LANDSAT AND AIRBORNE RADAR FOR

LAND COVER/USE MAPPING AND CHANGE DETECTION

IN SOUTHERN ONTARIO

by

© EMIL BOASSON

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ABSTRACT

Several remote sensing systems have been evaluated to determine their capabilities for providing land cover/use information. The systems studied were LANDSAT Multispectral Scanner (MSS) visual and digital data, LANDSAT Return Beam Vidicon (RBV) imagery and Synthetic Aperture Radar (SAR) imagery. Standard panchromatic aerial photography provided the ground information against which the imagery was evaluated. The study was carried out in the Hamilton-Wentworth Region of southern Ontario.

The visual data were analyzed using transparencies in a Zoom Transfer Scope to produce a land cover/use map at a scale of 1:50,000. The digital data were preprocessed using the Digital Image Correction System (DICS) at the Canada Centre for Remote Sensing. Land cover/use maps were produced from the data using both a maximum likelihood classifier and a parallelepiped classifier.

It was found that the visual data gave a higher classification accuracy than the digital data. With an increasing number of classes, the accuracy of classification decreases.

Using LANDSAT data from two dates, several digital enhancements were tested for their change detection capability. The overlay of Band 5 data from both dates, combined to give a colour image, was the most effective way to identify areas of change.

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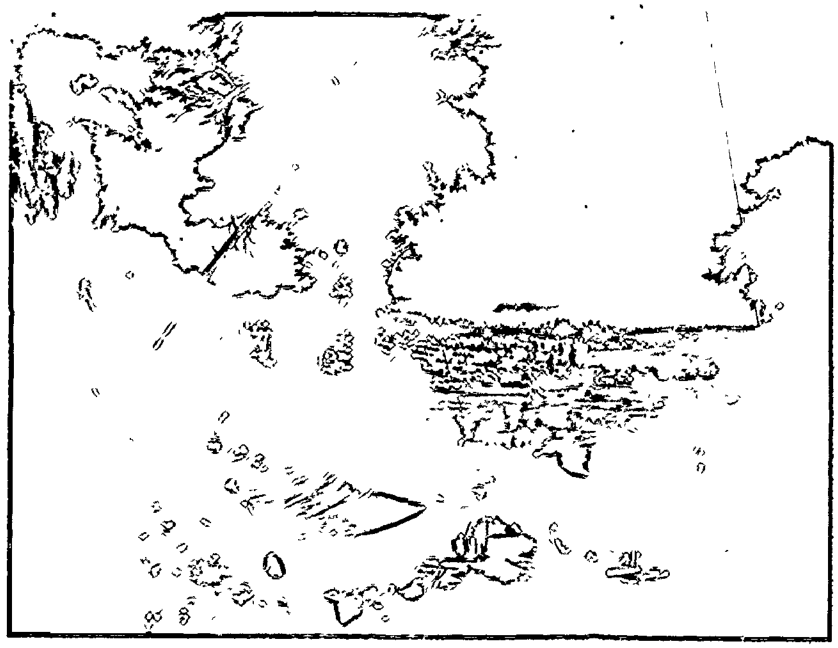

Whale, Robert (1805-1887) "General View of Hamilton", 1853.

Oil on canvas - 90.8 cm x 120.7 cm.

(By permission: National Gallery of Canada, Ottawa).

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Last but not least, to my father and family back home in Iceland; "án hvatningar og aðstoðar ykkar, hefði þessu verki aldrei lokið"

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CHAPTER 1

INTRODUCTION

1.1 Purpose of the Study

For several decades, remotely sensed data have been used to study the environment. Initially panchromatic aerial photography was used for this task, but in recent years other types of remote sensing data have become available. In the 1960s colour infrared photography was used for thematic mapping and in the early 1970s satellite data began to be acquired. Now relatively high resolution radar data are available on an experimental basis.

Although panchromatic photography can be used for environmental mapping, there are several problems that can be encountered. The nature of the problems vary depending on whether one is studying a developed or a developing country.

Southern Ontario can be taken as an example of a developed area. Standard provincial photographic coverage is now obtained at a scale of 1:10,000 (previously 1:15,840). To cover an area the size of the Hamilton-Wentworth Region requires approximately 1,000 photographs. In addition to the problems of handling and mapping with that number of photographs, the cost of obtaining the data is high.

Photographic coverage by the federal government is acquired occasionally, but the scale for large area coverage is usually about

1:50,000. At this scale, interpretation of the data on the panchromatic photographs is not always an easy task.

A further problem is that updating of both provincial and federal photography is done infrequently. Provincial coverage is acquired about every ten years, while federal photography is obtained when topographic mapping is needed. For an agency to acquire its own mapping photography is obviously an expensive proposition.

In the less inhabited parts of Canada, aerial photography is infrequently acquired. In developing countries, especially in the equatorial regions, photography is often difficult to obtain and the quality of the images is usually very variable.

For the above reasons, persons concerned with thematic mapping in both developed and developing areas have looked to the newer types of remote sensors to provide data, especially for covering large areas fairly rapidly.

As is human nature, initially many believed that satellite data (especially LANDSAT data) would be able to readily solve problems related to mapping the environment. However, many questions arise when new procedures become available for studies which have previously relied on traditional methods.

One aspect of the environment which has been studied perhaps more than others in many countries is the mapping of land cover/use. In spite of the interest in this topic, there are still a lot of questions to be answered relating to the capabilities of different sensing systems to provide land cover/use information.

There are several problems encountered by persons who wish to acquire land cover/use information. It is the aim in this thesis to address some of these problems and to evaluate the role that the newer sensing systems can play in their solution.

A major problem is obtaining land cover/use information that is up to date. For the urban or regional planner to make valid decisions, it is essential to have up-to-date information. In most cases, however, when the map is finally published, it is already out of date. This applies particularly in urban and urban fringe areas. It is not unusual, especially if dealing with large areas, for the map to contain information that is three to five years old when it is published.

To illustrate this point, maps of the study area that were available when the study was being carried out were several years old. A small scale map (1:250,000) showing the "Predominant Land Use for the Niagara Development Region" was published in 1971. An earlier map showing "Land Use of Southern Ontario" at a scale of 1:1,000,000 was published in 1960.

The most recent large scale (1:50,000) land use maps were published in 1962 and 1963 from data collected in 1960 and earlier. However, the maps only cover the southern part of the study area.

Thus a major question to be asked is:

1. To what extent can remote sensing data help to produce up-to-date land cover/use maps?

Land cover/use is changing constantly and it is important for the urban or regional planner to know the nature and trend of the changes. Given the infrequency with which the land cover/use maps are produced, it is difficult to know the rates of change which aid in understanding the processes involved. Thus, another major question is:

2. To what extent can remotely sensed data be used to detect and map changes in land cover/use?

There is always a tendency to be wary of new sources of information. Thus for the person producing the maps, as well as for the urban or regional planner, it is important to have an assessment of the accuracy of the maps that are being produced from different types of data. Thus a third and final question is:

3. How accurate are maps produced from different types of remote sensing data?

In the present study four types of remote sensing data have been evaluated for their capabilities to provide land/cover use information in both urban and rural areas of southern Ontario. Three of the data sources are acquired from the LANDSAT satellite. Multispectral Scanner (MSS) data from Landsat have been studied in both visu~~al and~~ digital formats. In addition, LANDSAT Return Beam Vidicon (RBV) ~~data~~ in a visual format have been analyzed. The fourth data type is Synthetic Aperture Radar (SAR) data acquired from an aircraft. To aid in the analysis of the data, panchromatic aerial photography at two scales has also been used in the study.

The specific objectives of the study may be summarized as follows:

1. To evaluate the capabilities of four types of remote sensing data for land cover/use mapping at scales of approximately 1:50,000:

a) LANDSAT MSS visual data,

b) LANDSAT MSS digital data,

c) LANDSAT RBV visual data, and

d) SAR imagery.

2. To test methodologies for land cover/use change detection in a complex urban/rural environment using LANDSAT digital data.
3. To compare the accuracies of land cover/use maps produced from the four types of data.
4. To put forward recommendations for using the four types of remote sensing data in land cover/use studies.

1.2 Study Area

The area chosen for study is the Hamilton-Wentworth Region of southern Ontario (Figure 1.1). There are several reasons for making this selection:

1. A wide variety of data sources is available for the study area.
2. Within the study area there is a wide range of land cover/use types from swamp and bush through agricultural land to high density residential and industrial areas.
3. The area is experiencing several types of land use changes.
4. The investigator is not familar with the area and will therefore be relatively unbiased in his analysis of the data.
5. At appropriate stages in the analysis, field data could be relatively easily acquired.

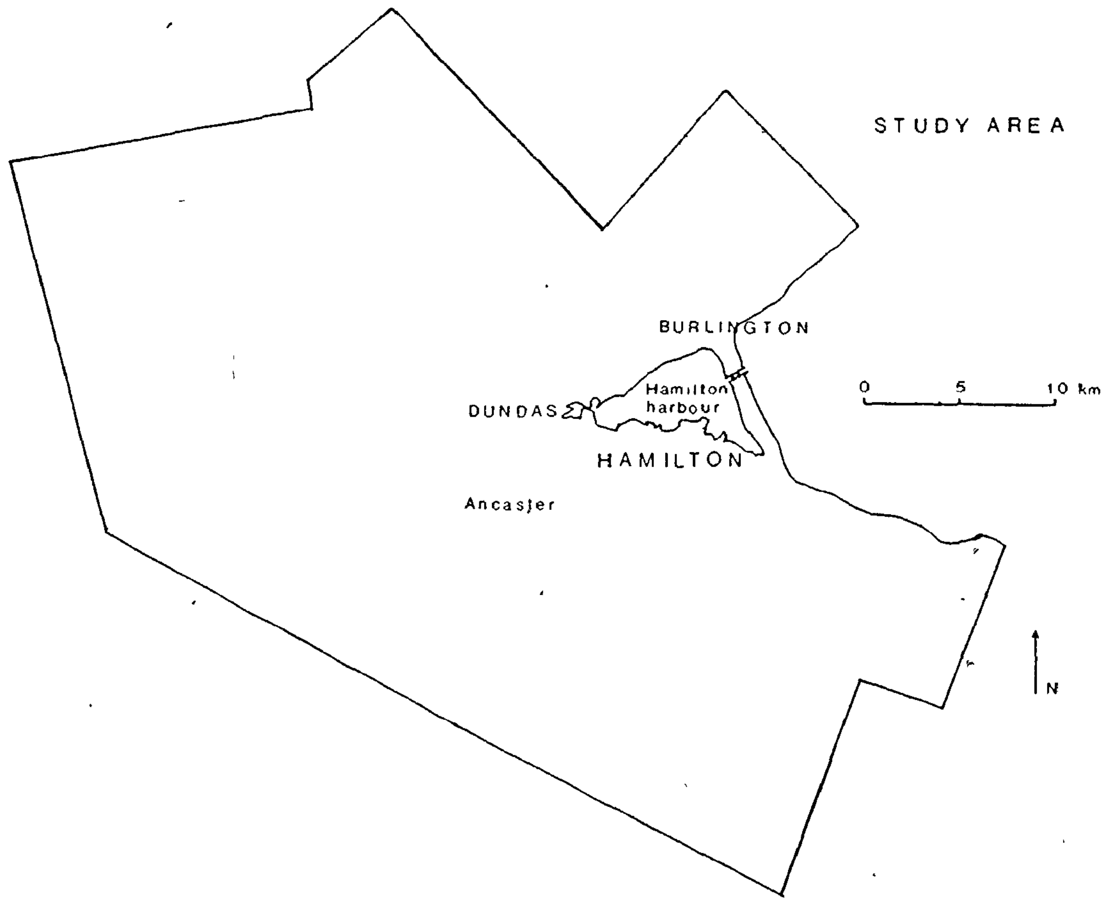


Figure 1.1: The Hamilton-Wentworth Region showing the major cities and towns. Note that part of Burlington is also included in the study area.

The study area is located between 70°37'W and 80°16'W and between 43°03'N and 43°28'N. It covers an area of approximately 1,300 km^2, with maximum dimensions east to west and north to south being 53 km and 46 km respectively.

As discussed later, several test sites within the study areas were selected for detailed analysis.

The study area covers six of the 52 physiographic regions of southern Ontario identified by Chapman and Putnam (1966). The regions are the Niagara Escarpment, the Horseshoe Moraines, the Flamborough Plain, the Norfolk Sand Plain, the Haldimand Clay Plain and the Iroquois Plain. Detailed physiography of the area is illustrated in Figure 1.2

Other than the Niagara Escarpment, the landforms are a result of glacial action (Chapman and Putnam, 1966). The escarpment was "created by the differential erosion of the hard Silurian dolomite and the softer underlaying shales" (Reeds, 1972, p. 4). It forms "the most striking topographic feature of southern Ontario" (Reeds, 1972, p. 3) and divides the study area in two parts. The primarily urbanised and industrial section occupies the area between the shoreline of Lake Ontario and the escarpment, while above the escarpment land cover/use is mainly agricultural and rural. For further details on the physiography of the study area see Chapman and Putnam (1966), especially pages 150-153, 173-188, 198-204, 251-260 and 324-328.

The urbanization of the area goes as far back as the 1790s with Dundas initially as the largest centre. However, Hamilton started to dominate with its selection as a district city in 1816. With "the cutting

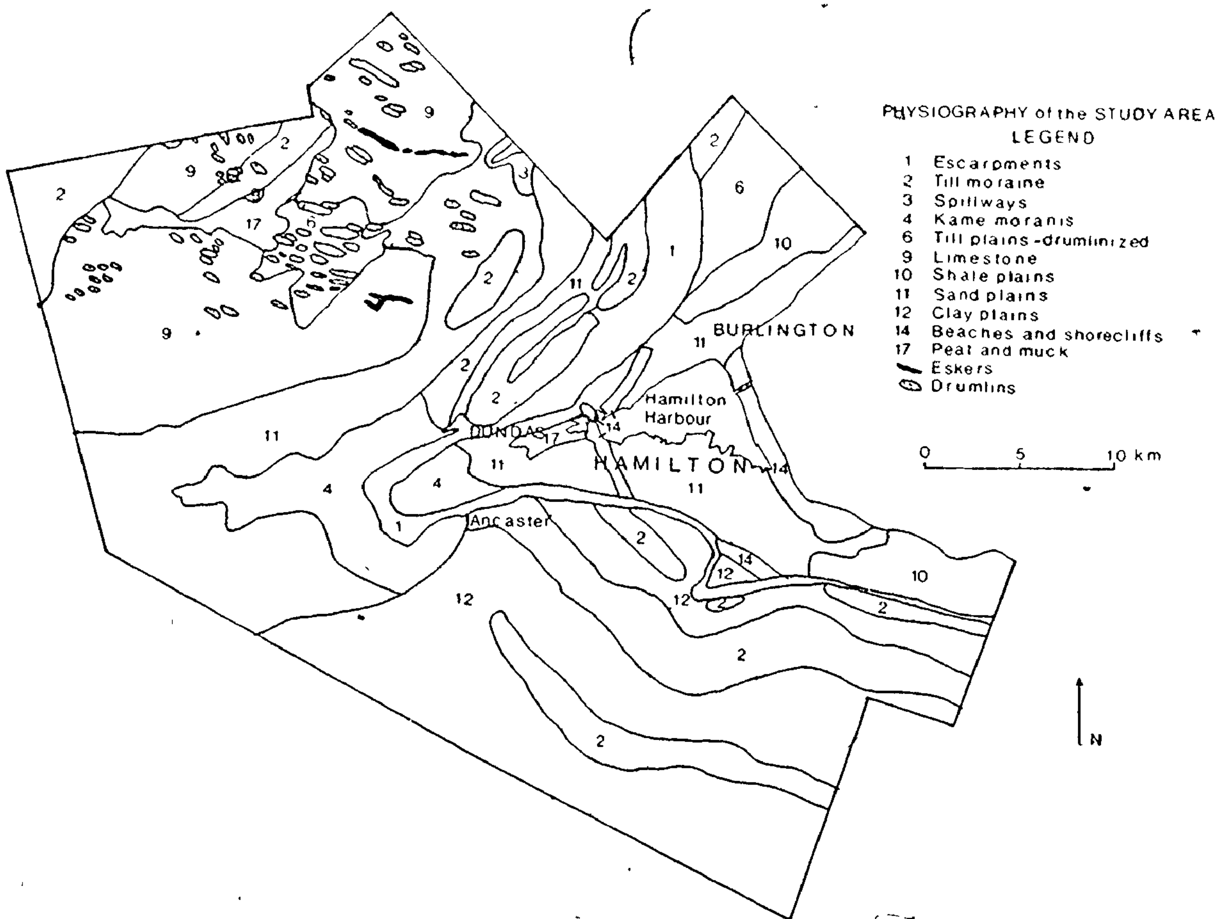


Figure 1.2: Physiographic units in the study area identified by Chapman and Putnam and displayed on Map 2226 of the Ontario Department of Mines (1972).

of a permanent channel through the harbour's outer bar in 1832" (Gentilcore, 1972 p. 32) and with the ensuing construction of the port and the railways, Hamilton became one of the major cities in Ontario, and a population boom followed (Gentilcore, 1972).

Thus, both in terms of its physiography and its land cover/use, the study area displays considerable diversity. Given the variety in the landscape, land cover/use that occurs in other parts of the southern Ontario is likely to be represented in the study area.

1.3 Spectral and Spatial Characteristics of Remote Sensing Data

To use remote sensing data effectively, it is important to be familiar with the electromagnetic spectrum. Each sensor is sensitive to different ranges of wavelength and records energy from the scene being studied in different ways. For example, when panchromatic film is used, the visible (green, blue and red) part of the spectrum is recorded (Figure 1.3). When film sensitive to the near infrared spectrum is used, however, green, red and near infrared are sensed and a different image is recorded. Depending on the environment, the ground characteristics will be recorded on the film as a variety of patterns, tones and textures.

In photography the minimum unit for the recorded area will depend on the scale of the photography, the size of grains in the film and the photographic paper or transparency. When a sensor such as a multispectral scanner (MSS) is used, however, the minimum picture element (usually known as a pixel) depends on the attitude of the sensor and its instantaneous field of view.

Each scanner has detectors which are assigned to record in specific parts of the spectrum. When in operation, the LANDSAT MSS records the reflected responses of the ground objects as a digital value for each pixel. These values are the basis for image production and for manipulation or digital classification of the data.

When radar is used, a somewhat different methodology and understanding applies. Aerial photography and multispectral scanners sense in the visible part of the spectrum or close to it. In the radar system, however, wavelengths in the range 1 mm to 1 m are used (Figure 1.3). Radar is an active sensing system supplying its own source of energy, in contrast to passive systems which only detect the reflected wavelengths from an object. The radar detects the energy which was transmitted by the sensor and was reflected back to the receiver from the ground (Lillesand and Kiefer, 1979).

Thus different sensors will record different types of electromagnetic energy at a variety of resolutions. The imagery produced will thus vary in appearance and in the information it contains. It is the task of the remote sensing specialist to interpret the data and translate them into information to be used in studies of the environment. To do this effectively, it is important to have a good knowledge of the capabilities and limitations of the different types of sensing systems that are available. As indicated earlier, it is an aim in this thesis to assess the capabilities of several new types of data for mapping land cover/use.

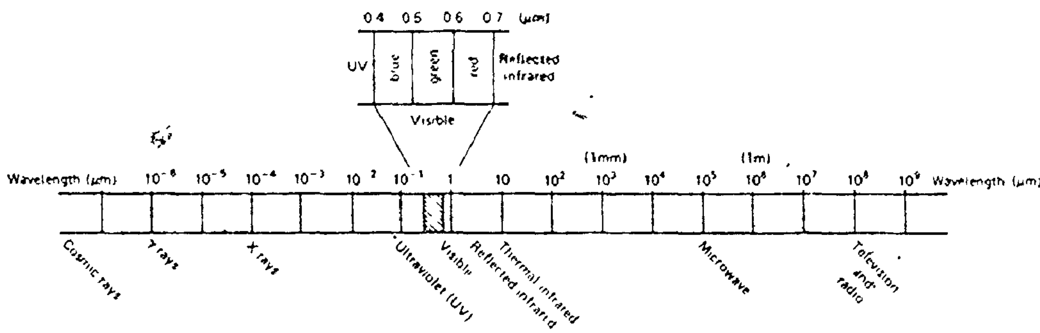


Figure 1.3: The electromagnetic spectrum (from Lillesand and Kiefer, 1979, p. 5).

1.4 Remote Sensing and Land Cover/Use Studies: Some Historical Points

As long as mapping has been carried out, some kind of land cover/use mapping has been undertaken. Nearly all known maps show some of man's activities at a particular point in time.

Remote sensing was introduced in France in the year 1839 when the first usable aerial photographs were taken from kites (Information EMR, 1979). Later balloons were used.

Perhaps the first "Land cover/use map" from aerial photography was made in the year 1862 when two French balloonist took photographs of the defences of Richmond in the U.S.A. From these photographs, maps of the positions of the Confederate forces were produced (Blair and Simpson, 1967).

Land cover/use mapping was developed in several countries. In the U.S.A., land use mapping for specific areas or industries began relatively early e.g. the Bureau of Forest, 1905 . Land utilization studies for the U.S. Department of Agriculture were started under the direction of O.E. Baker in 1912 (Clawson and Stewart, 1965). The progress from then up to the 1940s was slow until the Office of Land Utilization was established in 1940.

In Britain, the Land Utilization Survey was launched under the direction of L.D. Stamp in 1930. By the end of 1932, all counties of England, Scotland and Wales had been organized and surveying was in progress (Buchanan, 1968). This work was carried out by 20,000 volunteers, but aerial photography was not used.

Shortly after the Second World War, land use mapping was started in other countries. Stamp was the ~~spirit behind the work~~ and became the Director of the World Land Use Survey in 1950. East European countries started their land use surveys around the year 1950 (e.g. Poland, Hungary, Germany (P.R.) Soviet Union and Yugoslavia)(In Kostrowicki, ed. 1962). In Canada, the first aerial photography employed in land use studies was in 1937 for a survey of the Neutral Hills and Sullivan Lake Areas and Rosenneim in Alberta (Stewart and Porter, 1942).

After the war, new and improved analysis equipment and new types of film came on the market (e.g. the infrared film). In addition, new sensors such as radar were developed. The first attempt to use radar for land cover/use mapping was in the late 1960s and early 1970s (Moore, 1969; Simpson, 1969; Bryan, 1974 and 1975; Henderson, 1975). Side Looking Airborne Radar (SLAR) was used in this work, but because of military restrictions, only low resolution data were released at this time. All the results showed that the early radar could be effective for land cover/use mapping, but it was not better than existing data sources.

At the beginning of the 1960s, at the start of the so-called Space Age, earth scientists and others interested in environmental studies faced the possibility of sequentially photographing the Earth's surface from space. Orbital and terrain photography experiments were included on the final two Mercury flights in 1962 and 1963. The experiments continued on the Gemini missions in 1965 and 1966 and later in the Apollo program. Among earth resources studies carried out on the photography, land cover/use mapping was undertaken from Apollo 9 photographs in 1969 (Welch et al., 1971; Benson, 1971; Poulton et al., 1971).

Results from the above mentioned missions led finally to the launching of the Earth Resources Technology Satellite (ERTS) in 1972.

It was later renamed LANDSAT and data from this series of satellites are at present the most frequently used source of information for land cover/use mapping of large areas at a small scale.

The characteristics of remotely sensed data have led to some confusion about their suitability for land cover/use studies. Remotely sensed data do provided valuable information about land cover, but land cover does not always correlate directly to its use. The differences in and between covers and uses have made it difficult to come up with a satisfactory classification scheme to be used with remote sensing data. For example, some classification systems are based on the social structure of land holdings and would thus not be suitable for use with remote sensing data (Clawson and Stewart, 1965).

The variety of classification systems developed, as well as the need for standardization in the U.S.A., led to a conference held in 1971 where the problems of land cover/use classification were discussed. A result of the conference was the development of a classification system, for use with remotely sensed data (Anderson et al., 1976). The classification system is at present widely used, directly or as a basis for other classifications (Lairet, 1977; Ryerson, 1980; Ryerson and Gierman, 1975).

CHAPTER 2

METHOD OF ANALYSIS

2.1 Introduction

The purpose of this chapter is to describe and explain the analysis procedure used in this study. Even though a variety of remotely sensed data were used in the study, similar analyses were carried out for each sensor.

The analysis involved mapping land cover/use from imagery, not only from different sensors but also of different scales (from 1:500,000 to 1:10,000) and in different formats (i.e. digital and visual). The process to achieve the aims of the study requires several stages which are outlined in this chapter.

2.2 Data Sources

The remote sensing data used for the study are listed in Table 2.1. Selection of imagery presented few problems. The satellite imagery was chosen on the basis of time of year, cloud free images and the availability of aerial photography recorded at approximately the same time to serve as "ground truth". The imagery was selected using the Image Inventory Search System (IISS) at the Canada Centre for Remote Sensing.

The Landsat imagery was acquired both in visual and digital formats. Figure 2.1 shows the area coverage of one full frame LANDSAT

Table 2.1 Remote Sensing Data used for Land Cover/Use Studies in the Hamilton-Wentworth Region

Date	Image Type	Format	ID No.	Scale
1974-07-06	LANDSAT MSS	CIR-print/transp. CCT	10713-15274 10713-15274	1:500,000
1978-07-12	LANDSAT MSS	CIR-print/transp. CCT	21267-15025 21267-15025	1:500,000
1978-05-28	LANDSAT RBV	B/W transp.	30084-15233	1:500,000
1979-09-26	LANDSAT RBV	B/W transp.	30570-15225	1:500,000
1978-08-02	SAR X_{HH} X_{HV} L_{HH} L_{HV}	B/W print/transp.	F150 P6	~1:42,000
	X_{HH} X_{HV} L_{HH} L_{HV}		F151 P6	1:42,000
1976-06-02	Aerial photograph	B/W print	A-24404/196-205	1:50,000
1976-04-29		B/W print	A-24327/125-129	
1976-04-10			A-24317/47-65 and 125-126	
1978-June			(Total of 975 photos)	1:10,000

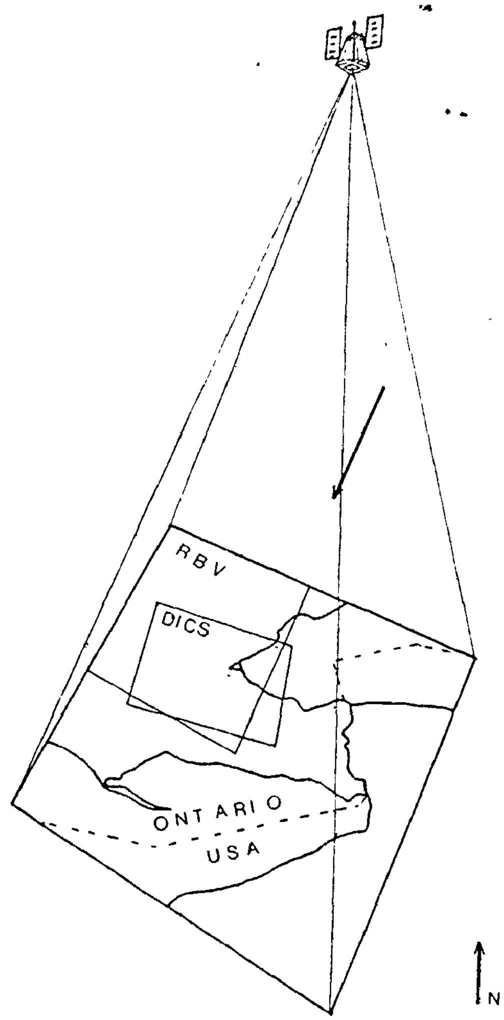


Figure 2.1: The area of coverage for one MSS scene, one RBV scene and the DICS imagery used in this study. The arrow shows the direction of orbit of the spacecraft.

scene of MSS data and also the area covered by an RBV frame. As described later, the digital data were geometrically corrected and reformatted. The area covered by the digital DICS image is also shown in Figure 2.1.

