the evidence sighted it would seem to suggest that the future seems rather bright for Thematic Mapper in this respect.

CHAPTER 2

METHOD OF ANALYSIS

2.1 Introduction

The purpose of this chapter is to describe and explain the analytic procedures used in this study. The analysis involved two major aspects. The first step in the analysis was ground truthing and the second step was the actual digital image processing. Both of these steps will be outlined, in greater detail, in this chapter.

2.2 Ground Truth

Rarely is remote sensing employed without the use of some form of reference data. The acqusition of reference data involves collecting measurements or observations about the objects, areas, or phenomena that are being remotely sensed. These data can take on any number of different forms and may be derived from a number of sources. For example, the data required for a particular analysis might be derived from topographic maps, a previous classification study, or even aerial photographs. They may also come from a "field check" on the identity, extent, and condition of land uses and vegetation types. Thus reference data are often referred to by the term ground truth.

This term is not meant literally, since many forms of reference data are not collected on the ground and they can only approximate the truth of actual ground conditions. Reference data is thus used to serve any or all of the following purposes:

(1) to aid in the analysis and interpretation of remotely sensed data (2) to calibrate a sensor (3) to verify information extracted from remote sensing data (Lillesand and Kiefer,1979).

The reference data collected for this particular study consists of time-critical measurements, that is, measurements made in cases where ground conditions change rapidly with time, such as in the analysis of vegetation. The actual steps involved in the ground truthing for this investigation consisted of reviewing Royal Botanical Gardens (R.B.G.) vegetation zone maps, topographic maps of the Hamilton area and visiting the sites that are under investigation. Reviewing the R.B.G. maps and topographic maps allows the investigator to become familiar with the different types of vegetation within each region as well as the varying topography, and thus one knows what to expect when a "field check" becomes necessary.

The next step in the ground truthing process was the "field check." The sites visited were, the north and south shore of Cootes Paradise, Rock Chapel, Hendrie Valley and Berry Property. Visual information was collected at each of these sites. The types of visual information collected consisited of a comparison between what was on the R.B.G. and topographic maps to what was actually found in the field. As well, visual information was collected about the degree of canopy closure of the forest stand, size of the various stands within each vegetation zone, transition boundaries between different vegetation, density of the stands and the amount of underbrush within the various stands. As well, any differences or discrepancies between the maps and the field observations were noted.

2.3 Digital Image Processing

Once all the ground truthing had been completed, digital processing of the TM image for the region was conducted.

The image for this study was obtained from LANDSAT-5 (TM) data taken on September 20, 1985. The satellite imagery was chosen on the basis of time of year, cloud free images and the availability of such images for the Hamilton region. The image selected was one that proved to be the best possible image, in terms of clarity, for this time of year. It was necessary to obtain an image this late in the season, for in order for an investigation such as this to be successful, the vegetation must be in full canopy and thus the maximum spectral reflectance is possible.

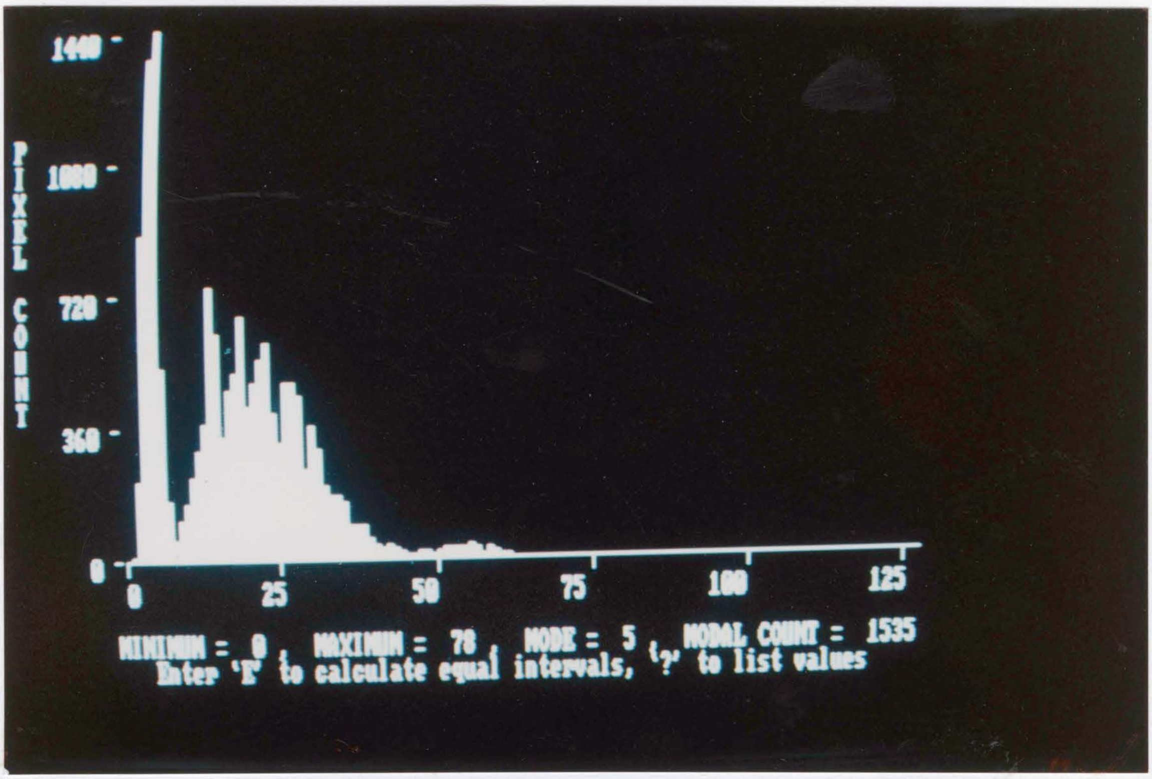
In order to process the data obtained from LANDSAT TM it was necessary to run the data through an image processing system. The system used for this study was called MICROPIPS 1.0, by the Telesys Group, Inc. of Columbia, Maryland. Micropips is an interactive image processing system designed expressively for the IBM-PC microcomputer. The focus of MICROPIPS centres on the analysis and classification of LANDSAT digital images. The MICROPIPS system allows for the transformation of image data into digital information through the direct use of the computer. The input data may be a "raw" image, a corrected image or an enhanced image, in any case the results of the image analysis are displayed as maps showing the regional extent of spectral classes of the various vegetation types. Due to the computer memory limitations of the IBM-PC, MICROPIPS can only analyse 1/4 of a full LANDSAT TM image. This is sufficient for the analysis of the R.B.G. lands.

The first step in the image analysis was to subset a scene. The purpose of this was to extract a portion of the larger original image for analysis. The larger original image is only 1/4 the size of a full LANDSAT image, due to the memory limitations mentioned above. The sub-area represents a region of the earth's surface that is approximately 5km x 3km. The sub-area selected for this study was centred on Cootes Paradise and adjacent R.B.G. lands. Once a sub-area was determined, the data collected by all the sensing bands of the satellite was transferred to a separate "data" disk and thus ready for analysis.

