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VISUAL INTERPRETATION OF THEMATIC MAPPER IMAGERY FOR
THE CHANGE DETECTION OF WETLANDS IN EASTERN ONTARIO.

by

Bruce Thomas, B.E.S.

A thesis submitted to the
Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Master of Arts
Department of Geography

Carleton University

Ottawa, Ontario

March 16, 1988

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Bruce Thomas, B.E.S.

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the degree of Master of Arts.

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April, 1988

ABSTRACT

Balancing the development and conservation of wetlands requires accurate information about the land use changes that affect them. In response to this need, an economical method for the visual interpretation of Thematic Mapper imagery has been developed. An interpretation key was constructed for spring imagery of Eastern Ontario. The imagery was compared with three maps from the Wetland Mapping Series. Changes were delineated with 85 % or better accuracy and converting land uses were identified with an overall accuracy of 90 %. Agriculture continues to be the major agent of wetland loss, primarily to pasture and forage crops. Agricultural uses were found to be consistent with the capability of the converted wetland soil. Area measurements suggest that the extent of existing wetland is underestimated on two of the three maps. Change rates could only be compared on the Russell sheet, where the previous net wetland gain is being reversed by recent losses. The method can be applied to updating the Wetland Mapping Series and to monitoring wetland changes in other provinces.

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CHAPTER 1

INTRODUCTION

Wetlands are a vanishing natural resource. Managing those that remain after two hundred years of conversion to other uses requires informed decision making. This begins with an understanding of the extent of wetlands and the nature of the changes that are affecting them. Recent developments in remote sensing technology provide the opportunity to develop an economical and simple method to monitor these changes on a regional scale.

1.1 Definitions

1.1.1 Remote Sensing

Remote sensing is a technique used in geography to locate, classify and measure features on the earth's surface (Curran, 1987). The interaction of electromagnetic radiation with the different features is recorded by a sensor, film or imaging device that is not in contact with the features. The resulting data can be used to provide an image of this interaction which can be analyzed to identify and study the features.

The data may be analyzed by computer using the methods of digital image analysis. While such methods provide quick results, digital data are expensive. For about one tenth of the cost it is possible to order a photographic reproduction of an image that can be analyzed using visual interpretation.

The Thematic Mapper (TM) aboard the Landsat satellite is part of the second generation of orbital sensors. The level of detail it provides is much improved over the Multispectral Scanner (MSS) that was the first carried on the Landsat series. Before TM, satellite data had only proven useful for general wetland classification. Fundamentals of remote sensing are covered in introductory texts (Lillesand and Kiefer, 1987; and Sabins, 1986).

1.1.2 Wetlands

Wetlands are areas where an abundance of water saturates the soil and favours the dominance of water loving or water tolerant plants and other biological activity adapted to the wet conditions (Ontario Ministry of Natural Resources and Environment Canada, 1984; and Tarnocai, 1979). These conditions occur where surface water collects in either seasonal or permanent shallows, or where the water table is at or near the surface.

1.2 The Extent of Wetland Conversions

Once a common feature on the landscape, wetlands have been cleared by European settlers and their descendants who have viewed them as obstacles to agriculture, urban development and related land uses. Across Canada, estimates of conversion range from 60 to 98 percent of the original wetland area (Environment Canada, 1986). Conflicts between wetland conservation and development are greatest in four major wetland regions of southern Canada where the concentration of population is the greatest (Figure 1-1).

In the Atlantic Coastal Region, about 65 per cent of the original wetland area has been converted to other uses since settlement began. As a result of declining demands for agricultural products from this region, some previously converted areas have been abandoned and the wetlands have been gradually reestablishing themselves. However, they face a serious threat from the development of energy resources. Peat mining would carve up considerable areas of wetland, and tidal power developments would affect the hydrologic regime of coastal marshes.

The Lower Great Lakes - St. Lawrence Estuary and Prairie Pothole Regions both have about 70 per cent wetland conversion, most of this to agriculture

Figure 1-1 : SIGNIFICANT WETLAND CONVERSION REGIONS IN CANADA

SOURCE: (Environment Canada, 1986)

but a significant proportion has been for urban uses. Shoreline wetlands in these regions are prime waterfowl habitat.

Land use pressures are greater in the Pacific Coastal Region, where the ocean and mountains limit the amount of available land. There, 80 per cent of presettlement wetlands have been converted, largely to agriculture, but more recently urban and recreation uses have become significant (Environment Canada, 1986).

Urban and industrial development are increasingly important factors in the loss equation. Eleven areas centred about Canadian cities continue to experience a decline in wetlands due to urban expansion. This is in part an indirect effect: wetlands are converted to replace lost agricultural land. Regina is the only urban region where wetlands are still being converted directly to agriculture (Kessel-Taylor, 1984).

Urban uses to which wetlands are converted include harbour facilities, landfill, airports, and shopping centres (Environment Canada, 1986). The trend towards the industrial use of wetlands may be attributable in part to the rising cost and decreasing availability of suitable land near urban centres. Adjacent urban and industrial uses can have an indirect impact on wetlands through surface runoff, air pollution, and landfill

leachates (Pilon and Kerr, 1984).

The value of wetlands as a recreational resource increases the land use pressures near urban centres (Lynch-Stewart, 1983). Recreational use can be either non-destructive, as in bird watching, hiking, nature photography, and cross country skiing; or destructive, the result of the construction of facilities such as marinas and golf courses. Recreational development of lakeshore wetlands in southern Ontario has been particularly damaging in the ~~Kawartha~~ Lakes region and along the Lake Erie shoreline (Bardecki, 1984).

Drainage for agriculture is the most significant agent in wetland loss. This activity includes the clearing and infilling of wetlands for purposes of cultivation, the diking of shoreline marshes for pasture and crops, the dredging of farm ponds, and the installation of drainage tiles. The major benefits of drainage include higher fertility due to increased aeration, higher soil temperatures, and improved soil structure. These combine with earlier germination, greater crop selection, and greater efficiency of farm machinery to increase yields (Bardecki, 1981). The effects on wetlands can be drastic, removing surface water and lowering the local water table. To help farmers afford these benefits, agricultural drainage

projects are often subsidized by government.

Between 1979 and 1984 drainage activity sponsored by the Eastern Ontario Subsidiary Agreement is estimated to have had some effect on 10 % (16,000 ha) of the total wetland area of the region (Cecile et al., 1985). A cost/benefit analysis shows, as a best estimate, that the benefits of drainage to agriculture are outweighed by costs in three quarters of the drains surveyed, indicating a lack of concern by the Agreement for both wetlands and the anticipated benefits to agriculture (Cecile et al., 1985).

The increasing scarcity of wetlands has increased our awareness of them. Combined with a better understanding of the functioning of wetland ecosystems, the prevailing attitude of good riddance towards wetlands has begun to give way to respect and concern for a valuable resource. Their disappearance may be noticed in a reduction of wildlife populations, an increase in river flooding and shoreline erosion, or a degradation of water quality.

1.3 Goal and Objectives

Easing the conflict over wetland resources requires recognition of the need for a balance between preservation and development. Accurate information

about the nature, extent and timing of land use change on wetlands is an essential but lacking element to their management (Lynch-Stewart, 1983).

The goal of this thesis is to assess the visual interpretation of Landsat Thematic Mapper imagery as an efficient and low-cost method for monitoring and assessing land use changes on wetlands in eastern Ontario. To this end, the following objectives have been identified:

1. Develop a visual interpretation key to identify wetlands and their adjacent land uses from TM imagery.
2. Identify, delineate and tabulate areas of change that have or are occurring in the use of wetlands at a scale of 1:50,000.
3. Assess the extent to which land use capability ratings indicate the pressures on wetlands in the study area.

1.4 Study Area

Eastern Ontario is a region that has experienced intensive agricultural drainage since 1969 (Bardecki, 1981). Between 1979 and 1984 drainage activity was sponsored by the Eastern Ontario Subsidiary Agreement (Cecile et al., 1985). The region is included on a list of representative areas for a national-scale wetland monitoring program (Lynch-Stewart, 1983).

Eastern Ontario is part of the Eastern Temperate Wetland Region defined by Zoltai (1980). Characteristic wetlands are swamps in deciduous basins and alongside streams. Marshes and the occasional fen are found along the banks of streams and rivers, and the shores of ponds and lakes. Bogs are less common. Average peat thickness is two metres in swamps and three metres in bogs, with the peat usually formed of moderately to well decomposed woody or sedge material and Sphagnum (Geographical Services Division, 1986).

The extent of wetland conversions has been estimated for the portion of eastern Ontario defined by the counties of Prescott, Russell, Glengarry, Dundas, Stormont, Grenville, and Ottawa-Carleton (Snell, in prep.). In 1982 this area was 15.6 percent wetland, down from 47.6 percent circa 1800. As of 1982, 3 percent (4340 ha) of the 1967 wetland area had been lost to agriculture. Figure 1-2 shows the distribution of these losses for both field crops and forage crops. Wetland gains, largely to scrubland and immature forest cover, amounted to 1.6 percent (2360 ha) for the same period (Snell, in prep.). This amounts to a net loss of 1.4 percent of the wetland area of eastern Ontario between 1967 and 1982.

Figure 1-2
WETLAND LOSS TO AGRICULTURAL USES IN EASTERN ONTARIO, 1967 - 1982.

(a) Cropland

(b) Hay, Pasture & Forage Crops

Percent of Total Wetland Change

SCALE - 1:1,950,000

SOURCE: (Snell, in prep.)

1.5 Methodology and Limitations

Change detection involves the comparison of data from an early date with data from a later date. In remote sensing investigations, the data usually consist of imagery from both dates. The later image would be superimposed onto the interpretation of the early image to locate any changes.

Uninterrupted TM data have only been available since 1984. The two year monitoring period that this would provide would probably not reveal many changes given that the annual rate of wetland loss is about 0.1 percent in eastern Ontario (Snell, in prep.). To overcome this limitation, the Wetland Mapping Series (Third Approximation) produced by the Ontario Region of Environment Canada was used as baseline data. This provided a monitoring period of four years, but imposed its own set of limitations. The image interpretation had to adhere to the definitions and assumptions used to compile the maps. These presented difficulties to the method and limit the confidence in the results of the change detection procedure. The Series was, however, the most comprehensive data available for the location of wetlands in Ontario.

The land capability ratings used to help assess the pressures on wetlands were compiled by superimposing

Canada Land Inventory maps of agricultural capabilities on top of the change map. The rating of land adjacent to the wetland change area was compared with the class of wetland soil. A full cost/benefit assessment of wetland losses was not possible because wetland evaluation data are only available for a few wetlands in Ontario.

1.6 Report Structure

Chapter 2 discusses the improvements in the sensors of the Landsat satellites by comparing results of wetland and land use applications of MSS and TM data. A review of the fundamental image elements provides the basis for a comparison of digital and visual approaches to image analysis, again in the context of wetland applications. Finally, a discussion of change detection introduces the method adapted for this thesis.

Chapter 3 describes the method used to produce accurate estimates of wetland change in greater detail, along with the data used and their limitations. The significance of the data limitations became apparent in the application of the method, in particular during the construction of the interpretation key. Method modifications were required to overcome the limitations are discussed in Chapter 4, which also presents and

analyzes the results obtained. A summary and avenues for future research appear in Chapter 5.

CHAPTER 2

REMOTE SENSING OF WETLANDS

2.1 Introduction

Resource management involves decision making about the allocation and development of a resource. Decision-making about wetlands should be based on inventory, evaluation and priority assessment (Lynch-Stewart, 1983). The level of detail of the information required depends on the scale of the management jurisdiction.

Regional management of wetlands requires general tabular statistics, such as number of wetlands in an area, and specific locational data, including boundaries, areal extent, soil type, plant species, biomass and surrounding land use (Carter and Richardson, 1981). Land uses affect wetlands with agricultural runoff, urban noise and pollution, and the economic pressures of subsidized drainage (Stearns, 1978). The management of individual wetlands has similar but more specific information requirements. These include the extent and duration of surface flooding, changes in vegetation cover, and detailed geologic, hydrologic, and cultural data (Carter and Richardson, 1981).

For wetlands, remote sensing has the potential to provide accurate information at greater cost savings than traditional survey methods, especially where frequent monitoring is required (Tomlins, 1986). Field surveys are made inefficient by dense and tall vegetation, poor trafficability, the frequent lack of high ground from which to overview the area, and the dynamic nature of wetland vegetation which requires several surveys to obtain an a complete picture of the vegetation composition (Roller and Colwell, 1978).

The aircraft and spacecraft used as platforms for remote sensing provide an elevated vantage point, and their mobility makes it possible to collect data about an area repeatedly. Remote sensing is thus able to survey not only the dynamic nature of the vegetation composition of a wetland, but also the dynamic nature of the land uses that threaten wetlands. Airborne platforms provide a detailed view of the earth's surface that satisfies local studies with specific information requirements such as the discrimination of plant communities in a wetland ecosystem. The regional view provided by orbital platforms is appropriate for investigating the impact of land use change on wetlands.

The second generation of satellite sensors is able to provide a level of detailed information that was

previously only available from airborne data. This chapter considers the improvements of the Landsat Thematic Mapper (TM) over the first generation Multispectral Scanner (MSS) for wetlands applications. The fundamentals of visual interpretation of the imagery are reviewed and contrasted with digital image analysis. Finally, multitemporal data are considered for the change detection of wetlands.

2.2 Landsat Developments

2.2.1 Multispectral Scanner (MSS)

Systematic imaging of the earth's surface began on July 23, 1972 with the launch of the first Landsat satellite. The primary sensor aboard was the multispectral scanner (MSS). MSS has a ground resolution of 79 metres, which limits the smallest area of wetland that can be mapped to 0.4 hectares. This contributes to mixed pixels that hinder the success of investigations using the data in complex wetland environments such as prairie pothole wetlands (Pokrant et al., 1987; and Wickware and Howarth, 1981).

In the Fraser Estuary in British Columbia, classification accuracies ranging from 85 - 90 percent were sufficient to support the use of MSS to aid marsh monitoring (Tomlins, 1981). Elsewhere, the spectral

response of hardwood swamp, shrub swamp and shallow marsh classes were too similar to permit their separation with the four MSS bands. While hardwoods are separable from other cover types, upland and swamp hardwood classes are very similar (Ernst-Dottavio et al., 1981). The combination of Landsat MSS data and soils information improved overall classification accuracy by 23.6 percent (Ernst and Hoffer, 1979).

2.2.2 Thematic Mapper (TM)

Limitations of the MSS led to the design of the second generation Thematic Mapper, first launched in July 1982 aboard Landsat 4. Improvements in TM over MSS include finer spatial resolution, spectral separation, geometric fidelity, and radiometric sensitivity (U.S. Geological Survey, 1982).

The 30 metre ground resolution of the Thematic Mapper is a significant improvement over the MSS. TM data are a cost-effective source of information about current wetland conditions, with sufficient detail for investigations up to scales ranging from 1:50,000 to 1:20,000 (Tomlins, 1986). Hydrophytic vegetation has been identified in both flooded and dry marsh sites and small depressions much smaller than 1 hectare (Pokrant et al., 1987). A linear regression analysis from that

study showed a very high correlation between estimates of wetland areas obtained from aerial photographs and the classification of TM data. In another investigation, TM marsh area calculations were better than 95 % accurate (Koeln et al., 1986).

The Thematic Mapper uses seven spectral bands that span a greater portion of the spectrum than the four bands used by MSS (Figure 2-1). The bandwidths were refined to improve the monitoring of vegetation, except band 7, which is tailored to geological applications.

A number of different approaches have been used to determine which of the seven bands will yield the most information for inventory and monitoring of wetlands. Table 2-1 compares the band selection rationale with their interpretability for different land uses. Wetlands are easily distinguished from forest or other vegetation by darker tones in all bands. Band 5 is the most useful single band, but a combination of spectral information in colour composites is generally more useful than a single band (Troler and Philipson, 1986).

