UNIVERSITY OF ALBERTA

Monitoring Changes in Field Geometry Using LANDSAT Digital Data

By

AMRO EL-SAWAF ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

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To my Parents,

for their endless encouragement and support

Abstract

Satellite data are widely used for monitoring land management practices. Some practices such as changing the size and shape of fields may not be as pronounced as others that are associated with changing land cover. The aim of this study is to investigate the temporal changes in the geometry of fields as indications of soil conservation management over a period of 16 years using LANDSAT TM and MSS image data.

The study sites, comprised of four townships, are located in the Parkland region, in the Northeast portion of the province of Alberta. Digital LANDSAT TM and MSS data were acquired for August 5th 1991 and August 4th 1975 respectively. For operational monitoring purposes, it would be tedious to extract the boundaries of the fields manually, therefore a more automated approach was developed based on the use of a series of image analysis techniques, primarily multispectral classification and spatial filtering.

The results of the application of these procedures are encouraging in that field identification accuracies of 92 % and 88 % were achieved with the TM and MSS data respectively. They show that it is possible to extract field boundaries adequately from LANDSAT TM and MSS and thereby reduce the labor, and time needed to provide such maps. The resultant maps could be used as an input for a GIS layer that could be useful in erosion studies.

The resultant raster maps of the field boundaries were converted to vector data format and were used for the visual analysis of change in field geometry by overlaying them onto the false color composites of the opposing date. Statistical analysis was conducted to test for the significance of difference between parameters (area, perimeter, and shape index)

that could provide information on the changes in sizes and geometry of fields between the two dates of imaging. Statistically significant differences in the shape index were found for two of the studied townships, where this change was towards more elongated shapes. The rest of the parameters tested, that indicate serious "fragmentation", such as the areas and the perimeter of fields did not show any statistical difference. The overlay analysis did not indicate any significant trend for the change in the sizes and geometry of fields.

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Chapter 1: Introduction

1.1 Introduction and objectives

The improving technology of satellite remote sensing has offered vital information to various facets of the study of the Earth's renewable resources, especially with respect to inventory monitoring purposes over time. This can be attributed to the synoptic view of the Earth and the relatively high spectral, radiometric, and temporal resolution of these satellites. The LANDSAT series is one of the most often used for providing remotely sensed data about the Earth. The first of this series was launched in 1972 and was the initial source of satellite data used specifically for observing the Earth's resources.

While there has been a great amount of research on both the application of satellite remote sensing to land degradation monitoring, and the automatic extraction of other linear features in Geologic mapping, there are very few on the application of flexible automated techniques for the extraction of field boundaries. Therefore, the objective of this research is to explore methods for the detection and extraction of field boundaries, and to use the resulting maps to test the hypothesis that field geometry in a selected area has changed over a period of years. The interest is in the possible trends occurring for total large area rather than analyses of changes to individual fields. To meet this objective, the study was divided into three major phases :

1. An examination of the extent to which LANDSAT TM and MSS data can be used to detect field boundaries.
2. An examination of the possibility to automate the delineation of field boundaries.
3. A comparison of the resultant boundaries over the different dates for an evaluation of the changes in geometry over a period of sixteen years for the fields included in the study.

A potential application would be in studies of soil erosion by water which constitutes a serious problem in many areas around the world. Cultivation and tillage practices play an important role in the reduction of erosion, the detail of the controlling methods depends upon the local conditions. In western Canada, over the years, it can be assumed that farm operators may have either shifted towards farming on a large scale as a result of the intensification of using larger machinery, or they have tended to change the sizes and shapes of their fields and plant according to the landscape. The change in the geometry of the fields in the latter case, may be considered a conservation practice, as it may potentially reduce the amount of soil loss within the fields due to the reduction of their sizes that will influence the slope length factor (L) in the Universal Soil Loss Equation (USLE). However, the practice of altering field geometry may not be as pronounced and widespread as other conservation practices. Nonetheless, the detection of changes in field geometry is of significance in large area monitoring. Remotely sensed data could be used to investigate whether or not there has been significant changes in field geometry over some period of years in different areas as a soil conservation practice.

Chapter 1 includes introduction, objectives, problem definition and motivation, and description of the study sites. A brief overview and a background of how changes in field geometry fall in the context of erosion, and on the satellite data used, related work, and a detailed discussion of the methods, are all presented in Chapter 2. Materials and methods used, results and their discussion, and a summary and conclusion are presented in Chapter 3. A general summary and conclusion, and suggestions for future work are discussed in Chapter 4.

1.2 Problem Definition and Motivation

The problems addressed in this research are two-fold; the first, is to introduce the issue of changes in field geometry as a conservation practice. The second, is to develop and test some guidelines for an automated procedure for the extraction of field boundaries, that with some modification would be suited for any other agricultural areas.