Next, the image data, from the "data" disk, was loaded into the computer's memory in order to begin the colour mapping and display of the subsetted image. The frequency distribution of the data set was a very important source of information for displaying an image. For it was necessary to know what values the data set had before thresholds (class limits) and colour codes could be assigned. Thus it was necessary for the computer to produce a histogram of the data collected in each band and then evaluate it. A histogram is a display of statistics about a data set such that all possible values are arranged in order along one axis of a graph. Along the other axis a line is drawn for each actual value; the line corresponds to the number of occurrences of that particular value in the data set. The x-axis on this graph is the spectral reflectance. Each pixel, in the data set, has a number representing spectral reflectance for each band of electro-magnetic energy. Values range from 0 - 255. The resulting graph displays the frequency structure of the data set. Figure 2.1 is an example of a histogram.

The evaluation of the histogram consisted of dividing it up into several different sections based on the selection of threshold values. The division into sections was achieved by examining the histogram and determining the data set value of each low spot in the histogram. The low spots were assumed to be a natural boundary within the data set and were thus chosen for that reason. The values selected were then used as the mapping limits (threshold values) for the different divisions (categories) determined from the evaluation. The entire process of histogram evaluation is known as density slicing.

Once the density slicing had been performed it was then possible to select colour for each category determined during the histogram evaluation. The MICROPIPS program produced a graphics display which contained 16 colours from which each category was assigned a colour. The number of colours assigned to each data set was dependent on the number of categories each corresponding histogram was divided into. The result was a colour coded display of the sub-image for each sensing band.



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MINIMUM = 0 , MAXIMUM = 78 , MODE = 5 , MODAL COUNT = 1535
Enter 'E' to calculate equal intervals, '?' to list values
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figure 2.1: Histogram of TM band 6 data showing all pixel counts within the image falling between 0 and 78.

The next step involved the selection of a training area. The process involved in this step was very similar to the subset a scene section mentioned above, except a even smaller su-area was chosen from the first sub-area. The subset represents a region of the earth's surface that is approximately 3km x 2km. The subset selected for this portion of the investigation was centred on Cootes Paradise. More specifically, it was centred on the many vegetation zones found on the north and south shore of Cootes Paradise. Thus, this entire process is known as subsetting a subset. Once this was complete the next step was to select a sample of picture elements (pixels) from the subset of a subset. Sample pixels are selected for each type of ground cover class that is in the image. The ground cover types were those presented on the R.B.G. maps initially. Ground cover types that were selected were, open water, vegetation, marsh, cultural featurs and fields. The selection was done by moving the cursor through the image and sampling from 50 or more "points" within each of the land cover classes. Thus, this section of the processing is known as signature training, for each of the samples taken from the different landcover regions are referred to as spectral signatures for each are different, just like human signatures.

With the creation of spectral signatures, it was then possible to manipulate these signatures in order to obtain results by use of statistical data rather than image data. Manipulations involved the displaying of an existing signature, listing all the signatures as one table, but most importantly a plot of two signatures against one another was possible. This plot is referred to as a graphic signature comparison. The plot was achieved by using a two-dimensional graphics display for vector space. The plot was then evaluated by noting the physical location and relationships among the various spectral signatures.

One final manipulation that was just as important as the graphic signature comparison was a mathematical signature comparison. The computer calculated one number that permitted a comparison based upon all spectral bands available. This number is called a "distance". The calculation was performed for each pair of spectral signatures and was repeated for every possible pair of spectral signatures. In two dimensions, the distance is, $C = [A1 - A2] + [B1 - B2]$. All of the calculated numbers are displayed in a "distance matrix". The distance matrix was then evaluated by determining which spectral signatures are closer than some minimum distance.

The last step in the image processing is the classification mapping. Classification mapping is a digital image processing procedure that uses the computer directly to find patterns in the image data. The procedure locates and identifies all pixels meeting the requirements of the classification procedure used.

MICROPIPS uses the parallelpiped (PPD) classification procedure. Basically, this procedure uses the upper and lower digital number limits for each spectral signature, determined in the signature training section. If a pixel from the image to be classified has values, in each band, that are below the upper limit and above the lower limit for that band, then the pixel is accepted as belonging to that category.

Multiple passes, of the PPD classification procedure, through the input image was necessary in order for pixels unable to be classified on one pass, to eventually be classified. These passes are called iterations. The upper and lower limits of the digital numbers were widened, with each iteration, so that the acceptance thresholds included a larger range of numbers, and thus the eventual classification of all pixels. With the classification complete, the next step involved producing a colour image. This was done by the density slicing (histogram evaluation) method, as outlined above.

Further processing techniques were applied to the image and this involved the creation of synthetic images. The synthetic images were the result of the combination of several of the bands. Thus the new bands became a ratio of all those combined. This resulted in a combination of all spectral signatures and thus produced images that would have been impossible to create by analyzing with single bands only. The creation of synthetic bands involved the difference between two bands, the sum of two bands and finally the ratio between the two newly created bands. The bands used in the synthetic image creation were ones that were expected to produce the best results in terms of vegetation discrimination (Lillesand and Kiefer).

2.4 Conclusion

In this chapter, the methodology used for this investigation was outlined in an overall, general manner. As for the actual application of these data methods, they will be examined in the subsequent chapter. From the information presented above it can be stated that the most important of the two data methods was in fact that dealing with the image processing. Although, the ground truthing was an essential tool in order to familiarize the remote senser with the investigation at hand.

CHAPTER 3

DISCUSSION OF RESULTS

3.1 Introduction

The purpose of this chapter is to present and discuss the results obtained from the image processing, as outlined in the previous chapter. This chapter will investigate the results of all the bands used for this study, as well as the synthetic bands created and the final classified image. The majority of the results discussed will focus on the Cootes Paradise study region. The other regions of the R.B.G. will be discussed in terms of their classified image only, for their classification was the result of applying spectral signatures obtained from the Cootes Paradise region to their various landcover classes.

3.2 Thematic Mapper Band Imaging

Separate images were created for each of the bands, of the electromagnetic spectrum, in which the Thematic Mapper sensed. These bands are bands one through seven, as listed in table 1.1. For this investigation, band six (thermal infrared) was not used for it was considered to be of no value for the classification of vegetation, for these regions. Thus, bands one through five remain the same but band seven is now referred to as band 6. All the images created, for each of the bands, were done by the density slicing method.