The six bands give rise to several possible combinations for colour composites. There is a certain amount of redundant spectral information about a given target between bands. Analysis of digital image data shows that similar wetland cover information is provided

Figure 2-1
 LANDSAT SPECTRAL BANDS AGAINST TYPICAL
 REFLECTANCE CURVES FOR COMMON FEATURES.

(After Lillesand and Kiefer, 1979)

Table 2-1

THEMATIC MAPPER BANDS: RATIONALE AND INTERPRETABILITY

<u>Band Design Application</u> ¹	<u>Ease of Interpretation</u> ²
BAND 1	
Blue-Green (0.45-0.52 μm). Water penetration for coastal mapping. Differentiating soil from vegetation; deciduous from coniferous.	Marginal identification of most urban land cover, with transportation and medium density residential easiest. Forest, bare soil, beaches, pits and quarries easily identified on rural landscape. Wetland identification not possible.
BAND 2	
Green (0.52-0.60 μm). Corresponds to visible green reflectance peak of vegetation for vigour assessment.	Similar to Band 1, but able to identify high density residential land cover.
BAND 3	
Red (0.63-0.69 μm). Chlorophyll absorption in this region is used to discriminate vegetation.	Similar to Band 2, but allows cropland and most urban cover classes to be differentiated. The preferred visible band due to minimal atmospheric scattering effects (haze).
BAND 4	
Reflected infrared (0.76-0.90 μm). Useful for determining biomass and delineating water bodies.	Strong absorption by water makes wetlands apparent. High reflectance by vegetation. Urban street patterns are quite clear.

¹ (U.S. Geological Survey, 1982)

² (Troler and Philipson, 1986)

Table 2-1 (cont'd)

BAND 5

Reflected infrared (1.55-1.75 μm). Indicates moisture content of vegetation and soil. Discriminates snow from clouds.

Strong absorption by water, reflection by bare soil and grasses. Useful in identifying wetlands, cropland, beaches, water bodies. Degradation in interpretability of most urban cover classes, except commercial.

BAND 6

Thermal infrared (10.40-12.50 μm). For use in thermal mapping, vegetation stress analysis, soil moisture discrimination.

120 metre resolution limits interpretability to forest, water, and marginally bare soil and heavy industrial.

BAND 7

(2.08-2.35 μm). Selected for the potential of discriminating rock types and for hydrothermal mapping.

Similar to Band 3, but better for wetlands, water bodies and vegetated cover, not as good for urban features.

by the three visible (TM 1,2,3) and the two shortwave infrared (TM 5,7) bands (Tomlins, 1986). The best combination of these is bands 3, 4, and 5. This results in very high contrast between different wetland types and good differentiation between other vegetated land cover such as forest, agriculture, and rangeland. In the prairies, this combination permitted consistent delineation of open water, separation of temporarily flooded areas from permanent water areas, and in most cases the separation of grasses from forage crops (Pokrant et al., 1987). Another study found these bands to be the most influential for determining wetland type (Koeln et al., 1986).

2.3 Image Analysis

The word remote in the term remote sensing implies the indirect presentation of spectral data (Fussell et al., 1986). In the case of false-colour composites, the spectral reflectance from the far regions of the spectrum is encoded into the visible wavelengths by assigning them colours. Decoding is accomplished with the methods of image analysis.

Image analysis is commonly divided into digital and visual methods. The predominant use of digital methods has focussed attention on aspects of computer science,

and away from the fundamental skills of visual interpretation. This distinction has masked the image elements that are common to both approaches (Estes et al., 1983).

2.3.1 Image Elements

An image is reconstructed from the digital data of a scanner in the form of a matrix. Each cell in the matrix is a picture element, or pixel. Every pixel contains a spectral reflectance measurement that is represented as a grey tone or colour. Tone is the shade of grey in black and white images or the combination of hue, chroma and saturation in colour imagery. Colour or grey tone is the result of an object's reflection, emission or transmission of electromagnetic radiation.

As the number of pixels in an image increases, additional interpretation elements are created (Figure 2-2). The edge created by differences in tone or colour between objects conveys more information than any other image element (Estes et al., 1983). While land cover can often be determined on the basis of colour and tone, the classification of land use requires additional clues from the other interpretation elements (Tomlins, 1986).

Texture is the tonal repetition within an object that gives the appearance of roughness or smoothness.

Figure 2-2
RELATIONSHIPS BETWEEN THE ELEMENTS OF IMAGE INTERPRETATION.

(after Estes, 1983)

The spatial repetition of objects in the image generates a pattern. The scale of the imagery changes the appearance of patterns and textures (Tueller, 1979). Scale also changes the size of an object on an image, which is a useful clue to the identity of an object (Estes et al., 1983). As the scale decreases, the pattern of the objects may become the texture of a larger object. For example, a regular matrix of fields of identifiable crops becomes a large expanse of a coarse textured agricultural land class.

Shape alone can be sufficiently distinctive to allow identification of an object (Estes et al., 1983). Site refers to the location of objects in relation to other objects or terrain features, such as aspect, topography, soil, hydrology, geology, and vegetation. The association of objects with others provides the opportunity to exploit convergence of evidence, an important procedure in object recognition (Estes et al., 1983). Together, site and association form the spatial context of an object.

Tone, texture, pattern, and association appear to be the major elements for the recognition of objects with Landsat imagery (Estes et al., 1983). Of these, texture and pattern are important to the interpretation of wetlands. Pattern is an important factor in the

recognition of peatlands in Vermont using airphotos at either 1:52,000 or 1:104,000 (Howland, 1980). The pattern was observed to be concentric, the result of plant response to environmental gradients or the circular expansion of some species of marsh vegetation. Similar patterns were observed in peatlands on the imagery used for this thesis.

Figure 2-3 shows the hierarchy of the image elements for both visual and computer-assisted analysis techniques. The computer's strength is in the identification of the subtleties of spectral response. Recognition of other image elements requires a specific sequence of increasingly complex processing algorithms. The human interpreter, on the other hand, can make use of several image elements in any sequence.

2.3.2 Digital Classification

Computer classification techniques are recommended for small scale (1:250,000) regional wetland enumeration and mapping (Tomlins, 1986). Wetland classification accuracies using MSS data range from 60 to 80 percent (Carter and Richardson, 1981). This has improved with the refined spatial and spectral resolutions of TM data. A specially developed classification algorithm distinguished wetland and upland cover classes with 91

Figure 2-3

HIERARCHY OF IMAGE ELEMENTS IN RELATION TO
INTERPRETATION TECHNIQUES.

(After Estes et al., 1983)

IMAGE ELEMENT	COMPUTER ALGORITHMS Examples Complexity	HUMAN INTERPRETATION SEQUENCE
TONE COLOUR TEXTURE PATTERN SIZE SHAPE SITE ASSOCIATION	Density Slicing Multispectral Classification Texture Classification Spatial Transforms and Classification Size Feature Classification Syntactic Classification A Priori's Modified Contextual and Syntactic Classifications

percent accuracy: marsh classes alone exceeded 92 percent (Koeln et al., 1986). A more specific classification of wetland plant associations produced overall accuracies ranging from 75 to 90 percent (Tomlins, 1986). However, the improvements over MSS have been offset by a ten-fold increase in data volume, which intensifies data handling, processing, and analysis problems (Tomlins, 1986).

2.3.3 Visual Interpretation

The speed, versatility, consistency and reliability advantages of digital image analysis systems are often compensated for by the expense of their acquisition and operation (Crapper and Hynson, 1983). Photographic image products are a small proportion of the cost of digital data (Troler and Philipson, 1986).

Visual image interpretation is no less accurate than digital analysis, although it is more time consuming and the results from different interpreters may vary. The human interpreter is able to make simultaneous use of both spectral and spatial information more readily than a computer. The use of these additional clues in visual interpretation makes it less prone to error, but given the intensity of labour required and the resulting fatigue, visual methods are

best suited to large scale wetland mapping over relatively small areas of up to 250 km², especially where the wetlands are small and scattered (Tomlins, 1986).

Visual analysis of MSS imagery for general wetland classes has proved 87.6 % accurate versus 65 % for a digital classification (Carter and Richardson, 1981). Digital classification of TM data for a complex wetland environment accurately mapped open water bodies as small as 5 ha, whereas a visual interpretation mapped lakes as small as 2.5 - 3.0 ha (Tomlins, 1986). The visual analysis of enlarged TM imagery has accurately identified as many as twice the number of classes obtainable from a digital analysis (Trolier and Philipson, 1986).

Visual image interpretation tasks include object detection and identification, measurement of the spatial and spectral dimensions of objects, problem solving using the orderly associations of objects, and communication of results (Estes et al., 1983). The detectability of a feature depends on the contrast with its surroundings. Vegetation is the most important factor in contrast, although topographic relief, cloud, snow cover, and the degree of urban and rural cultural development of the landscape also contribute (Moore et

al., 1982). Patterns and context provide evidence required for problem solving. The communication of the results of an interpretation begins with the labelling of an object.

Band selection and the assignment of colours are among the parameters that affect the results of a visual interpretation of TM imagery (Tomlins, 1986). Each false colour composite can have one of six different overall hues depending on the assignment of colour to the bands. Assigning band 3 (red) to blue, band 5 (reflected infrared) to green and band 4 (reflected infrared) to red (this combination can be denoted as TM 3-5-4) results in an overall image hue similar to false-colour infrared photography. However, the absorption of infrared wavelengths by water inhibits interpretation of wetland classes defined by submerged vegetation, confusing them with shallow, open water. A composite with a greater proportion of the visible region, such as TM 2-3-4, is recommended for the interpretation of ponds, lakes and coastal foreshore marshes (Tomlins, 1986).

Transparencies are the preferred image medium for fidelity to the original data. In the creation of photographic image products, image data are transformed to fit the density range of transparency film. Paper

prints made from this transformation have a narrower range of densities, so dark areas come out too dark and bright areas are washed out. The display and interpretation of transparencies requires illumination and projection equipment, however, and they are not as easily used in the field as prints.

2.4 Multitemporal data

The mobility of sensing platforms permits a given area to be revisited. Time-series data can help to identify targets that might appear similar in one season, but that have a contrasting appearance in another. Multitemporal data also provide the capability for detecting changes in targets. Aerial platforms do not provide routine and automatic revisits, while Landsats 4 and 5 return every 16 days. Being able to monitor wetland biomass and productivity with such data would be valuable for wetland management and modelling research (Bartlett and Klemas, 1980).

2.4.1 Seasonal Imagery

In some places, a variation in water depth of a few centimetres can shift a wetland boundary by hundreds of metres (Stewart et al., 1980). The use of spring-time imagery acquired near maximum water levels helps to

alleviate uncertainty about the exact extent of some wetlands. Early spring imagery that avoids the leafing-out of the plant canopy was crucial in delineating small wetlands (Tomlins, 1986). It also avoided the confusion of wetlands with upland classes that occurs in summer and early fall. However, a summer image acquired at the height of the growing season may be required in detailed investigations in order to classify adjacent land uses that appear similar on spring imagery.

2.4.2 Change Detection

Comparing remotely sensed information from different dates provides the basis for measuring changes over time. The information can take the form of imagery or derived maps, or non-image sources such as field survey notes. Maps represent an abstraction of image sources, and as such may contain some error from the process of cartographic communication (Kolacny, 1977).

The registration of multi-date imagery can introduce uncertainty in a change detection (see Figure 2-2). Computer methods have traditionally relied on image-to-image comparisons, although the development of geographic information systems (GIS) is making the integration of maps easier and more efficient. As with image interpretation, manual techniques can compare any

combination of data easily and accurately.

Wetland applications of change detection include identification of agents of change, of sensitive or priority management areas, and rates of vegetation succession (Roller, 1981). For example, co-processing May and summer data can produce a permanency index for a wetland basin and permits the measurement of the extent of different wetland types (Koeln et al., 1986).

Air photos provide very detailed change information. From 1:12,000 airphotos, changes in area as small as 0.04 ha were easily identified without magnification (Hardisky and Klemas, 1983). Roller and Colwell (1978) used air photos to detect changes over a 36 year period. The change detection was a simple matter of placing a grid over the vegetation maps interpreted from the photos and then coding and comparing each cell between the dates.

Digital techniques are based on the assumption that changes in land cover and land use are manifest in changes in spectral reflectance between the dates. A first attempt at using airborne multispectral data for wetland change detection was made only recently (Jensen et al., 1987). In Canada, Landsat data have been applied to the change detection of wetlands, mainly to examine the effects of major development projects

(Howarth et al., 1982; Tomlins, 1981; and Wickware and Howarth 1981). Digital change detection can be accomplished by a variety of enhancement or classification methods (Bonn et al., 1982; Jensen and Toll, 1982; Roller, 1981; Ryerson et al., 1982; Witt et al., 1982). Other approaches that can be considered involve finding the subset of original data that best describes the land cover change (Burns and Joyce, 1982).

A simple visual change detection technique involves registering a negative transparency from one date and a positive transparency of the other. Areas of no change appear as a uniform neutral tone and change areas appear either dark or light toned. A colour additive viewer can be used to detect change in more than one band at a time with this method (Crapper and Hynson, 1983).

Because TM data have been available only recently relative to the rate at which wetland changes occur in eastern Ontario, this thesis identifies changes by comparing an image to an earlier wetland inventory map. The method used was originally developed for the revision of National Topographic System 1:250,000 maps (Moore et al., 1982). A special image projection device known as the PROCOM-2 was used to delineate changes on the 1:50,000 maps that make up each 1:250,000 sheet. Using MSS data, an area of two million square kilometres

was revised in nine months with positional errors averaging 30 metres (Gregory and Moore, 1986). TM imagery is expected to improve the accuracy of the topographic map revisions, and should provide good results for the change detection of wetlands.

2.5 Summary

The Landsat Thematic Mapper is able to resolve areas less than half the size of the Multispectral Scanner and take measurements in seven specialized spectral bands. This extra detail has improved the ability of computers to classify the data, but the extra volume has magnified routine data processing problems. The improved spatial information provides detail in TM imagery that facilitates visual interpretation.

While more time consuming than digital analysis, the ability of the human interpreter to make use of all the image elements produces results that are no less accurate. Given the rate at which land use changes to wetlands occur, the rapidity of digital methods is not required. Visual analysis offers substantial cost savings: the cost of photographic image products is currently only about one tenth the cost of digital data, and expensive hardware and sophisticated software are not required.

Visual methods are also preferred for this thesis because the use of maps is required for the change detection. The registration of the image to the map in an image analysis system would require the geometric correction of the image and the integration of rasterized map data. Image-to-map registration is a fast, straightforward procedure using a device such as the PROCOM-2, and no special preparation of the image or map is required. For wetlands investigations, TM imagery should be acquired in the spring and reproduced using the 3-5-4 band combination.

The economy and simplicity of visual image analysis methods make remotely sensed information very accessible. In an operational wetlands management setting, the cost savings could be directed towards funds or activities to preserve wetlands identified on the imagery as being in danger of conversion.

CHAPTER 3

A VISUAL METHOD FOR THE CHANGE DETECTION OF WETLANDS

3.1 Introduction

The Thematic Mapper appears capable of providing accurate and timely information about the changes that are occurring in the wetlands resource. The start of continuous TM coverage in 1984 hinders the assessment of its imagery for the detection of changes up to 1986. Given the small number of wetland changes that occur each year in eastern Ontario, the comparison of imagery spanning a two-year period may not detect enough changes to make conclusions about the wetland conversion situation.

The next best source of information about the location of wetlands in Ontario is the Wetland Mapping Series (Third Approximation). Produced by the Ontario Region office of Environment Canada, the maps show the state of wetlands in 1982. These maps were substituted for a 1984 image, doubling the monitoring period but imposing its own set of limitations on the change detection. The limitations stem from the definition and assumptions used to compile the maps. This chapter

describes the steps involved in using maps and the visual interpretation of TM imagery to produce estimates of wetland change for eastern Ontario.

Visual interpretation involves the use of all the image elements described in section 2.3.1. These were systematically described for wetlands and adjacent land uses to create an image interpretation key. Wetlands were described by superimposing the image on to the Wetland Mapping Series, and adjacent land uses from the Agricultural Land Use Systems maps produced by the Ontario Ministry of Agriculture and Food.