The PARI (Parkland Agricultural Research Initiative) project was a part of a national initiative of Agriculture and Agri-Food Canada's Green Plan, on limiting greenhouse gases. The objective of PARI was to test and validate soil and water conservation practices and encourage their adoption in the Parkland area (Lindwall 1995).

One of the programs involved in the PARI project was Land Resource Monitoring and Evaluation. The objective of this program was to develop methods that would provide data on the type, rate, and changes of the adoption of soil conservation practices in the Parkland region at present and that could also be useful for predicting the picture in the future (Lindwall 1995). Remotely sensed data, including both satellite and aircraft imagery, were the major sources of the data used in the PARI research. This study falls in the framework of this program.

Changes in field sizes and geometry were not considered as other conservation practices were assessed in the PARI project. The research conducted in that program had concentrated on the study of the adoption of management practices that were directly related to land cover and land use. The changes in field geometry may be of great importance in the northeastern part of Alberta and the Parkland area, and information on these changes over a period of sixteen years would add to the picture of the adoption of different land management practices.

Although the identification of field boundaries could be a very important issue (Benjamin 1987, Whiting and Heyland 1988) it has not received much attention among the researchers in the field of remote sensing applications in resource management, and it is still a problem that has not been sufficiently solved. Manual procedures for generating and editing maps of field boundaries are often slow, tedious, labor intensive (Cheng et al. 1992) and the results obtained lack consistency and also can be controversial, as they are influenced by the analyst's subjectivity. Based on the enormous amount of information that the remote sensing satellites can offer for analyses for specific purposes, it is very intriguing to consider the development of an automatic method for the delineation of fields, that would be faster and more cost effective compared to manual approaches. Continuing to manually delineate field boundaries would limit the use of this amount of data. The importance of this type of study can be manifested by summarizing some of its advantages as follows :

- The flexibility of the procedure would allow its successful application to any area and certainly with more success in less complex terrain. Cihlar (1988) has pointed to the deficiency of the automated techniques for delineating fields boundaries, as these techniques are not flexible enough to handle the diversity of fields.

- The automation of the process would improve area measurements using satellite imagery (within the limitations of the spatial resolution) by accelerating the operation and reducing the amount of labor, and result in more accurate and reliable results by eliminating the user's bias that influence the delineation in manual approaches.

- Whiting and Heyland (1988) recommended that remote sensing data should be utilized as part of the planning and data gathering requirements for fields boundaries. Benjamin (1987) showed that the information gathered using satellite imagery would facilitate the establishment of data bases of field boundaries, and can be more conveniently up-dated so that the ground surveys could be eliminated or greatly reduced.

- The process could be used to prestratify the data before classification according to fields, which can help identify boundary pixels and thus avoid them during the training step. Metzler and Cicone (1983) evaluated various techniques for dealing with mixed pixels in LANDSAT MSS imagery, one of them was employing a method to stratify the image into pure and mixed pixels, so the latter could be avoided. Chhikara (1984) discussed the problem of boundary pixels in estimating acreage proportions of crop types. This procedure could also be used in post-classification sorting which may reduce the need for more complicated classification. Palylyk (1991) has discussed the importance of field size, shape, and spatial distribution for the interpretation process in the classification stage.

- If the process proved to be successful, it would add a new dimension to other studies of the phenomena that are strongly associated with field geometry, such as studies in soil erosion.

- With the growing importance of the integration of remotely sensed data and Geographic Information Systems (GIS), this procedure would provide a means to input maps of field boundaries that can be used as a layer in a GIS. Aronoff (1995) mentioned that the process of tracing lines in digitizing is error prone and time consuming and that data entry is the major bottleneck in implementing a GIS. Consequently, improvement in the process used would likely benefit many applications.

The primary objective was to locate field boundaries. For the purpose of this study a "field" is defined as a one continuous cover type identified by the same multispectral response (same color rendition) that is different than the adjacent land parcels. Parcels of land having the same cover or similar color representation, but separated by an observed physical boundary in the imagery such as a fence, treed areas, or a road, were identified as different fields. The location of the boundary was assumed to be detected where one kind of cover changed to another kind of cover. The specific cover types are not important, only the fact that there was a change. A narrow line of separation, as in a fence-row, would provide a change in cover that, if detected, would indicate a field boundary even if the same kind of crop was on either side. The concept is therefore similar to the thought process used during manual approaches. Management practices that result in variation in land cover within a field at a specific time of imaging, would be potential sources of error.