The image created for band 1 (blue visible light) (Figure 3.1) shows very little in terms of classification of different

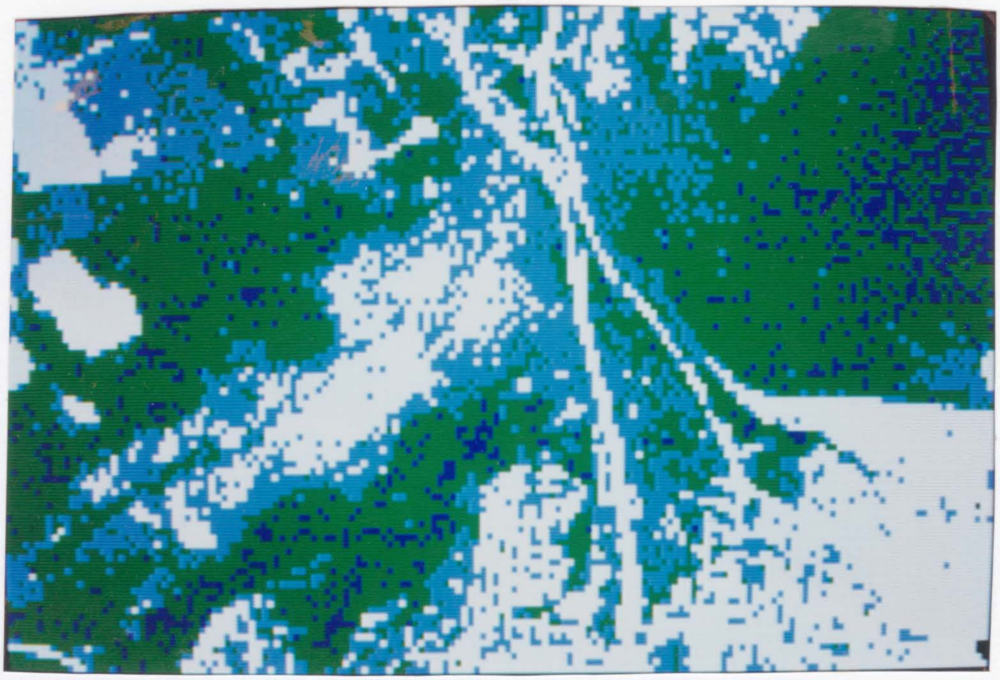

Figure 3.1: TM band 1 image created for the Cootes Paradise study area. For explanation of image, see text.

Green: forest and deep water
Dark blue: deep water and forest
Light blue: shallow water and cultural features
White: fields and cultural features

vegetation types, but it does display the general extent of the forest region around Cootes Paradise. This is represented by the green sections on the north and south shore of Cootes Paradise. Other than the forest vegetation, band 1 only identifies one other vegetation region, that being fields, which are represented by the white regions to the extreme left of the image. White also represents the majority of the cultural features.

As can be seen from this image, many landcover classes have been identified as having the same spectral response and thus the reason for a majority of landcover classes being coloured the same. The reason for this is that this band is very useful for cultural feature identification and thus some cultural features and natural features are interpreted as having the same spectral response and therefore classified as being the same. The same is true for Burlington Bay, for most of it has been classified as having the same spectral response as the forest regions around Cootes Paradise. Shallow water and cultural features have also been classified as being similar. Both are represented by the light blue colour.

The image created from band 2 (green visible light) (Figure 3.2) shows a better job of classification than did band one. An extra vegetation type has been classified in this region and it is represented by the green. The majority of the green corresponds with regions of marshy land. There is still a problem of similar classification of different landcover types however, and this is evident from the dark blue colour, which represents

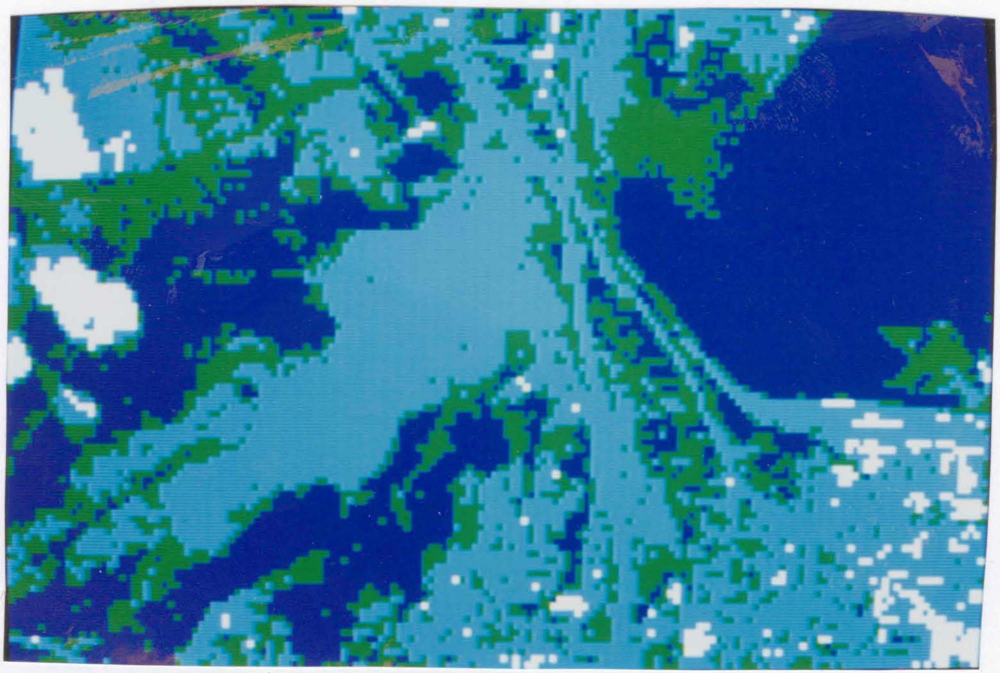

Figure 3.2: TM band 2 image created for the Cootes Paradise study area. for explanation of image, see text.

Green: marsh
Dark blue: forest and deep water
Light blue: shallow water and cultural features
White: fields

both forest vegetation and Burlington Bay. Cultural features and Cootes Paradise were also classified the same and are represented by light blue. Fields, represented by white, were now virtually separated from cultural features.

The image created from band 3 (red visible light) (Figure 3.3) revealed similar information as did the image of band two, but with a few changes. The main difference between the two bands was the extensive cultural landcover in the bottom right of the image. Also, the centre of Cootes Paradise was classified as if it were a cultural feature. This was most likely the result of sediment in the water. As for the rest of Cootes Paradise, it was largely separated from the cultural features that it had been classified with in the previous bands. It is represented by light blue. The major problem of forest vegetation and Burlington Bay classified as similar landcover classes was not solved by this band.