The SAR imagery listed in Table 2.1 is the only radar imagery available and just covers a small portion of the study area (Figure 2.2) As can be seen from Table 2.1, the imagery was recorded from two parts of the spectrum (X-band and L-band) and with two different polarizations (horizontal transmit and receive, HH, and horizontal transmit and vertical receive, HV). Thus there were four images for the same ground area, each displaying slightly different characteristics. The imagery was acquired through the Canada Centre for Remote Sensing.

The aerial photography at 1:50,000 scale was the most recent small scale photography available. It is standard federal photography from the National Air Photo Library in Ottawa. The 1:10,000 scale photography was again the most recent available. It was standard provincial photography from the Ontario Ministry of Natural Resources.

It is important to point out that the 1978 satellite imagery was acquired within one month of the 1:10,000 scale aerial photography. Few land cover/use changes will have occurred between the two dates so they can be considered as complementary.

2.3 Selection of Training Sites and Test Sites

Selection of training sites and test sites were done at the same time. It was decided at the beginning to establish a set of areas for "training" of the data and another set for testing the results of the.

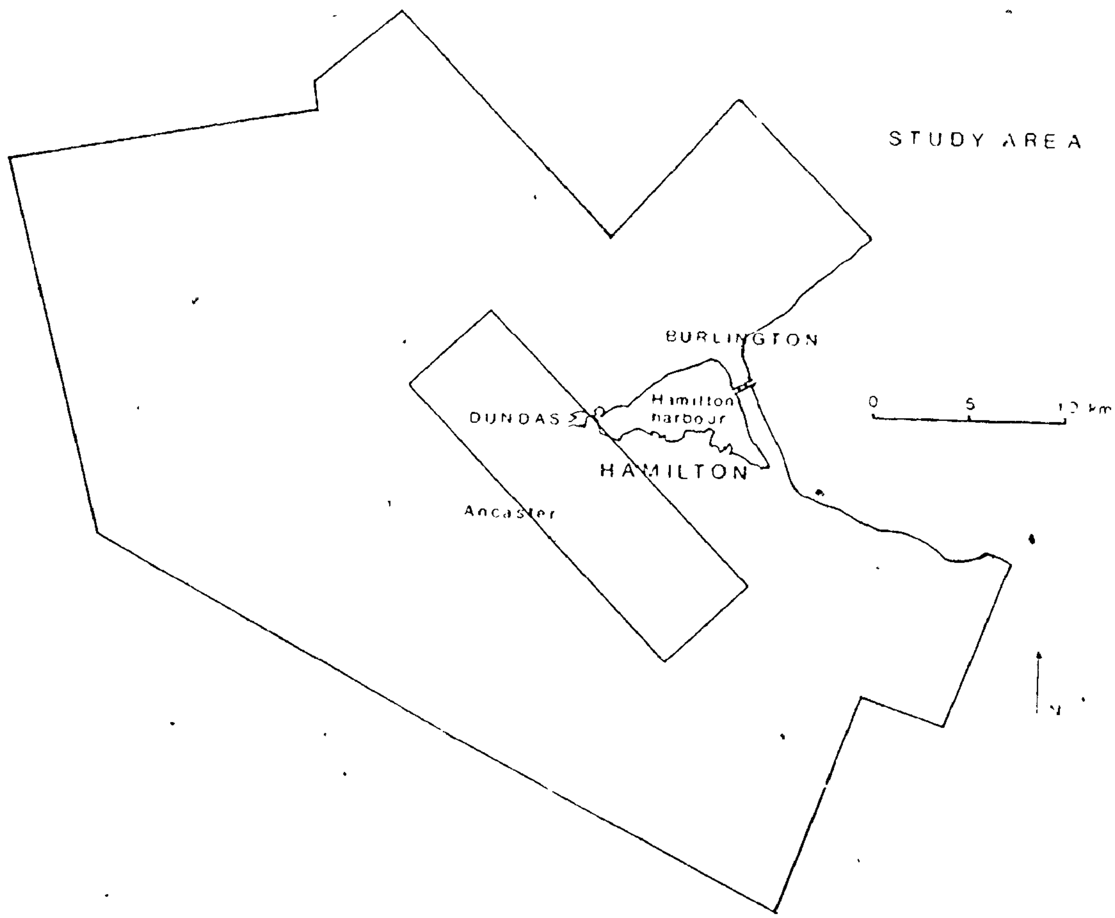


Figure 2.2: Coverage of airborne SAR imagery available for this study.

classifications. This process was especially set up for the LANDSAT data but also serves for the other data sets, within their limits of coverage.

To select the sites, the following procedures were used:

1. Each 1 km by 1 km interesection on the UTM grid of the study area at a scale of 1:50,000 was given a rank number (1-1371).
2. Three hundred intersections were selected out of the 1371 using computer generated random numbers.
3. Thirty-eight percent of the sampled intersections were identified as residential land use.
4. Random samples of various size were repeatedly selected for the 300 sites. A sample size of 90 was found to give the closest approximation to the observed proportion of residential land uses whilst maintaining the lowest necessary sample size. Ten random samples each of 90 sites yielded a mean proportion of 38% with a standard deviation of 4.88%.
5. Due to the variety of land cover/use in the area, with highly concentrated residential and industrial land in Hamilton, it was decided to use stratified random sampling for selecting the training and test sites. This method has been recommended by Stobbs (1968) and Zonneveld (1974), among others. The entire area was divided into 108 squares of areas. This provided logistically the most convenient areal division, which approached the calculated 90 samples. Each square included 20 intersections.
6. The test and training sites were selected for each of the 108 squares by selecting one intersection within each square using random number tables. This intersection was then the upper left

corner of the test or training site. Coverage was available from aerial photographs at scale 1:10,000. Basic aerial units employed in the study consisted of four squares on the U.T.M. system, equivalent to 4 km^2. The advantage of using this method is first and foremost that all areas are represented. The main disadvantage is the possibility of overlapping areas which occurred in seven cases.

7. The 108 test and training areas were divided in two groups (i.e. 56 test sites and 56 training sites) using random sampling. Figure 2.3 shows the distribution of the sites.

2.4 Ground Truth

Ground truth information for all the test and training sites was collected on aerial photography at 1:10,000 scale.. The information was drafted from the photographs on sheets of transparent drafting film, using the classification system developed for this study. Field checking was necessary in only a few cases. An air photo mosaic of part of the study area and a land cover/use map generated from photo interpretation are shown in Figures 2.4 and 2.5.

2.5 Classification System

The classification system for land cover/use in this study is a modified version of the Anderson et al. (1976) classification system. Their system is divided into four levels, based on the scale of the imagery and level of detail of the end product. Due to the type of data and the various resolutions of imagery used in this study the

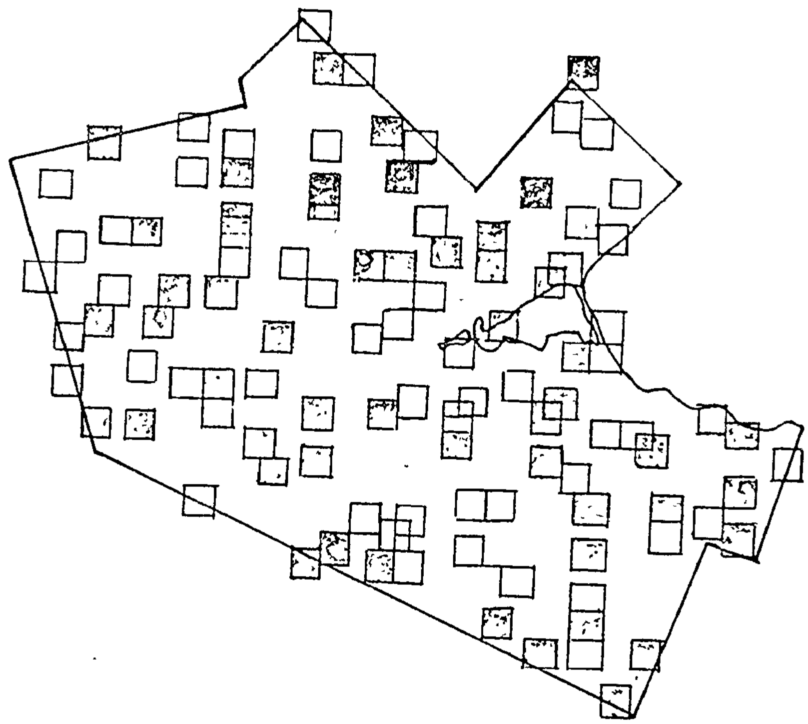
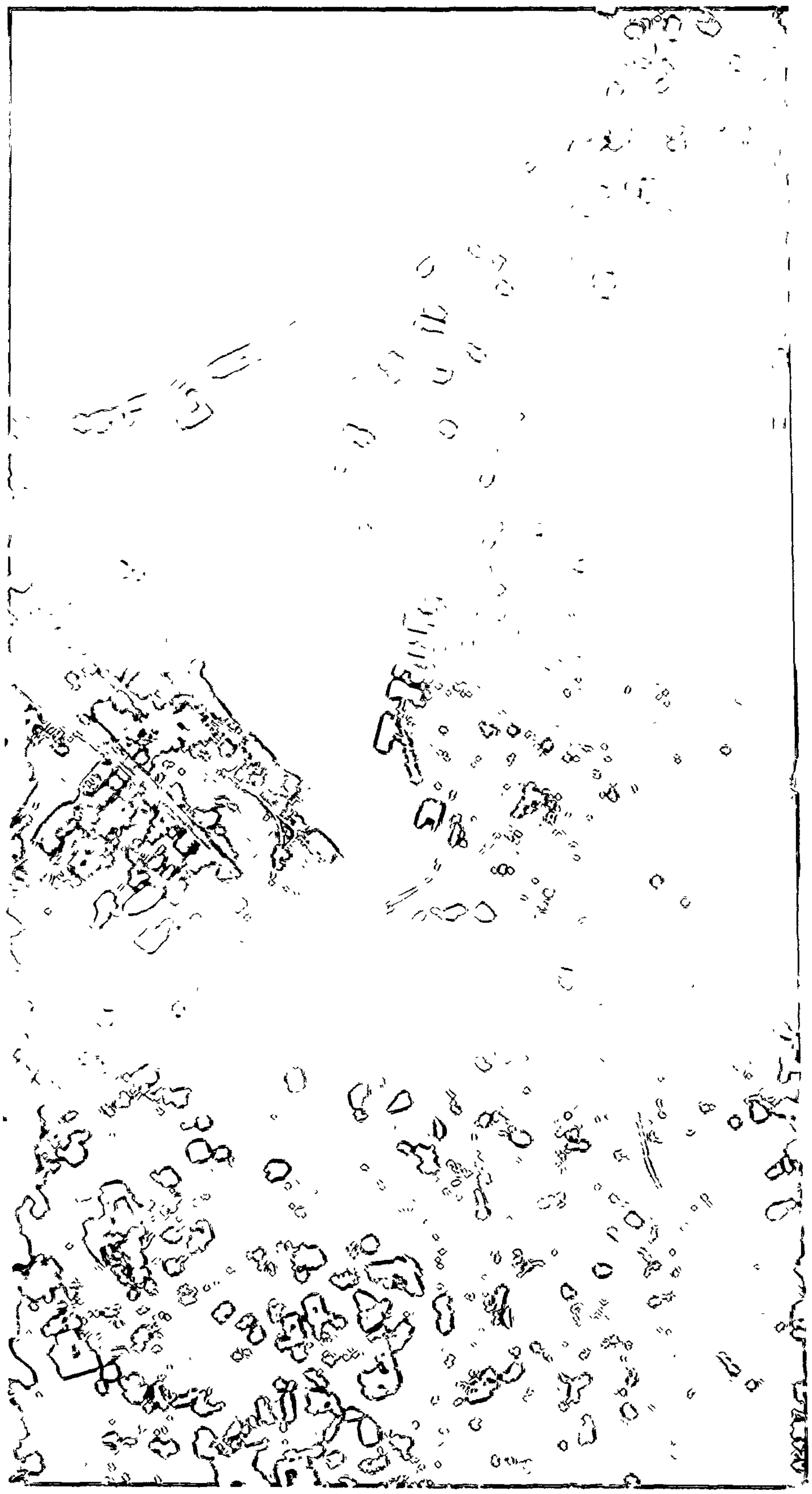


Figure 2.3: The distribution of training and test sites in the study area. The training sites are shaded.



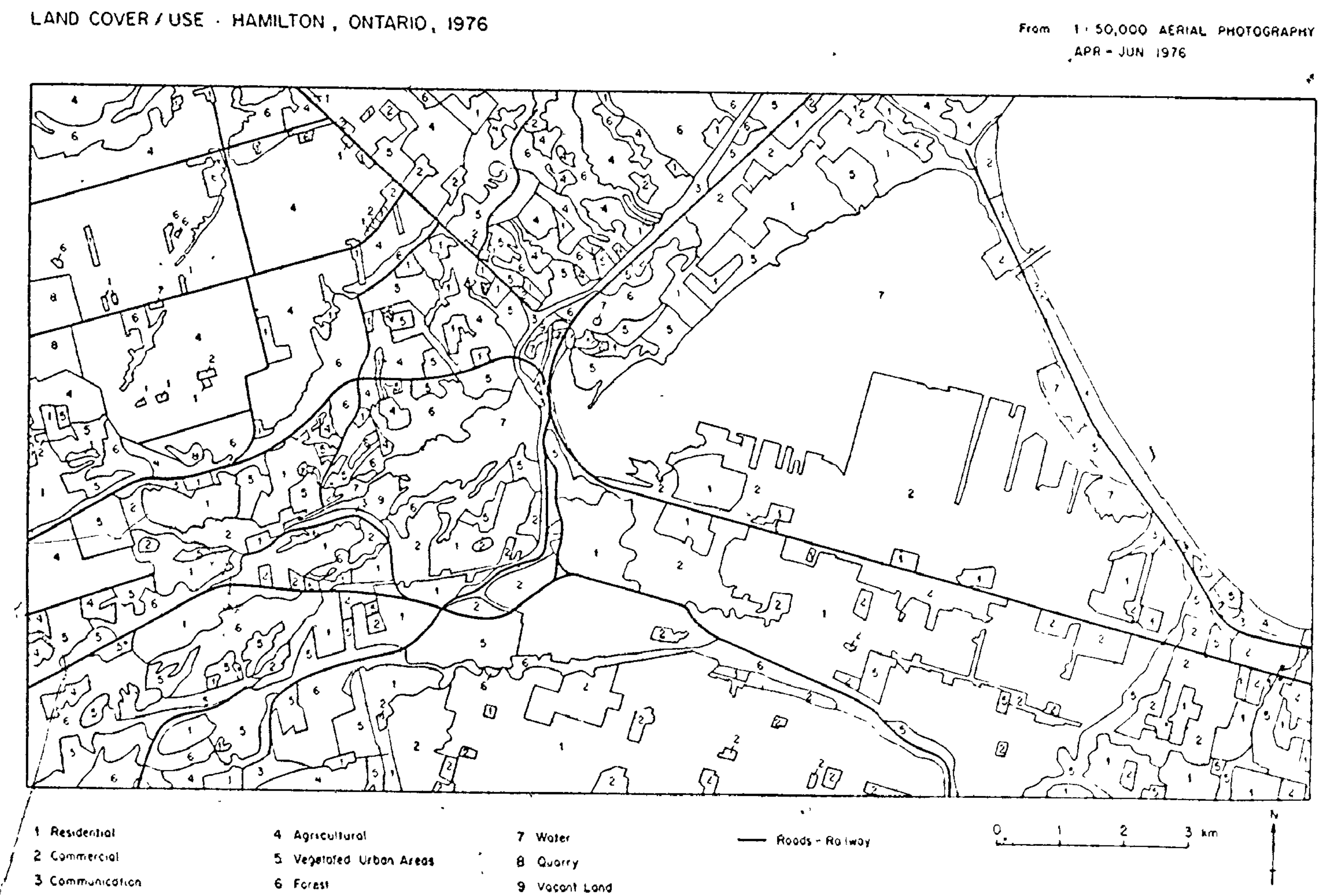


Figure 2.5: "Ground truth" map produced from the 1:50,000 scale aerial photography.

classification system is mostly adapted from levels I and II of the system developed by Anderson et al. (1976). A summary of the level I and II classifications of the system is shown in Table 2.1.

The classification used in this study, adapted from Anderson et al. (1976) is given in Table 2.2

Table 2.2. System for Land Cover/Use Classification Applied in This Study.

1. Residential	6. Forest
2. Commercial, Services and Industrial	7. Water
3. Communication	8. Quarries
4. Agricultural	9. Vacant Land
5. Vegetated Urban Land	

Definitions of the classes are as follows:

1. Residential land cover ranges from high density, represented by multiple-unit structures of urban cores, to low density where houses are on lots of more than 5,000 km^2 (0.5 ha) on the urban fringe. Residential development along major transportation routes extending outwards from urban areas is also included.
2. Commercial, Services and Industrial land are those predominantly for the sale of products, services and light to heavy manufacturing.
3. Communication . This class overlaps to some degree with classes 1 and 2 but, if mapped separately, includes major highways,

Table 2.1: Land Use and Land Cover Classification System for Use with Remote Sensor Data.

	Level I		Level II
1	Urban or Built-up Land	11	Residential.
		12	Commercial and Services.
		13	Industrial.
		14	Transportation, Communications, and Utilities.
		15	Industrial and Commercial Complexes.
		16	Mixed Urban or Built-up Land.
		17	Other Urban or Built-up Land.
2	Agricultural Land	21	Cropland and Pasture.
		22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas.
		23	Confined Feeding Operations.
		24	Other Agricultural Land.
3	Rangeland	31	Herbaceous Rangeland.
		32	Shrub and Brush Rangeland.
		33	Mixed Rangeland.
4	Forest Land	41	Deciduous Forest Land.
		42	Evergreen Forest Land.
		43	Mixed Forest Land.
5	Water	51	Streams and Canals.
		52	Lakes.
		53	Reservoirs.
		54	Bays and Estuaries.
6	Wetland	61	Forested Wetland.
		62	Nonforested Wetland.
7	Barren Land	71	Dry Salt Flats.
		72	Beaches.
		73	Sandy Areas other than Beaches.
		74	Bare Exposed Rock.
		75	Strip Mines Quarries, and Gravel Pits.
		76	Transitional Areas.
		77	Mixed Barren Land.
8	Tundra	81	Shrub and Brush Tundra.
		82	Herbaceous Tundra.
		83	Bare Ground Tundra.
		84	Wet Tundra.
		85	Mixed Tundra.
9	Perennial Snow or Ice	91	Perennial Snowfields.
		92	Glaciers.

From Anderson et al. 1976, p. 6.

railways and airports.

4. Agricultural land is used for the production of food and fiber.
5. Vegetated Urban land is primarly land used as urban parks, golf courses, cemeteries, waste dumps and under-developed land within an urban setting.
6. Forest lands have tree-crown areal density of 10% or more.
7. Water includes lakes, streams and reservoirs.
8. Quarries. Extractive mining activities that have significant surface expression.
9. Vacant land includes brush land, not used for agriculture and all land which is not included in the foregoing categories.

2.6 Conclusion

In this chapter, the methodology used for the study up to the development of the classification system has been described. As there were slight variations in the way each type of imagery was examined, the analysis is discussed separately in each of the next four chapters.

CHAPTER 3

VISUAL ANALYSIS OF LANDSAT MSS DATA

3.1 Introduction

Visual interpretation is probably the most widely used classification procedure based on remotely sensed data. It is and has been used with both high and low altitude aerial photography, satellite imagery, radar imagery and thermal infrared imagery.

The LANDSAT mission was designed with two sensor systems on board; the three channel Return Beam Vidicon (RBV) system and a four channel Multispectral Scanner (MSS) system.

In this chapter, the procedures and results for the visual analysis of LANDSAT MSS data will be discussed.

3.2 The Multispectral Scanner System (MSS)

The MSS system on board the LANDSAT satellites responds to reflected sunlight in four spectral bands, namely the green, red and two near infrared (IR) parts of the electromagnetic spectrum (Table 3.1).

The MSS is a line scanning device on a near polar orbit that covers the earth in a 185 km wide swath. The scan is from west to east. The scanning is done by an oscillating mirror which records six lines simultaneously in each of the four spectral bands (Figure 3.1). The scanning angle of coverage is 11.56° or 185 km on the surface from the

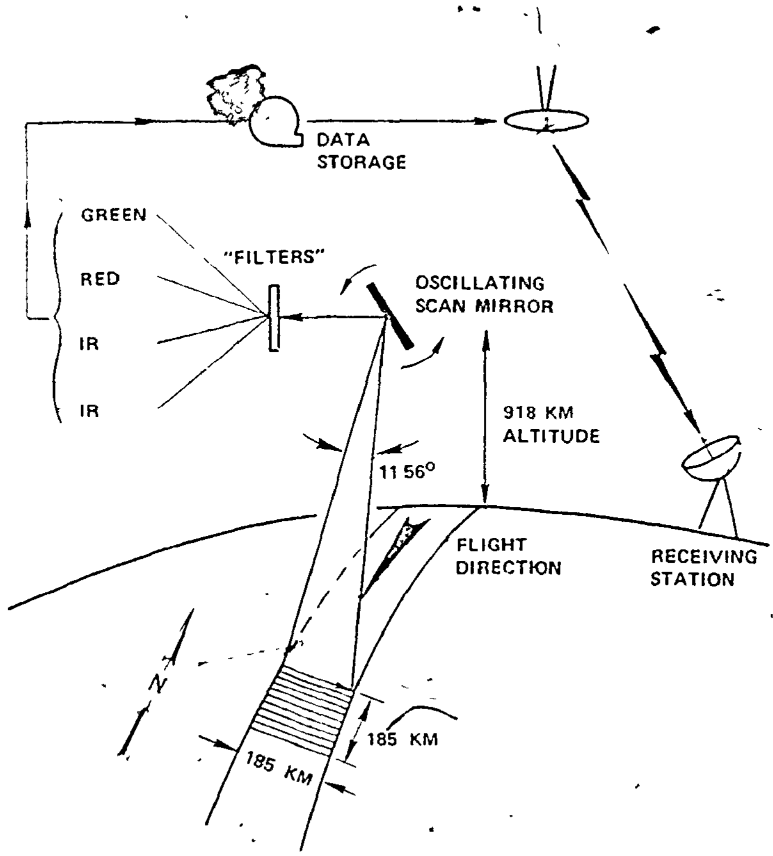


Figure 3.1: Ground coverage, data collection and ground reception for LANDSAT MSS imagery (from Sabins, 1978).

Table 3.1 Spectral Responses for LANDSAT Multispectral Scanner Data

Band	Spectral Response (Micrometers)	Colour
4	0.5-0.6	green
5	0.6-0.7	red
6	0.7-0.8	near IR
7	0.8-1.1	near IR

nominal altitude of 918 km. The data are recorded continuously along the orbit path and are transmitted to a ground receiving station (Fig. 3.1).

The ground resolution from an altitude of 918 km is 79 m by 79 m. This determines the spatial resolution, but due to the rate of sampling by the scanner the effective ground resolution is 56 m by 79 m (U.S. Geol. Survey, 1979; Sabins, 1978; Lillesand and Kiefer, 1979). The area covered by one LANDSAT MSS scene consists of 2340 scan lines with about 3240 pixels per line, or a total of approximately 7.6 million pixels. For this study, however, resampled data produced by the Digital Image Correction System (DICS) were used (Butlin et al. 1978). Figure 3.2 shows the area covered by the scene for Track 19 Row 30 from which the LANDSAT data used in this study were extracted. More details on the MSS system can be found elsewhere in U.S. Geological Survey (1979), Sabins (1978), Heffernan (1979), Lillesand and Kiefer (1979) and Freden and Price (1977).

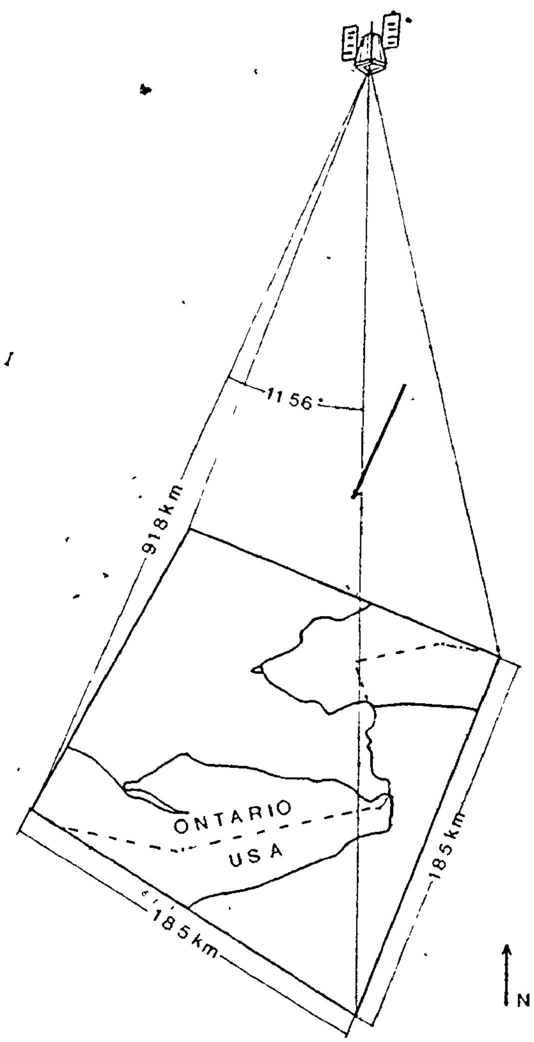


Figure 3.2: Area of coverage for the LANDSAT MSS scene used in this study.

3.3 Digital Image Correction System (DICS) Data

Inherent in the MSS data are both radiometric and geometric errors. CCRS has supplied data on computer compatible tapes (CCT) with some corrections for these errors, but in the past the data have not been "compatible with the Canadian National Topographic System (NTS) maps" (Butlin et al. 1978). To make LANDSAT data compatible with the NTS system, CCRS has developed a Digital Image Correction System (DICS). The data produced by this system consist of resampled pixels, 50 m by 50 m in size (instead of 79 m by 56 m), east-west oriented scan lines corresponding to the UTM projection and NTS compatible formats (Butlin et al., 1978; CCRS, 1981). Because of these advantages, a DICS subscene of about 1160 lines by 1660 pixels or about 1.9 million pixels was chosen for the study (Figure 3.3). The subscene covers NTS maps 30L, 30M, 40I and 40P.