The change detection involved projecting the image onto the Wetland Mapping Series sheets and looking for (1) adjacent land uses that had encroached into areas delineated as wetland on the map, and (2) natural vegetation that had reestablished in areas delineated as being previously lost wetland. Areas of change were delineated, labelled and then digitized to produce estimates of the extent of the changes.

In an effort to gain further insight into the nature of the changes, soils in areas of wetland lost to agriculture were compared with the agricultural capability of the soils in the surrounding upland area. The Canada Land Inventory was used to obtain the capability of the surrounding area, while the wetland

soil information was available from the Wetland Mapping Series.

3.2 Data

3.2.1 Imagery

Two TM bulk quadrants providing coverage of a large part of Eastern Ontario (Figure 3-1) were purchased from the Canada Centre for Remote Sensing. The scenes were acquired on May 13, 1986 and were reproduced using the TM 3-5-4 band composite. The images are cloud-free, although pixel dropout created minor interpretation difficulties along one swath (a group of 16 scan lines).

Nine black and white air photos were obtained to assist in the description of the imagery for the construction of the interpretation key. The photography was flown between 1975 and 1983 at scales ranging between 1:25,000 and 1:50,000. Colour air photos from 1985, at a scale of 1:15,000, were used to verify the labelling of changes interpreted from the TM imagery.

3.2.2 Maps

All maps used in this investigation were at a scale of 1:50,000. The information provided by the Agricultural Land Use Systems maps and the Wetland Mapping Series is described below. The methods used to

Figure 3-t IMAGERY COVERAGE AND SAMPLING AREAS.

produce the maps result in limitations that may be of significance to the results obtained. A discussion of these limitations is contained in Appendix A.

Both sets of maps were blue-line reproductions. If discernible, the Universal Transverse Mercator (UTM) grid, contour, road, and building information was faint. Corresponding map sheets from the National Topographic System (NTS) at a scale of 1:50,000 were used to obtain this information.

3.2.2.1 Agricultural Land Use Systems

The Agricultural Land Use Systems Maps were used to identify and describe agricultural areas on the image so that an interpretation key could be constructed for use in the change detection procedure. The maps are part of the Agricultural Resource Inventory of Ontario, which includes drainage system maps. When used in conjunction with soil or soil capability maps, the Land Use Systems maps provide a basis for making land use decisions (Capital Improvements Branch, 1983).

The concept of an agricultural land use system overcomes the problem of crop inventories becoming quickly outdated due to routine farm practices such as crop rotation. Each system describes the proportion and mix of crops grown on a given farm property or group of

adjacent properties. The type of system and its economic performance depend on the climate and soil conditions, crop demand and marketing facilities in an area (Capital Improvements Branch, 1983). Included on the maps are non-system land uses, such as forest, built-up areas and idle farm land.

Three townships were selected to represent the colours contained in the image (Figure 3-1). Montague Township has a high proportion of forest and wetland area, and supports predominantly hay and pasture systems and idle agricultural land. Montague contains large parcels that provide a good representation of the green, grey, and brown hues in the image. Winchester Township is a predominantly agricultural area characterized by corn, mixed grain and monoculture systems. There are few wetlands. Winchester was chosen to represent orange and blue hues in the image. Alfred Township contains a mix of large crop, hay, and pasture systems as well as part of the Alfred Bog. Alfred contains predominantly green, blue and orange coloured parcels.

3.2.2.2 Wetland Mapping Series (Third Approximation)

The Wetland Mapping Series consists of 125 maps at a scale of 1:50,000 that are distributed by the Federation of Ontario Naturalists. They show wetland

location and the spatial extent of wetland conversion since European settlement at a regional scale, and are intended to provide a baseline for future wetland monitoring (Snell, in prep). This third objective of the Series complements the second objective of this thesis: the identification and delineation of wetland changes in eastern Ontario.

Three maps were selected for the change detection procedure (see Figure 3-1). Each contains significant areas of wetland and together they represent the various agents of change affecting wetlands in eastern Ontario (Snell, in prep.).

3.3 Image Interpretation

3.3.1 Apparatus

The imagery was projected on to the maps using the PROCOM-2 optical transfer device designed by Gregory Geoscience Ltd. of Ottawa, Ontario. The instrument reflects a projection of a transparency on to a working surface that can accommodate large map sheets. The transparency is held between two glass plates that move together along horizontal and vertical axes, allowing the interpreter to roam through the image. The scale of the image is matched to the map using a zoom projection lens. Data registration is achieved by a

series of adjustments of image scale and map rotation. The PROCOM-2 is easy to operate and can be used for extended periods of time with little discomfort.

In the absence of a PROCOM-2, there are several alternatives for the use of image transparencies, such as the Zoom Transfer Scope. An overhead projector can be used to project the image on to a map mounted on a wall. Selected areas of interest can be reproduced on 35 mm film for use with a slide projector. The image can also be inspected using a light table and magnifier.

3.3.2 Classification

The land use and wetland classes defined in the legends of the basemaps (Table A-1 and Figure A-2) were grouped into interpretation classes for the development of a key that would help to identify land uses to which wetlands were converted. The categories were based on classification systems used in previous studies of land use dynamics on wetlands (Kessel-Taylor, 1984) and the detection of rural land use changes with TM imagery (Farmer et al., in prep). Table 3-1 shows the basemap categories included in the initial interpretation classes.

Although it was possible to differentiate on the image between wooded wetlands and those with emergent or

Table 3-1

Initial Image Interpretation Classes

<u>Interpretation Classes</u>	<u>Equivalent Basemap Classes</u>
C - Improved Agriculture	Agricultural Resource Inventory Corn (C), Hay (H), Mixed (M), Grain (MG), Monoculture (P) Systems and Sod Farms (T).
L - Unimproved Agriculture	Agricultural Resource Inventory Pasture System (HG) and idle agricultural land (A1, A2).
F - Forest	Agricultural Resource Inventory Woodland cover (Z, Zp, Zr).
U - Urban	Agricultural Resource Inventory Built-Up (B) and Extraction (E1).
W - Wetland	Agricultural Resource Inventory Swamp, Marsh or Bog (X); all Wetland Mapping Series existing wetland categories.

non-woody vegetation, wetland types were not distinguished. Such a level of detail was considered unjustified for explaining the small areas of change expected over the relatively short period of time of this study. Wetland type identification would be useful for inventories or the detection of subtle, indirect effects of human activity on wetlands. TM data have been shown to permit the delineation of wetland vegetation communities (Tomlins, 1986; Gross et al., 1987).

3.3.3 Interpretation Key Development

An image interpretation key is a decision algorithm that assists in the identification and assessment of objects. It serves as a reference, as a training aid, and can be used to develop a set of rules for digital image analysis (Williams, 1984). Keys organize information on the appearance of objects in an image in such a way that the interpreter is guided towards an identification of unknown objects.

Keys can be organized by selection or by elimination. Using the former, also known as a simultaneous key, an interpretation is made by selecting the closest description from a set of examples. Elimination keys, also referred to as sequential keys,

usually consist of a series of dichotomous pairs of image object characteristics. Sequential keys allow interpreters to become familiar with objects sooner than browsing through selective keys (Tueller, 1979).

The construction of the interpretation key followed the steps outlined by Williams (1984). Each land use system and wetland in the sample townships was treated as an object and described in terms of the image elements presented in Section 2.3.1. The total description of each township was chosen to accommodate: (1) the large number of different land use systems, (2) differences in the appearance of the various systems across the image, and (3) uncertainty about the validity of all land use system designations in 1986.

The information was recorded on object reference cards along with a serial number and UTM grid references (Figure 3-2). The object descriptions are summarized in a table called an object-character matrix. The matrix is inspected for preferably dichotomous characteristics that divide groups of objects until a single object or class of objects remains. The divisive characteristics form the decision structure of the key. Testing the key locates any decision couplets that need revision.

The scope of the key developed here is limited to use with spring TM imagery of the St. Lawrence Lowlands

Figure 3-2

SAMPLE OBJECT REFERENCE CARD

Number: 54 Sample Township : M NTS 31 C/16

UTM Easting : 417000 Northing : 4978000

OMAF Land Use System: HG

1. Dominant Colour: orange
2. Associated Colours: green, brown, blue
3. Tone: medium
4. Texture: medium
5. Edge: distinct
6. Shape: irregular curved concave polygon
7. Size: large
8. Pattern: irregular grid
9. Site: rolling upland
10. Association: transected by township roads, railroad, highway 15. Several buildings clustered along roadsides.
11. NOTES: system designation O.K. Field photos 1-28, 1-29.

(Eastern Temperate Wetlands Region) using the 3-5-4 band selection. Keys are specific because the appearance of objects will change as the plant growing season progresses, because the type of vegetation may differ between regions, and because objects appear differently in different band or colour combinations. Consequently, for a comprehensive inventory or monitoring program using visual image interpretation, several keys may be required to accommodate the changes in the appearance of targets over time and space.

In order to limit the size of the key, it is assumed that the interpreter would be able to identify distinctive common objects such as clouds, roads, utility corridors, lakes, ponds, rivers and streams. The appearance of these objects, with the exception of clouds, can be learned quickly and easily by projecting the image on to a topographic map.

3.3.4 Change Detection

Using the wetland definition and assumptions of the Wetland Mapping Series (presented in Appendix A), areas mapped as losses and gains were inspected using the image for, respectively, the presence or absence of natural vegetation cover that constitutes a change. When differences between the image and map represented a

loss of wetland, the area was delineated and the converting land use was interpreted and noted. This involved inspecting the area surrounding the change polygon because the definition of an agricultural land use system includes several neighboring fields in rotation.

Each change polygon was numbered and assigned a numeric change detection class that represented the agent of change and the Wetland Mapping Series wetland status (i.e., lost, gained, or existing). Also recorded for each polygon were UTM co-ordinates and township taken from the corresponding NTS sheet, the wetland vegetation and soil categories from the Wetland Mapping Series, and the interpretation key class. As a simple verification procedure, a binary code indicating whether or not the NTS map agreed with the interpreted presence, or absence of wooded cover was also noted.

3.3.5 Verification

The products of the change detection are updated sheets of the Wetland Mapping Series. Error present in the updated maps is the result of: (1) errors contained in the both the Wetland Mapping Series and the Agricultural Land Use Systems maps, and (2) errors introduced in the interpretation and change detection.

These can be referred to respectively as inherent and operational error (Vitek et al., 1984).

No definite accuracy estimates have been made for the Agricultural Resource Inventory. The user must assume that the land use system concept will accommodate changes resulting from routine crop rotation. It is possible that any changes in land use system designations could carry through to the compilation of the interpretation key and result in the misclassification of some of the land uses converting wetlands. To be sure this would not be the case, systems described as having colours different from the majority of others in the same class were visited in the field to ensure that the land use system designation was valid.

The Wetland Mapping Series has been estimated to be 85% accurate in its depiction of the location of current wetlands (Snell, in prep.). No evidence could be found to doubt this estimate during the construction of the key and during field visits.

Possible sources of operational error in the change detection include interpretation errors such as misclassification or imprecisions in image-to-map registration, and inaccuracies in delineation and classification of change polygons. The final results

may be further affected by errors introduced during map digitization and data entry.

A strategy for the validation of a land use map should ensure, using a minimum number of field verification samples, that there is both a low probability of accepting a map of low accuracy and a high probability of accepting a map of high accuracy (Ginevan, 1979). These criteria are met by procedures used in a branch of statistics known as acceptance sampling, which is used by manufacturers to ensure the quality of their products. Acceptance sampling identifies the probability of accepting an inaccurate map as the "consumer's risk" and the probability of rejecting a map of sufficient accuracy as the "producer's risk". The producer's risk is significant because unnecessary amounts of time and money could be spent rechecking a map which is acceptable.

The method produced polygons which have been interpreted either correctly or incorrectly as having changed. An optimal number of locations for field verification that meet the probability requirements can be determined using the binomial probability function (Ginevan, 1979). Because the binomial distribution is discrete, a given number of allowable incorrect interpretations will have several possible sample sizes.

Thus, the smallest sample size minimizes the producer's risk for a fixed consumer's risk (Ginevan, 1979).

Ginevan (1979) provides convenient tables that were used to determine the optimal sample size and the maximum number of misclassifications for the verification of the interpretation maps.

The choice of accuracy limits and risks to be used in the accuracy test varies with the mapping project. A minimum accuracy proportion of 0.85 or 0.90 and a consumer's risk probability of 0.05 are generally acceptable, and an upper accuracy of 0.99 for a producer's risk of 0.10 provide considerable protection for routine mapping projects (Ginevan, 1979). These recommendations were followed for the change map accuracy test, with minimum map accuracy set at 0.85 to remain consistent with the estimate of the accuracy of the Wetland Mapping Series provided by Snell (in prep.). Using Ginevan's (1979) tables, the optimal number of field verification sites was found to be 30, with one allowable incorrect interpretation.

Finally, to determine the accuracy with which the land use of the change polygons had been interpreted, a sample of polygons were compared with large scale aerial photography interpretations to produce a confusion matrix.

3.4 Canada Land Inventory Map Overlay

The agricultural capability of areas adjacent to the wetland change polygons were used to help assess the detected losses to agriculture. The updated wetland maps were overlaid on 1:50,000 Canada Land Inventory manuscript maps. The wetland soil (classed on the Wetland Mapping Series) was later compared with the soil capability of the adjacent area obtained from the overlay.

The potential for wetland conversion to agriculture will probably remain greatest for wet mineral soils in southwestern Ontario, where the soils are productive and land values are highest (Snell, in prep.). The Canada Land Inventory ranks soils for general agricultural capability with seven classes. Class 1 represents the most capable soils and Class 7 the least. Limitations, such as excess water, are part of the classification. Soils of class 2 and 3 which are limited by excess water are those most likely to benefit from drainage. In eastern Ontario, these soils comprise nearly 19% of the total area (Cecile et al., 1985). However, some drains affect large areas of wetland with capabilities below this level.

3.5 Database Preparation

The interpretation produced a database consisting of two sets of files. Using the facilities of the Cartographic Research Unit at Carleton University, the updated Wetland Mapping Series maps were digitized to produce a set of files of polygon vertices from which area measurements were calculated. These vector files were edited to remove common digitizing errors which affect the estimate of total area, such as duplicate polygons or extents digitized in the wrong direction. The area statistics were carried over to the second set of files consisting of the attributes of each wetland change polygon. These attributes are data acquired during the image interpretation and Canada Land Inventory overlay: UTM and township locators, wetland class, change detection class, and adjacent agricultural capability.

3.6 Summary

Figure 3-3 summarizes the steps of the method in relation to the data used and the products obtained. The Wetland Mapping Series provides a practical reference point for monitoring changes, given the scarcity of TM imagery before 1984. As outlined in Appendix A, the Series has limitations, such as the

Figure 3-3

A Method for the Detection of Changes in Wetlands using
the Visual Interpretation of Thematic Mapper Imagery.

under- and over-estimation of wetland losses and gains, which could create uncertainties in the estimates of wetland change obtained from the change detection procedure described above. Also, the difficulties associated with the application of the Wetland Mapping Series method outside of Ontario, Nova Scotia, or Prince Edward Island impose boundaries on the application of the method described in this chapter unless modifications are made.

The Agricultural Land Use Systems maps used to construct the interpretation key were also used to compile the Wetland Mapping Series. As a result, the key will be compatible with some of the assumptions used to define wetland changes in the Series. The change estimates derived from the image should thus be directly comparable with the 1982 wetland situation depicted in the wetland maps.

CHAPTER 4

APPLICATION AND RESULTS

4.1 Introduction

Informed decision making about wetlands requires timely information about the changes that are occurring in the resource. A monitoring effort should consider the dynamics of the surrounding land uses that determine the pressures put on wetlands. Agricultural Land Use Systems maps were used to identify adjacent land uses for the preparation of an image interpretation key. Limitations of the maps for this purpose became apparent during the application of the method outlined in the preceding chapter. This chapter describes these problems and the modifications to the method that were required. Also described are the uncertainties created by The Wetland Mapping Series (Third Approximation) in the change detection. These required field verification and affect the statistics derived from the procedure. The results are presented and analyzed to gain some insight into the wetland change situation in Eastern Ontario.