Band 4 (near infrared) produced an image (Figure 3.4) that did not reveal too much in terms of vegetation classification. This was due to the fact that this bands' main application is for the delineation of water bodies. This can be seen by the dark blue of Burlington Bay (deep water) and the light blue of Cootes paradise (shallow water), as well as the sharp coastlines. The major aspect of this band was the fact that the forest vegetation, of the north and south shore of Cootes Paradise, had been classified differently from Burlington Bay. Another aspect of this band was the classification of the

Figure 3.3 Legend

Dark blue: deep water and forest

Green: marsh and other vegetation

Yellow: cultural features and water sediment

Brown: fields and cultural features

Light blue: shallow water and cultural features

Figure 3.4 Legend

Yellow: fields and cultural features

Dark blue: deep water

Light blue: shallow water

Green: vegetation

Brown: marsh

Orange: marsh and fields

Pink: marsh and fields

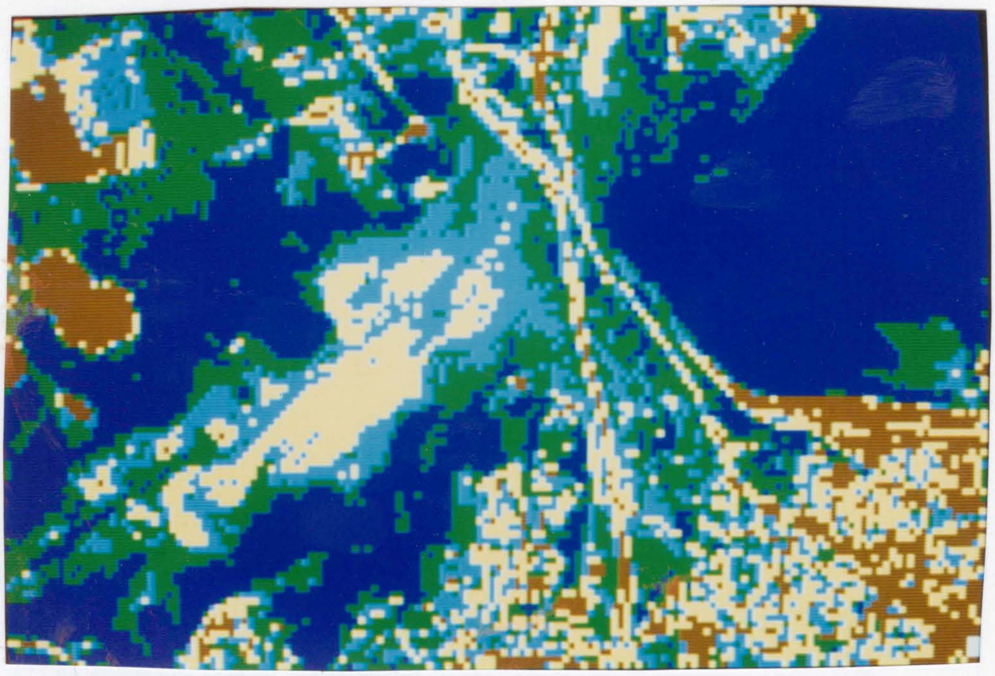

Figure 3.3: TM band 3 image created for Cootes Paradise study area. For expalnation of image, see text.

Figure 3.4: TM band 4 image created for Cootes Paradise study area. for explanation of image, see text.

different types of marsh land in the bottom left corner of the image, represented here by pink, orange and white. Once again several different landcover types were classified as being the same. An example of this is the various types of marsh land and some fields to the top of the image.

The image produced from band 5 (mid-infrared) (Figure 3.5) revealed the extent fields and/or mown grass, indicated by the colour yellow. As well, the distribution of marsh land was also revealed, as indicated by the green colour. The rest of the image was coloured purple due to the fact that this band is indicative of vegetation moisture content and soil moisture. Thus, any regions where the forest canopy was thick it was impossible to determine landcover on the basis of moisture. The same was true for the classification of the cultural features, therefore the result was a similar classification for both cultural regions and forest vegetation.

The image created for band 6 (mid-infrared) (Figure 3.6) was by far the best image created, from any of the Thematic Mapper bands, in terms of vegetation classification and in the number of different vegetation types classified. The full extent of the forest vegetation of the north and south shore of Cootes Paradise was determined, represented by the green. Marsh land was also represented fairly well by the colours brown and purple, in the bottom left of the image. As well, marsh land was classified within the forest vegetation of both the north and south shore. Fields and/or mown grass regions were also classified in this

Figure 3.5 Legend

Purple: vegetation and cultural features

Blue: water

Yellow: fields

Green: marsh

Brown: marsh and vegetation

Figure 3.6 Legend

Purple: marsh and vegetation

Brown: marsh and cultural features

White: field and cultural features

Green: forest

Blue: water

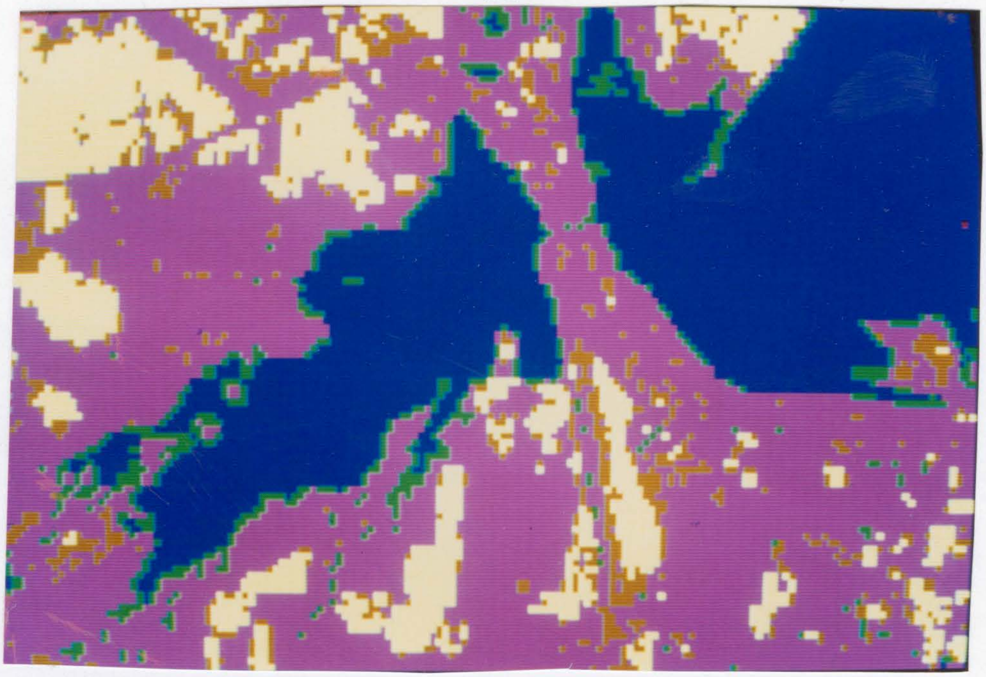

Figure 3.5: TM band 5 image created for Cootes Paradise study area. For explanation of image, see text.