3.4 Previous Studies Using LANDSAT Visual Analysis

Visual analysis of LANDSAT MSS data for land cover/use studies has been described and recommended as an appropriate method or preliminary step for further land cover/use studies. The main reason is the availability of the data and low cost.

Elifrits et al. (1977) have described a method for mapping land cover from satellite images which they consider a basic low cost approach. Their methodology, based on visual interpretation, involves direct tracing from single band or colour composite transparencies at scale 1:1,000,000 and basic tracing materials.

In 1977, MacDonald et al., described the use of visually

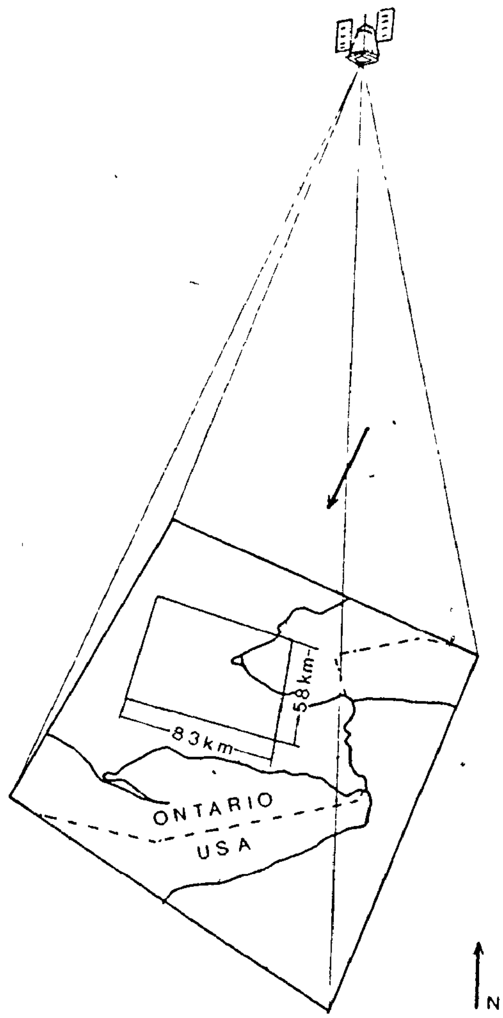


Figure 3.3: Area of coverage for the DICS subscenes used in this study. Note that the area corresponds to four 1:50,000 NTS maps.

interpreted LANDSAT data as part of a water quality monitoring system. The LANDSAT data were required to generate land use maps from two different dates.

Van Genderen et al. (1978) recommended visual interpretation of LANDSAT data for rural land use studies in developing countries. A similar approach was recommended by Rodrigues-Bejarano and Okoye (1977) in their study of land cover/use change in Nigeria.

Meyer et al. (1974) described visual interpretation of LANDSAT data as a method for land cover/use mapping in Montana. As a sign of their times, they concluded that in comparison with other remotely sensed data, LANDSAT did not add anything new to aerial photography but might be used for broad classification.

In Canada, the most recent work involving visual interpretation of LANDSAT visual data is the work of Prout (1980) suggesting strategies for land cover/use mapping and change detection in the Halifax area. For the Hamilton-Wentworth area there are no published studies which have used visual LANDSAT data.

3.5 Method of Analysis

LANDSAT MSS data for visual interpretation are available as black and white prints or transparencies for each of the four spectral bands or as colour composites of three bands. Those are available for the entire scene (scale 1:1,000,000) or as UTM corrected DICS images (scale 1:50,000). For the purpose of this study, a colour composite transparency of Bands 4, 5 and 7 was used. Figure 3.4 shows part of the subscene used for the visual interpretation.

As described in Chapter 2, 56 training areas and 56 test areas had been selected to determine the suitability of the various sensors for mapping land cover/use. Given the scale of the MSS image, however, it was decided in this case to map one large area which included all the various land cover/use classes, rather than just map the test areas. Training sites were used to learn the image characteristics of the different classes. The mapping scale was chosen as 1:50,000.

The area chosen for mapping included parts of Hamilton, the Hamilton harbour, the City of Dundas and part of Ancaster and Burlington (Figure 3.5). This area not only includes all classes, as mentioned earlier, but also provides excellent landmarks used for ground control points for orientation of the image. The size of the area is approximately 17 km from west to east and 10 km from north to south.

A major reason for choosing the scale of 1:50,000 as a mapping scale was that devices such as the Bausch and Lomb Zoom Transfer Scope (ZTS) cannot be used to compare imagery with scale differences of more than 14 times. It was decided to use a 10 times magnification to enlarge from 1:500,000 to 1:50,000. The analysis was done using the following steps.

1. The DICS transparency was mounted on the ZTS.
2. The transparency was magnified by a factor of 10.
3. Using the ZTS, the magnified image was superimposed on the 1:50,000 topographic map of the area.
4. The superimposed image was adjusted to ground control points using the rotation and stretch controls of the ZTS.

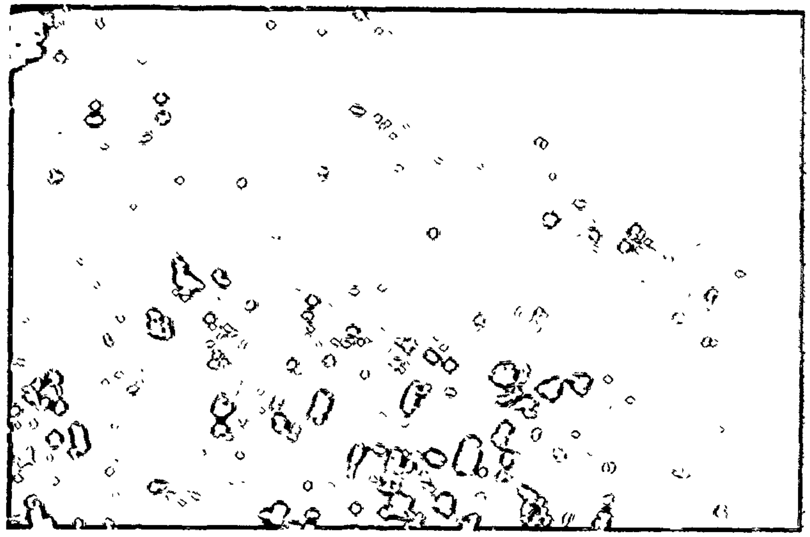


Figure 3.4: Colour composite (Bands 4, 5 and 6) showing the area studied in the visual analysis.

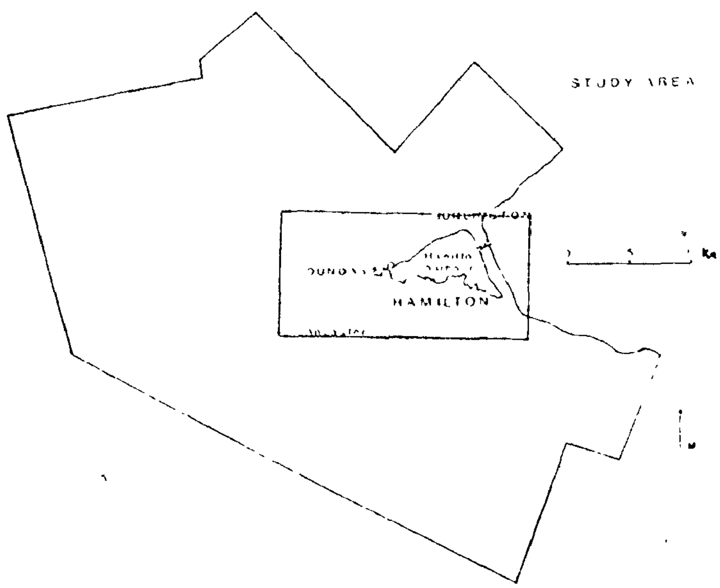


Figure 3.5: Area that was mapped as part of the visual analysis.

5. A land cover/use map was drafted from the image on an overlay transparent sheet placed over the 1:50,000 scale map (Figure 3.6).

Of the five steps described above, steps 4 and 5 introduced the most difficulties. The first problem to solve was how to ensure that the image stayed at exactly the same location while the drafting was done. To solve that problem, five points were selected on which the image could be oriented. The points selected all bordered Hamilton Harbour and could be clearly identified (Figure 3.7). While the drafting was being carried out the location of the control points was checked regularly.

Another problem encountered was the interpretation of the colour signatures and the task of keeping the interpretation consistent. The problem of visual interpretation in general is discussed later.

The third problem was to decide the minimum mapping unit. In this case the recommendations of Anderson et. al. (1976) for a minimum mapping unit of 2.5 mm in diameter were followed. At a scale of 1:50,000 this represents a ground area of 125 m^2. The minimum mapping unit is therefore equivalent to an area of approximately 2.5 pixels by 2.5 pixels or 6.25 pixels (Figure 3.8).

3.6 Results

When the transparency is viewed without magnification, all major highways clearly appear as long narrow light grey lines. General boundaries between urban and rural land can be identified, although in some cases open fields might cause some confusion. The

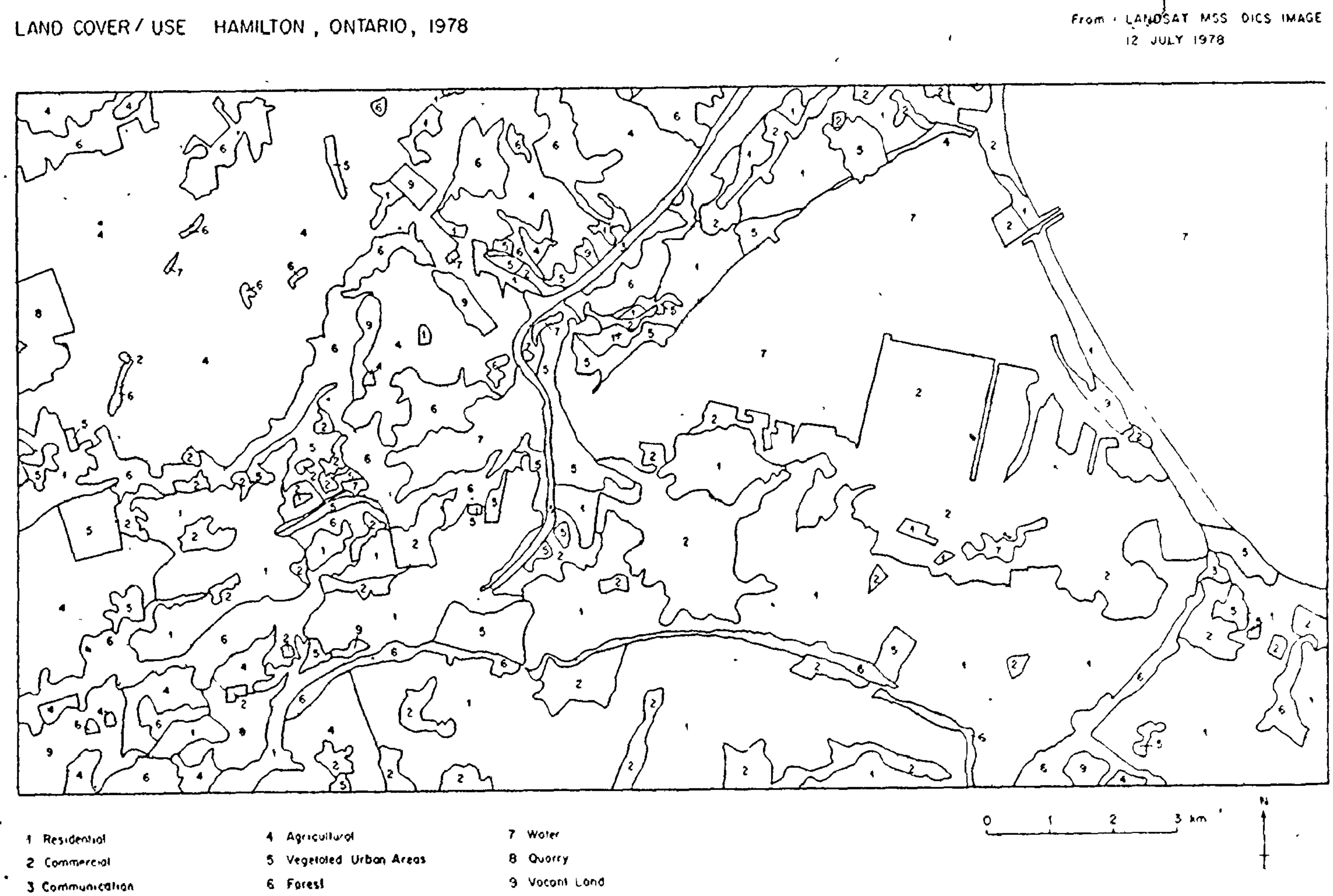


Figure 3.6: Land cover/use map produced by visual interpretation of the DICS transparency. The original scale of mapping was 1:50,000.

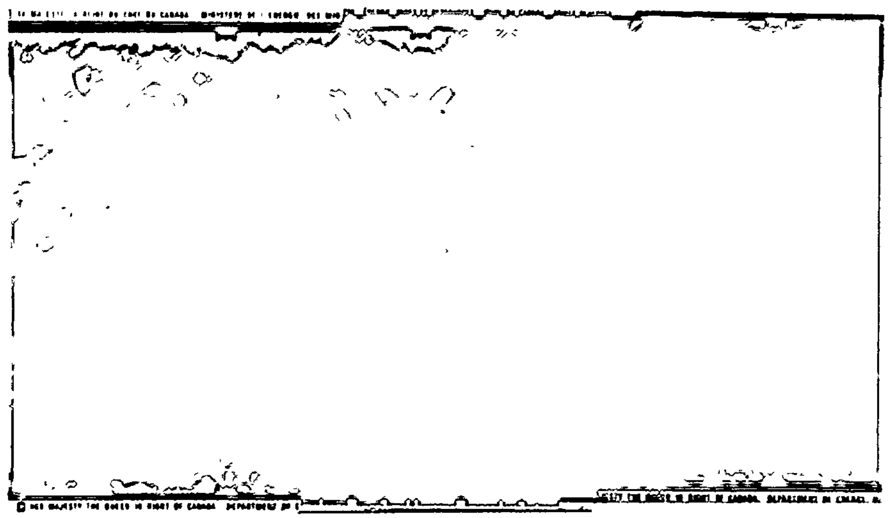


Figure 3.7: Ground control points used to orient each image to ensure registration between images.

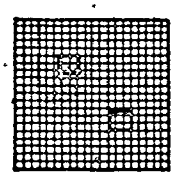


Figure 3.8: Comparison of pixel size (small squares) at 1:50,000 scale and the minimum mapping unit (larger squares).

urban land has a bluish tone indicating lack of vegetation, while the rural area in general is redish emphasizing the presence of vegetation. Water, both as lakes and rivers, appears as very dark blue or black.

Not only do the tones and colours help with the interpretation but so do the patterns. For example, the agricultural areas have large rectangular field patterns while the forests and uncultivated areas are of irregular shape.

When the image was enlarged 10 times the different tones and colours were more critical than before. The urban area may then be divided into industrial and commercial areas of dark or light blue, while the residential areas are stippled blue and red. The stipple is due to a combination of man-made surface and vegetation. The vegetated urban areas are light red or pinkish and water is still mainly black. The quarry is very white, and three golf courses are correctly identified as vegetated urban land.

On the rural side, the forests are dark red, while the agricultural areas have various tones such as light red, green and yellow. The green and yellow represent partly vegetated stubble and ripe grains, respectively. The visual interpreter obviously has to bear in mind all the patterns and tones while interpreting the image.

The results of the visual classification are shown in Figure 3.6 as a land cover/use map of Hamilton. Using the classification system described in Chapter 2, all classes were identified in the area that was mapped.

Although large sections of similar land cover/use are easily seen on the imagery, small areas can be identified just as correctly.

It became clear during the visual interpretation that street patterns in the city might be mapped, but they were not of interest for this study. If the mapping scale had been larger, the minimum mapping unit would have been smaller and it would have been possible to show more detail on the map. Further discussión on accuracy is to be found in Chapter 7.

CHAPTER 4

VISUAL ANALYSIS OF LANDSAT RBV DATA

4.1 Introduction

The second sub-system on board LANDSAT is the Return Beam Vidicon (RBV) system. On Landsat 1 and 2, the RBV system consisted of three channel camera system. Due to technical failure on both satellites, very few studies have been carried out using RBV images.

Improvements on the RBV system in LANDSAT 3 have given it better spatial resolution than the MSS system and data are now being used for several applications.

In this chapter, methods for the visual analysis of LANDSAT RBV data will be described.

4.2 The Return Beam Vidicon (RBV) System

The RBV system on board LANDSAT 3 is a two camera system. The ground is imaged by two RBV panchromatic cameras at the same time. They provide side by side pictures, each measuring 99 km by 99 km, with a total swath width of 185 km. Thus, there is slight overlap of 13 km between the two images (Figure 4.1). Each camera has the same spectral response covering the range of 0.51-0.75 μm or from yellow into the near infrared parts of the spectrum (U.S. Geological Survey, 1979). Four subscenes of RBV images correspond to one MSS image frame. They are designated A B C and D (Figure 4.1).

The ground resolution of an RBV scene is approximately 30 m by 30 m but the net pixel size is 18 m by 24 m. This is a greatly increased spatial resoltuion when compared with the approximately 60 m by 80 m resolution of the MSS system.

The data recorded by the satellite are transmitted to a ground receiving station in a similar manner to the MSS (Figure 3.1).

4.3 Previous Studies Using LANDSAT RBV Visual Analysis

Due to technical failures on both LANDSAT 1 and 2, few RBV images have been produced. This is the main reason why there are few papers dealing with this subject. Most have been published recently based on analysis of LANDSAT 3 data. Roller and Cox (1980) have compared the use of MSS and merged MSS/RBV data for the analysis of natural vegetation. They conclude that the merged image gives better ground resolution and more detail. In Canada, Prout (1980) has described the use of RBV imagery for land cover/use studies in the Halifax area. She concludes that RBV imagery provides good detail for mapping in urban areas.

4.4 Method of Analysis

The RBV data for visual analysis are available as black and white transparencies or prints at a scale of 1:500,000. Relatively few images of good quality have as yet been received from the system. In the CCRS image inventory for the period March 1, 1978 to April 1, 1980 only 7 frames with cloud coverage less than 50% are indicated

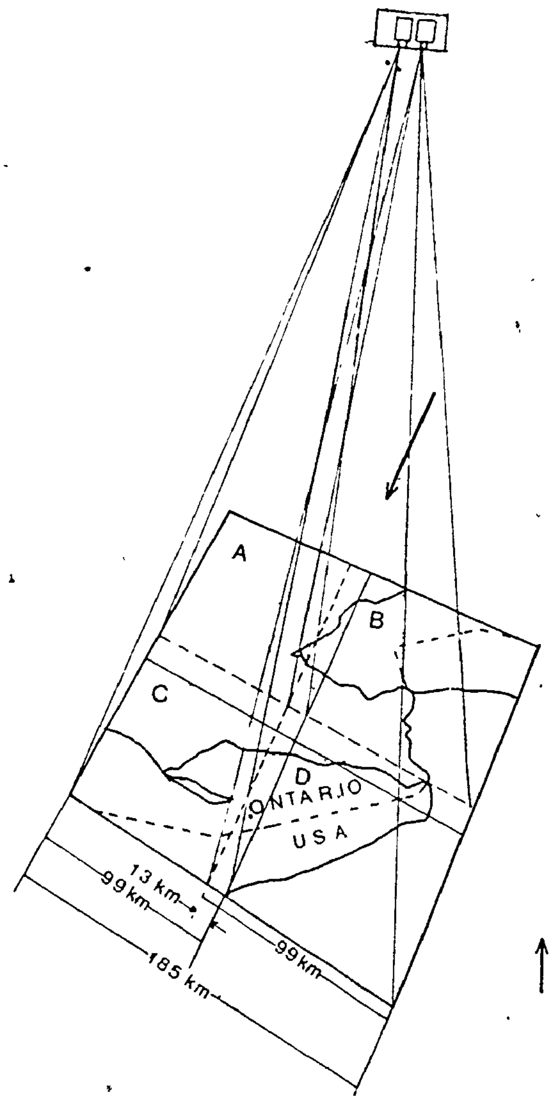


Figure 4.1: Area of coverage for four RBV frames. Note that they cover the same area as one MSS scene. The RBV image used in this study was Frame A which was acquired as a transparency at 1:500,000 scale.

for the study area. From these frames, two recorded on May 28, 1978 and September 26, 1979 were chosen for the study. No summer image was available. Due to the time of year and for comparison with the other data, the image from May 28, 1978 was selected for detailed study. The mapping scale and area are the same as selected for mapping from the MSS data. Reproduction of the RBV image used for mapping is shown in Figure 4.2. The analysis followed the same procedure as for the MSS DICS data, described in Section 3.5 of this thesis. In other words, the Bausch and Lomb Zoom Transferscope was used to enlarge the scene 10 times, superimpose the scene on the topographic map, adjust it to the ground control points and finally draft the map.

The problems encountered were basically the same as with the MSS, excluding the use of colour. The major difficulty was generalizing and comparing the different grey tones. The final result from the visual interpretation is shown in Figure 4.3.

4.5 Results

The map shown in Figure 4.3 is generated from an RBV image recorded on May 28, 1978. The interpretation is based on grey tones and pattern recognition. The map shows all the classes which are described in Chapter 2.

The residential class (1) is identified on the basis of its light tones and street patterns. The commercial/industrial area (2) is recognised and interpreted from the very light tones of large buildings and a range of light to dark tones with regular patterns, though not street patterns. The recognition is also based on location.

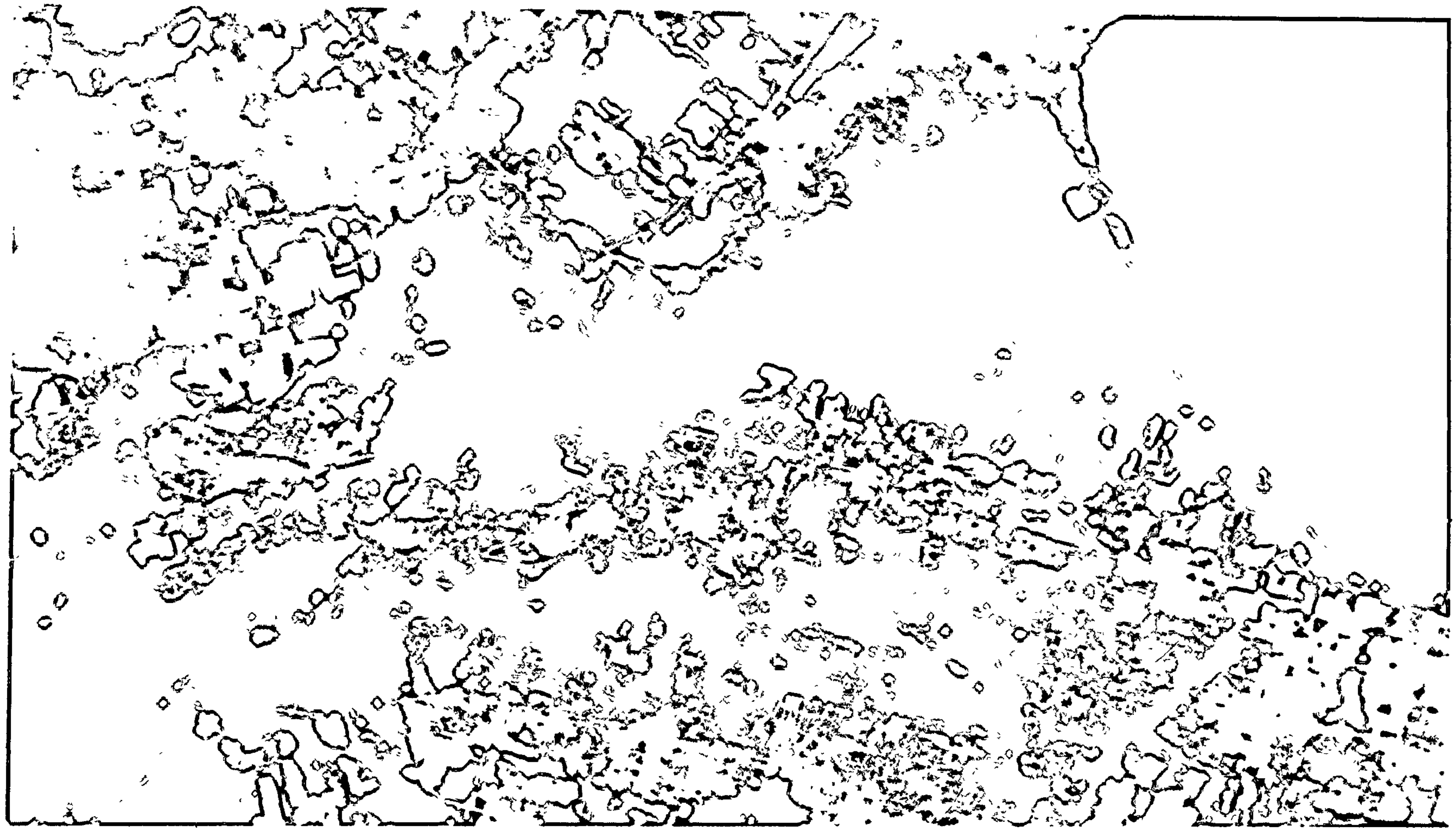


Figure 4.2: Enlargement from the RBV frame used in this study. The large crosses are resea marks on the original image.