4.2 Interpretation Key

An interpretation key presents systematic descriptions of the appearance of objects in an image such that a person using it will be guided to the most likely identification of an unknown object. Wetland areas of eastern Ontario were located and described using the Wetland Mapping Series (Third Approximation), and land uses adjacent to wetlands were described using the Agricultural Land Use Systems maps.

The inclusion of the same land cover in different land use classes by the Agricultural Land Use Systems maps required a more detailed description of the image in order to produce an adequate interpretation key. This section describes the construction of the interpretation key, and is divided into three parts. The first details the initial attempt at describing the appearance of the Agricultural Land Use Systems using the method outlined in the previous chapter. The second part presents the modifications to the method of preparing the interpretation key, and the third part describes the preparation and presentation of the key.

4.2.1 First Description

The description of the characteristics of objects in an image is subjective. Words used to describe the

appearance of features by the interpreter compiling the key may not convey the intended meaning to the user, especially in the communication of colour. Attempts were made to reduce the likelihood of misunderstanding.

Operational definitions were developed to simplify and standardize the description of the characteristics of each object. This was in response to the considerable amount of time spent searching for words to describe adequately some of the more complex characteristics such as pattern (see Table 4-1).

Three to four working days were required to describe all the Agricultural Land Use Systems and wetlands in each of the townships used to construct the key. The descriptions were first summarized by the classes of each of the thematic maps used. Unexpected dominant colour descriptions were inspected in the field to ensure the system designation of these areas was valid. An example is orange, most frequently the dominant colour of hay systems, dominating an idle, corn or pasture system. Most of these areas proved to be their respective map classes and not changes as suggested by the variant colour. The orange of the idle and pasture systems, for instance, could be explained by a weedy hay cover found at most sites. Without this informal verification, descriptions of invalid classes

Table 4-1

OPERATIONAL DEFINITIONS OF
IMAGE INTERPRETATION ELEMENTS

- Dominant Colour: The colour occupying largest proportion of an area, or if proportions are near equal, the colour first noticed. Dominant serves as a background for the mix and resulting patterns of the associated colours.
- Associated Colours: Other colours visible in the area, occurring alone, mixed with others as a tinge. Listed in order of decreasing proportion of area occupied, which is the order in which they are most likely to be noticed.
- Tone: A property of colour. Described as light, medium or dark. Ranges of tone often occur within and between colours.
- Texture: Tonal repetition in groups of objects too small to be individually resolved that give the appearance of roughness or smoothness to an object. Described as rough, smooth, fine grained, mottled (diffuse splotches), medium, coarse. Can exhibit ranges as does tone.
- Edge: sharp, diffuse, distinct or indistinct. A variable character due to dependence on contrast with adjacent parcels.
- Site: The location of objects with reference to other objects or terrain features, such as aspect, topography, soil, hydrology, geology, vegetation. Described here as upland or one of the wetland hydrologic sites.
- Shape: Described by naming definitive shapes (square, circle, triangle, etc.) or with the use of a general descriptor (i.e., regular/irregular or angular/curved polygon).
- Size: Relative (Small, Medium, or Large).

Table 4-1
(continued)

Pattern: Geometric repetition of objects. Descriptors based on those of Tueller (1979):

Continuous - uniform colour and texture with no or very small mixture of other objects, such as buildings.

Discontinuous - colours mixed against dominant background with large spaces between or a progression of colours or tones.

Regular - associates are regularly spaced or arranged in a discernible pattern (e.g., concentric, divided in fractions, or linear).

Irregular - no discernible pattern, random arrangement.

Grid - particular to agricultural covers, colours arranged in distinct cells (usually square or rectangular in shape).

Regular - cells of similar size and shape.

Irregular - cells of varying size and shape, as in a random, patchwork arrangement.

Association: The presence of objects indicating others, such as roads, buildings and drainage.

could be carried over to the interpretation key.

Differences between the object descriptions, when grouped by dominant colour, seemed too great to allow the Agricultural Land Use Systems class detail to be preserved in the key without a large number of decision paths. Inspection of the resulting object-character matrix showed much confusion among Land Use Systems, owing to common crop covers in the various Land Use System definitions. For example, a hay system is identified by the predominance of good quality hay cover, but lower proportions of hay cover form part of the definitions of pasture, corn, grain and mixed grain systems (see Table A-1). Another problem contributing to the confusion was that wetlands mapped on the Wetland Mapping Series and the NTS maps were identified as forest by the Agricultural Land Use Systems maps. This resulted in wetlands being described as forest, causing overlap of these classes in the object-character matrix.

Systems were then grouped into the initial set of generalized land use classes (Table 4-1). This eliminated the confusion among Agricultural Land Use Systems included in the Improved Agriculture class. However, the Unimproved class (L) was still very similar to both the Improved (C) and Forest (F) classes (Table

4-2). Improved Agriculture included hay systems which appear similar to pasture systems in the Unimproved class. Also, the idle land in the Unimproved class is a combination of recently abandoned land that is similar to pasture, and long abandoned land which can be very similar to wooded areas. The type of land cover determines its colour in the image for a given band selection and colour assignment. Because the different land use systems include a number of common land covers, it becomes difficult to separate the general land use classes when the descriptions have similar lists of colours.

Unfortunately, different classes with similar colours also appeared similar in the other elements. Much of this may be attributable to the operational definitions (Table 4-1) for describing the more complex image elements. Elements such as size, shape, and pattern were effectively classified, resulting in a potential loss of information that could have helped separate similar classes. This was compounded in summarizing the descriptions for the initial key classes. Throughout the sampling, however, it was thought that the level of detail in the operational definitions was adequate to reconstruct a mental picture of the object and separate the classes.

Table 4-2: PORTION OF THE OBJECT-CHARACTER MATRIX USING INITIAL LAND USE CLASSES AND OPERATIONAL DEFINITIONS

DOMINANT COLOUR	ASSOCIATED COLOURS	TONE	TEXTURE	EDGE	SHAPE	SIZE	PATTERN	CLASS
GREEN	blue and orange, occasionally with brown yellow	light to/or medium, occasionally including medium to dark	medium, occasionally ranging from light, or to coarse. Blue often mottled	diffuse	regular angular, typically rectangular or square	usually small, but medium and large occur	irregular grid often longitudinal cells	C
	blue, alone or as a hue, possibly mixed with one or all of brown, orange, white, yellow or black	light to/or medium	medium or between medium and coarse, sometimes from smooth	distinct or diffuse to natural covers	regular angular, typically square or rectangular, also irreg. ang. & curv	small or very small, although discontinuous some pasture systems large	irregular discontinuous or grid, occasionally regular	I
	brown and/or orange, occasionally with blue, white, or yellow	light to medium. Occasionally ranging to dark.	medium or coarse, sometimes the range. Seldom fine grained.	most often distinct	square or irregular angular polygons, also round/oval or irreg. curved	small, occasionally medium or large	irregular discontinuous	F
	brown and/or orange, possibly mixed with white, yellow.	light to/or medium, occasionally ranging medium to dark	most often medium; can be fine grain or coarse, or ranging from medium to either extreme	distinct edge, often diffuse	regular angular, typically square or rectangular, also irregular curved	typically small, or very small, occasionally medium	discontinuous, most often irregularly though continuous occurrences noted	L

4.2.2 Method Improvements

To overcome these difficulties and make a functional key, a two point strategy was implemented involving:

- 1) the detailed description of a subsample of the object descriptions, and
- 2) the redefinition of the land use classes to reduce the confusion between them.

Frequency distributions of the colours present in each Agricultural Land Use System were used to select a subsample of 76 out of 322 sites representative of the range of colours.

4.2.2.1 Detailed Description

The detailed descriptions focused on the colours present in each of the Agricultural Land Use Systems and wetlands. The improvements to the description procedure added significantly to the time required to record the appearance of an object. It was possible to make 20 to 30 object records per day using the relatively casual approach of the first description, while with the detailed approach the rate was about 5 to 10 per day. The extra time was worthwhile as the improvements also added significantly to the ability to discriminate between previously similar object descriptions.

Because of common land covers in different Agricultural Land Use Systems, the general land use classes would be more successfully identified on the basis of relative proportions of colours rather than a simple list. The associated colours were first divided into lists of secondary and additional colours to provide a better indication of the proportions of the object that each colour was occupying. Secondary colours consisted of parcels of a size smaller than those of the dominant colour but which occupied a substantial portion of the object and formed part of the pattern. Additional colours, if present in an object, refer to very small parcels, such as woodlots or building areas that are usually clustered or randomly distributed throughout an object.

As a subset of Shape, Colour Form was used to describe the shape, size and edge of each of the various coloured parcels. The arrangement and association of the colours were described as a refinement to the overall pattern of the object.

To help reduce the subjectivity associated with the communication of the colours, and to mitigate the loss of colour information that might result from the photographic reproduction of parts of the image, a colour standard was adopted. This consists of a

commercially available set of numbered colour samples designed for use in the graphic arts. Since they are not transparent, a separate viewing arrangement, consisting of a standard government fluorescent desk lamp mounted on a table opposite the PROCOM, was used. The separation of the image from the colour chips required dependence on the interpreter's colour memory: the ability to recall colour perceptions (Konerup and Wanscher, 1978). Because of the combination of colour memory and the limited number of samples in the colour set, the selected colour reference represents the closest possible match between the image colour and the standard. While not an exact representation, the reference was sufficient to discriminate similar colours and proved useful in grouping decision couplets when drafting the key.

A better estimate of the size of the object was made by counting the number of UTM grid squares occupied by an object. The site descriptions, made primarily on the basis of the NTS sheets, were expanded to include topography and drainage (natural or artificial). Spatial association was refined so that the description of the local transportation network gave an indication of the accessibility of an area, and topographic sheets were again used to identify buildings or other objects

that would explain the presence of any additional colours.

4.2.2.2 Class Redefinition

The land use classes were redefined (Table 4-3) to eliminate as much of the confusion as possible resulting from common covers in different Agricultural Land Use Systems. The classes were also renamed to represent the specific land covers that are the result of the land use activity in an area.

Hay systems were first moved from Improved Agriculture to the Pasture and Forage Crops class. The idle agricultural land of the initial Unimproved class consists of two classes on the Agricultural Land Use Systems: recently abandoned land and land abandoned more than ten years ago. The former consists of weedy hay and small shrubs and trees that resemble pasture cover and could conceivably be used for this purpose. It remained in the Unimproved Agriculture class, renamed Pasture and Forage Crops. Land abandoned more than ten years ago was moved to the Forest class because it consists of established natural vegetation, primarily scrub and immature forest, and as such: 1) is often similar in appearance on the image to forest, and 2) if on wet soil would be considered to represent a recent

Table 4-3
 Redefined Classes for Land Use

<u>Interpretation Classes</u>	<u>Equivalent Basemap Classes</u>
Field Crops	Agricultural Resource Inventory Corn (C), Mixed (M), Grain (MG), Monoculture (P) Systems and Sod Farms (T).
Pasture and Forage Crops	Agricultural Resource Inventory Hay (H), Pasture Systems (HG) and recent idle agricultural land (A1).
Forest	Agricultural Resource Inventory Woodland cover (Z, Zp, Zr) and land idle more than ten years (A2).
Built-Up	Agricultural Resource Inventory Built-Up (B).
Extraction	Agricultural Resource Inventory Extraction (E1).
Wetland	All Wetland Mapping Series categories for existing wetland.

wetland gain by the definition and assumptions of the Third Approximation of the Wetland Mapping Series (see Appendix A). The redefined classes are thus compatible with the Wetland Mapping Series which should facilitate the detection of changes.

Extraction was separated from the Urban class and placed in a category of its own. This is because the grid pattern of built-up areas is quite different from the concentric pattern of a sand or gravel pit, and because the latter usually occur in rural areas away from cities and towns.

Finally, descriptions for the wetland class were restricted to those obtained from the Wetland Mapping Series. The Agricultural Land Use Systems maps classified too many wetlands as forest.

4.2.3 Key Preparation

The detailed descriptions were first grouped by dominant colour. Each colour group was then separated into subgroups according to differences in other characteristics. The divisions occur at the levels of secondary or additional colours, colour form or arrangement, and spatial association. The characteristics of each of the subgroups were summarized and used to produce the decision paths of the key, which

is contained in Appendix B. Because it systematically organizes a limited number of observations, the user should not regard the character states as being absolute, but rather should be guided by the decision path that is the closest match to the unknown object.

The key is large because of the detail that was required to describe the various land covers in the Agricultural Land Use Systems of eastern Ontario. The decision tree presentation of the key provides all the details of appearance of the different classes while giving the user the flexibility of quickly skipping over learned or unnecessary information.

The numbers along the bottom row of the key cross-reference a list of the colour standard reference numbers. The standard samples observed for each colour are listed together for each key column to provide an indication of the variability present for that colour in a given class.

To assist in understanding the thinking that led to the descriptions in the key, and to allow users to accommodate their own way of thinking and experience, a photographic reproduction of a portion of the image (Plate 1) is included in Appendix B. The plate can be compared with coverage from the Agricultural Land Use Systems Map (Figure B-1) in conjunction with the land

use class definitions (Table 4-3).

Sufficient knowledge and experience was gained about appearance of image objects during the construction of the key that it was only required to distinguish objects with very similar appearances. These were primarily parcels of Field Crops and Pasture and Forage Crops. Descriptions were improved as required. Thus, extensive testing of the key was deemed unnecessary.

4.3 Change Detection Procedure

The change detection involved looking for differences between the image and map that might constitute change. The main problem encountered was deciding whether or not the apparent change had actually occurred in the time frame suggested by the Wetland Mapping Series.

A minimum number of assumptions of the Wetland Mapping Series apply to losses detected from current wetlands. These changes had the least amount of doubt. Similarly, it is possible to be fairly confident that gains to wetlands lost before 1967 had actually occurred so long as the assumption about the failure of drainage and restoration of wet soil conditions used in the mapping is valid.

Important uncertainties arise in the losses and gains detected on the changes mapped by the Wetland Mapping Series for the period 1967 - 1982. The uncertainties are attributable to:

- 1) inherent errors in the Agricultural Land Use Systems map, and
- 2) errors introduced in the use of the Agricultural Land Use Systems maps in the compilation of the Third Approximation.

An example of the first was found on the Land Use Systems map for Montague Township. In registering either the image or the topographic map to the road network, the boundaries of some systems did not agree by as much as 250 metres ground distance. It is therefore possible that some mismatched boundaries may have carried through to the Third Approximation of the Wetland Mapping Series. These could have introduced some error in the results of the change detection procedure. When registration discrepancies were obvious, the best fit of the map polygon to the image prevailed over the routine registration to the road network.

Errors introduced into the Wetland Mapping Series by the use of the Agricultural Land Use Systems maps are due to the delineation of the systems based on property lines rather than vegetation boundaries. The area shown on the map as being lost or gained between 1967

and 1982 may be larger than the area of real change. Most of the gains during this period were to scrubland and immature forest that became established on agricultural land abandoned at least ten years before. Because this cover extends to the property boundary, it is possible to be fairly confident about losses detected from areas of recent gains.

Some gains detected to wetlands lost between 1967 and 1982 may not be real because the four year period between 1982 and 1986 would not be sufficient to restore wetland conditions. Gains that are smaller than the minimum mapping unit of the Agricultural Land Use Systems maps could be well established naturally vegetated areas included as part of the surrounding land use system.

4.4 Change Map Verification

Because it was uncertain whether an apparent change had actually occurred, the task of determining the accuracy of the change detection procedure was divided into two parts. A sample of polygons was first checked in the field to ensure that the land cover (i.e., the presence or absence of natural vegetation) represented the change identified with the imagery. A number of sites were then checked using airphotos to be sure

that the land use to which the wetland had been put was correctly classified in the image interpretation.