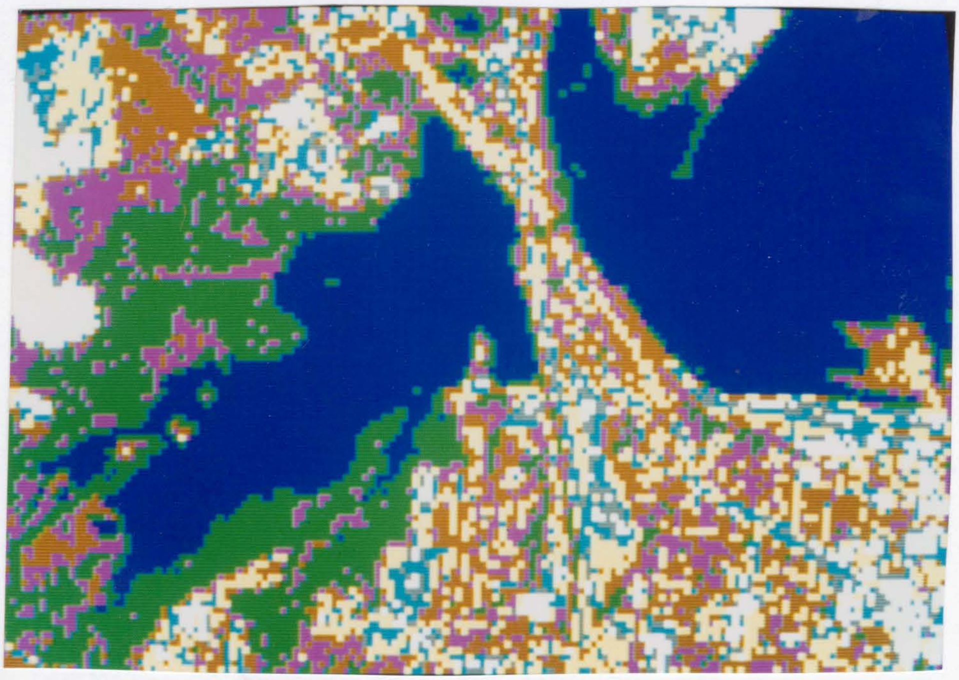

Figure 3.6: Tm band 6 image created for Cootes Paradise study are. For explanation of image see text.

band and they were located to the extreme left of the image and represented by white. Once again various landcover classes had been classified as being the same and this was a result of similar spectral responses of the landcover type.

The final images created were synthetic images and they became bands 7 (Figure 3.7) and 8 (figure 3.8). Band 7 was created by obtaining the difference between digital values of band 4 (near infrared) and band 3 (red visible light), whereas band 8 was the sum of these same two bands. The image for band 7 and band 8 revealed basically the same degree of classification, if not poorer, that resulted from band 6, except for the classification of fields was of better quality in band 8 and they were represented by the colour white. Basically, the classification of the landcover types did not remain constant between the different bands and thus resulted in certain bands being better able to classify particular landcovers, while others were next to useless.

3.3 Spectral Signature Evaluation

Once a sample of picture elements (pixels) had been selected from the subset of the subset, for each of the landcover types as mentioned above, it was then possible to evaluate this set of spectral signatures. Spectral signatures had been collected using the Cootes Paradise image and then applied to the other R.B.G. lands under investigation in this study. The reason for using this method was that the samples obtained from Cootes Paradise were expected to represent a much larger number of

Figure 3.7 Legend

Brown: fields and cultural features

Yellow: fields and marsh

White: fields and marsh

Red: cultural features

Blue: water

Purple: marsh and vegetation

Figure 3.8 Legend

Dark green: forest vegetation

Light green: forest vegetation

White: fields

Yellow: marsh

Brown: vegetation and cultural features

Blue: water

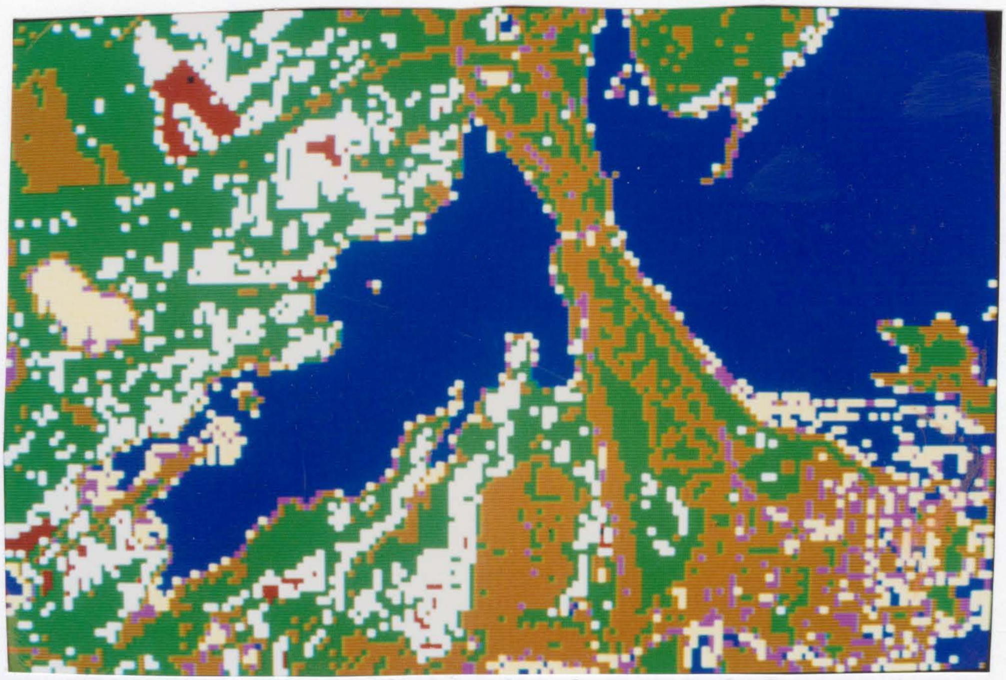

Figure 3.7: TM synthetic band created for Cootes Paradise study area. For explantion of image, see text.

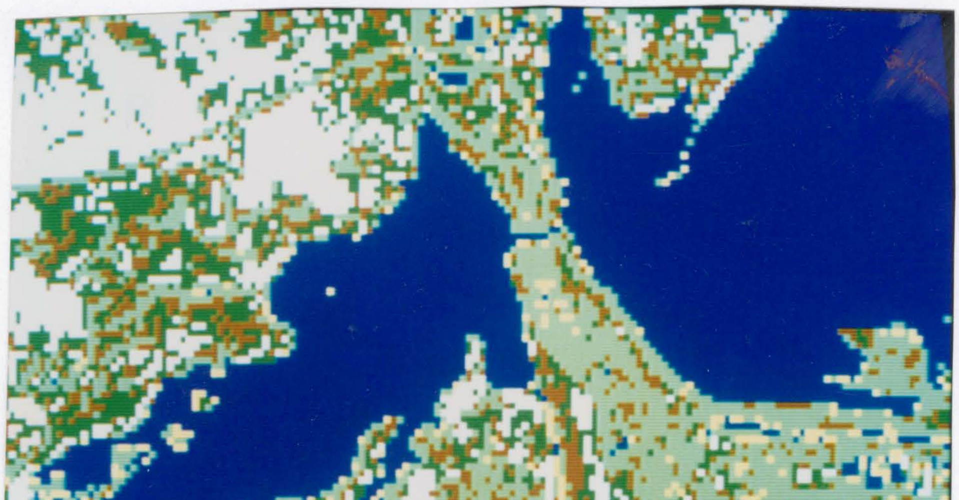

Figure 3.8: Synthetic band created for Cootes Paradise study area. For explanation of image, see text.

pixels that had the same characteristics. Table 3.1 represents the spectral signatures collected over the Cootes Paradise region.