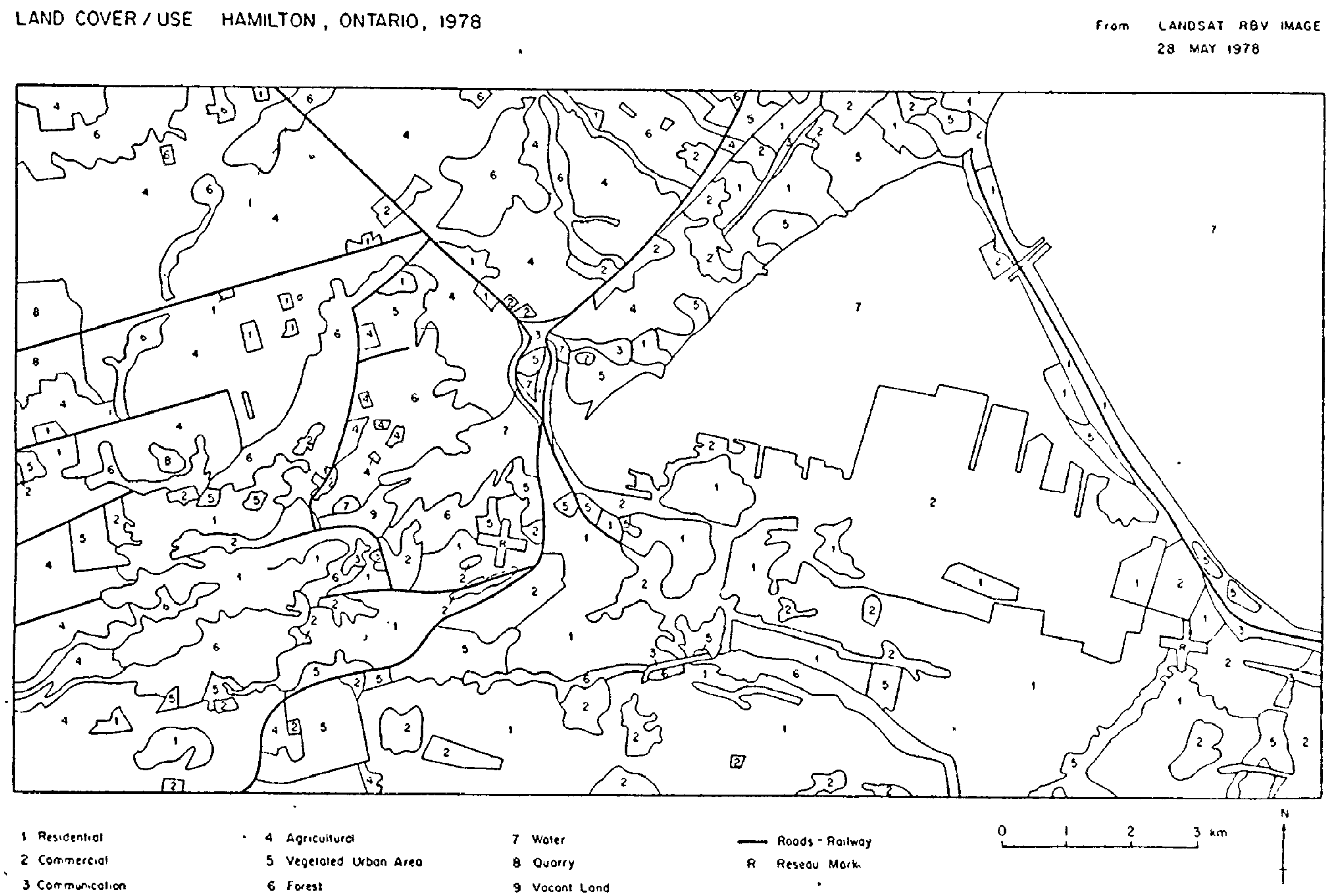


Figure 4.3: Land cover/use map produced by visual interpretation of the RBV transparency. The original scale of the map was 1:50,000.

Communication (3) clearly show linear pattern such as highways and railways, excluding areas included within Classes 1 and 2.

Agriculture (4) appears in a wide range of tones from nearly white to a light grey which is similar to the urban areas. The class was mainly distinguished by its patterns, particularly large rectangular fields.

The vegetated urban areas (5) appear in light tones but their texture is smoother than enountered in the residential areas, although similar to some agricultural areas. The spectral similarity between grassland in the urban areas and pasture in rural areas can readily be appreciated. To separate vegetated urban areas from the agricultural areas the factor of relative location was used.

Forest (6) is recognized from its dark, smooth tones with irregular outlines, although it often has straight boundaries where it borders agricultural land. Water (7) is one of the easiest classes to recognize with its dark tones, but the Quarry (8) is near white and could be easily confused with agricultural land. Vacant land (9) was the class most difficult to identify, and in fact only one area, which was wetland, could be interpreted as such.

The RBV image gave good representation of all major street patterns within the built up area, and in many cases even minor street patterns could be recognized. Although it was not possible to identify different crop types, boundaries between fields are clear. Due to the differences in tones, boundaries between rural and urban areas are clearly identified as are the boundaries between land and water. Discussion on accuracy of land cover/use mapping using an RBV image is in Chapter 7.

CHAPTER 5

VISUAL INTERPRETATION OF SYNTHETIC APERTURE RADAR DATA

5.1 Introduction

Radar was developed during the Second World War, primarily for navigation and target location. In the 1950s, Side Looking Airborne Radar (SLAR) was developed "to acquire reconnaissance imagery without the necessity of overflying unfriendly regions" (Sabins, 1978, p. 177). Due to the unavailability of radar data until recently, few studies have been carried out on the capabilities of radar for land cover/use mapping and urban studies.

5.2 The Synthetic Aperture Radar (SAR) System

Radar systems record energy of longer wavelength than other sensors used in this study. They operate in the microwave region of the spectrum at wavelengths of 1 mm or greater (Figure 1.3). Another major difference is that the radar sensor is an active system (i.e. the radar generates its own energy and transmits it from its antenna). The other sensors used in this study are passive as they only record reflected solar energy.

The strength of the reflected wave is based on the ability of the object to reflect energy. The slope of the ground surface, the look direction and the overall geometry have a great influence on the strength of the reflected signal, as well as the physical characteristics of the objects and surfaces being recorded.

A central principle to all imaging radar systems is the return time of signal echoes (i.e. the range or distance between the transmitter/receiver and the reflecting objects). In Figure 5.1, ground coverage and signal processing from different surfaces are explained diagrammatically. Further details are to be found in Lillesand and Kiefer (1979) and Sabins (1978).

The ground resolution cell (i.e. pixel size of the SLAR) is controlled by two independent sensing system parameters, namely pulse length and antenna beam width. The pulse length dictates the spatial resolution in the direction of energy propogation, which is referred to as the range direction. The width of the antenna beam determines the resolution of the cell in the flight or azimuth direction (Figure 5.1). To be recorded the distance between two objects has to be more than half the pulse length.

There are two basic imaging radar systems, known as real aperture or Side Looking Airborne Radar (SLAR) and Synthetic Aperture Radar (SAR). The main difference between the two systems is that in the real aperture system the beam width of the signal is controlled by the physical length of the antenna (i.e. for a small beam width a long antenna is required). In the synthetic aperture system, the antenna is physically short, but through the recording and processing system it is able to store the signal and simulate the effects of a long antenna. Thus SAR is capable of much higher resolutions than SLAR.

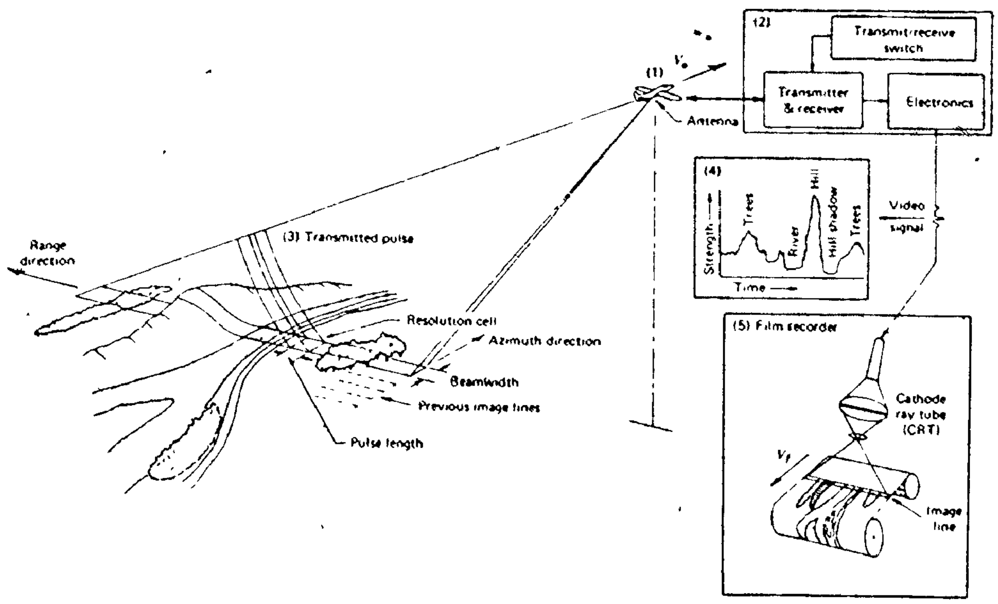


Figure 5.1: Diagrammatic representation of the operation of an airborne SAR system (from Lillesand and Kiefer, 1979, p. 495).

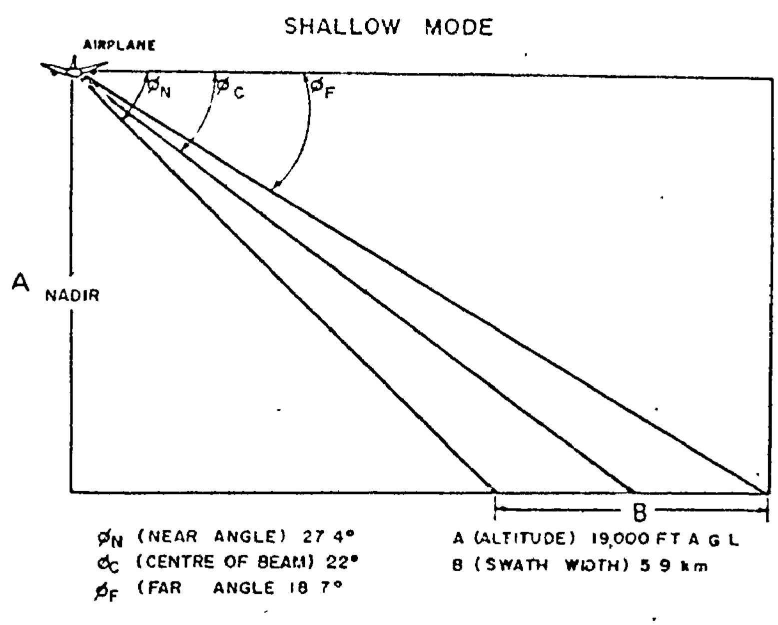


Figure 5.2: Geometry of the SAR shallow mode recording system.

Radar signals can be transmitted and/or received in different modes of polarization. The signal is either transmitted or received as horizontal (H) or vertical (V). Several combinations are possible. Different polarizations can bring out different characteristics of the area being imaged.

The imagery used for this study is SAR imagery, which was obtained on August 2, 1978. The imagery was acquired by Intera Environmental Consultants Ltd. for the Surveillance Satellite Project of the Federal Government using an X-Band and L-Band four channel SAR owned at that time by the Environmental Research Institute of Michigan (ERIM). The ERIM SAR can operate in four antenna modes which are steep angle, shallow angle, grazing and wide swath. The coverage of each of the two sets of images used in this study is about 6 km wide by 20 km long. The area of coverage is shown in Figure 2.3. The imagery was recorded from an altitude of 5,800 m A.G.L. using the shallow angle mode (Fig.5.2). The data were recorded in both X-Band and L-Band (Wavelengths 3.0 cm and 23.0 cm, respectively). They are in both HH and HV polarizations with a ground resolution of 3 m by 5 m.

5.3 Previous Studies Using Airborne Radar

The literature on radar for land cover/use studies only spans a decade. The first reports (Simpson, 1969a; 1969b) deal with the geographic evaluation of radar imagery of New England, primarily to determine if radar imagery can be used to differentiate urban from rural land. Moore (1969) concludes that SLAR can be used to detect linear elements of transportation networks, gross patterns of industrial, residential and open spaces, but not to map local boundaries. These preliminary studies with relatively poor resolution (15 m by 15 m) K-Band SLAR data did not give promising results. Radar was initially classified for military uses, which meant that the academic researcher was only able to examine data at a low resolution.

The next studies on radar were not published until the mid 1970s (Bryan, 1974, 1975, 1976). Bryan was able to use SAR data with a resolution of 10 m by 10 m. He concludes that SAR radar can be used to detect urban land cover, but does not add anything to existing sensors (i.e. aerial photography). It would, however, be helpful in darkness and foggy situations, especially for acquiring imagery of disaster areas.

In a report from An Active Microwave Workshop, Matthews (1975, p. 134) states: "In summary the evidence strongly support the view that multispectral sensing in the radar region will probably be at least as successful as that in the visible and near IR regions, with of course different strong and weak areas." From the year 1975, Henderson (1975, 1976, 1977, 1979) has published several papers on the use of K-Band SLAR at 15 m by 15 m resolution for small scale land cover/use mapping. The main interest in the papers is to test the accuracy of land cover/use classification using the scheme developed by Anderson et al. (1976). Using the low resolution radar, the results are similar to Bryan's, namely that radar can be used for land cover/use mapping, but does not do better than existing aerial photography.

In Canada, few studies on the use of SAR for land cover/use studies have been published. Most of the Canadian work has been undertaken as part of the Surveillance Satellite (SURSAT) Project (Intera, 1980a; 1980b). About one fourth of the papers published in the Proceedings of the Sixth Canadian Symposium on Remote Sensing deal with radar. Of these, however, only two discuss the use of SAR for land cover/use studies.

Rubec and Cihlar (1980) have evaluated SAR for ecological and land cover/use classification in southern Manitoba. They concluded that SAR images "can be successfully applied to classification of general land use, land cover and vegetation patterns" and that "factors which govern standard aerial photographic interpretation, could also be used when interpreting radar images" Rubec and Cihlar (1980, pp. 209 & 210). The other paper which deals with SAR for land cover/use mapping is by Prout (1980) in which the tone and textural appearances on the SAR image of various land cover/use classes are discussed.

5.4 Method of Analysis

The original SAR data had been transcribed on to 70 mm film at a scale of 1:103,000. The data were supplied by the SURSAT Office as both prints and transparencies at an approximate scale of 1:43,000. A total of 8 prints and 8 transparencies was available, but in the study only the transparencies were used as they gave better definition.

There were several steps to the analysis procedure:

1. A visual comparison of the two sets of imagery was made as a

preliminary quality test. No significant differences in image quality were observed.

2. The set which provided more variability in land cover/use was then selected for more detailed study. A visual comparison indicated that Scene F150 P6 included all the classes that were described in Chapter 2. Furthermore, the image covered the western part of the area which was studied using the LANDSAT data, as discussed in Chapters 3 and 4.

   As the SAR imagery only covers a small portion of the study area, it was impossible to use the training site and test site approach described in Chapter 2. The training sites, however, were used to learn the image characteristics of the different land cover/use classes.

3. The next step involved a comparison of the four images (X_{HH}, X_{HV}, L_{HH}, and L_{HV}) for Scene F150 P6. The images are shown in Figures 5.3 and 5.4, and details of the comparison are given in the results in the next section.

4. From the comparison, the X_{HH} image was selected as the best from which to produce a land cover/use map. In addition to the land cover/use map, the image was used to produce maps showing linear features and also area of strong and weak returns. Again, the results are described in the next section.

   It was decided to make the maps at contact scale, rather then reduce or enlarge the scene. This kept the mapping scale for each data set used in this study at approximately the same scale of 1:50,000.

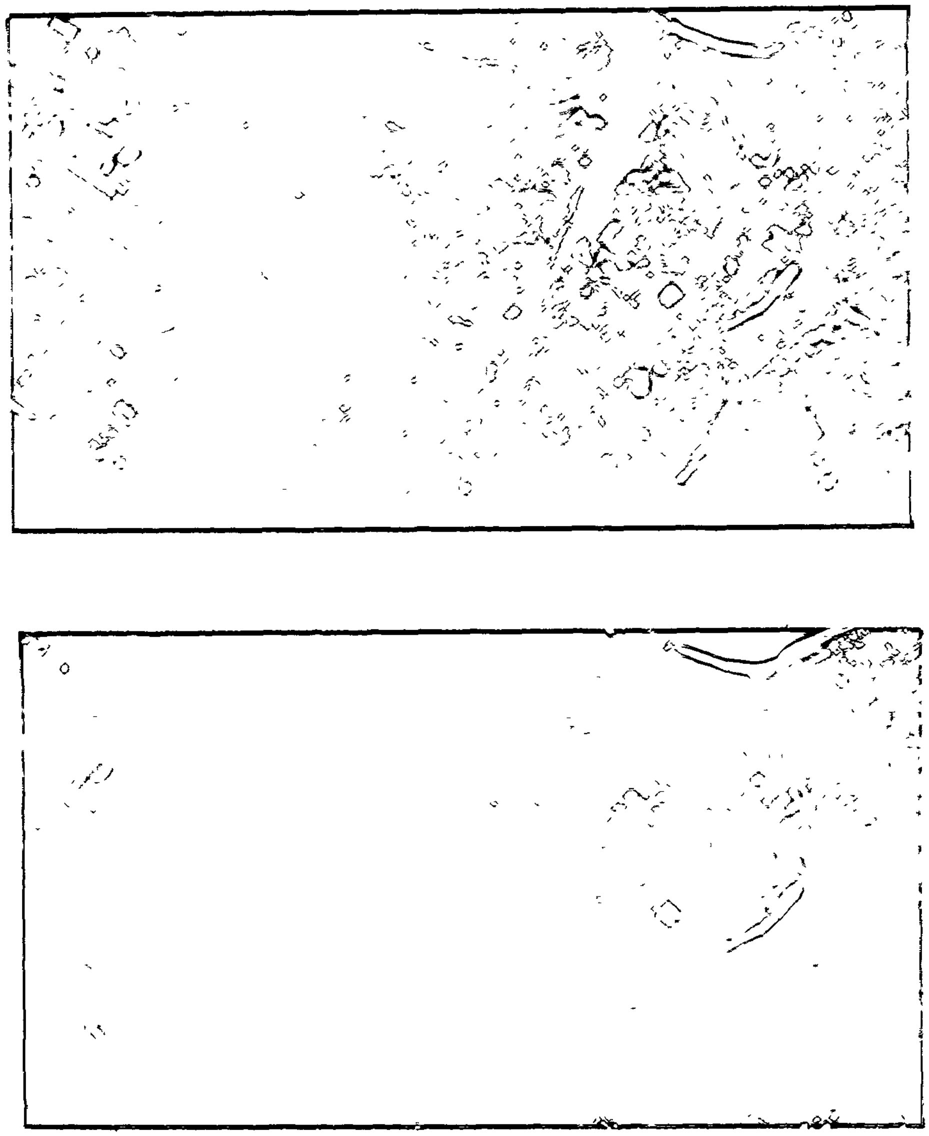
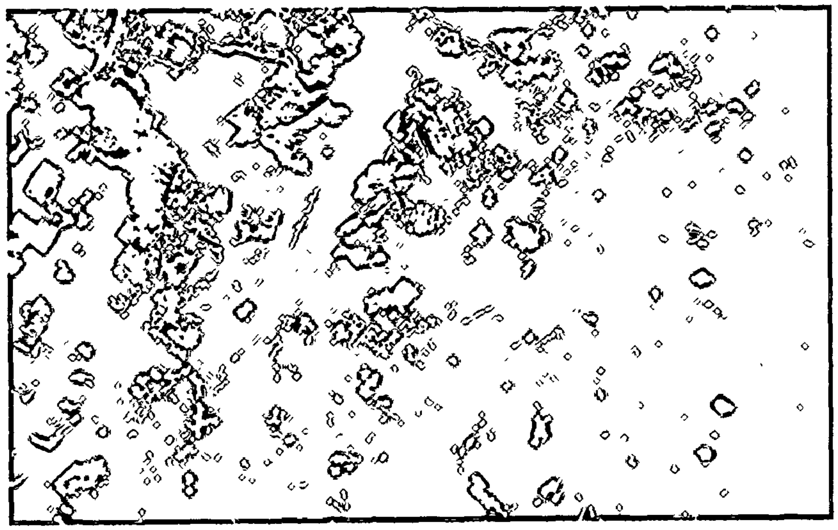


Figure 5.3: X-Band SAR imagery for Scene F150 P6. The X_{HH} image is in the upper half of the figure and X_{HV} image in the lower half.



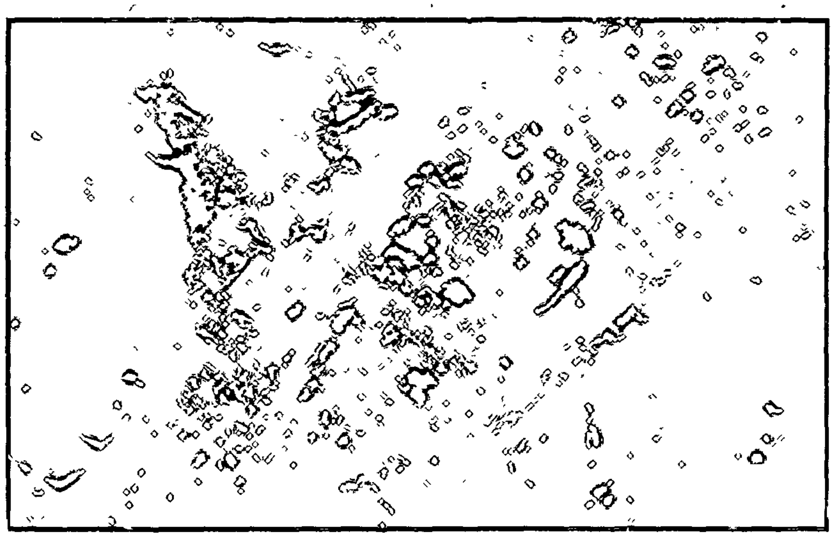


Figure 5.4: L-Band SAR imagery for Scene F150 P6. The L_{HH} image is in the upper half of the figure and X_{HV} in the lower half.

To do the mapping, acetate overlays were placed on the transparency and a light table was used to illuminate the transparency. The land cover/use, linear features and strong and weak return maps were produced in turn.

5.5 Results

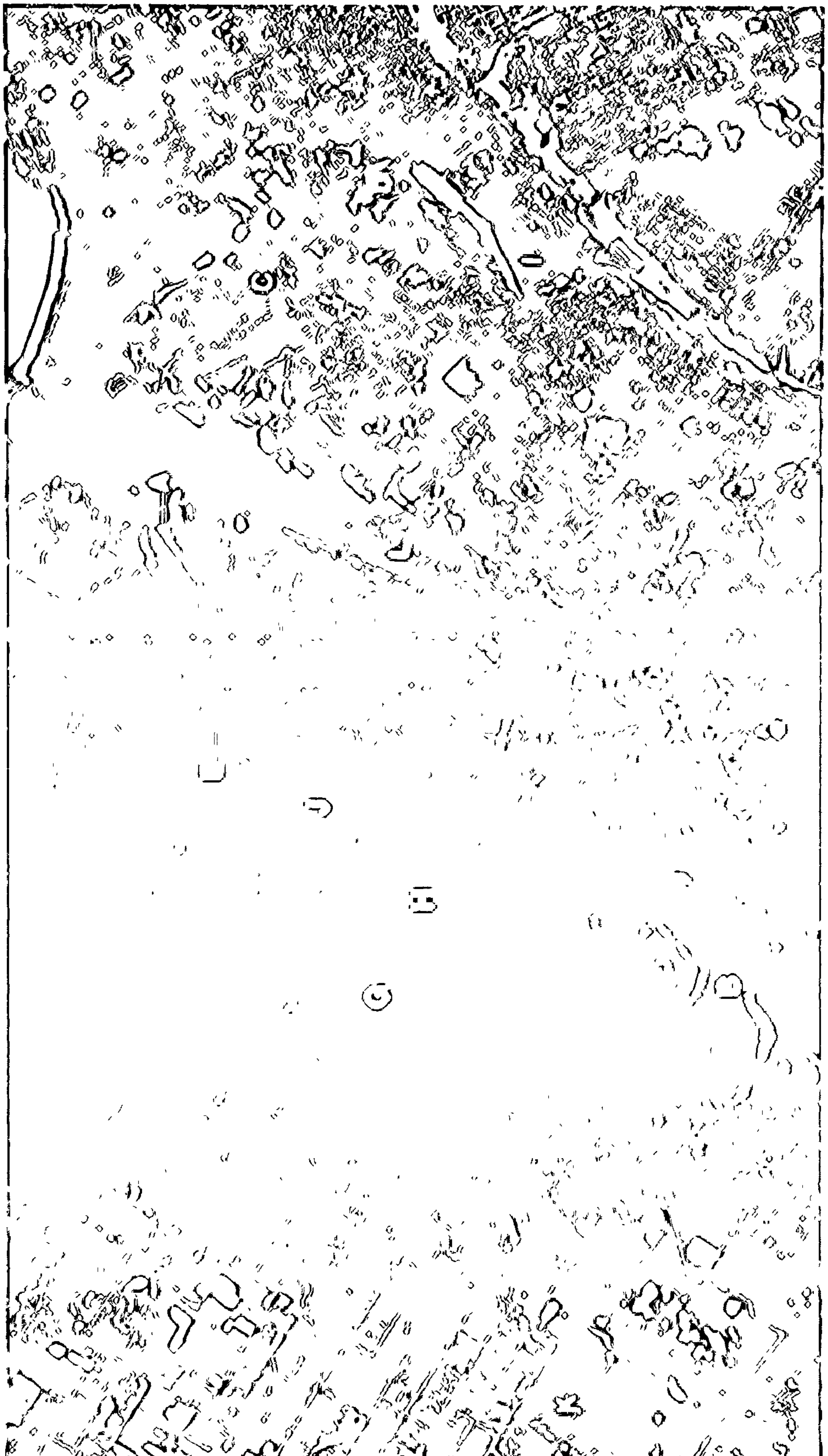
5.5.1 Comparison of Images

The four images can be compared in Figures 5.3 and 5.4. To aid in identification of locations on the images, however, the X_{HH} image has been enlarged as Figure 5.5. Letters on the image help to indicate some of the points made in the descriptions. From a detailed study of the four images, the following observations can be made:

1. X-Band, HH Image. On this image, boundaries between water and land (A) are clear (Figure 5.5), but the very dark tone of the water surfaces is similar to areas of radar shadow (B). This can cause confusion, so during thematic mapping topographic maps would have to be used to check the locations of water bodies. In addition, there is no information in areas of radar shadow.

Built-up areas (C) are identified by the pattern of streets, the relatively light tone of these areas and the occasional very bright returns. The distinction between residential areas and commercial areas is based on the very high back scatter from large industrial complexes (D).

Major transportation routes are identified by their long, narrow linear shape, with constant tone. Railroads show up as light tones (E) but concrete or asphalt highways are dark to black (F).



The stronger return from railroad tracks is thought to be due to the gravel ballast and metal rails, while road surfaces are smooth and do not generate strong returns.

Agricultural land was detected by its patterns and related smooth texture. The tones are light and medium dark. The light tones relate to strong returns from corn fields (G), which have a relatively rough surface, while darker tones represent weak returns from small grains, hay fields or pasture (H).

Identification of vegetated urban areas was based on their location and dark, smooth tones (I). Forests have strong returns, similar to urban areas, but there is no regular pattern (J). The quarry (K) was identified by its patterns and shape rather than tone. The identification of vacant land (L) was based on location and light tones. It appears similar though to vegetated urban land and therefore, is difficult to identify.

2. X-Band, HV Image. In general, the X_{HV} or crosspolarized image shows the same features as the X_{HH}, but the contrast ratio is lower. The image is more monotone and in some cases washed out. All the features mentioned for the X_{HH} frame were located and a comparison of the images can be made in Figure 5.5.

The only advantage of the X_{HV} image compared to the X_{HH} image, is the reduction of the star effect around areas of strong return. The agricultural areas display similar tones to the X_{HH} image, but the contrast between corn and other crop types is far lower than on the X_{HH} image.

3. L-Band, HH Image. This image has a large contrast ratio, but is more coarse than the X-Band images. Basically all the same classes that have been mentioned before can be identified, but due to the coarse nature of the image, identification is more difficult. Major disadvantages are the large shadows created around strong returns and the lack of a good range of grey tones. This means that parts of the image contain no information and, for example, for water, small grain and vegetated urban areas is the same. Thus interpretation would be more difficult than with the X-Band data.