4.4.1 Change Identification

The problem posed for verification of the change detection is that the prior conditions that would confirm a given conversion scenario no longer exist and therefore cannot be verified in the field. In the case of wetland gains to areas lost before 1967, the observed changes did not all take place between 1982 and 1986. Many of them could be verified by the presence or absence of the woodland cover symbol on the NTS maps which were compiled with 1979 aerial photography. Regardless of the timing of the change, if the land cover conditions interpreted from the image can be verified, then the updated map will be an accurate representation of the wetland situation in 1986.

According to acceptance sampling theory, one incorrect change detection out of 30 test sites will cause the user of an updated map to face a 5 % risk that the map is not between 85 and 99 % accurate (Ginevan, 1979). To comply with the requirement that each site be unambiguously determined being either correct or incorrect, 30 sites were randomly selected from a stratum of sites adjacent to roads.

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The sites were visited on November 8 and 15, 1987. Photographs were taken at each site and the type of vegetation noted along with other evidence (e.g., construction stakes, salt licks, piles of cleared trees) that could support the correct or incorrect designation of the change interpretation.

Only one site was clearly in error. It had been interpreted as a forested wetland that had been partially cleared for pasture. Field investigation revealed that the clearing was a cattail community. The emergents produced an appearance on the image similar to nearby pasture areas: smooth textured light blue-green with a distinct edge. By the criteria of the test, the method used in this thesis has produced a map that is at least 85 % accurate in its representation of the status of eastern Ontario wetlands in 1986. The exact producer's risk, the chance of rejecting an acceptably accurate map, is 3.6 % (Ginevan, 1979).

At five of the sites there was evidence that small portions of the area were either incorrectly delineated or classified. At two of these sites, the doubts could be attributed to registration errors either in the change detection procedure or in transferring the change polygon to the map taken into the field. At one site, the apparent error was the result of an incorrect

matching in the field of the locations of the polygon boundary on the map. At the remaining two sites, the change was correctly delineated but the converting land use was misclassified. These areas were of similar appearance to the correct classification at the time of imaging. None of the five sites were sufficiently in doubt to be considered a completely incorrect change delineation.

4.4.2 Land Use Classification

The classification accuracy of the current land use of converted wetlands was estimated by using 1:15,000 scale colour aerial photography from the summer of 1985. It was assumed that all the changes detected in the May 1986 satellite image had occurred by the time the aerial photography was done. To conform with the definitions and assumptions of the Wetland Mapping Series, all sites interpreted as forest were grouped with sites classified as wetland. Areas used in the preparation of the key were avoided in the classification verification.

Hay (1979) recommends verifying a minimum of fifty sites for each class. However, due to the limited coverage of the aerial photography this was not possible for all classes. The 114 sites compared provided an estimate of 90.4 % for overall accuracy (Table 4-4).

Table 4-4
CONFUSION MATRIX RESULTING FROM THE CLASSIFICATION OF WETLAND CHANGES.

		Number of Sites Classified by Image Interpretation						
CLASS	Number of Sites Classified by Air Photo Interpre- tation.	C	P	B	E	W	TOTAL	% Omission
		31	1				32	3.1
C		2	19			1	22	13.6
P			1	3			4	25.0
B				1			1	100.0
E		1	4			50	55	9.1
W								
TOTAL		34	25	4	0	51	114	
% Commission		8.8	24.0	25.0		2.0		
% Correct		91.2	76.0	75.0		98.0		
OVERALL ACCURACY : 90.4 %								

CLASSES: C - Field Crops, P - Pasture and Forage Crops,
B - Built-Up, E - Extraction, W - Wetland.

This level of accuracy is attributable to the broad class definitions needed to accommodate the Agricultural Land Use Systems, and the spectral and spatial detail provided by the Thematic Mapper.

Confusion was greatest between the Field Crops and Pasture and Forage Crops classes. Some grassy pasture sites appeared similar to grain or bean fields on the air photos. Presumably these would have a similar appearance on the image. One site interpreted as being converted to pasture turned out to be a golf course, a case of similar cover but different use. In the absence of a recreation class, the golf course was considered an urban amenity and classed as Built-Up. Built-Up areas are also similar in appearance to the sand and gravel pits of the Extraction class. The Extraction site misclassified as Built-Up is located at the edge of Stanley's Corners, a small town in an area with many extraction operations.

Five of the agricultural sites were found to have a tree or shrub cover, which are wetlands by the Wetland Mapping Series definition. Thus in this sample, 4.3 % of the sites proved to be errors in change detection. This is within the limits of the acceptance sampling test.

4.5 Area Measurements

The smallest change polygon detected measured 0.37 ha. This represents the minimum mapping unit of TM imagery for the method used in this thesis. The detection of such a small polygon was possible due to the combination of a unique shape on the Wetland Mapping Series and a colour on the image distinctly different from that of natural cover.

The area measurements obtained from the digitizing of the three change interpretation maps are presented in Tables 4-5, 4-6, and 4-7. All the estimates for the periods circa 1775 - 1967 and 1967 - 1982 were determined directly from the Wetland Mapping Series, while those for the period between 1982 and 1986 were determined from the change detection. The Maximum Potential Extent of Wetlands given in the footnotes is the sum of the area of wetlands existing at and lost before 1967. Following the wetland definition used in the Series, this represents the wet soil area that has the potential for being wetland given a cover of natural vegetation.

Accompanying each table is a plot of the change polygons for the map sheet (Figures 4-1, 4-2 and 4-3). They illustrate the density and spatial distribution of the wetland changes, but because of the small scale of

Table 4-5
SUMMARY OF WETLAND CHANGES ON SHEET 31 B/13

Measurements are rounded to the nearest hectare. Except where noted, percentages are of the wetlands from the first year of the time frame (e.g., 1967 for 1967 - 1982).

CHANGES FROM 1982 WETLAND MAPPING SERIES

	Existing	1967 Lost	1967 - 1982 Gained	1982 Lost	Total
	23,508 59.4%	16,093 40.6%	429 1.8%	255 1.1%	
TO 1986 COVER					
Field Crops	22				22
Pasture/Forage	233		45		278
Extraction					0
Built-Up	6				6
Wetland		3,001		134	3,135
Total	261 1.1%	3,001 12.7%	45 0.2%	134 0.6%	3,441 14.6%

Changes from 1967 - 1982

Net Change	174 ha	0.4 %
Rate	12 ha/yr	0.05 %/yr
1982 WETLAND EXTENT	23,682 ha	59.8 %

Changes from 1982 - 1986

Gross Loss	306 ha	1.3 %
Rate	76 ha/yr	0.3 %/yr
Gross Gain	3,135 ha	13.2 %
Rate	784 ha/yr	3.3 %/yr
Net Change	2,829 ha	7.1 %
Rate	707 ha/yr	2.7 %/yr
1986 WETLAND EXTENT	26,511 ha	66.9 %

Percentage of the Maximum Potential Extent of Wetlands, which is 39,600 ha or 36 % of sheet 31 B/13.

Figure 4-t DISTRIBUTION OF CHANGE POLYGONS FOR SHEET 31 B/13.

Table 4-6
SUMMARY OF WETLAND CHANGES ON SHEET 31 G/4

Measurements are rounded to the nearest hectare. Except where noted, percentages are of the wetlands from the first year of the time frame (e.g., 1967 for 1967 - 1982).

CHANGES FROM 1982 WETLAND MAPPING SERIES

	Existing	1967 Lost	1967 - 1982 Gained	1982 Lost	Total
	18,994 36.8%	32,674 63.2%	388 2.0%	995 5.2%	
TO 1986 COVER					
Field Crops	162				162
Pasture/Forage	166		21		187
Extraction					0
Built-Up	9				9
Wetland		1,218		367	1,585
Total	338 1.7%	1,218 6.2%	21 0.1%	367 1.9%	1,944 9.9%

Changes from 1967 - 1982

Net Change	-607 ha	-3.2 %
Rate	-41 ha/yr	-0.21 %/yr
1982 WETLAND EXTENT	18,386 ha	35.59 %

Changes from 1982 - 1986

Gross Loss	359 ha	2.0 %
Rate	90 ha/yr	0.5 %/yr
Gross Gain	1585 ha	8.6 %
Rate	396 ha/yr	2.2 %/yr
Net Change	1226 ha	6.7 %
Rate	307 ha/yr	1.7 %/yr
1986 WETLAND EXTENT	19,612 ha	38.0 %

Percentage of the Maximum Potential Extent of Wetlands, which is 51,667 ha or 47 % of sheet 31 G/4.

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MicroD

Figure 4-2: DISTRIBUTION OF CHANGE POLYGONS FOR SHEET 31 G/4.

Table 4-7
SUMMARY OF WETLAND CHANGES ON SHEET 31 G/6

Measurements are rounded to the nearest hectare. Except where noted, percentages are of the wetlands from the first year of the time frame (e.g., 1967 for 1967 - 1982).

CHANGES FROM 1982 WETLAND MAPPING SERIES

	Existing	1967 Lost	1967 - 1982 Gained	1982 Lost	Total
	20,045	46,393	2,276	764	
	30.2%	69.8%	11.4%	3.8%	
TO 1986 COVER					
Field Crops	189		107		296
Pasture/Forage	224		91		315
Extraction					0
Built-Up	14		1		15
Wetland		186		458	644
Total	427	186	199	458	1271
	2.0%	0.9%	0.9%	2.1%	5.9%

Changes from 1967 - 1982

Net Change	1,512 ha	7.5 %
Rate	101 ha/yr	0.5 %/yr
1982 WETLAND EXTENT	21,556 ha	32.4 %

Changes from 1982 - 1986

Gross Loss	627 ha	2.9 %
Rate	157 ha/yr	0.7 %/yr
Gross Gain	644 ha	3.0 %
Rate	161 ha/yr	0.8 %/yr
Net Change	18 ha	0.1 %
Rate	4 ha/yr	0.025 %/yr
1986 WETLAND EXTENT	21,574 ha	32.5 %

Percentage of the Maximum Potential Extent of Wetlands, which is 66,438 ha or 61 % of sheet 31 G/6.

Figure 4-3: DISTRIBUTION OF CHANGE POLYGONS FOR SHEET 31 G/6.

the plots (approximately 1:200,000), losses and gains are not distinguished.

4.5.1 Merrickville (31 B/13)

The amount of wetlands converted between the start of European settlement, circa 1775, and 1967 is at least 20 % less on the Merrickville sheet than on the other sheets. This is attributable to the presence of large wetlands that would be very difficult to convert: peatlands and hardwood swamps with perennial standing water.

Pasture and Forage Crops are the major user of wetlands, reflecting both the limited capabilities of the soil for intensive cultivation and the importance of dairying to the local farm economy. Field Crops represent only 10 % of the agricultural conversion activity, whereas on the other maps the proportion is about half. Built-Up land uses, as is the case on the other maps, do not pose a significant threat to wetlands.

What is surprising is that 3,135 ha of wetland gain: natural vegetation, primarily wooded cover and scrubland, that has reestablished itself on areas cleared mostly before 1967. This should not be construed as a sudden recovery of wetlands, even

though the figures have a disproportionate effect on the net change rate. The large figure appears to represent an underestimation by the Wetland Mapping Series of the area of existing wetland. The presence of the wooded cover was confirmed by the green shading symbol on the topographic maps at 96 % of these sites. Of these, 17 % could be further confirmed by the presence of the wetland symbol. In the field, the forest cover at most of the sites of this type appeared to be at least twenty-years old, i.e., established before 1982.

Since the gains do not appear to have occurred between the wetland mapping and the date of imaging, it is not possible to compare net change rates between the periods 1967 - 1982 and 1982 - 1986. The percent gross loss of wetlands is about the same for the two periods, but because of the different lengths of time involved, the rate of gross loss has increased: from 0.07 %/yr to 0.3 %/yr. The current rate compares with the average southern Ontario rate of 0.35 %/yr for the period 1967 - 1982 (Snell, in prep.).

Some of the sudden increase in loss rate may be due to the fact that it is possible from the TM image to detect loss areas that are smaller than the 10 ha minimum mapping unit of the Wetland Mapping Series.

Figure 4-4 shows the frequency distribution of most of

Figure 4-4
SIZE DISTRIBUTION OF CHANGE POLYGONS

the area measurements. Polygons with areas less than 10 ha make up 69 % of the population.

4.5.2 Kemptville (31 G/4)

The 63 % of wetlands converted up to 1967 for the Kemptville sheet (Table 4-6) approaches the estimate of 68 % for southern Ontario (Snell, in prep.).

Losses detected from the image are mostly to agriculture, with a slightly higher proportion being to Pasture and Forage Crops rather than to Field Crops. Gains of 1,218 ha to areas of previous loss are again much larger than expected, although they are not as high a proportion as on the Merrickville sheet, especially considering that there have been more wetlands converted on this sheet. The gross loss rate of 0.4 %/yr for the period 1967 - 1982 is equal to the rate for southern Ontario during the same period and is only slightly lower than the rate for the period 1982 - 1986 interpreted from the imagery. This would suggest a relatively balanced situation compared to the difference in rates for the other maps.

4.5.3 Russell (31 G/6)

The Russell map measurements show the greatest wetland conversion before 1967 (70 %) of the three sheets, and for the period 1982 - 1986 had the greatest area of loss. Like the other maps, Pasture and Forage Crops are responsible for slightly more wetland conversion than Cropland among the agricultural uses. The number of hectares lost to Built-Up uses is also greatest on this map.

Gains on areas of previously lost wetland were much less on this map than the others. This would suggest that the problem of underestimation of current wetland area affects only some of the sheets in the Wetland Mapping Series. Because the gain estimates are closer to expected levels, the net change detected with the TM imagery is easier to compare with the changes between 1967 and 1982 measured from the map.

The rate of gain between the two periods has remained the same at about 0.7 %/yr, while the rate of loss is up to 0.7 %/yr from 0.3 %/yr. This increase in loss has reduced the net rate of change from a gain of 0.5 %/yr in 1982 to a perfect balance of losses and gains in 1986. If the rate of loss of the 1982 - 1986 period continues or increases, the Russell area ought to be experiencing a net loss of wetlands.

4.6 Land Capability Comparison

Contingency tables were used to test the relationship between the agricultural capability of the land surrounding wetlands converted to agricultural uses and: 1) the class of the converted wetland soil, and 2) the class of use.

If the variables are independent, there would be cause for concern that wetlands are being pressed into service regardless of the limits suggested by the capability of the soil. However, the results (Appendix C) indicate that the soil of the converted wetland is compatible with the capability of the agricultural land surrounding it. Moderately fertile to fertile clayey and medium textured wetland soils are being put to use in areas of soils capable of fair to high agricultural productivity. Similarly, wetlands with low fertility are converted primarily in areas with soils of low productivity or limited to perennial forage crops. The contingency coefficient indicates that the relationship between the variables is significant, but alone it is probably insufficient to predict which wetlands are likely to be converted in the future because of other factors involved such as the economy and the desires of individual land owners. In eastern Ontario, it appears that a wetland with soil at or about the same capability

of the surrounding land will be at risk of loss to agriculture.

The second test helps to confirm the soil relationship by showing that the use to which wetlands are put is related to the type of agriculture indicated by the capability of the surrounding soil. In particular, Canada Land Inventory classes 2, 3 and 4 are most frequently adjacent to wetlands converted for the production of Field Crops and classes 3, 5 and 6 for Pasture and Forage Crops. Class 3 and 4 soils would appear to be cross-over categories, the use likely determined by the severity of the limitations. A larger number of observations and a more detailed crop classification might permit a more thorough evaluation of the conversions.

4.7 Summary

The thematic base maps used in the construction of the interpretation key and the change detection have limitations which presented additional challenges to the visual interpretation of Thematic Mapper imagery for mapping changes in the wetlands of eastern Ontario.

Some of the Agricultural Land Use Systems maps had misregistration problems in addition to the problem of the classification of wetlands as forest, even where NTS

wetland symbols were present. The range of land covers contained in the various Agricultural Land Use Systems required the development of detailed descriptions of their characteristics for the interpretation key. The use of a colour standard was of great assistance in separating similar characteristics. Once constructed, the key was only needed to distinguish objects which appeared similar. This demonstrates the value of a systematic approach to object description in familiarizing an interpreter with an image, although it may seem that the amount of use the key obtained is disproportionate to the length of time required for its construction.