Two methods were employed in order to evaluate the spectral signatures collected, they were, the use of a mathematical signature comparison or distance matrix and a graphic signature comparison. The distance matrix (Table 3.2) shows the statistical separation between category spectral response patterns for all the signature classes. The divergence between the category means was the method used for the evaluation of this matrix. The larger the divergence, the greater the mathematical distance between training patterns and the higher the probability of correct classification of classes. By examining Table 3.2 it can be seen that some of the signatures for the different categories have relatively small divergence and thus have little statistical distance between the training patterns. As a result, those with the smallest distances have been incorrectly classified. Table 3.3 lists those categories that had a low probability of being classified correctly. The main reason for certain categories having small statistical distances between them is that they exhibit spectral over lap. What this means is that the categories listed against one another, in table 3.3, are spectrally similar and thus have been classified by the computer as being the same landcover type. That is the reason why some vegetation types were coloured the same as certain cultural features in some of the images.

Table 3.1 Spectral signatures collected during the training stage for Cootes Paradise

		fields	cootes	marsh.1	veg.1	res.1	res.2	veg.2	res.3
1	min	80	75	70	70	72	74	71	73
1	avg	90	81	75	73	81	82	79	79
1	max	95	85	81	79	88	90	88	87
2	min	34	30	27	26	29	30	29	30
2	avg	41	36	31	28	35	35	33	34
2	max	46	37	38	34	40	40	40	39
3	min	31	25	22	21	26	27	24	26
3	avg	47	32	26	23	32	35	32	33
3	max	54	36	33	31	42	45	42	47
4	min	49	18	41	28	40	48	34	46
4	avg	58	21	69	58	64	63	65	74
4	max	81	30	102	78	88	86	101	88
5	min	75	4	43	15	45	53	34	54
5	avg	89	8	56	41	66	73	60	85
5	max	106	12	66	52	90	94	79	102
6	min	41	2	17	10	26	30	21	33
6	avg	51	4	19	13	27	31	24	34
6	max	59	7	20	16	29	32	25	35
7	min	34	6	60	34	41	46	39	44
7	avg	62	13	139	120	107	108	114	137
7	max	155	48	217	166	178	176	210	180
8	min	108	24	70	43	74	83	62	88
8	avg	123	38	104	85	104	112	105	121
8	max	150	54	158	116	140	138	159	138

TABLE 3.2 Divergence matrix used to evaluate training class spectral separability

Signature*	1	2	3	4	5	6	7	8
1	0	328	218	236	147	124	167	146
2	328	0	320	258	285	308	289	372
3	218	320	0	78	71	94	51	82
4	236	258	78	0	101	122	83	156
5	147	285	71	101	0	25	22	87
6	124	308	94	122	25	0	43	70
7	167	289	51	83	22	43	0	85
8	146	372	82	156	87	70	85	0

* 1-fields, 2-cootes, 3-marsh.1, 4-veg.1, 5-res.1, 6-res.2, 7-veg.2, 8-res.3.

TABLE 3.3 Minimum distances between signature values

from Signature	to Signature	Distance
5	7	22
5	6	25
6	7	43
3	7	51
6	8	70
3	5	71
3	4	78
3	8	82
4	7	83
5	8	87

The graphic signature comparison (Figures 3.9 and 3.10) reveal the success of classifying the spectral signature categories in terms of the different bands. Figure 3.9 shows band 6 plotted against band 4. What this plot reveals is that band 6 is very good for classifying the different categories, for there is no overlap of categories in this band. Band four, on the other hand reveals poor classifying capabilities for there is a lot of overlap of the different categories. Figure 3.10 is another plot, but with band 5 against band 4. What this plot reveals is that both bands were unsuccessful in classifing the different categories because of the tremendous overlap occurring. It was discovered, through the plotting of all the bands against one another, that only band 6 was successful in classifing the different categories, for it was the only band that did not result in the overlap of spectral categories.

3.4 Final Image Classification

Figures 3.11 through 3.13 represent the final classified image for the regions of Cootes Paradise, Hendrie Valley and Rock Chapel and Berry Property, respectively, using bands 1 - 8. Only eight bands were used because the parallelpiped classifier can only classifiy a maximum of eight bands.

Figure 3.11 shows the extent of the forest vegetation, dark green, marsh land, light green and brown, and fields, yellow and white. This image does not differ much from the image created for band 6, for both reveal the same extents of the various vegetation types and cultural identification. Therefore, this

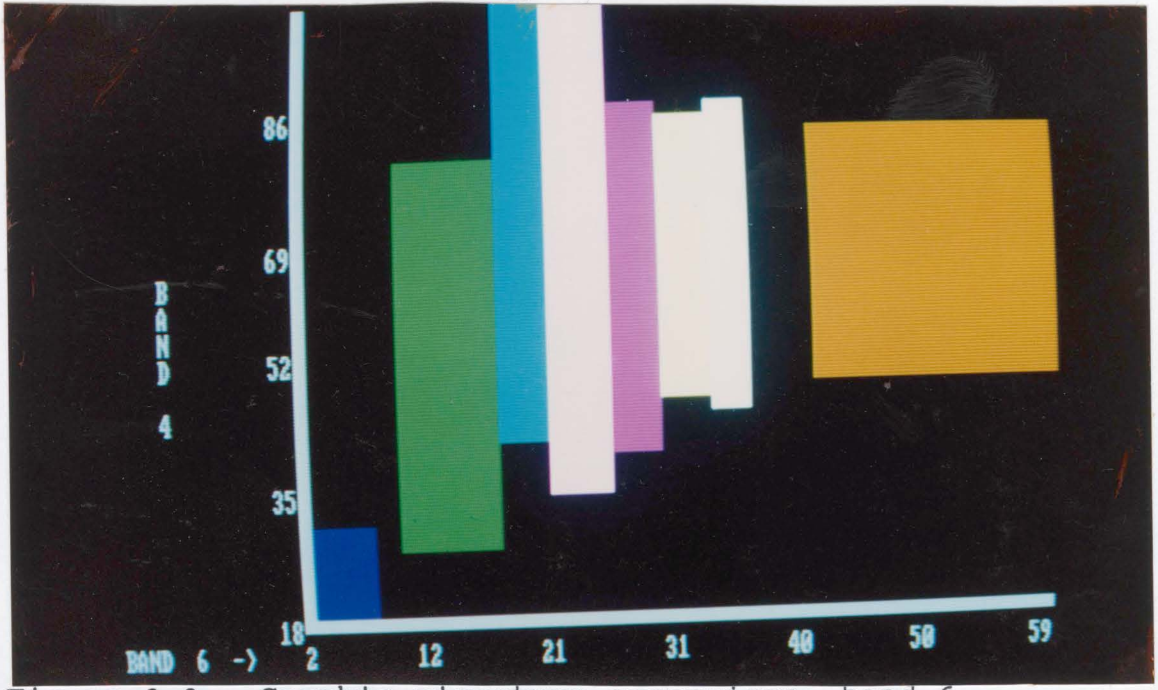

Figure 3.9: Graphic signature comparison, band 6 vs. band 4. Signature categories: dark blue-cootes, green-veg.1, light blue-marsh.1, purple-res.1, yellow-res.2, white-res.3, gold-fields, pink-veg.2.