4. L-Band, HV Image. The whole frame is rather grainy and gives the appearance of being out of focus. The cross polarization has the same effects as in the X band to reduce the strong starlight effects from structures with strong return signals. Main urban areas can be identified by the patterns, but detail is not as clear as on the X-Band images.

The comparison of the four images led to the conclusion that the X_{HH} Frame would be the most appropriate image to use for land cover/use studies.

5.5.2 Linear Features

The X_{HH} image was used to produce a map showing linear features (Figure 5.6). The linear features consist primarily of street patterns, major highways, railways and field boundaries. As can be seen from Figure 5.5 it is not possible to identify the complete street network.

In rural areas, boundaries between fields are clearly identified if trees or brush occur along the fence line. In other cases,

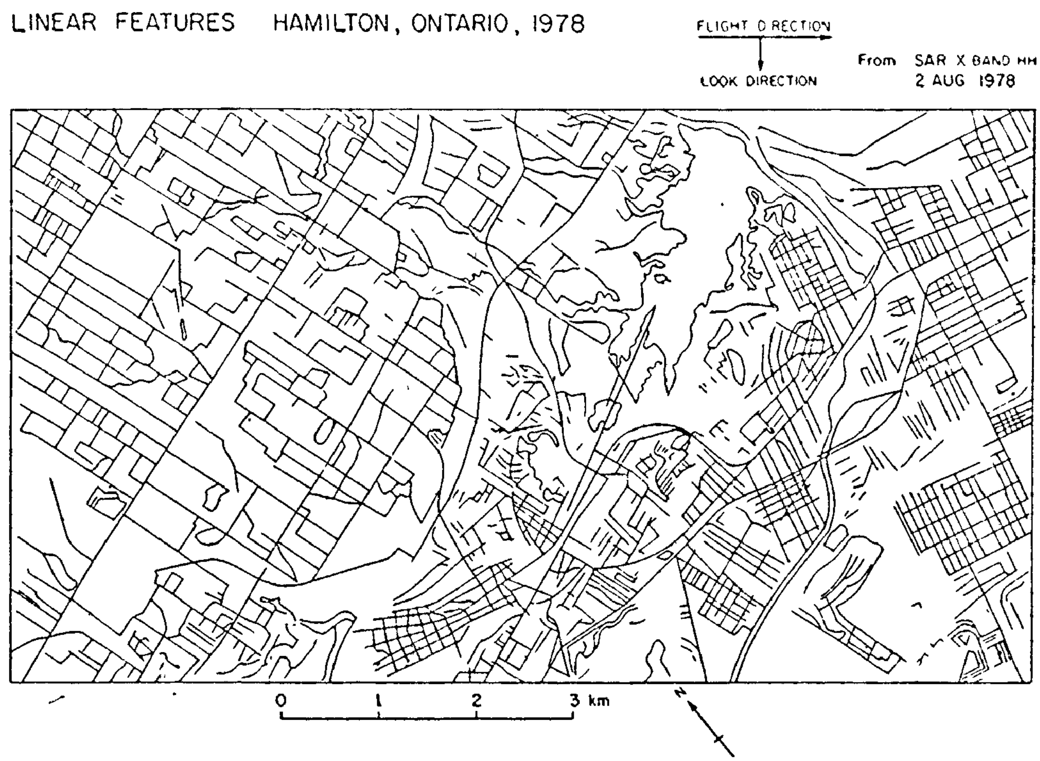


Figure 5.6: Map of linear features produced from the X_{HH} image of Scene F150 P6.

a change in tone between two fields identifies the boundary. Roads in rural areas are usually identified as dark lines due to lack of return from the smooth surface.

5.5.3 Strong and Weak Returns

Due to the nature of the radar waves, strong and weak returns have a different significance from the dark and light tones on aerial photographs. The map in Figure 5.7 shows metal structures, hydro towers (M) and fences (N) as bright points and lines indicating strong returns. Buildings sometimes act as corner reflectors to produce strong returns (O), if oriented towards the nadir line. Water, shadow and the dark areas around strong point sources represent the main sources of dark points and areas representing weak returns.

The information provided by areas of strong and weak returns is of little value when preparing a land cover/use map.

5.5.4 Land Cover/Use Map

The final step in this analysis was the creation of a land cover/use map. The basic source of information was the X_{HH} transparency and the map created from it is shown in Figure 5.8.

As can be seen, all the classes described in the classification scheme in Chapter 2 can be identified. Major highways, railroads and power lines interpreted from the image are also shown in Figure 5.8.

A discussion of the accuracy of the map is presented in Chapter 7.

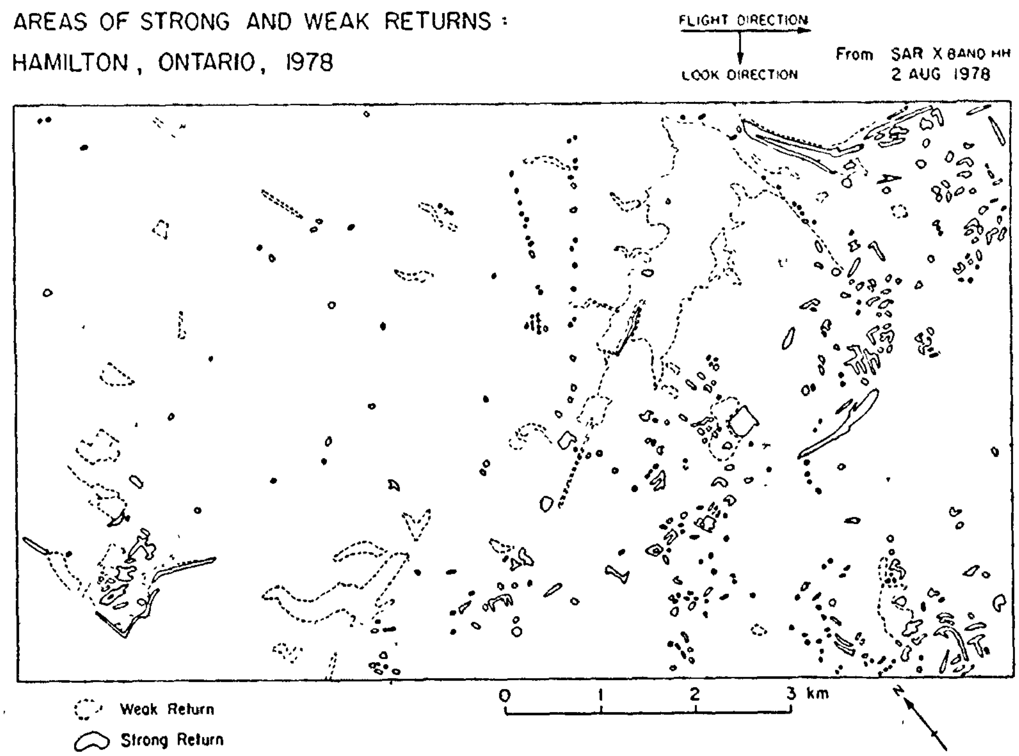


Figure 5.7: Map of strong and weak returns produced from the X_{HH} image of Scene F150 P6.

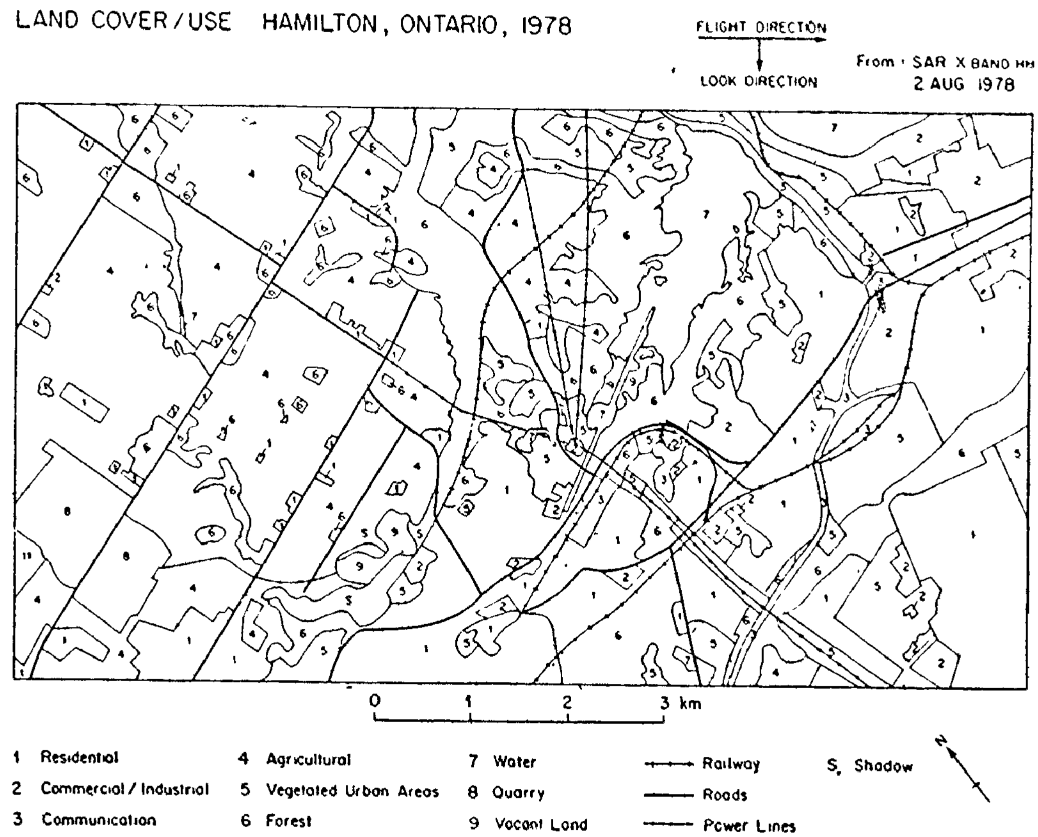


Figure 5.8: Land cover/use map produced by visual interpretation of the SAR X_{HH} image, Scene F150 P6.

CHAPTER 6

DIGITAL CLASSIFICATION OF LANDSAT MSS DATA

6.1 Introduction

As described in Chapter 3, LANDSAT MSS data are recorded as numerical values representing reflectance from ground surfaces. The reflectance is recorded on a scale of 0-63 for each of four wavelength bands. Digital analysis consists of manipulating the numerical values through procedures generally known as spectral pattern recognition. This is done using an image analysis system which consists of a TV monitor to display an image and the classifications, a computer and software to drive the system, and several ancillary pieces of equipment.

The idea of numerical representation of MSS data is illustrated in Figure 6.1. Such data can be collected from an aircraft or a spacecraft. The figure shows an MSS scan line consisting of squares or pixels. The MSS measures the reflectance, and in some scanners the emittance, as digital numbers in each of the spectral bands. In this case five bands are shown, but LANDSAT only has four. Examples of relative digital numbers recorded over six land cover types are shown. The set of values for a particular land cover type is known as its signature. Spectral pattern recognition or multispectral classification is a process by which the digital values are analyzed and then pixels are assigned to classes based on similar signatures.

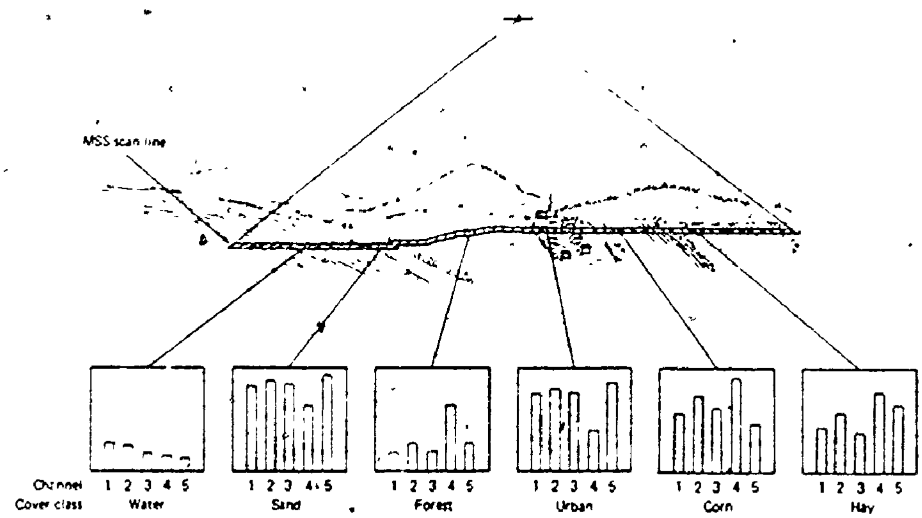


Figure 6.1: Typical spectral reflectance values recorded by a multispectral scanner system (from Lillesand and Kiefer, 1979, p. 459). Note that the LANDSAT MSS only records in four channels or bands, but the principle is the same.

There are two general methods of digital classification, namely supervised classification and unsupervised classification. In this chapter, methods for digital classification of LANDSAT MSS data are described.

6.2 Previous Studies Using Digital Analysis of LANDSAT MSS Data

A wide range of studies using LANDSAT MSS data has been undertaken in the decade since the first data became available. In the literature there are articles covering all aspects of the manipulation of MSS data. Some of these papers provide technological descriptions of system design (e.g. Shlien and Goodenough, 1974), while others discuss application methodologies.

Land cover/use studies embrace a wide range of topics. Some deal with urban studies only(Todd et al.,1973); others deal with the differentiation of urban and rural land (McKeon et al., 1978; Friedman and Angelici, 1979). Several papers discuss the integration of socioeconomic data and land use data obtained from LANDSAT (Bryant, 1976; Landini and McLeod, 1979).

Specific types of land cover/use have been studied, e.g. agriculture and forestry (Erb, 1974; Lee, 1977, 1980; Kalensky, et al., 1979; Gautreaux, 1977). A particular emphasis in Canada has been land cover in remote areas (Kozlovic and Howarth, 1977; Cihlar,et al.,1978;Wickware,1979 1978; Wicken, et al., 1980; Wickware and Howarth, 1981). The coastal zone has also been studied (Prout, 1978).

Last, but not least, are several studies on general land cover/ use in which diverse ranges of classes have been identified (Dornbach and McKain, 1973; Goodenough and Shlien, 1974; Economy et al., 1974; Prout, 1977; Schubert et al., 1977; Rubec, 1978; Gaydos and Newland, 1978; Schneider, 1980).

The general conclusions of these studies present positive attitudes in the use of LANDSAT digital data. Problems such as spectral and spatial resolution, the time factor and costs involved are acknowledged. However, the advantages of large area coverage, the availability of data and the short time required to undertake classification for a large area are emphasized.

6.3 Methodology for Digital Analysis of Landsat MSS Data

There are two general methods for the digital classification of MSS data, namely unsupervised and supervised classification.

6.3.1 Unsupervised Classification

In this method, algorithms are used to test the image data and divide them into similar categories or natural groupings of the digital values. The result of this procedure is a series of spectral classes. The analyst must then identify the classes and relate them to the ground cover. The methodology and results have been discussed by several Canadian authors (Goldberg et al., 1975; Lee, 1977; Schubert et al., 1977; Rubec and Wickware, 1978; Rubec and Thie, 1978; Wickware, 1978; Prout, 1978; Cihlar et al., 1978). In most of these studies, however, supervised classification is presented as being superior to unsupervised classification. The unsupervised method, however, is of value where little or no ground information is available prior to fieldwork.

As a result of the above recommendations, a detailed unsupervised classification of the study area was not undertaken. The time to produce an unsupervised classification, however, is relatively short and an example for west Hamilton is given in Figure 6.2. A brief inspection of the image indicates that the spectral classes identified by the different colours represent the following:

Black: water

Dark blue: residential and open vegetated areas

Orange: commercial, industrial, highrise, residential and services

Purple: mainly residential and communication

Yellow: agricultural and vegetated urban areas

Light pink: forest and agricultural areas

Light blue: forest and vegetated urban areas.

From the description of the classes, the problem of land cover/use classes being represented by more than one spectral class can readily be appreciated.

6.3.2 Supervised Classification

In Figure 6.3, the process of spectral pattern recognition using supervised classification is illustrated. Although the diagram shows a data set with five channels or bands, exactly the same principles apply with LANDSAT which has only four bands.

In contrast to unsupervised classification, supervised classification requires input from the analyst. Independent information is

Figure 6.2: An example of an unsupervised classification produced for part of west Hamilton.

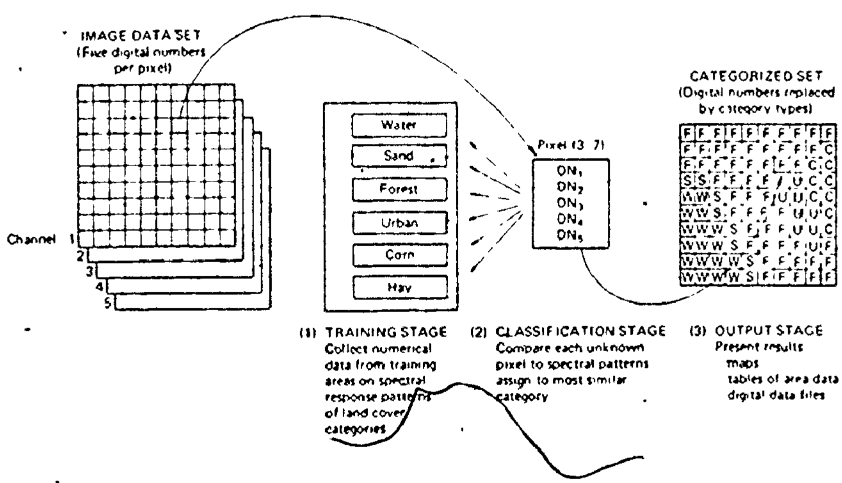


Figure 6.3: The process of spectral pattern recognition (from Lillesand and Kiefer, 1979, p. 460).

used to establish classes. This could consist of known spectral information about each class, but in most cases it consists of knowledge about ground cover in selected parts of the study areaa. The ground cover information is used for establishing training sites.

As illustrated in Figure 6.3, supervised classification consists of three major stages, namely training, classification and output:

1. Training. This is the most vital stage in the supervised classification process. It begins with the selection of training areas that are good representatives of each class to be identified during the classification stage. These areas are selected on the basis of ground observations, often supported with large scale aerial photographs. Once defined, the training set is stored in the memory of the computer.

In selecting training areas, data are usually collected from more than one site. When using a classifier based on the statistics of the image, at least n + 1 pixel observations must be collected for each class, where n is the number of spectral bands. In practice, a minimum of 10 to 100 pixels is used (Lillesand and Kiefer, 1979; Sabins, 1978). Another reason for selecting data from more than one site is to sample the variability of the ground cover for each class so that in classification all revelant areas will be put into the appropriate class.

2. Classification. At this stage, each unknown pixel is examined and compared to the known pixels selected during the training stage. Each pixel is then assigned to the most similar class, the decision being made using one of several possible mathematical procedures.

The two methods most commonly used in Canada involve the parallelepiped classifier and the maximum likelihood classifier. The parallelepiped classifier is described in detail by Shlien and Goodenough (1974) and Lillesand and Kiefer (1979). Within each class or category in the training set, a maximum and a minimum value can be identified in each band. In a two-dimensional scatter diagram the maximum and minimum values define the limits or boundaries of the decision region. The decision region is a rectangular area, as illustrated by the dashed lines in Figure 6.4. The figure shows a scatter diagram for six classes. The letters indicate typical values that might be obtained for water, urban, sand, corn, hay and forest.

In classification an unknown pixel (e.g. number 2 in Figure 6.4) is assigned to the class in which it is located. Problems obviously arise if a pixel is located in the decision region for more than one class. Various procedures can be used to decide in which class the pixel should be placed.

In Figure 6.4, only two bands are displayed. Using LANDSAT data with four bands it is possible mathematically to define four dimensional decision regions which are referred to as parallelepipeds.

The second method of automated classification involves using the maximum likelihood classifier. The basic concepts have been described by Shlien and Goodenough (1974), Goodenough and Shlien (1974), Schubert et al. (1977) and Lillesand and Kiefer (1979). The maximum likelihood classifier evaluates both the variance and the correlation of the class when placing an unknown pixel into its appropriate class. In using this classifier, the basic assumption is made that the distribution of the pixels forming each class in the training set is normally distributed. "Under this assumption, the distribution of a category response pattern can be completely described by the mean vector and the covariance matrix (which describes the variance of correlation)" (Lillesand and Kiefer, 1979, p. 466).

Using the mean vector and the covariance matrix, the probability of a given pixel value being in a particular class can be computed and as a result gives probability density functions. These are then used to classify unknown pixels by calculating the probability of the pixel value belonging to each category. After that the pixel is assigned to the most likely class or is defined unknown if the probability values are below certain threshold levels.

The maximum likelihood classifier uses decision regions delineated by ellipsoidal "equiprobability contours". This is illustrated in Figure 6.5 where the shape of the contours expresses the sensitivity of the classifier to correlation.

The major drawback to using the maximum likelihood classifier is the large number of calculations required to classify each pixel. With ten classes a total of 200 calculations is required to classify each pixel. Methods have been devised, however, to speed up the process (Shlien and Goodenough, 1974).

The decision on which classifier to select is often a matter of personal preference. The maximum likelihood classifier is slower and more expensive to use, but the final classification is generally considered to be of a higher accuracy.

Following classification of the data, it is possible to filter or smooth the results. This removes isolated pixels and gives the final classification a more generalized appearance, which is similar to a map produced by convent[illegible] methods.

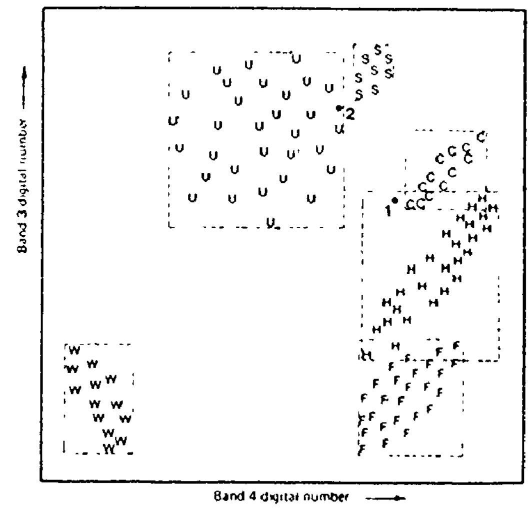


Figure 6.4: An example of parallelepiped classification using two bands of data (from Lillesand and Kiefer, 1979, p. 465).

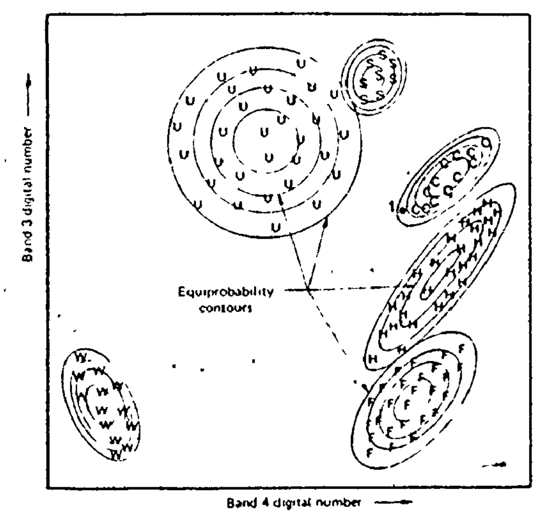


Figure 6.5: Equiprobability contours defined by a maximum likelihood classifier (from Lillesand and Kiefer, 1979, p. 468).

3. Output. This is the last of the three stages illustrated in Figure 6.3. There are several methods of output available:

a) Images photographed off the TV monitor or reproduced on a colour image recorder.

b) Lineprinter or electrostatic printer outputs of data, classifications and grey line maps

c) Tabulations of results.

Storage of data and classifications can also be done on computer tape for further analysis.

6.4 Results

Both the maximum likelihood classifier and the parallelepiped classifier were used in the present study. The two investigations are reported separately.

6.4.1 Maximum Likelihood Classification of LANDSAT Data

The maximum likelihood classification was carried out at the Ontario Centre for Remote Sensing in Toronto. The image analysis system used was a Norpak RGP 3050 Image Display Subsystem driven by a PDP 11/34 computer with 64K memory. Software on this system is the ARIES application software developed by DIPIX Systems Ltd. of Ottawa.

The analysis followed the three steps of training, classification and output outlined previously.

1. Training. The 56 training sites identified and mapped on 1:10,000 scale photographs (Chapter 2) formed the basis for selecting

training pixels for each class. In practice, the 56 sites proved to be too many and good representative samples from different parts of the study area were obtained just using 13 of the training sites. Figure 6.6 shows the distribution of the training sites.

The training procedure was done as follows:

a) A training area was selected and displayed on the TV monitor of the image analysis system.

b) Using the 1:10,000 scale aerial photographs as a guide, training pixels for the different classes were selected (using a cursor to outline the areas) and stored in the computer memory.

c) Steps a and b were repeated for another training site and the training pixels were added to the appropriate classes.

Step b is based on visual interpretation of the scene with Bands 4, 5 and 6 displayed on the TV monitor as a colour composite. Figure 6.7 shows one of the training areas displayed on the monitor, while part of the same area on a 1:10,000 scale aerial photograph is shown in Figure 6.8.

The intention had been to train the system to classify the scene into nine classes, as described in Chapter 2. However, because of the difficulty of training on narrow linear features such as highways (often only one pixel wide), the communication class was dropped from the classification scheme.

Several other training problems were also encountered in the initial experiments. First, there was wide variability in the spectral characteristics of the water. As a result of this, many of the water

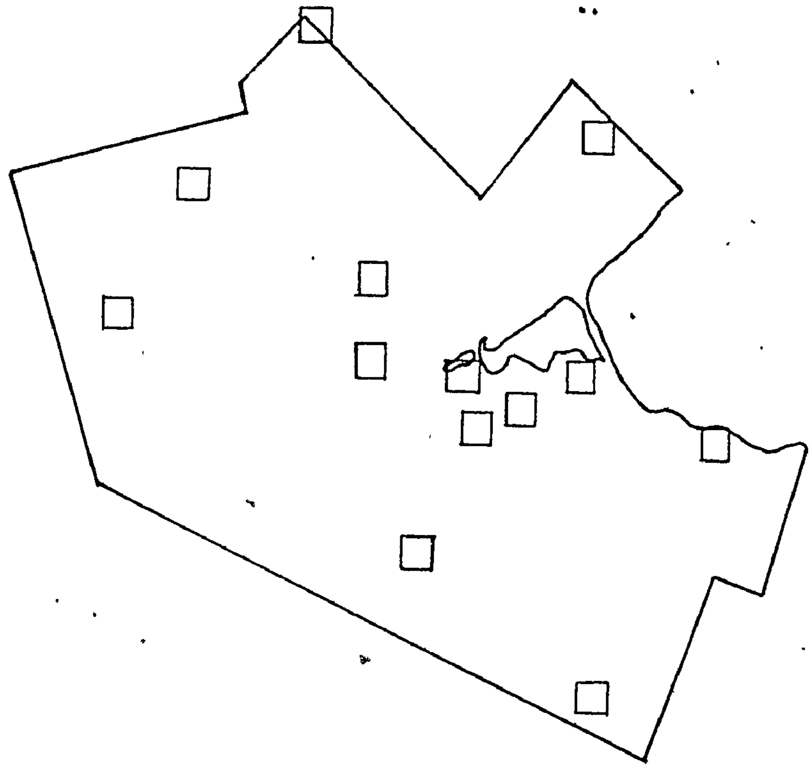


Figure 6.6: Distribution of training sites used for the maximum likelihood classification.