The Wetland Mapping Series (Third Approximation) created a number of uncertainties about whether the observed changes were apparent or real. Regardless, the method was shown to be at least 85 % accurate in the identification of changes and 90 % accurate in identifying the present land use of wetland change areas. The area measurements suggest that the Wetland Mapping Series underestimates greatly the extent of current wetland area on some sheets. The resulting large estimates of net gain for the period of 1982 - 1986 could not be compared realistically with net change estimates from 1967 - 1982. It does appear, however,

that losses in the Russell area have caught up to recent gains and the area should have experienced a net loss of wetland at the next update.

Finally, the analysis of adjacent CLI ratings suggests that wetlands are being put to uses consistent with their capabilities for agriculture.

CHAPTER 5

CONCLUSION

5.1 Synopsis

Effective management of wetlands is hindered in part by the lack of information regarding the demands being put on them. Our ability to map and monitor wetlands from orbital platforms has improved with advances in sensor technology. While orbital imagery cannot provide the same site-specific detail as large-scale aerial photography, satellites can provide very useful information at a regional scale. This thesis has shown that the visual interpretation of Thematic Mapper imagery provides a cost-effective means of identifying wetland changes as small as 0.4 ha with at least 85 % accuracy. The combination of image acquisition in mid-May and its reproduction using the 3-5-4 colour composite provided good delineation of the wetlands and discrimination of adjacent land covers.

Common land covers in the different Land Use Systems of the Agricultural Resource Inventory maps required a more detailed approach to the description of the generalized classes for land use adjacent to

- wetlands. Although time consuming, the compilation of an interpretation key makes visual image analysis explicit by looking systematically at the elements that make up an image. The use of Agricultural Land Use Systems maps made the interpretation key compatible with the assumptions and methods of the Wetland Mapping Series, on which the change detection procedure was based. Large wetlands could be easily identified and delineated with the imagery alone, but distinguishing smaller swamps from forests or woodlots required information about the extent of wet soils provided by the Wetland Mapping Series.

The four year period between the image and the wetland base maps was sufficient to produce results that give some insight into the changes that are occurring. Three map sheets were updated. Apparent sudden gains of 13 % on the Merrickville (31 B/13) sheet and 8 % on the Kemptville (31 G/4) sheet can be attributed in part to the ability of the Thematic Mapper to resolve below the minimum mapping unit of the Wetland Mapping Series. The extent of current wetlands does not appear to be underestimated on the Russell sheet, however. There, the losses detected with the image show that the previous rate of net gain is being reversed.

Wetlands were converted primarily to agricultural uses, with pasturing and the production of forage crops being the dominant activity. With the absence of large urban centres, built-up land uses do not present a significant threat to wetlands in the area surveyed. The detail available in Thematic Mapper imagery and the general level of the classification allowed these land uses to be identified with an accuracy of 90 %.

Further insight into the nature of the changes was obtained by taking the updated Wetland Mapping Series sheets and registering them to the corresponding Canada Land Inventory maps of Land Capability for Agriculture. The capability of the wetland soil and the use to which it was put were compared with the capability of the surrounding area. The results indicate that the wetlands are not being converted indiscriminately to agriculture. Wetlands with fairly good soils of about the same capability as the land surrounding them are the ones more likely to be converted in eastern Ontario.

5.2 Operational Considerations

The method used here is simple, accurate and cost-effective, although there are ways in which the efficiency can be improved. At 1987 prices, the cost of a colour transparency of a Thematic Mapper image

quadrant is about \$ 0.04 per hectare.

The preparation of the interpretation key¹ took up about half of the time needed to complete the steps of the method, once it had been refined. In an operational setting, the number of keys required to describe different regions can be kept to a minimum by using a standard band combination and season of imaging. If the monitoring period is infrequent, in the order of five or ten years, the time required to prepare a set of interpretation keys may not be justified. This is because sensor developments may surpass the performance of the current technology. The Thematic Mapper, for example, is able to provide the detail necessary for the regional inventory and monitoring of wetlands that was previously unavailable from MSS data. A key developed for Thematic Mapper imagery may not apply to the imagery of some future sensor that may have superior spatial resolution or different band specifications. The preparation of a set of interpretation keys would be advisable as a reference for frequent monitoring or to reduce training time for projects involving several interpreters or a high turnover in staff. Interpretation keys provide for more consistent classification and mapping when several interpreters are involved.

The time required for change detection and the compilation of the estimates could be reduced if more powerful digitizing software or a geographic information system were used. The measurement of the area of the change polygons was completed in about 8 hours, but digitization of the entire Wetland Mapping Series sheets was required for the purpose of comparison. This took three weeks. A software capability to convert digitized coordinates to UTM coordinates would have greatly reduced the time required to delineate changes. This averaged about 24 hours per sheet. The most time consuming part of this was the registration of the topographic map to the area to obtain UTM grid coordinates and the name of the township. Sophisticated digitizing editing features permit prompt correction errors such as duplicate extents or extents digitized in the wrong direction. The correction of these errors afterwards and the tabulation of the change statistics took two weeks. In an operational setting, specialized digitizing staff are suggested.

The capability to overlay maps and analyze the results is well developed in geographic information systems. If land use capability or wetland evaluation data are easily input, such a system could provide an efficient means to gain further insights into the land

use change identified with the satellite imagery. The manual overlay of the Canada Land Inventory maps and the contingency table analysis of adjacent agricultural capabilities were performed in about five hours per map sheet, much less time than expected. Geographic information systems offer flexible analysis and output capabilities that could be used to target conservation efforts and funds.

5.3 Future Applications and Research

Thematic Mapper imagery and the method used in this thesis can be applied to updating the Third Approximation of the Wetland Mapping Series. Particular attention should be given to the extent to which natural vegetation has returned to areas mapped as being converted before 1967. The imagery provides the detail to identify these areas, which should have been included as recent gains on the Third Approximation. They were probably missed because of the limitations of the data used in the compilation of the Series.

The method can also be used to provide land cover information for the application of the Wetland Mapping Series method in other provinces. Where the Canada Land Inventory used complex agricultural capability codes, local soil survey data would have to be used to

discriminate hardwood swamps from forest cover and to determine the extent of wetland losses since European settlement. The different scales of soil survey maps are easily accommodated by the PROCOM-2 device.

Independence from the uncertainties presented by the use of thematic maps as the baseline data for change detection can be achieved by comparing an image to an image-derived map. At present, there are only about four years of continuous Thematic Mapper data. The next complete aerial photography coverage would provide the earliest opportunity to establish an independent baseline. A detailed image interpretation key can be prepared directly from a sample of land covers identified on the air photos (Farmer et al., in prep.). This would be the best approach where Agricultural Land Use Systems mapping is not available or crop inventory maps are outdated.

Wetlands and adjacent land uses could then be delineated on a topographic map. This baseline would only have uncertainties related to the accuracy of the interpretation, which can be rigorously tested with acceptance sampling. The accuracy of future monitoring by visual image interpretation could thus be improved. This independent approach could be used for monitoring other categories of land use change, such as the loss of

size of a wetland. The human interpreter can easily extract spatial information from an image such as a wetland's shape, site, and hydrologic and regional context. Together this information can be used to evaluate the wetland in terms of the different natural functions it performs. It would also permit the assessment of the quality of wetland lost versus the gains to society made by its conversion to another land use.

As the spatial and spectral resolutions of orbital sensors improve, the volume of data that the digital image analysis system must handle increases as does the accuracy of classification of some objects. At the same time, the amount and quality of spatial information available to the human interpreter also increases. Combining the different strengths of visual and digital image analysis provides the basis for a powerful, integrated approach to image analysis that would be of particular benefit to wetlands.

APPENDIX A

METHODS AND LIMITATIONS OF THEMATIC BASE MAPS

A.1. Wetland Mapping Series (Third Approximation)

The method used in the Wetland Mapping Series is based on the wetland definition of Tarnocai (1979), which is paraphrased by Snell (in prep., p. 2) as:

"... an area with natural vegetation and, for most of the year, shallow water or wet soils."

Using the 1:50,000 Canada Land Inventory (CLI) agricultural capability manuscript maps, wet soils were identified by polygons limited by wetness, and peaty soils by polygons designated as organic. CLI land use maps from 1967 were superimposed and wet soil areas with natural cover were assumed to be wetland. Wet soil areas lacking natural vegetation were assumed to be converted wetlands. The two CLI data bases were used to classify the 1967 wetland areas by vegetation and soil categories. Using the Agricultural Land Use System maps (see section A.2 below) as representative of 1982 land cover conditions, the 'Third Approximation' of the Series was produced to show wetlands converted and existing in 1982 (Figure A-1). Each wetland mapped as existing and converted in 1967 was checked, using the

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Figure A-1

Portion of the
Wetland Mapping Series (Third Approximation)
sheet 31 B/12, 1:50,000 scale.

same wetland definition and assumptions, for natural vegetation in 1982. The legend for the Series is presented in Figure A-2.

Areas of 1967 wetland where the vegetation was absent in 1982 were mapped as converted on the 'Third Approximation'. For a previously converted area to be mapped as a wetland gain, natural cover had to be more than ten years old (i.e., the Agricultural Land Use System A2). This was based on the assumption that any artificial drainage would have failed, allowing the abandoned land to return to wet conditions (Snell, in prep.). Small differences in wetland boundaries between the two maps were ignored as there was no information available to identify which map was correct.

A.1.1 Limitations:

The maps used in the production of the Wetland Mapping Series (Third Approximation) (listed in Figure A-2) have inherent limitations that affect the representation of wetlands in the Series (Snell, in prep.).

A.1.1.1 Current wetlands:

1. The minimum mapping unit of 10 ha dictated by the soil and land use maps used caused wetland areas less than 10 ha to be omitted unless they were shown on the topographic maps.

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THÈSES CANADIENNES

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AVIS

Figure A-2
(continued)

METHOD OF MAP DEVELOPMENT

FOR THE SERIES WETLANDS WERE CONSIDERED AREAS WHERE BOTH 1) THE SOILS SATURATED ALL YEAR WITH OR WITHOUT YEAR ROUND SURFACE WATER AND 2) NATURAL VEGETATION.

THE DEFINITION WAS APPLIED USING BEST AVAILABLE INFORMATION. THUS, FOR EACH OF THE TWO CONDITIONS, THOSE AREAS WHERE THE TWO CONDITIONS WERE CONSIDERED WETLANDS. AREAS WITHOUT NATURAL VEGETATION BUT WITH SOILS CLASSIFIED AS CURRENTLY SATURATED OR AS SATURATED IN THEIR PRE-MANAGEMENT STATE WERE ASSUMED TO ONCE HAVE HAD A NATURAL VEGETATION COVER AND WERE CONSIDERED LOST WETLANDS. SUCH AREAS CLASSIFIED AS CURRENTLY SATURATED OR AS SATURATED IN THEIR PRE-MANAGEMENT STATE WERE ONLY INCLUDED AS SUCH IF THEY LAY BETWEEN TWO ADJACENT WETLANDS.

LAKE SHORE MARSHES ARE OFTEN NOT INCLUDED IN THIS MAP SERIES. THERE ARE SEVERAL REASONS FOR THIS. FIRST, THE MARSHES ARE OFTEN NOT MAPPED BY THE CANADIAN TOPOGRAPHIC SYSTEM IN THE WETLANDS UNIT. INSTEAD, THEY ARE MAPPED AS OPEN SPACE OR AS OTHER LAND USES. SECOND, THE MARSHES ARE OFTEN NOT MAPPED BY THE CANADIAN TOPOGRAPHIC SYSTEM IN THE WETLANDS UNIT. INSTEAD, THEY ARE MAPPED AS OPEN SPACE OR AS OTHER LAND USES. THIRD, THE MARSHES ARE OFTEN NOT MAPPED BY THE CANADIAN TOPOGRAPHIC SYSTEM IN THE WETLANDS UNIT. INSTEAD, THEY ARE MAPPED AS OPEN SPACE OR AS OTHER LAND USES.

DATA SOURCES

SOURCE	SCALE	SPATIAL EXTENT
1) MOST CURRENT AVAILABLE COUNTY SOILS MAPS	1:20,000 TO 1:75,000	COMPLETE COVERAGE
2) CANADA LAND INVENTORY AGRICULTURAL CAPABILITY MAPS	1:50,000	COMPLETE COVERAGE
3) CANADA LAND INVENTORY PRESENT LAND USE (CIRCA 1987)	1:50,000	COMPLETE COVERAGE
4) MOST CURRENT AVAILABLE NATIONAL TOPOGRAPHIC SYSTEM MAPS	1:50,000	COMPLETE COVERAGE
5) CANADIAN MAPS SERVICE GREAT LAKES SHORELINE MAPS	1:50,000	SHORELINE OF LAKES ST. CLAIR, ST. MARY AND ST. LAWRENCE RIVERS
6) LAND USE MAPS FROM NATIONAL AND PROVINCIAL PARKS	VARIETY	PARKS ONLY
7) AIR PHOTO INTERPRETATION	1:50,000 TO 1:100,000	SEVERAL SMALL SAMPLE AREAS
8) CONTRIBUTIONS OF CURRENT BOUNDARIES OF SPECIFIC WETLANDS FROM VARIOUS WETLAND RESEARCHERS	VARIETY	SEVERAL SPECIFIC WETLANDS
9) BENTON COUNTY OF AGRICULTURE AND FOOD AGRICULTURAL LAND USE SYSTEMS MAPS 1980	1:50,000	ALMOST COMPLETE COVERAGE
10) LAND RESOURCE RESEARCH INSTITUTE AGRICULTURAL LAND USE SYSTEMS MAPS 1980	1:50,000	AREAS OF SAGINAW AND DETROIT-CASSIOWAY
11) LARGE SCALE QUANTITATIVE URBAN CENTERS REGIONAL LAND USE MAPS 1980	1:50,000	AREAS WITH OVER 25,000

LIMITATIONS OF DATA BASES FOR WETLAND MAPPING

SOILS MAPS

VARIETY OF LEVELS OF DETAIL AMONG COUNTIES THIS MAY ALSO CREATE SOME ANOMALIES AT COUNTY BOUNDARIES. OLD MAPS + BROAD SCALE AND NEW ARE VERY GENERAL.

ABOUT 20% SMALL UNCLASSIFIED INCLUSIONS

NO RECOGNITION OF EPHEMERAL WETLANDS + BEAVER PONDS

UNDERESTIMATES LOSS OF LAKE SHORE MARSHES

LAND USE MAPS

THE DATA FROM DIFFERENT SOURCES HAS DIFFERENT CLASSIFICATION SCHEMES. THE DATA ARE NOT ALWAYS APPROPRIATE. SPATIAL COVERAGE MAY BE LIMITED. DIFFERENT DATA SOURCES MAY BE ONLY BEING CURRENT IN SOME AREAS. THE DATA FROM DIFFERENT SOURCES MAY BE ONLY BEING CURRENT IN SOME AREAS. THE DATA FROM DIFFERENT SOURCES MAY BE ONLY BEING CURRENT IN SOME AREAS.

LAKE SHORE MARSH MAPS (DATA SOURCES 4 AND 5)

VARIETY OF DATA FROM LAKE SHORE MARSH RESEARCHERS. THE DATA FROM DIFFERENT SOURCES MAY BE ONLY BEING CURRENT IN SOME AREAS.

TO MINIMIZE THE EFFECTS OF DATA BASE LIMITATIONS, ONLY WETLANDS 2 TO 10 HECTARES WERE INCLUDED IN THE OVERLAY APPROACH. THE FEW WETLANDS INDICATED ONLY BY THE NTS + SYMBOL WERE INCLUDED AS SMALL AS 2 HECTARES. THE AREA COVERED BY ONE + SYMBOL.

2. Inconsistencies in the delineation of polygons on county soil maps created an occasional discrepancies at county boundaries.
3. Lack of data caused bottom land wetland areas to be underestimated.