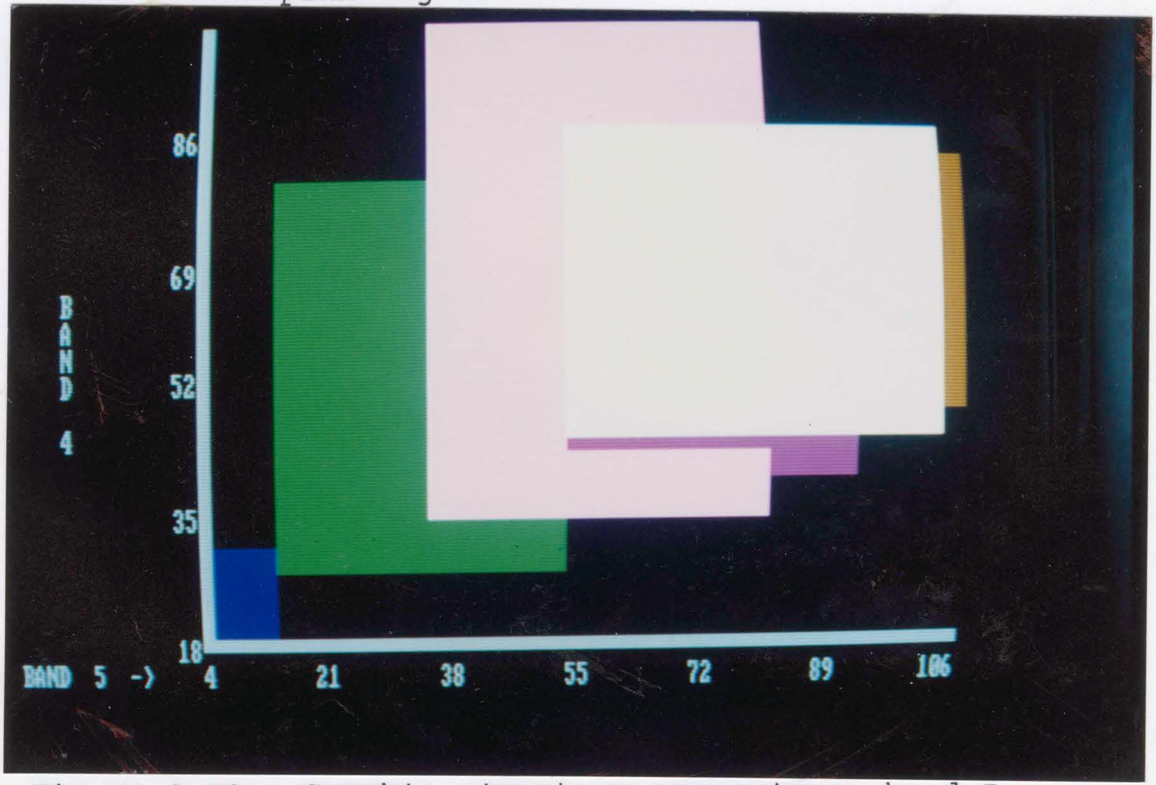

Figure 3.10: Graphic signature comparison, band 5 vs. band 4. See figure 3.9 for colours.

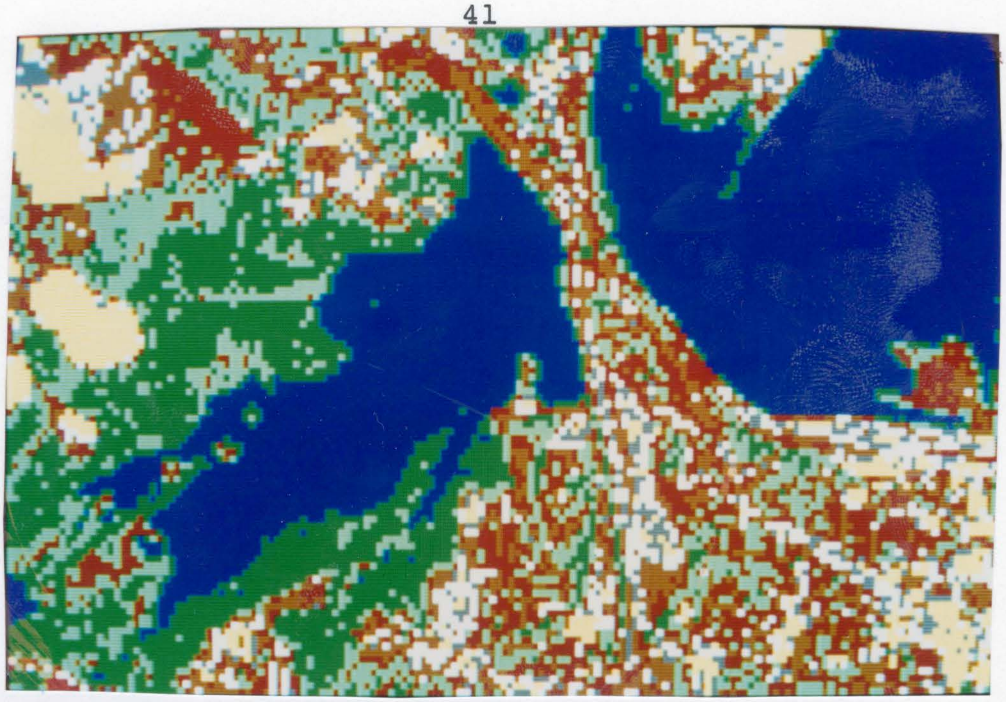

Figure 3.11: Final classified image, of Cootes Paradise study area, produced using the parallelpiped classifier.