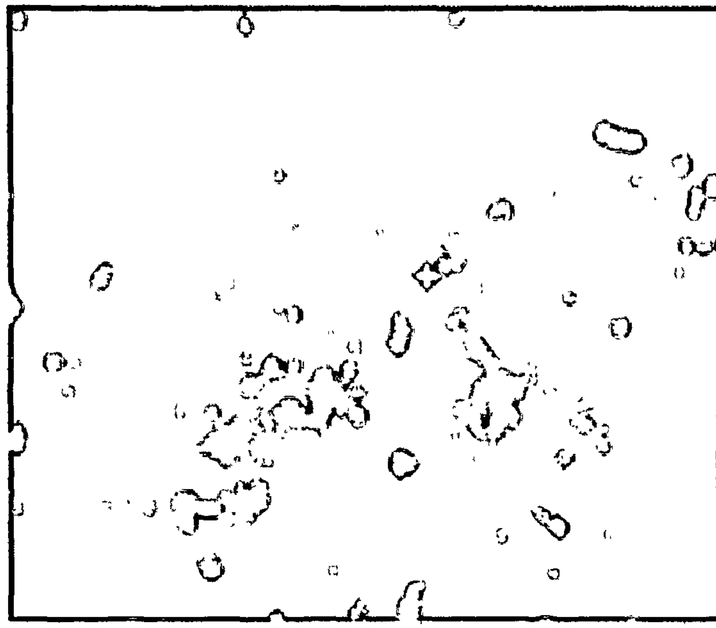


Figure 6.7: A training area from part of west Hamilton, displayed on the TV monitor.

Figure 6.8: Part of the area shown in Figure 6.7 seen on a reduced 1:10,000 scale aerial photograph.

pixels were not classified and particularly in polluted areas, several of the pixels were classified as industrial land.

A second problem was encountered in classifying new residential areas which had different spectral characteristics from the older residential areas. Many of the new residential areas remained unclassified.

A third problem occurred in agricultural areas where surfaces consisted of both vegetation and bare soil. Fields with bare soil or little vegetation were often classified as industrial or residential areas.

The above three problems were overcome by using additional training sets. Instead of eight categories a total of eleven was used. Water was subdivided into clear lake water and harbour and/or polluted water. Two classes were established for new and old residential areas and similarly agricultural areas were divided into vegetated and bare areas.

To determine the spectral separation of the training sets, it is possible to generate some of the statistical measures for each class. Unfortunately, the original training statistics were inadvertently dumped by another user on the system. However, it was possible to regenerate statistics very similar to the original ones by selecting groups of classified pixels and treating them as training sets. They were selected from the same areas in which the training was done.

In Table 6.1, the mean and standard deviations for each band of the eleven "regenerated" training sets are listed. Values are on a scale of 0-255. Graphs of the mean values (Figure 6.9) give a much clearer picture of the trends and ranges of the data. It can be seen

Table 6.1 Maximum Likelihood Classification Mean Digital Value and Standard Deviation for Each Band of the Training Sets

	BAND							
	4		5		6		7	
Training set	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
New residential	49.4	4.2	55.4	6.6	73.5	5.1	70.8	9.3
Old residential	51.9	6.3	61.7	10.0	93.3	9.9	98.8	14.8
Industrial, commercial, services	45.7	3.7	51.4	6.4	57.0	10.4	48.6	14.4
Vegetated agricultural land	45.0	3.8	51.1	7.4	98.9	5.0	114.5	8.2
Bare soil	44.8	7.3	48.4	10.6	97.1	8.6	113.1	19.0
Vegetated urban areas	53.6	12.8	63.3	19.5	107.0	15.7	120.3	32.6
Forest	36.9	5.4	36.1	8.9	103.4	8.0	127.1	15.2
Lake water	30.3	1.1	24.5	1.0	17.6	1.1	7.7	1.7
Harbour or polluted water	35.6	2.3	33.9	4.0	27.7	7.9	15.2	9.5
Quarry	97.0	5.6	131.3	8.1	136.6	7.8	119.9	8.9
Vacant land	55.5	15.6	68.5	24.8	113.0	8.6	122.9	11.5

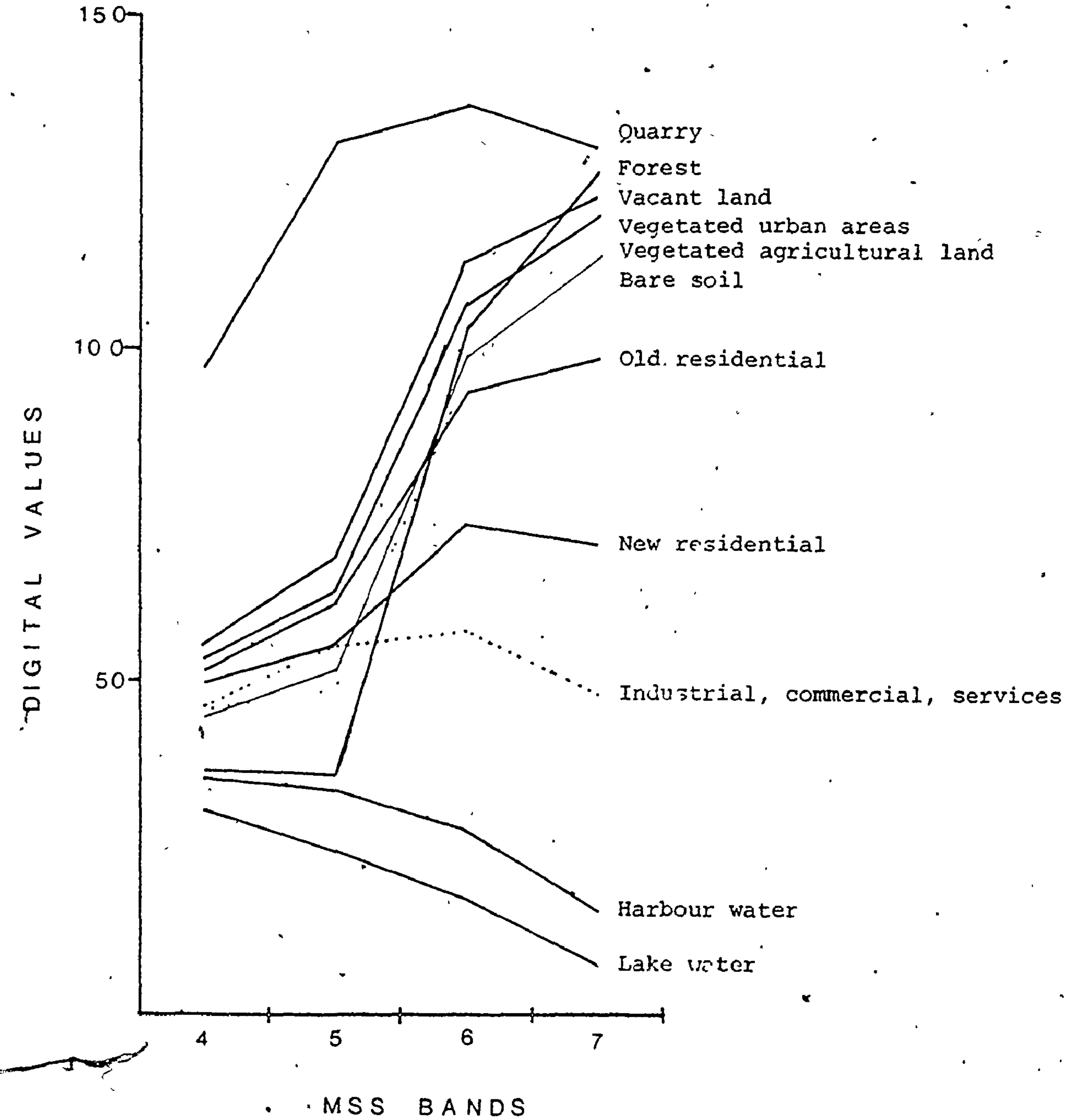


Figure 6.9: Graphs of mean digital values in each band for the eleven training sets used in the maximum likelihood classification.

that in general there is a wider range of digital values in the infrared (Bands 6 and 7) than in the visible part of the spectrum (Bands 4 and 5). The classes which have vegetation associated with them have higher values in the near infrared, as is to be expected.

The quarry and industrial areas have relatively high values in Band 5, but they decline in the infrared bands. Water has low values in all four bands.

The standard deviation gives a measure of the variability of the data so that high standard deviations in classes with similar mean values are likely to experience spectral overlap in that particular band. Confusion between classes will only occur if this is the situation in all four bands. As can be seen from Table 6.1 and Figure 6.9, the only major confusion would appear to be between vegetation covered agricultural land and old residential land and vegetated urban areas and old residential areas.

2. Classification. The maximum likelihood classifier was applied using eleven classes for which training sets had been selected. Approximately 1000 pixels were contained in the eleven training sets. They thus consisted of approximately 0.05% of the total pixels for the entire MSS DICS data.

The area classified measured 1160 pixels by 1660 pixels or approximately 58 km by 83 km. The PDP 11/34 was dedicated to the task of classification for a total of 2 1/2 hours.

Although eleven classes were generated, when the image was displayed, the two water classes, the residential classes and the agricultural classes were displayed in the same colours. Results of the classification for the area shown in Figure 6.7 are illustrated in Figure 6.10.

In addition to combining classes, filters were applied to the initial classification to generalize the results. Two examples are shown in which the image displayed in Figure 6.10 has been generalized. In Figure 6.11 every third pixel is displayed, but it covers nine times the area. Thus, the rectangular pattern of the original image and classification is retained.

In Figure 6.12, a 5 x 5 strong filter has been applied. The central pixel is compared with the surrounding pixels in a 5 pixel by 5 pixel block. If similar to surrounding pixels, the classification of the central pixel will be changed. Smoothing of the classification making it more akin to a conventional map is the result.

In both of the above cases, detail of the land cover/use might be lost. For this reason the accuracy tests discussed in Chapter 7 were only carried out on the unfiltered data.

3. <u>Output</u>. The following outputs were selected:

a) Displays of the final classification on the TV monitor for the whole area and for sub-areas. Photographs of these were taken with a 35 mm camera.

In Figure 6.13, the entire area as classified by the maximum likelihood classifier is displayed. It is also possible to display small areas, and the classified area shown in Figure 6.7 and 6.8 is displayed in Figure 6.10. The latter figure is out of order so that the comparisons can be more readily made between the classified and unclassified image.

Figure 6.10: Maximum likelihood classification for the area displayed in Figure 6.7. Classes are represented by the colours as follows:

Red:	residential
Pink:	industrial, commercial, services and wetland
Green:	agriculture and vegetated urban areas
Dark brown:	vegetated urban areas
Yellow:	forest
Dark blue:	water
Light blue:	vacant land
White:	quarry
Black:	unclassified

Figure 6,11: A generalized maximum likelihood classification. Every third pixel is displayed at nine times its size. Classes have also been grouped so that the colours represent the following:

Red:	residential
Light blue:	industrial, commercial, services and wetland
Yellow:	agriculture and vegetated urban areas
Green:	forest
Light brown:	vacant land
Dark blue:	water
Purple:	quarry
Black:	unclassified.

Figure 6.12: Application of a 5 x 5 strong filter to an extension of the classification shown in Figure 6.10. Colours are the same as in Figure 6.11.

Figure 6.13: Entire DICS scene classified using the maximum likelihood classifier. Colours are the same as in Figure 6.10.

b) Tables listing the number of pixels in each class and the number of hectares, km^2 or percentage of the screen that each class represents were prepared.

In Table 6.2, the final numbers of pixels in each class are displayed as a percentage of the total scene. Given that each pixel is 50 m by 50 m, the ground areas represented by each class could be readily calculated.

c) Theme (i.e. class) printouts on the electrostatic printer using grey tones can be generated at any chosen scale. Although several were generated, they did not aid in the present analysis.

d) Theme printouts can be generated at any scale on the Applicon Colour Plotter. A land cover/use map of the study area at a scale of 1:50,000 was produced for an area measuring 35 km by 20 km. The PDP 11/34 took 4 hours of dedicated time to generate a tape for the plotter. Production of the map on the plotter took 15 minutes.

The outputs generated serve different purposes. A major advantage of using the plotting systems discussed under c and d is that geometrically correct printouts at specified scales can be generated. Colour production in particular takes a great deal of time.

6.4.2 Parallelepiped Classification of LANDSAT Data

The parallelepiped classification was undertaken at the Canada Centre for Remote Sensing in Ottawa using the Image Analysis System (CIAS). The system has been described by Goodenough and Shlien (1974).

1. Training. Using the parallelepiped classifier on the CIAS,

Table 6.2 Maximum Likelihood Classification for the Total LANDSAT MSS DICS Scene Data Set Used in the Study

Training Theme.	No. of Pixels	% of Scene
New residential	80,197	4.16
Old residential	237,964	12.36
Industrial, commercial services	18,194	0.94
Vegetated agricultural land	379,102	19.69
Bare soil	301,591	15.66
Vegetated urban land	191,281	9.93
Forest	224,321	11.65
Lake water	256,178	13.30
Harbour water or polluted water	3,212	0.17
Quarry	5,943	0.31
Vacant land	219,384	11.39
Unclassified	8,233	0.43
TOTAL	1,925,600	100.00

training and classification are much more interrelated. Using the maximum likelihood classification, all training areas have to be identified before the classification can be produced. With the parallelepiped classifier, the result of training on only one class can be displayed on the TV monitor of the CIAS almost immediately. Modification to extend or reduce the size of the training area can then be made to more accurately portray the extent of the class being generated. In addition, areas of overlap between two classes can be inspected and adjustments made, if necessary.

Due to the above characteristics of the parallelepiped classifier and the time limit available, it was decided to train in only one area that measured 130 pixels by 130 pixels. The area centred on Cootes Paradise, that was studied in detail using the other sensors, was selected for analysis.

The aim was to use the same classes that had been generated using the maximum likelihood classifier. Due to extensive overlap in the vacant land category with agricultural, vegetated urban areas and residential, changes in the classification scheme had to be made. The final classes selected were:

a) Residential
b) Industrial, commercial services
c) Construction areas
d) Agricultural
e) Vegetated urban areas
f) Forest
g) Water
h) Quarry

The new class added was construction areas. In part it overlapped with residential and with industrial, commercial and services, but was for the most part spectrally distinct.

In Table 6.3, the upper and lower limits, the means and the standard deviation for the digital values in each band of each class are displayed. These are on a scale of 0-255 for increased spectral resolution. To be spectrally unique, a class must have values that differ from all other classes in at least one band. If there is to be no spectral confusion between two classes, there must be no overlap of digital values in at least one band. From an inspection of Table 6.3, it can be seen that the quarry is the only spectrally unique class, but most of the classes can be separated from each other in at least one band.

A plot of the mean reflectance values for each class in each band is given in Figure 6.14. As with the maximum likelihood classification, the anticipated pattern of values is observed with the major differences occurring in the infrared bands.

2. Classification. As pointed out earlier, training and classification are carried out at the same time so that the classification is gradually built up in stages. Gaps can be filled in by training on pixels not yet classified and then adding the new pixels to the appropriate class

In Figure 6.15, the final classification generated using the spectral values given in Table 6.3 is presented. The classification took approximately 3 hours to generate. The classes represented in the figure are as follows:

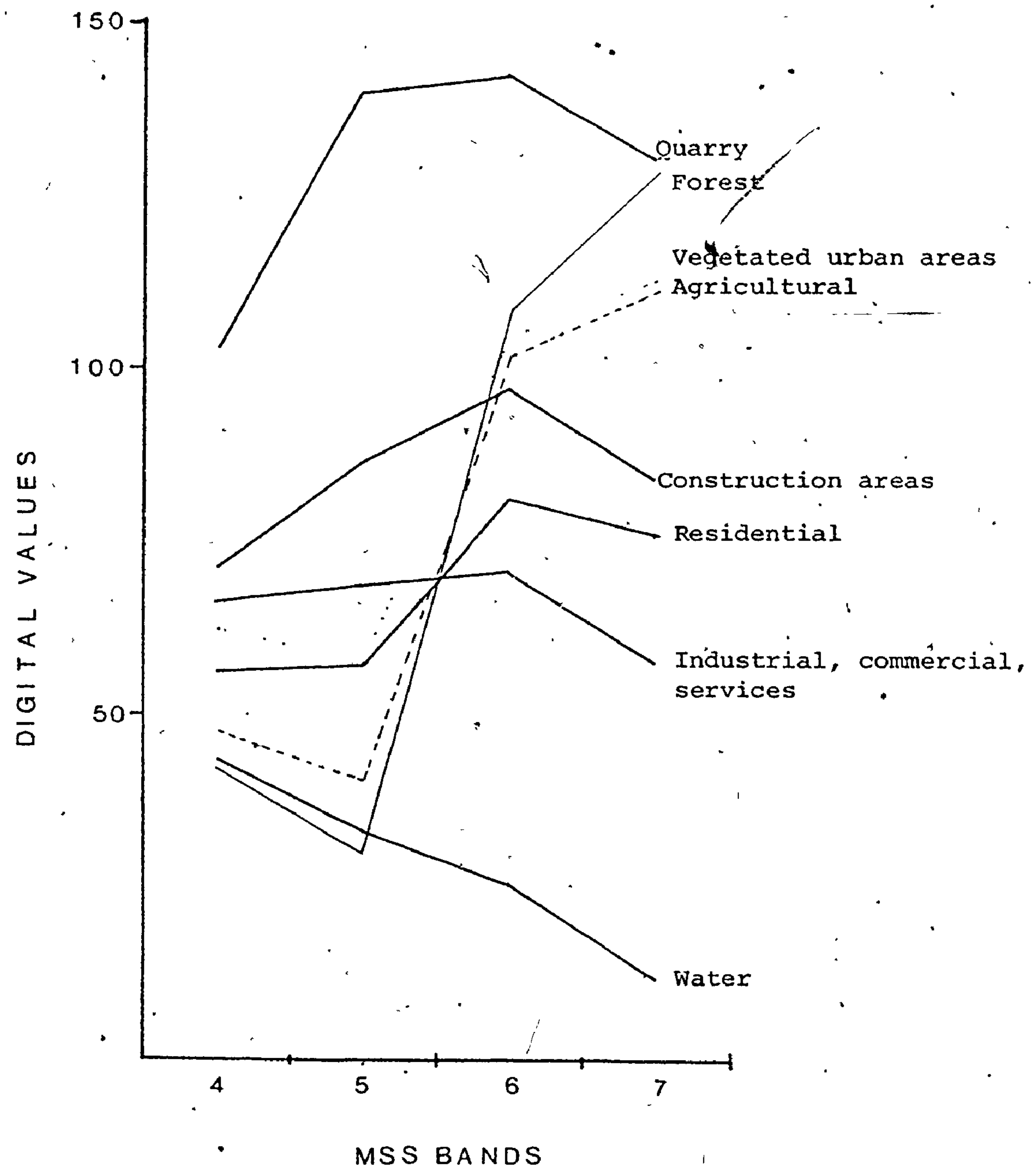


Figure 6.14: Graphs of mean digital values in each band for the eight training sets used in the parallelepiped classification.

Table 6.3 Parallelepiped Classification: Lower and Upper Limits, Means and Standard Deviation of the Digital Values in Each Band for Each Class

	BAND							
	4		5		6		7	
Class	Lower mean	Upper St. dev.	Lower mean	Upper St. dev.	Lower mean	Upper St. dev.	Lower mean	Upper St. dev
Residential	48 56.4	66 3.7	47 56.8	70 6.1	65 80.9	93 6.6	60 76.1	89 8.4
Industrial, commercial, services	55 66.3	79 4.5	60 68.3	94 7.0	51 71.0	85 7.3	35 58.0	70 8.4
Construction areas	63 71.6	89 5.7	74 86.9	119 10.2	84 97.6	117 9.2	66 84.3	104 11.0
Agricultural	43 47.8	52 2.4	33 40.2	47 4.1	69 101.7	126 13.4	70 111.1	146 18.2
Vegetated urban area	49 52.3	59 2.5	39 47.4	55 4.6	89 104.8	143 11.2	90 112.6	169 16.2
Forest	36 41.6	45 2.0	24 30.0	34 2.5	65 108.7	139 13.2	69 128.4	170 18.2
Water	36 43.2	48 2.2	24 33.0	43 3.5	10 26.1	65 9.8	1 12.1	57 11.3
Quarry	92 102.6	118 6.2	124 139.9	165 9.0	127 142.9	164 8.4	114 130.4	149 8.1

Yellow: water

Green: residential

Orange: industrial, commercial and services

Purple: construction areas

Pink: forest

Dark blue: agriculture

Light blue: vegetated urban areas

Black: unclassified

(not included - quarry)

As can be seen, quite a few pixels have remained unclassified. To attempt to remove unclassified pixels and to generalize the data, a 3 x 3 weak filter was applied to the scene (Figure 6.16). Although many isolated unclassified pixels were removed and correctly assigned, others became incorrectly classified. For example, pixels forming the water boundary in the centre of the scene became classified as industrial, commercial and services. In other words, shallow water, wetland and pixels containing both land and water have similar reflectances to many industrial and commercial areas. Although remaining distinct after careful supervised training, the generalization provided by the filter has led to incorrect classification.

The final manipulation with the scene was to apply the maximum likelihood classifier to the classified scene. This procedure is normally used when there is considerable spectral overlap, but in this case it has eliminated almost all of the unclassified pixels (Figure 6.17). The boundary problems observed along the water are not as extensive as

Figure 6.15: Final classification produced using the parallelpiped classifier. For a description of the colours, see the text.

Figure 6.16: The same scene displayed in Figure 6.15, but after application of a 3 x 3 weak filter.

before and overall the effect appears to be beneficial. Further investigation of this procedure to remove unclassified pixels would be worthwhile.

Signature file extension was finally applied to the data. In this case, the spectral data from the training scene is applied to a larger area, as illustrated in Figure 6.18. As is to be anticipated, the further one goes from the training scene, the less accurate the classification appears to become.

As a different procedure was used for the parallelepiped classification, when compared with the other classifications, the scene was not subjected to an accuracy test. It is generally agreed, however, that the parallelepiped classification is of lower accuracy than the maximum likelihood classification (Lee, 1980; Goodenough and Shlien, 1974).

3. Output. A variety of outputs is available from the CIAS. In this case, however, only display of the image on the TV monitor for photography with a 35 mm camera was undertaken. In addition to the classifications already discussed, several split screen presentations were recorded (e.g. Figure 6.19) to aid in the comparison of the original scene and the classified data.

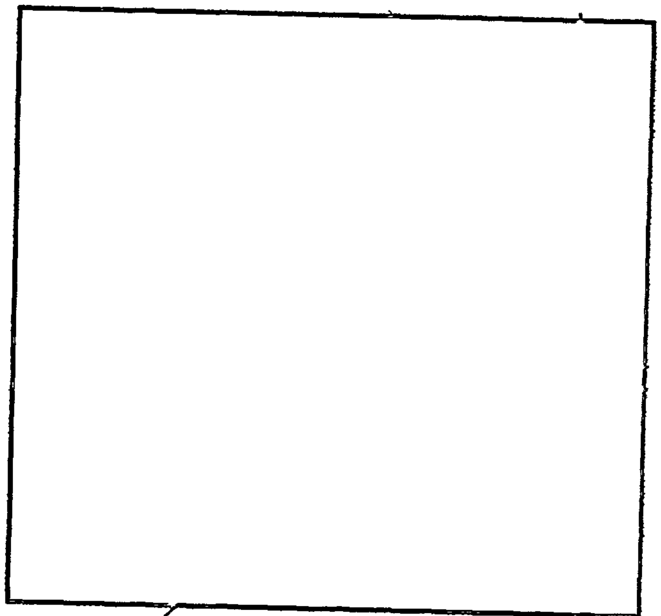


Figure 6.17: A maximum likelihood filter has been applied to the scene displayed in Figure 6.15. Note that the vegetated urban areas (light blue) are eliminated by the filter.

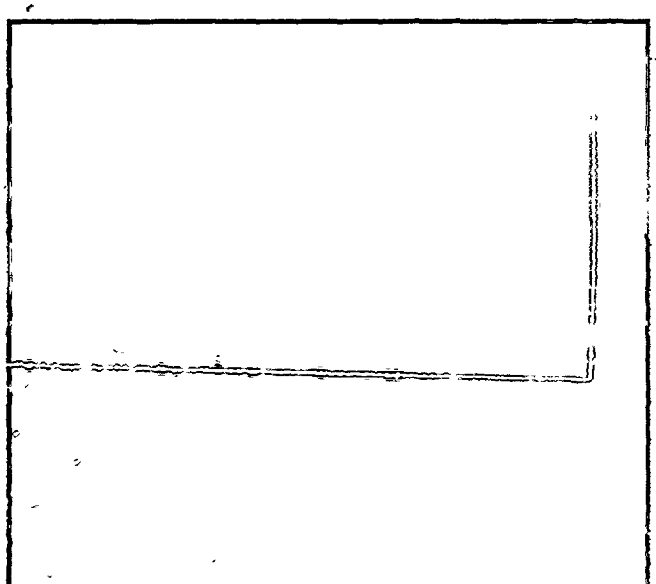


Figure 6.18: Signature file extension of the scene shown in Figure 6.15. Note that the quarry (upper left) is displayed as light pink.

Figure 6.19: A split screen display showing the original image (upper half) and the classified scene outlined by the white cursor in Figure 6.18.

CHAPTER 7

CLASSIFICATION ACCURACY

7.1 Introduction

When mapping land cover/use from any remote sensing data source, a concern is always the accuracy of the mapping. Even the accuracies of maps prepared by traditional field methods are sometimes questioned (Reeds, 1965). In this chapter, the method used to test the accuracy of the remotely sensed data for land cover/use mapping will be described, as well as the results that were obtained.

Traditionally, aerial photographs have been accepted as the closest information to "ground truth", next to actual field investigation (Fitzpatrick-Lins, 1978). When field investigations are carried out, the aerial photograph is usually used as a basis for drafting the land cover/use map (e.g. Reeds, 1954; Hare, 1959; Boasson, 1979). In this study, panchromatic aerial photography flown in June 1978 at a scale of 1:10,000 was chosen as the "ground truth". For each photograph used as a training area or test site, the land cover/use information was drafted on to acetate overlays.

7.2 Methodology for Measuring Classification Accuracy

How accuracy tests should be carried out is still open to debate. Several methods have been used and described in the literature:

a) For each class, compare the area delineated on the map prepared from the remotely sensed data with the area as indicated on the traditional map (Jensen et al., 1977; Kalensky et al., 1979).

b) In agricultural areas, count the number of fields with each crop type and compare the results with ground information (Ryerson and Wallen, 1977).

c) Use randomly selected areas and compare the classification that is shown (in this case from satellite data) with what is indicated on existing maps and can also be seen on large scale aerial photographs (Wickware, 1979).

d) Use large scale aerial photography and compare with the classification produced from the other remote sensing data being tested (Fitzpatrick-Lins, 1978).