A.1.1.2 Losses and Gains:

1. Insufficient data forced the assumption that all land use areas with natural cover are undrained. This can be a significant limitation in areas indirectly affected by drainage. Losses are underestimated where artificially drained areas have retained their natural cover. Similarly, where drainage has been maintained in long abandoned areas, gains are overestimated.
2. Possible inconsistencies in distinguishing abandoned wet pasture and wetland between the 1967 and 1982 land use maps may have caused minor gains and losses to have been missed. The significance of this is thought to be minor since they would likely cancel each other out (Snell, in prep.).

A.1.2 Application of the method in other provinces.

The Canada Land Inventory was considered as the best data source for delineating wet and organic soils in southern Ontario because of availability, mapping uniformity, consistency and year of completion. The extensive use of complex capability codes in the Inventory limits the application of the Wetland Mapping Series method in New Brunswick, Quebec, Northern Ontario, Manitoba, Saskatchewan, and British Columbia (Kessel-Taylor, 1983). Complex codes indicate the

proportion of two or three capabilities included in a soil polygon. This makes it difficult to delineate wet or organic soils, although statistical evaluations would be possible (Kessel-Taylor, 1983). Canada Land Inventory coverage for Newfoundland is not available at 1:50,000. In Alberta, the scale of the basemaps is inconsistent. Outside southern Ontario, simple capability codes were extensively used in Nova Scotia and Prince Edward Island.

The definitions and assumptions used in the Wetland Mapping Series were found to be applicable to prairie pothole wetlands, but the method requires more detailed soil and land use information than is provided by the Canada Land Inventory (Kessel-Taylor, 1983). Soil survey information and habitat zone delineations provided the basis for the application of the approach to land use dynamics on wetlands in the Southwestern Fraser Lowland of British Columbia (Pilon and Kerr, 1984). The Wetland Mapping Series method was found to work well in Nova Scotia. Combining the results with those of the Wetland Protection Mapping and Designation Program currently underway in the Maritimes would provide a detailed wetland inventory for Nova Scotia (Kessel-Taylor, 1983).

A.2. Agricultural Resource Inventory: Land Use Systems

The land use system approach helps to overcome the problem of premature obsolescence associated with earlier field-by-field crop inventories. Crop rotation and changes in ownership were among the factors that often caused such surveys to become outdated before their completion (Capital Improvements Branch, 1983). The land use system approach allows the crops on a given field to change without affecting the system designation of the properties. In this way, the inventory is expected to remain valid for many years and provides a relatively high degree of accuracy (Capital Improvements Branch, 1983).

Periodic field checks are used to ensure the validity of the system designations over time. The task is also well suited for the application of remote sensing methods. Multidate Landsat data are currently being integrated into a geographic information system for the automatic revision of the maps (Mussakowski et al., 1987).

The maps were produced between 1975 and 1983 using a series of mylar overlays for each township. The first mylar consisted of an airphoto interpretation of agricultural fields which were later identified by driving along township roads. It is estimated that

about one percent of each township was not identified because of tree cover, topography and lack of roads (Capital Improvements Branch, 1983).

A second mylar layer showing land ownership was superimposed on the airphoto interpretation mylar to derive a land use system designation. This is based on the mix and proportion of crops within each property. Although the designation of the land use systems requires a certain amount of judgement, the results were fairly consistent among those mapping the systems (Capital Improvements Branch, 1983). A final mylar was prepared by deleting property boundaries between common systems. Township base maps were prepared by cutting and piecing together 1:50,000 sheets from the National Topographic System. The final mylar was transferred to this base to produce the Draft Township Land Use map, which was in turn traced on to a chronaflex master of the Final Township Land Use map (see Figure A-3).

The minimum mapping unit of 2.5 hectares is an important limitation of the inventory. Farmsteads, small woodlots, and rural residential and commercial lots that could be identifiable on the TM imagery were included as part of the land use system that surrounds them. In the case of the small woodlots, this limitation could result in the detection of wetland

Figure A-3

Portion of the Agricultural Land Use Systems Map
for Matilda Township.

gains (the woodlot being natural vegetation on wet soil) that are not real but appear to be because they were omitted from the Wetland Mapping Series.

Finally, the land use system approach does not identify the actual crop areas within a system, but they could be estimated from the system criteria (Table A-1).

Table A-1

AGRICULTURAL LAND USE SYSTEMS FOUND IN SAMPLED TOWNSHIPS

(after Capital Improvements Branch, 1983)

- A1 - Idle Agricultural Land: Land idle for 5 - 10 years and in a state of reversion to natural vegetation: small alders, willow or thorn bushes several feet in height.
- A2 - Idle Agricultural Land: Land idle for more than 10 years and supporting natural vegetation larger than can be cleared with farm machinery.
- B - Built Up: Urban related uses including churches, cemeteries, rural strip developments of four or more houses, transformer stations, sewage lagoons or water treatment facilities.
- C - Corn system: A contiguous arrangement of four or more fields of uniform size. A rotational system in which 40 - 75 % of the area is corn, the remainder is a mixture of beans, hay, pasture (less than 10%), and sometimes grain. Indicators include silos and corn cribs, and possibly barns for the feeding of hogs or dairy and beef cattle.
- E1 - Extraction: Pits and quarries for sand and gravel.
- H - Hay System: A contiguous arrangement of four or more fields of predominantly good quality hay, with a mixture of grain and pasture. Corn may be present in small amounts, usually less than 5 acres.
- HG - Pasture System: A contiguous arrangement of two or more fields with minimal evidence of recent cultivation. Nearly equal quantities of poor quality weedy hay and/or pasture occupy more than half the area. Associated with extensive or unconfined grazing of livestock.

Table A-1 (cont'd)

- M - Mixed system: A contiguous, rotational arrangement of four or more fields of uniform size, usually small. No single crop dominates the system. Corn and beans constitute less than 40 % of the area, and sod crops over more than 20 %. The remainder is a mixture of hay, grain and pasture. Associated with traditional farming methods, barns are usually old and silos smaller and less frequent.
- MG - Grain system: A combination of grains and good quality hay or pasture. The grains occupy between 85 and 100 percent of the area. Fields are large and usually without fences.
- P - Monoculture: A single intensive, continuous row crop such as corn or beans. There are no grain crops or hay. Consists of a minimum 16 hectare contiguous arrangement of four or more fields. Good indicators are corn dryers, elevator storage systems and machine sheds. Barns are absent.
- T - Sod Farms: Public or commercial sales of grass sod.
- X - Wetland: Includes all wetland types.
- Z - Woodland: Forest cover with a minimum of 45 % crown closure density and not less than a hectare in size.
- Zp - Pastured Woodland: Woodlands grazed by livestock, as indicated by cow-paths, manure, and vegetation cut-offs on the lower branches of trees.
- Zr - Reforestation: Land supporting a stand of artificially stocked trees.

FOR FURTHER INFORMATION, PLEASE
REFER TO THE "BANDS 3-5-4" AT
THE END OF THE THESIS.

POUR PLUS D'INFORMATION, VEUILLEZ
VOUS REFERER A LA "BANDE 3-5-4" A
LA FIN DE LA THESE.

APPENDIX B

INTERPRETATION KEY FOR SPRING THEMATIC MAPPER IMAGERY (Bands 3-5-4) OF EASTERN ONTARIO.

The interpretation key and the accompanying table of colour reference numbers are contained in the envelope on the inside of the back cover. To use it, leave the title page folded out. This serves to label the object characteristics which form the rows of the key. Start with the dominant colour of the object at the top of the key and follow the column that provides the closest match to the observed object. Note that objects will appear differently if the image was acquired in a different season, if it was reproduced with a different colour combination or if it covers a different area. Use the column number at the bottom of the key to look up the colour standard (Pantone Colour Formula Guide 747 XR) reference number. In the case of transparency of the same image area acquired in a different year or reproduced with a different band combination, the importance of the colour standard references will diminish. Object recognition will become more dependant on other characteristics such as

shape, pattern, texture, and site.

Plate 1 illustrates the appearance of some of the objects in the northeast portion of Winchester township at a scale of approximately 1:50,000. The plate can be compared with the Agricultural Land Use System map coverage of the same area, also at 1:50,000 (Figure B-1). The land use systems are described in Table A-1 and the key class to which these systems belong is given in Table 4-3. Due to the photographic reproduction process, colours on the plate are not are not an exact recreation of those in the image.

Carleton University
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This thesis contains coloured
photomicrographs & explanatory tables
which when microfilmed lose their
significance. The hardcopy of the
thesis is available upon request
from Carleton University Library.

Plate 1

Image Reproduction showing northeast portion of
Winchester Township. Scale approximately 1:50,000.

Figure B-1

Portion of the Agricultural Land Use Systems map for
Winchester Township. Scale approximately 1:50,000.

APPENDIX C

CONTINGENCY TABLE ANALYSIS OF SOIL RATINGS.

This Appendix presents the details of the contingency test used to establish the relationship between the soil class of the converted wetland and the soil capability for agriculture of the area surrounding all wetlands converted to agricultural cover (Field Crops and Pasture and Forage Crops).

C.1 Classification Combinations

The Chi-square test statistic was used. In order for the cells of the table to have expected frequencies greater than 5, soil classes combinations were required.

C.1.1 Canada Land Inventory Agricultural Capability

The Canada Land Inventory (CLI) rates the agricultural capability of land in seven classes, with Class 1 being highly productive for a wide range of field crops and Class 7 having no capability for field or forage crops. There were no observations for Class 7. Classes 1 and 2, and 5 and 6 were grouped to produce the following:

Class 1 + Class 2: Soils with no or moderate limitations to a wide range of field crops.

Class 3: Soils with moderately severe limitations and fair to moderate productivity.

Class 4: Soils with severe limitations and low to fair productivity.

Class 5 + Class 6: Soils that restrict production to perennial forage crops.

C.1.2 Wetland Mapping Series

The Wetland Mapping Series (WMS) classifies mineral wetland soils into six groups numbered 2 - 7. The classes are based on texture and fertility. To achieve the required expected frequencies, the classes were grouped as follows:

Classes 2 + 3: Fertile, medium-textured soils + moderately fertile heavy clay soils.

Classes 4 + 5 + 6: Low to very low fertility sand and/or gravel, or shallow soil over bedrock. Poor or very poor drainage.

C.2 Adjacent vs. Wetland Soil Capabilities

C.2.1 Hypotheses

$H_0: O_i = E_i$ versus $H_a: O_i \neq E_i$

- OR -

H_0 : Canada Land Inventory agricultural capability rating of soils surrounding wetlands converted to agricultural uses is statistically independent of the soil class of the converted wetland.

H₁: The soil ratings of wetlands converted to agriculture are statistically dependent upon the capability of the agricultural land surrounding them.

C.2.2 Assumptions

- i) Nominal measurement
- ii) $\sum ((O_{ij} - E_{ij})^2 / E_{ij})$ is distributed as a Chi-Square variable.
- iii) Independent random sample of $n = 134$
- iv) Significance Level = 0.05

C.2.3 Test Statistic

$$\chi^2 = \sum (O_{ij}^2 / E_{ij}) - n$$

C.2.4 Rejection Region

$$\begin{aligned} \chi^2 &\geq [\chi^2, p = 1 - 0.05, df = (r-1)(c-1)] \\ &\geq [\chi^2, p = 0.95, df = 3] \\ &\geq 7.815 \end{aligned}$$

C.2.5 Calculation

C.2.5.1 Table of Change Polygon Frequencies

\CLI	1 & 2	3	4	5 & 6	Totals
WMS \					
2 & 3	35	25	5	6	71
4 - 6	10	8	23	22	63
Totals	45	33	28	28	134

C.2.5.2 Table of expected frequencies

\CLI	1 & 2	3	4	5 & 6	Totals
WMS \					
2 & 3	23.8	17.5	14.8	14.8	71
4 - 6	21.2	15.5	13.2	13.2	63
Totals	45	33	28	28	134

C.2.5.3 Table of (O_i^2 / E_i) for X^2 calculation

\ CLI		1 & 2	3	4	5 & 6	Totals
WMS	2 & 3	51.4	35.7	1.7	2.4	91.2
	4 - 6	4.7	4.1	40.2	36.8	85.8
Totals		56.1	39.9	41.9	39.2	177.0

$$X^2 = 177 - 134$$

$$X = 43$$

C.2.6 Conclusion

43 > 7.815, therefore reject H_0 and accept H_1 . There is a statistical relationship between Canada Land Inventory agricultural capability and the soil class of wetlands converted to agricultural uses. The strength of the relationship is given by the Contingency Coefficient, which has a minimum value of 0 for no relationship (statistical independence) and a maximum value of less than 1 that is determined by the size of the contingency table. The contingency coefficient of the above test (0.49) is at least greater than half strength, indicating a significant relationship. The relative contribution of individual class combinations to the chi-square statistic is indicated by the cells of the calculation table (Clark and Hosking, 1986).

C.3 Adjacent Land Capability vs. Interpreted Use Class

C.3.1 Hypotheses

$$H_0: O_i = E_i \text{ versus } H_1: O_i \neq E_i$$

- OR -

H_0 : Canada Land Inventory agricultural capability rating of soils surrounding wetlands converted to agricultural uses is statistically independent of the class of the agricultural use.

H_1 : The class of agricultural use of wetlands is statistically dependent upon the capability of the agricultural land surrounding them.

C.3.2 Assumptions

As C.1.2 above, except sample size $n = 172$.

C.3.3 Test Statistic

$$\chi^2 = \sum (O_i^2 / E_i) - n$$

C.3.4 Rejection Region

$$\begin{aligned} \chi^2 &\geq [\chi^2, p = 1 - 0.05, df = (r-1)(c-1)] \\ &\geq [\chi^2, p = 0.95, df = 5] \\ &\geq 11.070 \end{aligned}$$

C.3.5 Calculation

C.3.5.1 Table of Change Polygon Frequencies

Key Class	CLI		C L A S S				TOTAL
	1	2	3	4	5	6	
Field Crop	9	20	15	17	9	2	72
Pasture	9	19	25	15	8	24	100
TOTALS	18	39	40	32	17	26	172

C.3.5.2 Table of expected frequencies

Key Class	CLI			C L A S S			TOTAL
	1	2	3	4	5	6	
Field Crop	7.5	16.3	16.7	13.4	7.1	10.9	72
Pasture	10.5	22.7	23.3	18.6	9.9	15.1	100
TOTALS	18	39	40	32	17	26	172

C.3.5.3 Table of (O_i^2 / E_i) for X^2 calculation

Key Class	CLI			C L A S S			TOTAL
	1	2	3	4	5	6	
Field Crop	10.8	24.5	13.4	21.6	11.4	0.4	82.0
Pasture	7.7	15.9	26.9	12.1	6.5	38.1	107.2
TOTALS	18.5	40.4	40.3	33.7	17.9	38.5	189.2

$$X^2 = 17.22$$

C.3.6 Conclusion

17.22 > 11.07, therefore reject H_0 and accept H_a . There is a statistical relationship between Canada Land Inventory agricultural capability and the class of agricultural use to which wetlands are put in eastern Ontario. The value of the contingency coefficient is 0.302, significantly different than 0 which suggests a fairly strong relationship.

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APPENDIX B

INTERPRETATION KEY FOR SPRINGTIME THEMATIC MAPPER IMAGERY (Bands 3-5-4) OF EASTERN ONTARIO.

N.B. - The key is a systematic presentation of a limited number of observations. Descriptions of the various characteristics should not be regarded as being absolute for a given object. Choose the decision path that most closely matches the unknown object.

✓ Leave this page folded out for label descriptions.

DOMINANT COLOUR	OVERALL PATTERN	TEXTURE	SPATIAL ASSOCIATIONS	CLASS	Key Column Number
SECONDARY COLOURS	Colour Arrangement/ Association	SIZE			
ASSOCIATED COLOURS		SITE			
TONE					
OVERALL SHAPE					
Colour Form					

APPENDIX B

INTERPRETATION KEY FOR SPRINGTIME THEMATIC MAPPER IMAGERY (Bands 3-5-4) OF EASTERN ONTARIO.