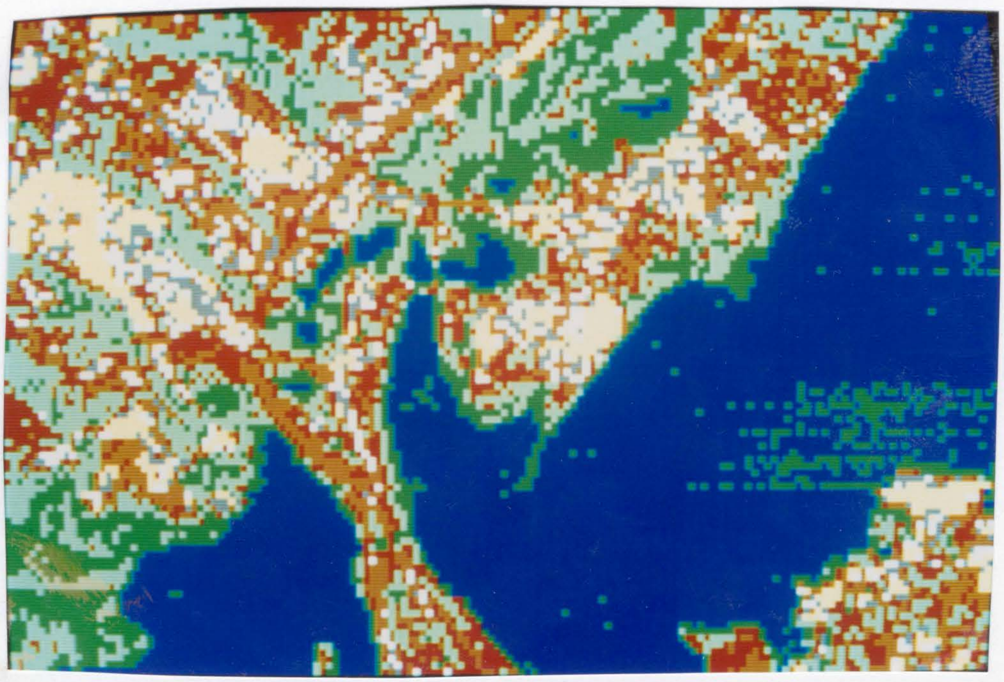

Figure 3.12: Final classified image, of Hendrie Valley study area, produced using the parallelpiped classifier.

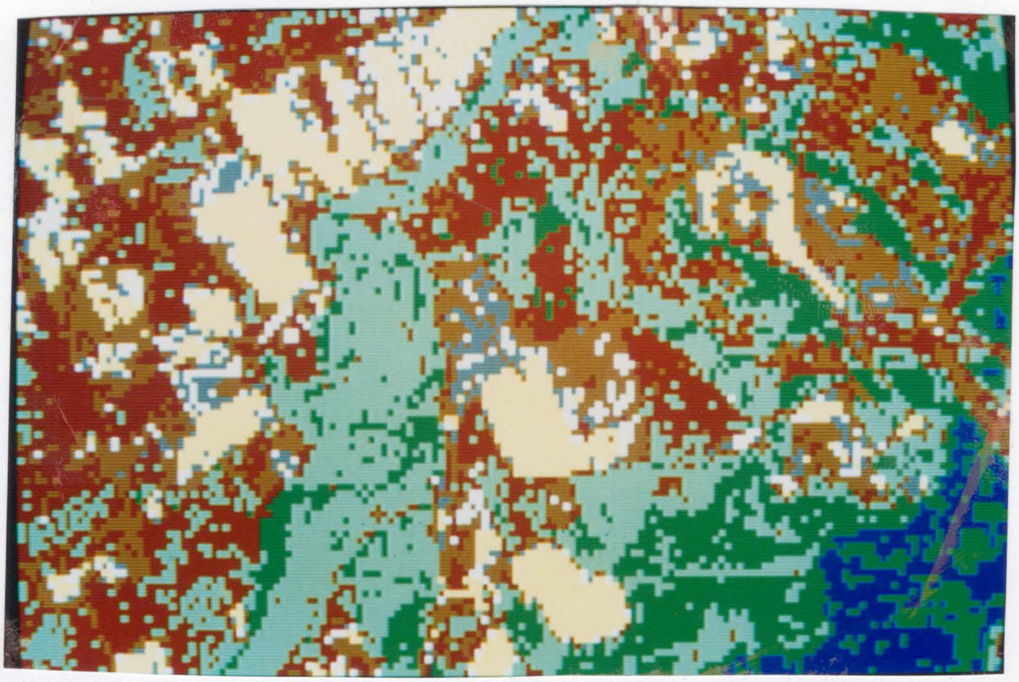

Figure 3.13: Final classified image, of Rock Chapel and Berry Property study areas, produced using the parallelpiped classifier.

Dark green:	vegetation
Light green:	forest
Yellow:	fields and mown grass
White:	fields
Dark brown:	cultural features
Light brown:	cultural features

shows that band 6 is the most important of the sensing bands and that all the others could be deleted, for they are useless.

Figure 3.12 shows the Hendrie Valley region (centre of the image). This image does not reveal much of the extent of the classification of various vegetation types, but it does classify a few. Those that are classified include forest vegetation (dark green), and some marsh land with flood plain forest (light green). Other than these, the classified image of Hendrie Valley was unable to classify any other vegetation type, as outlined in the R.B.G. classification.

Figure 3.13 is the final classified image for the lands of Rock Chapel and Berry Property. This image was also very poor in classifing the various vegetation zones and could only classify forest vegetation, represented by the light green strip in the centre of the image. Although it appears that some marsh land may be represented in this image, possibly by the dark green colour in the centre of the forest vegetation.

3.5 Conclusion

In this chapter, the results of the image processing were presented and discussed. From the information presented it can be concluded that the final classified images for both Hendrie Valley and Rock Chapel and Berry Property were very poor in terms of the vegetation types classified. The image for Cootes Paradise, on the other hand, revealed a greater classification potential and was thus by far the better of the classified images. Conclusions as to why things occurred the way they did will be presented in the subsequent chapter.

CHAPTER 4

SUMMARY AND CONCLUSIONS

4.1 Summary

An investigation to determine the feasibility of using LANDSAT TM data for fine scale vegetation classification in southern Ontario has been carried out for the lands of the Royal Botanical Gardens, of Hamilton, Ontario.

Before the analysis was undertaken, a "field check" was conducted to investigate the types and extent of the vegetation found in each of the regions. This served as background analysis in order to familiarize the investigator with the data being analyzed.

Digital classification was carried out using an IBM-PC with an image processing program, MICROPIPS 1.0. The final classified image was the result of evaluating the spectral signatures of each land cover category and then applying the parallelepiped classification method.

The final stage in the analysis was to compare the images created from this investigation with the vegetation zones maps of the Royal Botanical Gardens (figures 1.2, 1.3, and 1.4). The purpose of this comparison was to determine the level of vegetation classification obtained from the LANDSAT TM analysis.

4.2 Conclusions

It can be concluded, from this investigation, that LANDSAT TM data, with the assistance of MICROPIPS 1.0, can be used for land cover/ use mapping, with a relatively high accuracy at a general level of classification. This can be seen by examining the images created. It can also be concluded that, at a more detailed level of classification, such as that in figures 1.2 - 1.4, the accuracy decreases substantially. The extent of vegetation classification remained at a general level, such as the extent of forest vegetation, marsh land, fields and water. It was hoped that the various stands within the forest vegetation would be classified, as it had been in figures 1.2 - 1.4.

The application of spectral signatures from Cootes Paradise study region to Hendrie Valley, Rock Chapel and Berry Property was determined to be insufficient for a proper classification of land cover for these regions. Thus, it can be concluded, that in order to produce a correctly classified image it is necessry to obtain sample pixels, and their reultant spectral signatures, from each separate region being analyzed and not to apply them to other regions having similar land cover classes.

One problem encountered during this investigation was the classification of different land cover types as being similar. This was the due to the similarity of the spectral signatures of these land cover types. Thus, it can be concluded that ground truthing is an important part of an investigation of this type, for without doing so the investigator may not realize the misclassification of some of the land cover types.

Finally, it is concluded that using LANDSAT TM data is not feasible for fine scale vegetation classification for the regions investigated, as outlined in this study.

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