The identification of boundaries, in this study, is based initially on the observable multi-spectral contrast among fields due to differences in reflection properties of different cover types, or the presence of an observable line of separation between adjacent fields of the same cover type. Then, the variations within a field are reduced through classification procedures to produce more homogenous areas, with an abrupt change in gray level values between them. Finally, these boundaries are highlighted. The time frame of imaging is assumed to be a very important factor in this study. It may have been most suitable if images from the beginning of the growing season were available to maximize the spectral differences among various cover types. More detail on crop calendar for this area can be found in Crown (1982) and Crown and Klita (1995). Also as the season advances the boundaries may become less distinct, especially if adjacent fields have the same type of cover, are at the same growth stage, and had no physical boundaries such as trees, separating them. The satellite image archive developed for the PARI program was used for this study. This archive did not include yearly multi-season imagery spanning the 15 to 20 year period over which change would be measured. The only available image acquired on almost the same day of the year were an MSS image from August 4th 1975 and a TM image from August 5th 1991. A degree of spectral contrast could still be maintained on that date, which could be attributed to the differences in cover type, planting date, and density of vegetation.

1.3 Study Areas

The study areas are located in the Parkland region of Northeastern Alberta, where other related studies on the adoption of soil conservation practices were carried out (Crown et al. 1994). The Parkland forms a narrow arc that extends between the Boreal forest and the Mixed Prairie. It consists of grassland with some forest intrusions (Clayton et al. 1977).

Four study sites were chosen, each was 10 X 10 km to conform to areas of other related work (Crown et al. 1994). The topography was considered in choosing the segments, as the size and the geometry of the field is assumed to be determined partly by relief conditions. Some study areas were located in nearly level relief areas, where it was assumed that the fields were relatively large and rectangular. Small fields were anticipated in study sites of more rugged topography, dissected by numerous drainage channels that hinder cultivation. The study sites also represent different soil types, as this may also influence the size of fields as farmers are aware of the erosion potential of some soils. Therefore the study areas included :

Township 53-Range 10-W 4th

Township 55-Range 7-W 4th

Township 51-Range 11-W 4th

Township 49-Range 9-W 4th

Township 53-Range 10-W 4th and nearly all of Township 55-Range 7-W 4th were located in the soil survey of the county of Two Hills (Macyk et al. 1985). Township 51-Range 11-W 4th, Township 49- Range 9-W 4th, and the rest of Township 55-Range 7-W 4th were included in the soil survey of the Wainwright and Vermilion area (Wyatt et al. 1944).

The dominant land use for all the study sites is agriculture, mainly cereal crops, forage cultivation, and some pasture areas (Crown and Klita 1995). The native vegetation in this areas is representative of the Parkland belt in Alberta. Aspen poplar (*Populus tremuloides*) is the dominant tree species with paper birch (*Betula papyrifera*), white spruce (*Picea glauca*), balsam poplar (*Populus balsamifera*), and Willow (Salix Spp.) (Macyk et al. 1985). The climate of this area is characterized by fairly cold long winters and warm summers. January is the coldest month with an average temperature of -18 °C, the warmest month is July with a mean of 17 °C (Macyk et al. 1985).

The highest total precipitation reaches 200 - 230 mm, occurs from June - August, the mean annual precipitation ranges from 400 - 450 mm, the average frost free period is 81.4 days (Macyk et al. 1985). A specific description of the geographic location, topography, and the soils of each Township is provided below :

Township 53-Range 10-W 4th : The upper left corner has UTM coordinates of E = 468500, N = 5942150, and the lower right E = 478250, N = 5932275. The soil parent geologic material (PGM) is mainly till and glaciofluvial, with some gravel in the Vermilion river valley. The topography of the area ranges from level to undulating, and with some hilly areas in the north east part. Soils are mainly Dark Gray Chernozems, Dark Gray Luvisols, and Orthic Gray Luvisols. Texture is mainly loamy to loamy sand. The soils are "fairly good to well drained" (Macyk et al. 1985, Wyatt et al. 1944).

Township 55-Range 7-W 4th : The upper left corner has a UTM coordinates of E = 497100, N = 5961400, and the lower right corner E = 506950, N= 5951600. The PGM is mainly till and some glaciofluvial. Soils are Dark Gray Luvisols and Orthic Gray Luvisols, Dark Gray Chernozems, and Black Chernozems. The texture of the soils is mainly loamy, some areas loamy sand, "fairly good to well drained". Topography ranges from level and undulating to gently rolling, some areas are hilly (Macyk et al. 1985, Wyatt et al. 1944).

Township 49-Range 9-W 4th : The upper left corner has a UTM coordinates of E = 478600, N = 5902950, and the lower right corner E = 488350, N = 5893250. The PGM is dominantly till. Soils are loamy shallow Black Chernozems, "fairly good to well drained". The topography is mainly rolling, while some areas are gently rolling, and hilly in the south west part, with numerous sloughs (Wyatt et al. 1944).