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Leave this page folded out for label descriptions.

DOM

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ON

OVER

Colour

SPATIAL

Key Co

DOMINANT COLOUR

SECONDARY COLOURS

ASSOCIATED COLOURS

TONE

OVERALL SHAPE

Colour Form

OVERALL PATTERN

Colour Arrangement/
Association

TEXTURE

SIZE

SITE

ADDITIONAL ASSOCIATIONS

CLASS

BLUE-GREY

white
orange and green

light
rectangular

BLUE-GREY: small, diffuse
square
OTHERS: small, distinct
angular polygons

IRREGULAR ARRANGEMENT

Gray-blue tinged by green
in places, and white by blue.

mottled

small (125 ha)

Slight slope. No drainage.

Bounded by roads with
groups of buildings
alongside.

Pasture

black

orange and white

medium
rectangular

BLACK AND WHITE: small distinct
spots
ORANGE: very thin band

CONCENTRIC

Black and white spots form
centre, surrounded by blue-
grey, then orange.

coarse

very small (10 ha)

Topographic depression,
undrained.

Buildings on opposite side of
bordering road. Black is
ponded water.

Extraction

greenish-brown
whitish

medium
rectangular

BLUE: distinct
GREENISH-BROWN: distinct irregular
parcels.
ORANGE: small
regular angular
WHITE, BLACK: small
spots.

IRREGULAR

Blue lines form
which the other
arranged. Orange
smaller than
greenish-brown
inside blue. White
found in blue
spots are found
and greenish-brown

small (20 ha)

Level. No drainage
in agricultural
sites, but may be
streams or rivers.

Located at the
major local road
utility and transport
nodes (eg. train
stations, green
Sewage treatment
situated near

Buildings

BLUE			
black	greenish-brown, orange, white, black.	Orange, Green	
orange and white	none	May include one or more of grey-blue or grey-green, yellow, brown, white.	
medium	medium	light to dark	
rectangular	regular angular		
CONCENTRIC	IRREGULAR MATRIX	PATCHWORK (Irregular assemblage of cells with varied dimensions)	IRREGULAR OR NEAR-REGULAR
Orange and white spots form a grid, surrounded by blue-grey, then orange.	Blue lines form a grid around which the other parcels are arranged. Orange parcels are smaller when they occur inside greenish-brown parcels than inside blue. White spots are found in blue parcels. Black spots are found both in blue and greenish-brown areas.	Orange and blue parcels occupy nearly equal proportions. Orange spots are scattered in the green and blue rectangles. Green may be mixed with orange occasionally.	Green lines divide parcels into rectangles. Green may also be mixed with orange. Blue and orange are alternate. Small squares of yellow and grey are clustered near roads. Brown spots may be scattered randomly throughout.
coarse	coarse	smooth	fine grained or
very small (10 ha)	small (20 ha) to very large	medium (200 ha)	Small to large (50-500 ha)
Topographic depression, undrained.	Level. No drainage patterns as in agricultural or natural sites, but may be transected by streams or rivers.	Rolling. Natural and artificial drainage.	Level or gently sloping. Artificial and natural drainage possible.
Orange on opposite side of watering road. Black is ponded water.	Located at the intersection of major local roads. Includes utility and transportation nodes (e.g. train and utility stations, grain elevators). Sewage treatment ponds often situated near smaller centres.	Bounded and transected by local rural road network. Buildings correspond to orange spots.	Bordered and transected by local rural road network. Building clusters in orange and correspond to orange spots. Very small orange, yellow, grey-blue, or green.
Extraction	Built-Up	Pasture and Forage Crops (Hay system)	Field Crops (Mixed corn, and monoculture)
2	3	4	5

BLUE-GREEN

Orange and/or greenish-brown

medium

Large, distinct square or regular angular, may have curved edge bordering woodland or waterway.

HITE: Small distinct y of near often grouped regular

GREENISH-BROWN: thin lines and small distinct squares.
ORANGE: small distinct squares.

BLUE-GREEN: may be subdivided by green lines.
ORANGE: small distinct rectangles with dimensions similar to blue-green.

DITIONAL very small les.
GREY-BLUE, o appear as ts.

REGULAR GRID

IRREGULAR GRID of long cells with equal width.

angular nglles. mixed with range parcels quares of e usually ds. Green or scattered t.

Blue-green subdivided into rectangular parcels by greenish-brown lines. Small squares irregularly clustered near roads.

Repetition of parcel colour is irregular. Orange parcels are speckled by clusters of dark spots.

r mottled -500 ha)

mottled small (150 ha)

mottled small (100 ha)

oping. Jral drainage

level, artificially drained

Level, artificially drained.

ected by atwork. include silos clusters of yellow, n squares.

Bounded by rural roads. Buildings, including silos, are clustered near road, corresponding to orange squares.

Bounded by paved roads. A few buildings may be clustered near the road.

ad grain, re systems).

Field Crops (mixed grain system)

Pasture and Forage Crops

		ORANGE
Blue and/or Grey-blue		Green
Brown and/or Green or Green-Blue, Yellow.		
medium to dark		medium
Regular angular, may have curved edges along borders with wooded areas and streams.		regular an
ORANGE, BLUE, GREY-BLUE, GREEN-BLUE: Small or medium sized, squares or rectangles. Often assembled into a larger regular angular polygon with cells separated by contrasting lines or variations in tone.		Small to medium-rectangles, so
GREEN, BROWN AND YELLOW: Small irregularly curved polygons OR very small distinct squares.		
IRREGULAR GRID (patchwork) of cells which are often long and of near-uniform width.		Vivid, high co patte
Regular angular parcels not distinct, BLUE-GREEN are large. GREEN and BROWN may be mixed with ORANGE or clustered; BROWN loosely and GREEN near roads. Very small ORANGE squares may be clustered near roads.	Regular angular parcels distinct. BLUE may be very light toned, approaching white; is mixed with GREEN infrequently. GREEN may be mixed with ORANGE. YELLOW clustered near roads in association with very small GREY-BLUE parcels.	
Medium, fine or coarse.	Smooth to medium	Fine grain
Small to medium (25 - 400 ha).	Medium to large (400 - 1500 ha)	Large (600)
Gently sloping, may be drained naturally or artificially.	Fairly level. Artificially and naturally drained.	Level, artificial.
Access by bordering rural road network and private lanes. Green and orange square clusters correspond to buildings, which include silos, clustered near and away from roads.	Very small yellow, blue and grey-blue squares correspond to building clusters (including silos) alongside roads. Bordered and transected by local road network.	Regular angular ri provides access th area. Small cluste buildings at centri
Pasture and Forage Crops (Hay Systems)	Field Crops (Corn and Mixed Grain Systems)	Field Crops (Sod

IGE

len

Ors 14

um

angular

in-sized distinct
some very thin.

contrast MOVEN
tern.

ain

0 ha)

ally drained.

road network
throughout the
ster of
ntre of area.

od operation)

Brown, Blue and White

medium

irregular angular or curved

ORANGE, GREEN AND BLUE: Small
and medium-sized square or
rectangular parcels.
ADDITIONAL BROWN, WHITE, AND
ORANGE: small, distinct,
round or oval shaped.

IRREGULAR GRID created by mix
of parcels of varying
dimensions.

BROWN spot tends to occur near
edge, in GREEN area. GREEN may
be mixed with ORANGE. WHITE
spots occur in BLUE and ORANGE
near road.

Medium

Small (100-200 ha)

Level to gently sloping or rolling. Drainage may be
present in the form of streams or artificial drains.
Might include small ponds or intermittent lakes.

Access provided by bounding and transecting rural road network.
If present, buildings are clustered in small groups alongside
roads. These corresponding to spots of WHITE, YELLOW, LIGHT ORANGE,
and possibly BLUE or GREEN.

Pasture and Forage Crops

Brown, Yellow, White, Black

Light to Dark

1) irregularly curved OR
11) regular angular, possibly
with one or more curved edges.

Parcel form varies. The same
colour may have different forms
for different tones in a
system. Generally, dominant
and secondary colours are
larger, more distinct and tend
toward angular shapes than
additional colours. However,
one shape, such as rectangular
or rounded, may prevail
according to the system shape.

1) IRREGULAR ARRANGEMENT
(predominately rounded parcels)
OR
11) IRREGULAR GRID
(predominately angular parcels)

1) Random distribution of
spots. Some spots may be
concentric associations of
YELLOW - ORANGE, ORANGE -
GREEN, BLACK - GREY - GREEN -
BROWN. OR,
11) Squares and rectangles
combine into larger regular
angular polygons, component
cells distinguished by tone
or contrasting lines.

Coarse, fine or mottled (blue)

Very Small to Very Large
(20 - 3000 ha)

Fine

Small (100 ha)

Gentle slope. Stream drainage

Bordered by roads. A few
ings correspond to the
of BLUE and ORANGE squares

Field Crops (mixed grain)

GREEN

Orange and/or Blue

White, Black

Medium

Regular angular, possibly with curved sides bordering woodland.

GREEN: large distinct square
ORANGE: medium-sized distinct
rectangles or small diffuse
squares
BLUE: small distinct squares

1) small, distinct angular
polygons OR 11) GREEN: small,
distinct rectangle or rounded;
BLUE: small distinct square

PATCHWORK (irregular grid)

1) UNIFORM or 11) NEAR REGULAR GRID

GREEN and ORANGE occupy nearly
equal proportions of the area
and may be mixed. BLUE mottled
by lighter tones, found inside
ORANGE parcels.

1) Continuous OR 11) Rounded dark
GREEN parcel contained in medium
green rectangle. BLUE squares
and medium GREEN rectangles
create grid.

Fine

Fine OR Medium

Small (100 ha)

Very small (10 ha)

Gentle slope. Stream drainage.

Gentle slope. No surface
drainage.

Bordered by roads. A few build-
ings correspond to the locations
of BLUE and ORANGE squares.

No buildings or interior
access.

Field Crops (mixed grain system)

Forest

GREEN

..... Brown and/or Orange

Irregularly Curved OR Regular
Regular Angular with possibly
some edges curved by bordering
streams, woodlands.

irregularly curved

GREEN: Small to medium sized
distinct regular angular or
irregularly curved polygons,
and possibly small, distinct
spots (darker tone)
BROWN and ORANGE: Small
squares, rectangles, wedges; OR
long, irregularly curved
polygons; OR diffuse spots
WHITE and YELLOW: Small,
distinct and diffuse spots
BLUE: Small distinct squares.

GREEN: Distinct, medium-sized
rounded parcels.
BROWN: Distinct, linear form
OR small, diffuse, rounded
parcels.

GREEN, BROWN, GREY-GREEN
BLACK, ORANGE: Small to
medium sized, distinct and/or
irregular curved polygons
ORANGE, REDDISH-BROWN
distinct angular polygons
include squares and
rectangles). BLACK, REDDISH
BROWN: small distinct
WHITE: small distinct
rectangles

IRREGULAR ARRANGEMENT OF
SOMETIMES CONCENTRIC SPOTS.

CONCENTRIC.

IRREGULAR ARRANGEMENT

Random clustering of parcels.
GREEN tonal variations may
suggest a grid-like pattern.
Some YELLOW spots may have an
ORANGE or BROWN centre. BROWN
can be mixed with GREEN or
ORANGE, or enclose some orange-
green concentric associations.
These and BLUE squares occur
near road.

GREEN parcels surrounded and
separated by BROWN.

Clusters of small ORANGE
and/or YELLOW spots occur
alongside roads at near equal
intervals. BLACK, if present,
occurs at edge in association
with BROWN and dark GREEN.

Parcel
spotted
GREY-GREEN
mixed
Dark REDDISH
present as
squares
and WHITE

Fine grained to coarse

Mottled

Coarse

Very Small to Medium
(20 - 300 ha)

Small (100 ha)

Small to Medium (150 - 400 ha)

Level to rolling terrain,
artificial drainage possible.

Low-lying, artificial
drainage.

Gently sloping to hilly.
No drainage.

Low lying
drained

Loose surface, dry weather
roads provide access along
boundaries. If present,
buildings are few and isolated.
They occur near roads,
corresponding to yellow spots.

No access or buildings. If
present, cart track or road
circumnavigates perimeter.

Loose surface road provides
access to regularly spaced
clusters of 2-3 buildings,
these correspond to orange
and yellow clusters in image.

Generally
traversed
road network

Forest

Wetland

Pasture and Forage Crops

One or more of Orange

One or more of Yellow, Black, White, Blue, Brown, Grey-Green, Orange

Grey-

light to dark
irregularly curved

GREEN: Distinct, medium-sized rounded parcels.
BROWN: Distinct, linear form OR small, diffuse, rounded parcels.

GREEN, BROWN, GREY-GREEN, BLACK, ORANGE: Small to medium sized, distinct and/or diffuse irregular curved polygons
ORANGE, REDDISH-BROWN: distinct angular polygons (may include squares and rectangles). BLACK, REDDISH-BROWN: small distinct spots
WHITE: small distinct rectangles

Disti
irreg
vario
predo

CONCENTRIC.

IRREGULAR ARRANGEMENT

CO

GREEN parcels surrounded and separated by BROWN.

Clusters of small ORANGE and/or YELLOW spots occur alongside roads at near equal intervals. BLACK, if present, occurs at edge in association with BROWN and dark GREEN.

Parcel clusters create a spotted appearance. GREEN, GREY-GREEN or BLACK may be mixed or concentric with BROWN. Dark REDDISH-BROWN may be present as small distinct squares near edge of system, and WHITE near roads.

BROWN
parce
envel
mixed
found

Mottled

Coarse

Medium (possibly mottled)

Small (100 ha)

Small to Medium (150 - 400 ha)

Small to Large (150 - 80

Low-lying, artificial drainage.

Gently sloping to hilly. No drainage.

Low-lying level to slightly sloping or drained by small streams. May contain lakes that correspond to BLACK

No access or buildings. If present, cart track or road circumnavigates perimeter.

Loose surface road provides access to regularly spaced clusters of 2-3 buildings, these correspond to orange and yellow clusters in image.

Generally no buildings or access, although transected by gravel road, railroad or road network is usually routed around t

Wetland

Pasture and Forage Crops

Wetland

Table B-1: COLOUR STAND

KEY COLUMN:	1	2	3	4	5	6	7	8
COLOUR								
BLACK		426 U	426 U					
BLUE			2995 U		317 U 318 U 549 U			317 318
BLUE-GREEN						546 U		
BLUE-GREY		5493 U						
BROWN					4625 U			131 459
BROWNISH-GREEN								
GREEN	3925 U				351 U 365 U 374 U 390 U			367 3975
GREEN-BLUE				397 U			523 U	338
GREENISH-BROWN			5825 U			5845 U		
GREY-BLUE	563 U				5493 C			5483 563
GREY-GREEN					557 U			
ORANGE	1375 U	1375 U	151 U	1375 C	137 C 1375 C 021 C 151 C 150 U	151 C	151 C	151 C 021 C
REDDISH-BROWN								
YELLOW					4625 U			

[illegible]

Table B-1: COLOUR STANDARD REFERENCES (PANTONE Colour F

1	2	3	4	5	6	7	8	9	10	11	12
426 U	426 U										419
	2995 U		317 U 318 U 549 U				317 C 318 U	317 U 317 C	317 U 317 C	302 U	291 304 317 317
				546 U							
5493 U				4625 U			131 U 459 U			471 U 1595 U	
											3975
3975 U			351 U 365 U 374 U 390 U				367 U 3975 U	360 U 373 U	362 C 360 U 373 U	352 U 584 U	112 345 352 353 359 362 367 370 374
				397 U		573 U	338 U	331 U	331 U		
	5825 U				5845 U						
563 U			5493 C				5483 C 563 U	5483 U 5493 U	5483 U 5493 U		556
			557 U								
4375 U	1375 U	151 U	1375 C	137 C 1375 C 021 C 151 C 150 U	151 C	151 C	161 C 021 C	150 U	150 C 151 C 151 C	150 C 150 U 1345 C	1365 151 150 151 1575
				4625 U				100 U	100 U		100 101 393

[illegible]

END

22.08.88

FIN