In nearly all the cases described above, an area is being compared to an area, rather than a point with a point, as described by Fitzpatrick-Lins (1978; 1981). This will probably lead to a higher accuracy than occurs in reality, as has been pointed out by Kalensky et al. (1979). The reason for this is that the area comparison is based on total measurements from each class and does not take into consideration the actual location of the class or field being assessed.

7.3 Accuracy Measurement used in this Study

The following approach to accuracy measurement was used in this study:

a) A 1 cm square grid network on a transparent overlay was placed over a 1:50,000 scale aerial photograph. Thus at the ground scale, the distance between intersections of the grid represented 500 m.

b) The aerial photograph was used as the "ground truth" information to compare with the maps produced from the different types of remote sensing data being tested. Rather than compare areas or measurement of areas, it was decided to select each intersection point for comparison of land cover/use between the aerial photograph and the map being tested.

c) The land cover/use classification at each intersection of the grid on the 1:50,000 scale aerial photograph was determined. As the photography had been recorded in 1976, the classification was checked on the 1978 photography at 1:10,000 scale to see if any modifications were required. A total of 530 points on the grid network was checked for all data sets, except the SAR for which 232 points were checked.

d) The 1:50,000 scale aerial photograph was mounted on the Bausch and Lomb Zoon Transfer Scope. Each image and map being tested was then compared with the aerial photograph.

There were obviously scale differences between the aerial photograph and the images. In addition, there were slight distortions in the geometry of the different images which had to be compensated for using the Zoom Transfer Scope. To do this, the boundary of Hamilton Bay was selected to match each image to the photograph. The same clearly identifiable points, described in Chapter 3, which had not changed during the period of data collection were selected for matching the data (Figure 3.7).Using the scale change and stretch adjustments on the Zoom Transfer Scope, each image was matched in turn to the photograph using the five fixed points.

e) When set up, the aerial photograph was removed so that only the grid network could be seen superimposed on the image and the map being tested. The land cover/use at each intersection was then recorded.

The field of view of the Zoom Transferscope is relatively small. Thus it was impossible to look at the whole area without moving the grid and the images. Each image had to be studied using either two or three scans. After any move of the image or the grid network, the positions of the fixed points were checked. In addition the classifications at overlap points between the two scans were checked. Using this procedure, no discrepancies were identified between two scans at any of the grid intersections.

f) Finally, an accuracy matrix was generated. A computer program was prepared and data were coded and input to the system. For each grid intersection point, the program permitted a comparison between the classification interpreted from the image being tested and the classification identified from the aerial photograph or "ground truth". The results were output in the form of a matrix to show the number of points and percentages of each class correctly and incorrectly identified.

7.4 Levels of Accuracy

Accuracies of classification depend upon the detail of information sought. For example, the classification of land and water can be achieved to almost 100% accuracy using most remote sensing data sources. There are considerable spectral differences between these two surfaces which ensures good accuracy of classification. To separate wheat and barley or pasture and parkland, however, becomes a much more difficult task for a sensing device as the spectral characteristics of the surfaces being studied are very similar. Classification accuracies would thus be relatively low.

For the above reasons, it was decided in this study to test the classifications from each data source at a general level and a detailed level of classification.

7.5 General Level of Classification

7.5.1 Results

For testing the capabilities of the different data sources at a general level, the classification at each intersection of the grid network was identified as urban, vegetation or water. Areas designated as "urban" consisted of man-made and bare surfaces. Using the data from the 1:10,000 scale aerial photographs as the "ground truth", classifications from each image type were compared in turn with it. The results are shown in Tables 7.1 to 7.4.

To determine the "overall performance" of each data type in providing the correct classification, a measure was calculated for each matrix. This simply consisted of determining the percentage of data points for which the correct classification was obtained using the formula:

$$OP = \frac{CP}{nP} \cdot 100$$

where OP is overall performance in percent,

CP is the total number of correctly classified pixels, and

np is the total number of pixels.

As an example, in Table 7.1:

$$OP = \left(\frac{252 + 123 + 86}{530} \right) . 100$$

$$= 87\%$$

This type of a test is sensitive to the number of points. Thus if classes are of uneven size, the classes with a large number of points correctly identified will weight more in the final results than the smaller classes. An additional test was therefore done to determine the average classification performance (AP), which calculates the averages of classification accuracy for each class, in percentages. In other words:

$$Ap = \frac{C_A}{n_C}$$

where Ap is average performance in percent

C_A is the sum of the classification accuracies for all correctly identified classes

and n_C is the number of classes.

As an example, from Table 7.1:

$$A_p = \frac{90.3\% + 80.4\% + 87.8\%}{3}$$

$$A_p = 86.2$$

Table 7.1 Accuracy Matrix for Ground Truth and DICS Visual Interpretation

	DICS Visual									
Ground Truth	Urban		Vegetation		Water		Unclassified		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Urban	252	90.3	17	6.1	10	3.6	0	0.0	279	100.0
Vegetation	28	18.3	123	80.4	2	1.3	0	0.0	153	100.0
Water	12	12.2	0	0.0	86	87.8	0	0.0	98	100.0
TOTAL	292		140		98	92.7	0		530	-

Overall performance OP = 87%
Average performance AP = 86.2%

Table 7.2 Accuracy Matrix for Ground Truth and RBV Visual Interpretation

	RBV Visual									
Ground Truth	Urban		Vegetation		Water		Unclassified		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Urban	263	94.3	12	4.3	4	1.4	-	-	279	100.0
Vegetation	43	28.1	108	70.6	2	1.3	-	-	153	100.0
Water	5	5.1	1	1.0	92	93.9	-	-	98	100.0
TOTAL	311		121		98		-	-	530	-

Overall performance OP = 87.4%
Average performance AP = 86.3%

Table 7.3 Accuracy Matrix for Ground Truth and SAR Visual Interpretation

	SAR Visual									
Ground Truth	Urban		Vegetation		Water		Unclassified		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Urban	95	94.1	6	5.9	0	0.0	0	0.0	101	100.0
Vegetation	17	14.0	100	82.6	2	1.7	2	1.7	121	100.0
Water	0	0.0	0	0.0	10	100.0	0	0.0	10	100.0
TOTAL	112		106		12		2		232	-

Overall performance OP = 89.2%
Average performance AP = 92.2%

Table 7.4 Accuracy Matrix for Ground Truth and DICS Maximum Likelihood Digital Classification

	DICS Digital									
Ground Truth	Urban		Vegetation		Water		Unclassified		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Urban	229	82.1	47	16.8	0	0.0	3	1.1	279	100.0
Vegetation	38	24.8	113	73.9	1	0.7	1	0.7	153	100.0
Water	8	8.2	2	2.0	87	88.8	1	1.0	98	100.0
TOTAL	275		162		88		5		530	-

Overall performance OP = 80.9%
Average performance AP = 81.6%

7.5.2 Discussion

From a study of the accuracy matrixes, several observations can be made:

1. Visual classification gives overall a slightly higher classification. Digital classification is only based on the spectral characteristics of the data, while visual interpretation is also based on patterns, location and the interpreter's knowledge of the area.
2. Of the visual data, the highest overall performance is for SAR data, though DICS visual and RBV have performances of similar levels. SAR data are acquired from a far lower altitude than the satellite data; 5.8 km and 920 km respectively.
3. Highest accuracy is found for the water class using SAR visual data and DICS digital data (100% and 88.8% respectively), but the urban class displays the highest accuracy using DICS visual and RBV visual data (90.3% and 94.5% respectively). Water has a uniform reflectance value in most cases, but where high concentrations of suspended sediments or pollution occur, its reflectance might be misclassified as urban areas. In the study area, water areas bordering the urban area might explain the misclassification. In addition, urban areas have a uniform tonal appearance, and for the three visual data sets the accuracy is similar (90.3% to 94.3%). The urban areas are aided by location, which is not a factor using digital data.

4. The lowest accuracy is recorded for the vegetation class with an accuracy range of 70.6% to 82.6%. The lowest accuracy is found for the RBV data and the highest for SAR data. The vegetation classes are mostly misclassified as urban areas. This might be explained by the variety of patterns and tones in the urban area.
5. In two of the tables (7.3 and 7.4) there are a few unclassified points. Those points using SAR visual data (Table 7.3) represent areas of radar shadow, but using digital classification (Table 7.4) they indicate pixels, which do not fit in to the statistical groupings used for the classification.

From the above points, it might be concluded that all the systems can be used to produce land cover/use maps at a general level of accuracy approaching 90%. It would therefore be the users choice which of the sensors is selected to produce the final map. The decision will depend on the availability of data, accuracy, how rapidly the map can be produced and the size of the area to be mapped.

7.6 Detailed Level of Classification

7.6.1 Results

For testing the accuracies at a detailed level of classification, nine classes were identified and an unclassified category was also established. The classes were residential; commercial, industrial and services; communication; agricultural; vegetated urban areas; forest; water; quarry, and vacant land, as described earlier. Again the data were compared with "ground truth" obtained from the 1:10,000 scale aerial photographs. The accuracy matrices that were generated are shown in Tables 7.5 to 7.8.

7.6.2 Discussion

Looking at the individual classification accuracies, there are several points to note:

1. Classification accuracy is lower than at a general level of classification. By increasing the number of classes from three to nine, the overall accuracy has dropped from 80.9 to 89.2% to 53.2% to 73.3%.
2. Accuracy for each class varies from 0.0% to 100.0%. The lowest is for communication using the maximum likelihood classifier (Table 7.7), and highest for the quarry using all methods, plus water using SAR (Table 7.8).
3. Misclassification occurs between related classes (e.g. residential and industrial) rather than between unrelated classes (e.g. residential and forestry).
4. The highest accuracy for classifying residential areas (85%) is using the maximum likelihood classifier (Table 7.7), followed by SAR (73.0%) RBV (72.0%) and lastly DICS visual (57.0%). Residential areas are most often misclassified as the industrial, commercial and services class (in 4% to 32% of the cases). The maximum likelihood classifier is the exception where residential areas are most often misclassified as agricultural land (9%). Explanations as to why residential areas are misclassified

Table 7.5 Accuracy Matrix for Ground Truth and DICS Visual Interpretation

Ground Truth	Residential No.	Residential %	Industrial, commercial, Services No.	Industrial, commercial, Services %	Communication No.	Communication %	Agricultural No.	Agricultural %	Vegetated urban land No.	Vegetated urban land %	Forest No.	Forest %	Water No.	Water %	Quarry No.	Quarry %	Vacant land No.	Vacant land %	Unclassified No.	Unclassified %	Total No.	Total %
Residential	57	57.0	32	32.0	3	3.0	3	3.0	2	2.0	2	2.0	1	1.0	0	0.0	0	0.0	-	-	100	100.0
Industrial, commerical, services	15	15.5	69	71.1	3	3.1	2	2.1	0	0	2	2.1	6	6.2	0	0.0	0	0.0	-	-	97	100.1
Communication	16	44.4	8	22.2	5	13.9	4	11.1	3	8.3	0	0.0	0	0.0	0	0.0	0	0.0	-	-	36	99.9
Agricultural	4	4.7	1	1.2	0	0.0	64	75.3	3	3.5	13	15.3	0	0.0	0	0.0	0	0.0	-	-	85	100.0
Vegetation urban land	8	20.5	9	23.1	5	12.8	2	5.1	10	25.6	2	5.1	3	7.7	0	0.0	0	0.0	-	-	39	99.9
Forest	6	11.3	4	7.5	1	1.9	11	20.8	3	5.7	26	49.1	2	3.8	0	0.0	0	0.0	-	-	53	100.1
Water	1	1.0	5	5.1	2	2.0	0	0.0	4	4.1	0	0.0	86	87.8	0	0.0	0	0.0	-	-	98	100.0
Quarry	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	7	100.0	0	0.0	-	-	7	100.0
Vacant land.	1	6.7	2	13.3	0	0.0	5	33.3	3	20.0	3	20.0	0	0.0	0	0.0	1	6.7	-	-	15	100.0
TOTAL	108		130		19		91		28		48		98		7		1				530	

Overall classification performance 61.3%
Average classification performance 54.1%

Table 7.6 Accuracy Matrix for Ground Truth and RVB Visual Interpretation

	Residential		Industrial, commercial, services		Communication		Agricultural		Vegetated urban land		Forest		Water		Quarry		Vacant land		unclassified		Total	
Ground Truth	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Residential	72	72.0	15	15.0	5	5.0	2	2.0	6	6.0	0	0.0	0	0	0	0.0	0	0.0	-	-	100	100.0
Industrial, commercial, services	16	16.5	72	74.2	1	1.0	4	4.1	1	1.0	0	0.0	3	3.1	0	0.0	0	0.0	-	-	97	100.0
Communication	12	33.3	6	16.7	11	30.6	3	8.3	1	2.8	1	2.8	1	2.8	1	2.8	0	0.0	-	-	36	100.0
Agricultural	8	9.4	6	7.1	2	2.4	63	74.1	2	2.4	4	4.7	0	0.0	0	0.0	0	0.0	-	-	85	100.0
Vegetated urban land	14	35.9	8	20.5	4	10.3	1	2.6	11	28.2	1	2.6	0	0.0	0	0.0	0	0.0	-	-	39	100.0
Forest	3	5.7	3	5.7	4	7.5	8	15.1	10	18.9	23	43.4	2	3.8	0	0.0	0	0.0	-	-	53	100.0
Water	0	0.0	4	4.1	0	0.0	0	0.0	1	1.0	1	1.0	92	93.9	0	0.0	0	0.0	-	-	98	100.0
Quarry	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	7	100.0	0	0.0	-	-	7	100.0
Vacant land	1	6.7	0	0.0	2	13.3	9	60.0	2	13.3	0	0.0	0	0.0	0	0.0	1	6.7	-	-	15	100.0
TOTAL	126		114		29		90		34		30		98		8		1		-		530	

Overall classification performance 66.2%
Average classification performance 58.0%

Table 7.7 Accuracy Matrix for Ground Truth and Maximum Likelihood Digital Classification

Ground Truth	Residential No.	Residential %	Industrial, commercial, services No.	Industrial, commercial, services %	Communication No.	Communication %	Agricultural No.	Agricultural %	Vegetated urban land No.	Vegetated urban land %	Forest No.	Forest %	Water No.	Water %	Quarry No.	Quarry %	Vacant land No.	Vacant land %	Unclassified No.	Unclassified %	Total No.	Total %
Residential	85	85.0	4	4.0	0	0.0	9	9.0	0	0	1	1.0	0	0.0	0	0.0	1	1.0	0	0.0	100	100.0
Industrial, commercial, services	24	24.7	53	54.6	0	0.0	17	17.5	1	1.0	0	0.0	0	0.0	0	0.0	0	0.0	2	2.1	97	99.9
Communication	22	61.1	5	13.9	0	0.0	5	13.9	2	5.6	1	2.8	0	0.0	0	0.0	1	2.8	0	0.0	36	100.1
Agricultural	16	18.8	1	1.2	0	0.0	41	48.2	10	11.8	3	3.5	0	0.0	0	0.0	14	16.5	0	0.0	85	100.0
Vegetated urban land	18	46.2	1	2.6	0	0.0	10	25.6	7	17.9	2	5.1	0	0.0	0	0.0	0	0.0	1	2.6	39	100.0
Forest	6	11.3	0	0.0	0	0.0	8	15.1	1	1.9	29	54.7	1	1.9	0	0.0	7	13.2	1	1.9	53	100.0
Water	1	1.0	7	7.1	0	0.0	0	0.0	0	0.0	1	1.0	87	88.8	0	0.0	1	1.0	1	1.0	98	99.9
Quarry	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	7	100.0	0	0.0	0	0.0	7	100.0
Vacant land	3	20.0	0	0.0	0	0.0	2	13.3	1	6.7	1	6.7	0	0.0	0	0.0	8	53.3	0	0.0	15	100.0
TOTAL	175		71		0		92		22		38		88		7		32		5		530	

Overall classification performance 53.2%
Average classification performance 55.8%

Table 7.8 Accuracy Matrix for Ground Truth and SAR Visual Interpretation

	Residential		Industrial, commercial, services		Communication		Agricultural		Vegetated urban land		Forest		Water		Quarry		Vacant land		Unclassified		Total	
Ground Truth	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Residential	27	73.0	7	18.9	1	2.7	0	0.0	2	5.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	37	100.0
Industrial, commercial, services	3	16.7	14	77.8	0	0.0	0	0.0	1	5.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	18	100.1
Communication	1	7.1	2	14.3	8	57.1	2	14.3	0	0.0	1	7.1	0	0.0	0	0.0	0	0.0	0	0.0	14	99.9
Agricultural	4	5.7	0	0.0	0	0.0	61	87.1	1	1.4	3	4.3	0	0.0	0	0.0	1	1.4	0	0.0	70	99.9
Vegetated urban land	5	20.0	0	0.0	3	12.0	0	0.0	14	56.0	3	12.0	0	0.0	0	0.0	0	0.0	0	0.0	25	100.0
Forest	6	15.4	1	2.6	1	2.6	1	2.6	1	2.6	26	66.7	2	5.1	0	0.0	0	0.0	1	2.6	39	100.0
Water	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	10	100.0	0	0.0	0	0.0	0	0.0	10	100.2
Quarry	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	7	100.0	0	0.0	0	0.0	7	100.0
Vacant land	1	8.3	0	0.0	0	0.0	1	8.3	2	16.7	4	33.3	0	0.0	0	0.0	3	25.0	1	8.3	12	100.0
TOTAL	47		24		13		65		21		37		12		7		4		2		232	

Overall classification performance 73.3%
Average classification performance 71.4%

as industrial commercial class relate to the similar spectral characteristics and the location.

5. The highest accuracy for classifying the industrial, commercial and services class is obtained using SAR imagery (77.8%) then RBV (74.1%) DICS visual (71.7%) and lastly DICS digital data (54.6%). The industrial class is most often misclassified as residential areas, due to the same explanation given above.
6. Communication scored highest when identified using SAR data (57.1%) and second highest using RBV (30.6%), then DICS visual (13.9%) and finally DICS digital (0.0%) (where it was not included in the classification). The class in most cases is misclassified as residential land or industrial commercial areas, and in some cases as agricultural areas. This class is usually narrow lines such as highways or railways. Therefore it is difficult to detect those on images with a minimum pixels size of 50 m by 50 m or 30 m by 30 m. The same reason explains why this class was not used in the digital classification, as explained in Chapter 6. The communication network is most dense near to the city and built up areas. Thus, the highest mistakes in classification occur there.
7. The best classification accuracy for agricultural land is using SAR data (87.1%), secondly DICS visual (75.3%), thirdly RBV (74.1%) and lowest for DICS digital (48.2%). The agricultural class has a wider range of misclassification than the previous classes described here. It is mostly misclassified as residential (4.7-18.8%) and secondly as forest using DICS visual (15.3%)

and SAR (4.3%), as vacant land (16.5) using DICS digital and as industrial land (7.1%) using RBV.

There are obvious problems regarding classification of agricultural land. As discussed earlier, the major problem is the variance in spectral response from the different agricultural fields. Bare soils have similar responses to built up areas, while others have dense vegetation which might be confused with dense forests.

8. Classification of the vegetated urban land had relatively low accuracy using all data. The accuracy range is from 17.9% using DICS digital to 56.0% using SAR. DICS visual gives 25.6 and RBV 28.2%. The class is most often misclassified as residential areas (20.5% to 46.2%) or the other urban classes. In some cases, it is confused with agriculture or forest.

The lower accuracy and high misclassification of other urban classes, is basically due to the similar textures and tones of the class when compared with others. Even though land in the class is mostly grass, it appears more similar to lawns and backyards than to agricultural land.

9. It was expected that classification of forests would be relatively high but the results range from 49.1% using DICS visual to 66.7% using SAR data. RBV gave a result of 43.4% and DICS digital 54.7%. The misclassification of forest appears to be as agricultural (20.8%) using DICS visual and 15.1% using DICS digital, as vegetated urban land in 18.9% of the cases using RBV and as

residential in 15.4% using SAR. The misclassifications occur due to the spectral responses from the surface. In old residential areas the crown coverage of the trees is dense. Thus when looked at from above the area appears similar to forest. In city parks there are trees which are classified as such when the cover is large, and in some cases the responses from agricultural land and forests are similar, as discussed earlier.

10. Classification of water gives the second best results for all the four data sets, or 87.8-100% accuracy. The SAR data gives 100%, second best is RBV with 93.9%, then DICS digital 88.8% and lastly DICS visual 87.8%. Most of the misclassification is with the industrial class in all three cases. The misclassified points are in Hamilton Harbour, where the harbour water is likely to be polluted. Other misclassifications occur on the borders between land and water.

11. The quarry class is identified correctly using all four data sets. The class has unique spectral responses and clear boundaries.

12. The last class identified is the vacant land. The class has a classification accuracy of 6.7% using RBV and DICS visual, 25% using SAR and 53.3% using DICS digital. The class is misclassified as various classes, e.g. agriculture using RBV (60%) and DICS visual (33.3%), as forest (33.3%) with SAR and as residential (20.0%) using DICS digital. This class has diverse types of cover and for this reason is often misclassified.

From the above 12 points, it can be concluded that:

1. Classification accuracy decreases with increasing an number of classes.
2. Classification accuracy is highest for the smallest pixel size.
3. With decreasing pixel size, accuracy does not increase proportionally.

CHAPTER 8

CHANGE DETECTION USING DIGITAL LANDSAT DATA

8.1 Introduction

Changes in land cover/use are of great interest to the planner and development agencies. As emphasized by Anderson (1977, p. 143) "information on the rate and kind of changes in the use of land resources is essential for the proper planning, management and regulation of the use of such resources".

Two major problems encountered in change detection studies are frequency of data collection and comparability between data sets. Need and financial considerations will determine how frequently data are collected, but obviously data collection at the same time of year is preferable for change detection studies. Weather conditions, however, can cause postponement or cancellation of data collection.

In the past, change detection has been carried out primarily from aerial photography (e.g. Kruger, 1960; Ellefsen and Davidson, 1979; Prout, 1980). However, LANDSAT covers the earth on a regular basis. "For this reason it is ideally, suited to monitoring or detecting change over time" (Wickware and Howarth, 1981).

The LANDSAT system has been shown to be an ideal system for primary investigation of changes where more detailed studies can follow. For example, Fleming (1980)has described the use of LANDSAT visual data as a guide for planning aerial photography for the revision of topographic maps. Both MSS and RBV data are used to detect the change. In a comparison it is found that the use of LANDSAT data would decrease the number of photographs to about 10%, while flying time would be decreased about 15%.

Some papers have been presented on the use of LANDSAT data for land cover/use change studies in fairly homogeneous environments. For example, Joyce et al. 1979 used LANDSAT data for detecting land use change in forest areas, using what they referred to as "ends-of-period" methodology. This means that classification is done for the first year of study and then for the most recent year. The nature of the change is obtained, but more frequent data are needed to determine rates of change. Lee (1975) and Murtha and Watson (1975) have also discussed methodologies for determining changes in forest cover due to clear cutting.

The problem of determining vegetation change is relevant when studying both the agricultural landscape and the natural environment (Stow et al., 1980; Wickware and Howarth, 1981).

A major area of interest is changes at the urban/rural fringe. There are several papers outlining different procedures and results, including Friedman and Angelici (1979), Rodrigues-Bejarno and Okoye (1979), Todd (1977), Ellefsen and Davidson (1979), Carter and Jackson (1976), Stauffer and McKinney (1977), Angelici et al. (1977) and Gordon (1980).

All the above papers describe digital and/or visual methods for change detection and all mention the problem of accurate registration of images from two or more moments in time.

In Canada, there have been few studies emphasizing change detection. Using visual data, however, Fleming (1980) has updated topographical maps from LANDSAT MSS and RBV data. Digital data to give better spatial and spectral resolution have, however, proved more popular. For example, Rubec and Thie (1978) used digital LANDSAT data to detect and map land use change in part of Manitoba. Other man-induced changes that have been studied include water and vegetation changes in the Peace-Athabasca Delta (Wickware and Howarth, 1981; Howarth and Wickware, In press), while Tomlins and Thomson (1980) have studied the effects on marine vegetation of the Roberts Bank terminal near Vancouver.

As far as is known, no land cover/use change studies have been carried out for the Hamilton Wentworth Region using either remote sensing or ground based studies. In this chapter, several methodologies for change detection are presented and the results discussed.

8.2 Methodology

There are several data sources and procedures that can be used to detect changes in the landscape over time. It is obviously a concern of the historical geographer and early paintings(e.g. Frontispiece) and maps can be of value in determining historical changes.

Aerial photography is available from the late 1920s/early 1930s for many parts of Canada and this can be compared with more recent photography. Figures 8.1 and 8.2, for example, show the same area of Hamilton in 1934 and 1978.

The methodology developed for this study is as follows:

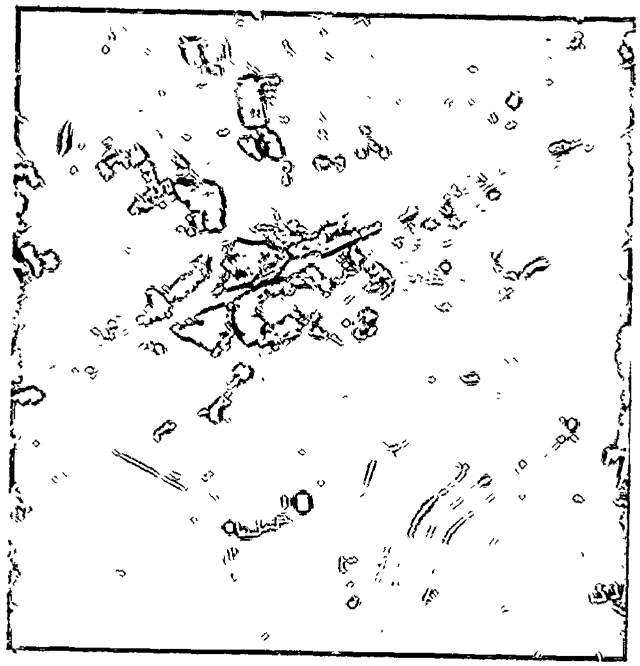


Figure 8.1: Part of west Hamilton recorded on aerial photography flown in 1934.

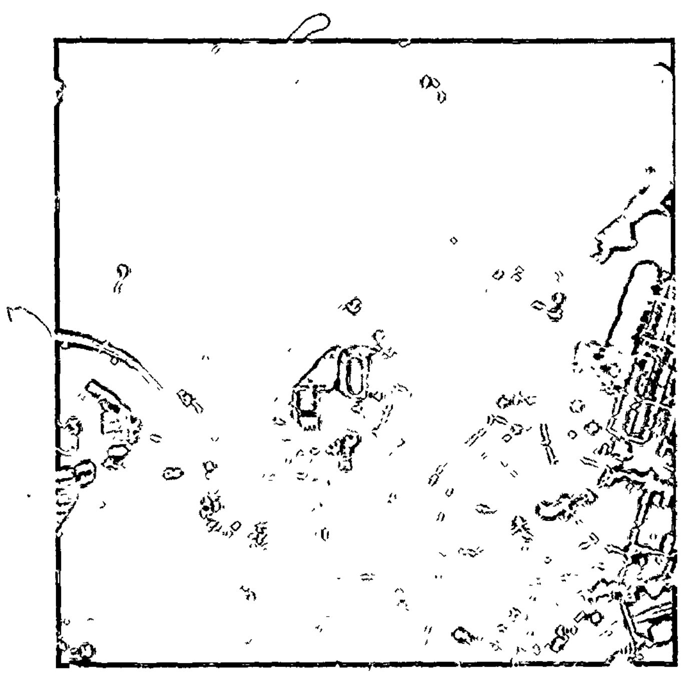


Figure 8.2: Aerial Photograph recorded in 1978 showing approximately the same area displayed in Figure 8.1. Considerable changes can be detected.

1. Selection of Area. The study area was selected and displayed on the TV monitor at a resolution of 512 pixels by 512 pixels, the maximum number that can be achieved without decimation of the data.

2. Registration of Images. Images from the two dates of study (1974 and 1978) were registered. In comparison with previous studies, this was an easy task because both computer tapes had been resampled and reformatted using the Digital Image Correction System (DICS), described earlier. Thus, perfect registration was possible.

3. Change Detection. Several methods are available for determining changes between two dates.

a) Overlay. One band, the same for each date, is selected. They are displayed on the TV monitor with one colour assigned to the band from one year and another assigned to the band from the second date. Areas of little or no change appear grey. Any areas that have changed are highlighted in one of the two colours.

b) Ratios. The pixels from one date are ratioed with pixels from the second date. Areas of no change would give a ratio of 1.0 (assuming no atmospheric effects) and appear grey. Areas of change would have values either higher or lower than one and would be displayed in either light or dark tones. The lighter or darker the image, the more change there has been.

c) Subtraction. A new data set can be generated by subtracting the values of each band on one date from the values of the same bands on the second date. Again light and dark tones indicate areas of greatest change.

d) Vegetation Index. The vegetation index was designed to emphasize differences in biomass on an image. For any date it is determined on a pixel by pixel basis using Band 5 and Band 7 data in the formula:

$$V.I. = \frac{Band\ 7 - Band\ 5}{Band\ 7 + Band\ 5}$$

By assigning each vegetation index a different colour on the TV monitor, vegetation changes are emphasized.

e) Post-Classification Change Detection. A supervised or unsupervised classification for two dates is carried out. The classifications are compared on a pixel by pixel basis and not only the areas of change are identified. A detailed methodology for this procedure is outlined by Howarth and Wickware (In press). As pointed out by Stow et al. (1980), however, the accuracy of the method is dependent upon the accuracy of the initial classifications.

4. Change Identification. Following detection of change by one of the first four methods described above, it is then necessary to identify or interpret the change. (This is done automatically in post-classification change detection). The images may be interpreted and maps or tabulations can be produced. Several digital outputs may be generated, as discussed in Chapter 6.

8.3 Results

Analysis followed the steps outlined in the previous section, although as explained later, post-classification change detection was not carried out.

1. Selection of Area. The area selected for study includes the City of Hamilton and several of the surrounding towns (Figure 8.3). It includes the area covered in much of the land cover/use mapping from the different data sources.

2. Registration of Images. The images selected for the study were recorded on July 6, 1974 and on July 12, 1978. They were thus from the same time of year, but recorded four years apart. As indicated in the previous section, DICS images were used for the analysis. Perfect registration should have occurred, but the images had to be moved by two pixels relative to each other to achieve this. Registration was checked by studying points of land in the Hamilton Harbour that had not changed between the two dates.

3. Change Detection. The methods of change detection followed the procedures outlined in the previous section.

a) Overlay. Overlays between the two dates for each band were produced. The combination which provided the most detail was the Band 5 images. The 1974 Band 5 image was assigned to the blue and green guns of the TV monitor, while the 1978 Band 5 image was designated red. A photograph of the image produced on the TV monitor is included as Figure 8.4.

Areas that stayed the same between the two dates were displayed as a grey tone (i.e. the colour balance between the blue/green and the red was balanced to produce the grey tone). Areas that had been light in tone in 1974, but were dark in 1978 appeared as blue on the screen. This was particularly noticeable in agricultural areas. Finally areas that were dark in

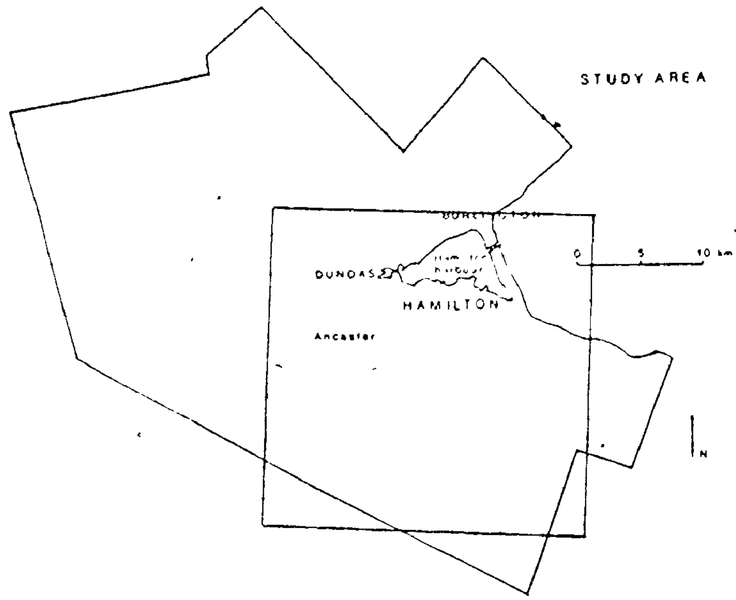


Figure 8.3: The area selected for change detection studies.

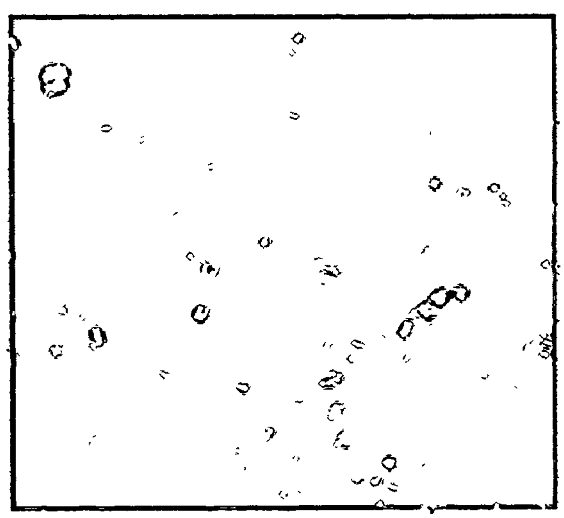


Figure 8.4: Change detection using Band 5 overlays from 1974 and 1978. For explanation, see the text.

tone in 1974, but light in 1978 appeared red in colour. Most noticeable amongst these areas are locations of new construction sites and the rectangular block in the upper left corner of Figure 8.4 which represents the extension of the quarry in that area. The dark vegetated surface visible in 1974 had been cleared to reveal the light bedrock surface in the quarry by 1978.

An area of change at the urban/rural fringe was selected from the southwest edge of Hamilton. It was displayed at a 4x enlargement on the TV monitor. The Band 5 image for July 6, 1974 is shown in Figure 8.5 and the Band 5 image for July 12, 1978 in Figure 8.6. A composite of the two images, using the colour guns as described above, is shown in Figure 8.7. Part of the 1:10,000 scale 1978 aerial photograph of the same area (reduced in scale) is shown for comparison in Figure 8.8. The letters in each figure refer to the same area. Letters A and B indicate road intersections. Area C has a low reflectance and appears dark on the 1974 image (Figure 8.5). In 1978, however, it is light in tone (Figure 8.6) and as the red gun is assigned to this image, it appears red in the colour composite (Figure 8.7). The aerial photograph clearly shows construction of a new residential area at this location.

In contrast, area D has a high reflectance in 1974 (Figure 8.5), but only moderate in 1978 (Figure 8.6). As a result of the high reflectance in 1974, the area appears blue on the colour composite (Figure 8.7). In 1974, construction in the area had recently been completed. There were few trees and a lack of vegetation.

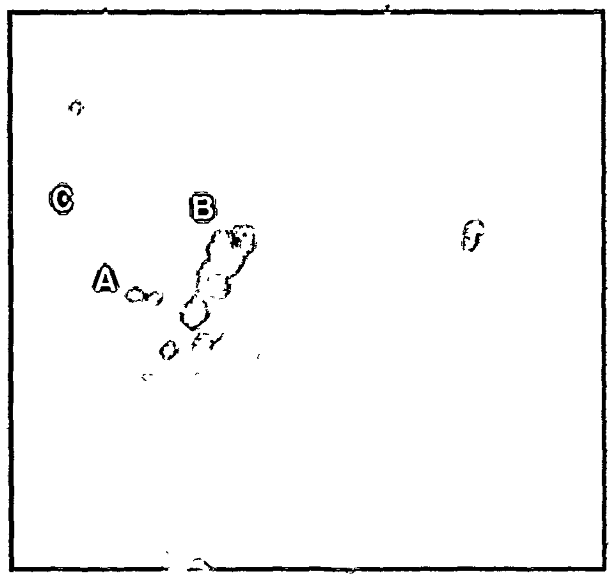


Figure 8.5: Part of southwest Hamilton recorded by LANDSAT in 1974.

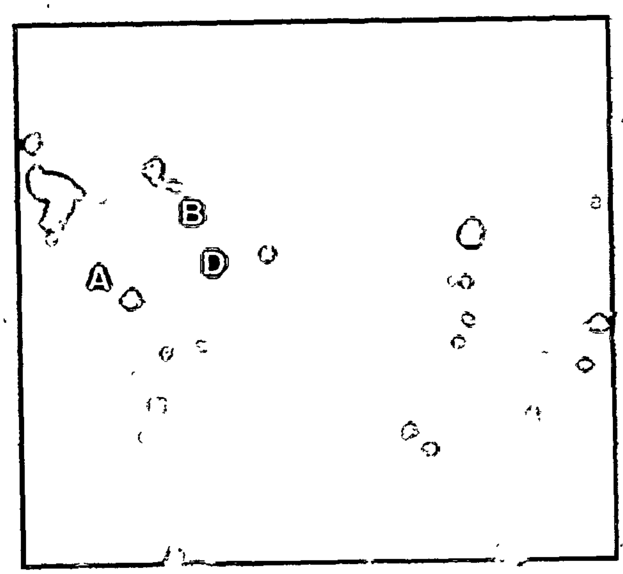


Figure 8.6: 1978 image of the same area shown in Figure 8.5.

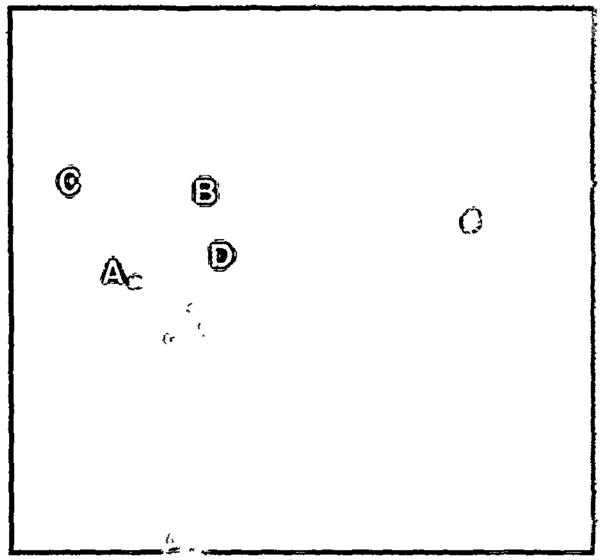


Figure 8.7: Band 5 overlays produced from the images shown in Figures 8.5 and 8.6. The red area "C" indicates areas of new construction between the two dates of imagery. For other explnations, see the text.

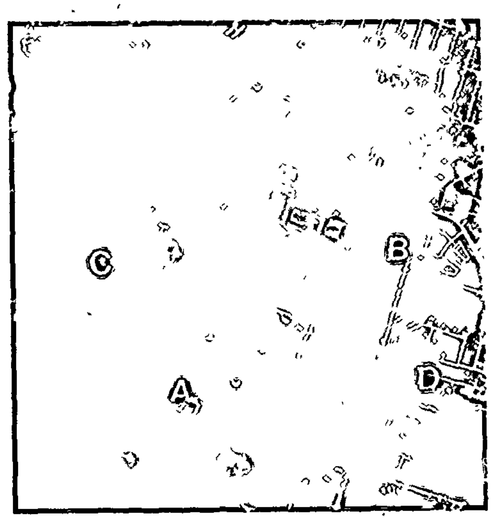


Figure 8.8: An aerial photograph, at reduced scale showing part of the area displayed in Figures 8.5, 8.6 and 8.7.

By 1978, the area had matured and the vegetation in particular gave the area a darker tone.

b) Ratios. For analyzing ratios, it was decided to use Bands 5 and 7. Band 5 is sensitive to cultural features, while Band 7 is sensitive to water and vegetation. As indicated in the previous section, areas of change will give either high or low ratio values which will be displayed as either light or dark tones on the image.

The ratio for Band 5 1978 and Band 5 1974 is shown in Figure 8.9. Areas of change in the quarry and on the urban fringe of Hamilton (discussed under overlays) can be seen as light tones. Changes in the agricultural areas are also emphasized. Some differences are also noticed in the waters of Hamilton Harbour where the Band 5 reflectance for 1978 was lower than for 1974.

The Band 7 1978 to Band 7 1974 ratio is seen in Figure 8.10. With this particular ratio it is very difficult to detect any cultural change. However, the ratio emphasizes water quality differences. The dark areas indicate lower reflectance values in 1978 than in 1974, while for light areas the reverse is true.

A colour composite from the two ratios is shown with the red gun applied to the Band 5 ratios and the blue and green guns displaying Band 7 ratios (Figure 8.11). When the composite is compared with the original ratios, it can be seen that changes in one direction on Band 5 are complemented by changes in the other direction on Band 7. The ratios would appear to have no more benefit than a simple Band 5 overlay.

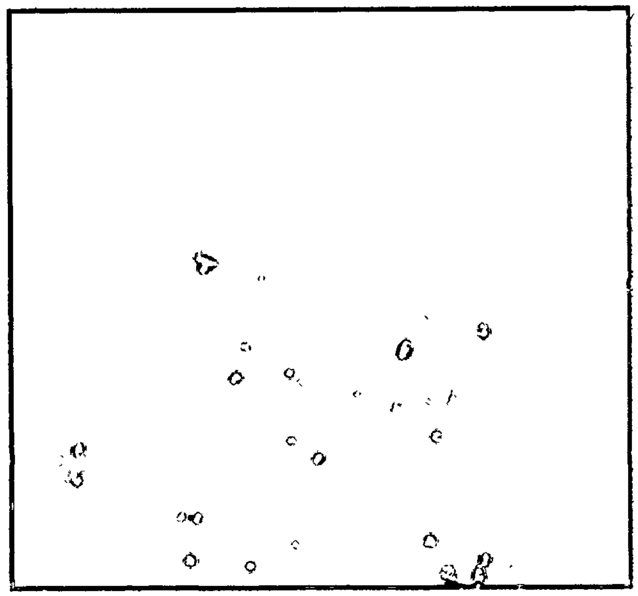


Figure 8.9: Change detection using a Band 5 ratio of images recorded in 1974 and 1978.

Figure 8.10: Change detection using a Band 7 ratio of images recorded in 1974 and 1978.

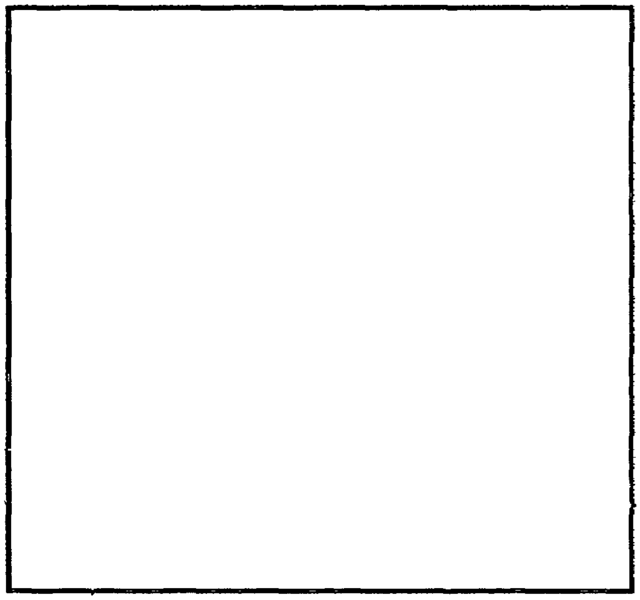


Figure 8.11: Change detection using a combination of the Band 5 and Band 7 ratios displayed in Figures 8.9 and 8.10.

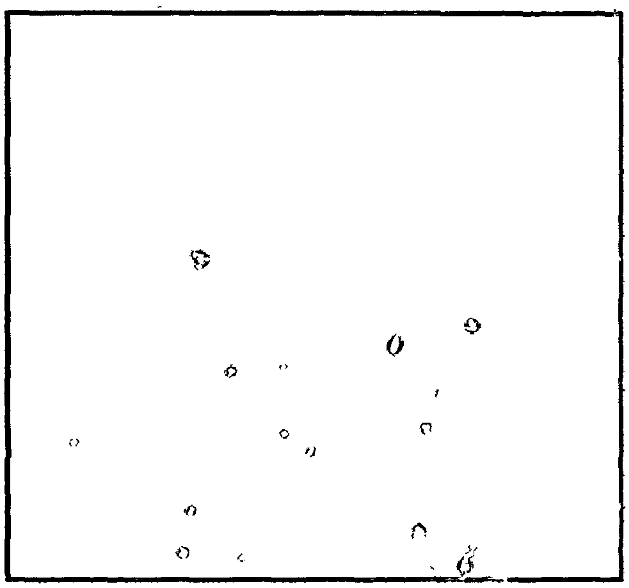


Figure 8.12: Change detection using Band 5 subtraction of images recorded in 1974 and 1978.

c) <u>Subtraction</u>. Band 5 data from 1974 were subtracted from Band 5 1978 data to produce a composite image (Figure 8.12). As with the previous images, grey tones indicate areas of no change while dark and light tones emphasize differences. Comparison of this image with the ratio for Band 5 shows little difference.

d) <u>Vegetation Index</u>. The vegetation index was calculated for each date, as described in the methodology. Using the vegetation index, areas with healthy vegetation will appear in light tones, while areas of low reflectance in Band 7 but higher in Band 5 will appear dark.

The vegetation indices for 1974 and 1978 are shown in Figures 8.13 and 8.14, respectively. The two data sets were overlayed and the vegetation index for 1974 was assigned to the blue and green guns and the index for 1978 to the red gun (Figure 8.15). The quarry and the areas of urban change, discussed in the previous sections can be identified in red, while both red and blue are encountered in the agricultural areas.

e) <u>Post Classification Change Detection</u>. Originally it had been planned to carry out this method of change detection, but for two reasons it was decided not to. First, computer time was running out, but more importantly the accuracy of the change detection would have had to rely on the accuracy of the classifications for each date. Given that the maximum likelihood for the 1978 scene using 9 classes was only about 60%, it is unlikely that the change detection accuracy would be more than 36%. Accuracies of this low level would be of little interest .

Figure 8.13: Vegetation index for 1974.

Figure 8.14: Vegetation index for 1978.

Figure 8.15: Change detection using vegetation indices for 1974 and 1978, as displayed in Figures 8.13 and 8.14.

8.4 Conclusions

When all four non-classification or enhancement methods for change detection are compared, there is little difference between them. The simplest method (i.e. the Band 5 overlays) appears to give slightly better results than the others.

The Band 5 overlays, ratio and subtraction give information on both cultural and agricultural changes, as well as changes in water characteristics. The Band 7 ratio gives less information on cultural changes than the Band 5 ratio, but emphasizes both vegetation and water changes. The ratioed colour composite gives more information than each ratio independently.

It would appear that the more complex methods do not give better results. Thus the simplest method, the overlay, is recommended. Using other methods it is easy to fall into the trap described in the old German saying:

"Warum einfact ist, machen complitziert"

or make simple things complex.

Given the present spatial resolution of LANDSAT, it is not recommended to determine change in urban and urban/rural fringe areas using classification procedures. LANDSAT should be used to monitor areas where changes are likely and determine if and when they have occurred by using enhancement techniques. The nature of the change can then be determined using aerial photography or fieldwork.

The above procedure would make change detection more effective than before. Instead of flying a large area with photography and comparing it to another complete set of photography, flights could be concentrated in areas where changes have been detected in the broad LANDSAT scene. This is a similar procedure to the one recommended by Fleming (1980) for updating topographic maps.

Obvious problems will arise when using LANDSAT digital data for change detection in agricultural areas. Observed changes could be due to phenological effects, differences in environmental conditions from one year to the next or simply a change in crop type as part of a crop rotation system. Such changes are complex and beyond the scope of this thesis.

In conclusion, it has been demonstrated that LANDSAT digital data are effective for identifying change in urban and urban fringe areas. The nature of the change, however, should be determined using aerial photography or field checking.

CHAPTER 9

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

9.1 Summary

Evaluation of various remote sensing data for land cover/use studies has been carried out for the Hamilton-Wentworth region of southern Ontario. The data used were:

a) LANDSAT MSS visual data

b) LANDSAT MSS digital data

c) LANDSAT RBV visual data and

d) SAR imagery

Before the analysis was undertaken, a land cover/use system with nine classes was designed to provide a uniform classification system for each data set. Training and test sites were also selected.

The visual interpretation of the data sets was concentrated in an area surrounding Hamilton Harbour (Figure 3.5) and covering approximately 200 km^2. The mapping scale selected was 1:50,000 and classification was done at two levels of detail (i.e. three general classes and nine detailed classes).

Visual classification was carried out for SAR, MSS DICS and RBV imagery and a ground truth map was produced from aerial photography (Figure 1.4).

Digital classification was carried out at both the Ontario Centre for Remote Sensing (OCRS) and the Canada Centre for Remote Sensing (CCRS). The area mapped digitally covered approximately 4,800 km^2 using a maximum likelihood classifier at OCRS and a parallelepiped classifier at CCRS.

After the land cover/use maps had been drawn their accuracy was tested in detail using 1:10,000 scale aerial photography as ground truth and a grid network with 500 m ground distance between each intersection.

The final stage in the analysis was to study land cover/use changes which had occurred during four years, using LANDSAT MSS DICS digital data. Various methods of ratioing, overlaying and substracting images were studied.

9.2 Conclusions

The major conclusion is that all the data sets can be used for land cover/use mapping, with a relatively high accuracy at a general level of classification. Visual interpretation has an overall higher accuracy than automated classification (87-89.2% and 80.9%, respectively).

At a more detailed level of classification, the accuracy decreases to an overall performance of 61.3% to 73.3% for visual classification and 53.2% for automated classification. At the detailed level, misclassification occurs mainly between related classes but there are a few misclassifications between dissimilar categories.

Increased ground resolution does not seem to increase classification accuracy to any large extent (66.2% over all accuracy for RBV while 61.3% for MSS DICS visual). But one should bear in mind that the data are of different characters. RBV data are mainly black and white panchromatic photographs, while the MSS data were analysed as colour composites.

SAR provides the most accurate maps at both levels of detail. SAR data were also collected at a lower altitude than the LANDSAT data (5.8 km compared to 917 km) and at a higher resolution (3 m by 5 m compared with 60 m by 80 m and 30 m by 30 m). Thus, the accuracy using SAR would be anticipated higher than the LANDSAT.

Increased spatial resolution will probably provide more detailed ground information. It is planned to place a Thematic Mapper on board LANDSAT D which will have the same ground resolution as the RBV system (i.e. 30 m by 30 m pixel). This system will no doubt give better information on the ground than the existing system provides. However, for thematic mapping the system might give too detailed information and instead of producing a satistactory land cover/use map, it might rather produce one with a lot of minor detail that is difficult to generalize (Clark, 1980; 1979).

Land cover/use maps for a large area can be produced using LANDSAT digital data in a relatively short time. A map covering approximately 4,800 km^2 in southern Ontario was produced in about eight hours; five hours for training the system and three hours for the actual digital classification. This map in eight classes is approximately 55% accurate, but if only calculated for the classes trained on it is approximately 64% accurate.

It is important to point out, however, that this was the first LANDSAT digital classification undertaken by the author. Although done under supervision, there is a lot of room for improvement. It is anticipated that with practice and possible modifications to the classification scheme, better results could be achieved.

Land cover/use maps can be produced in a short time for large areas on a repetitive basis. More accurate maps made by traditional methods are usually two to five years out of date when published. Their accuracy might, therefore, be assumed to have decreased with time.

Land cover/use changes changes can be monitored using LANDSAT digital data. Various enhancement methods were tested, but a comparison of classifications between two dates was not attempted due to the low accuracy of classification achieved from the one date. With a classification accuracy around 60%, the maximum accuracy for two dates would be approximately 36%.

It is concluded that the overlay of one band to the same band of another date provides the best information on change. It is also concluded that rather than carrying out classification of the changes, the LANDSAT data are better used to point out areas of changes. Other methods can then be used to interpret the actual changes.

One problem encountered using the data for change detection is in the agricultural areas where changes in reflectance occur due to different plantings and different stages of the crops. The final conclusion is that the nature of visual interpretation, or digital supervised classification based on visual recognition of the environment, will probably never be accepted as pure science. It is based on what one can see, and this is based on knowledge, as accumulated through experience (Skinner, 1969; Piaget, 1971).

Detailed classification systems are therefore used to try to minimize the effects of individual interpretation, but still the final decision is made by the individual. This problem has not, and probably never will, be overcome by the use of computer assisted classification devices designed to do automated mapping. These devices will never do better in terms of accuracy than the analyst who undertakes the work.

9.3 Recommendations

As the final part of this thesis a few recommendations are presented:

1. Future work using radar imagery should include studies of different look directions and different modes of depression.
2. More studies should be undertaken which investigate methods to try to understand the nature of radar return signals. This might aid the interpreter and improve classification.
3. Studies should be continued on the use of LANDSAT for land cover/use studies, particularly to improve the classification accuracy. Such studies really require unlimited access to image analysis systems such as those at CCRS or OCRS. Only by repetitive testing can the best methods and the best accuracies be attained. Ideally an image analysis system should be available in a university in Ontario.
4. When LANDSAT-D has been launched, detailed assessments of the effects of increased resolution on accuracy and ability to map should be undertaken.
5. If the accuracy is improved, further studies relating to change

detection using automated classification would be justified.

6. Further studies of the RBV system for land cover/use should be undertaken, especially for the urban areas.
7. Merged RBV/MSS data should be studied for land cover/use classification.

It is believed that although the results of the classifications produced in this study are not especially high, with further work and improvements in methodology, the analysis systems will give results with higher accuracies.

"In the beginning of time there was nothing"

Völuspá (The Sibyl's Prophecy).

Every field needs its childhood, and youth before it becomes an adult. Remote Sensing using satellite data for land cover/use studies is still only a child.

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