Township 51-Range 11-W 4th : The upper left corner has a UTM coordinates of E = 458500, N = 5922800, and the lower right corner E = 4683500, N = 5912850. The PGM is dominantly till. Soils are Black and Dark Gray Chernozems having sandy loam to loamy texture, "fairly good to well drained". Topography is mainly gently rolling with some areas rolling and some level to undulating (Wyatt et al. 1944).

A color composite that shows the relative location of the study sites within a 185X185 LANDSAT MSS scene is presented in Figure1.1. Figures 1.2, and 1.3, and Figures 1.4 and 1.5 are MSS and TM color composites, respectively, of the individual study sites.

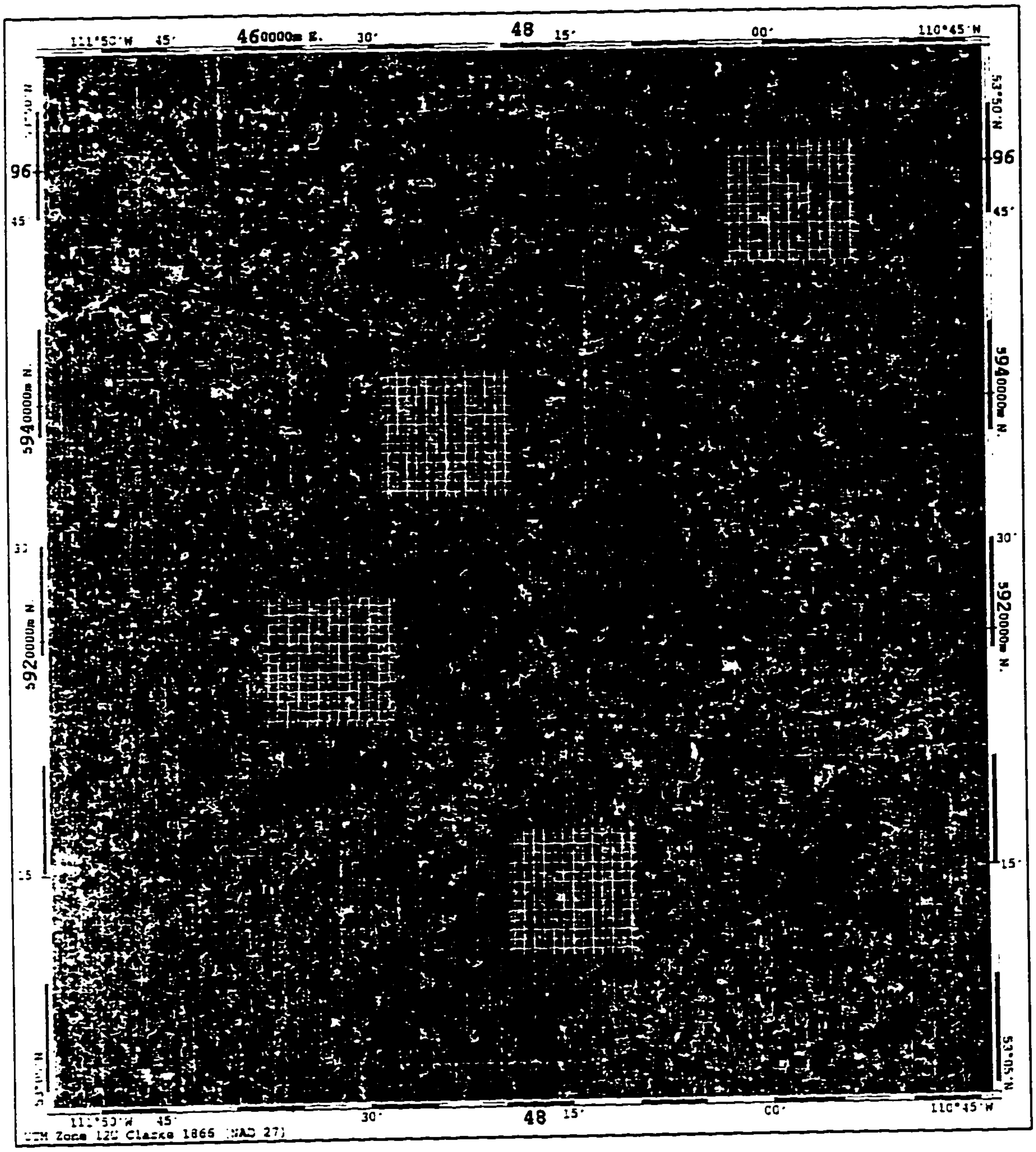

Figure 1.1 August 4, 1975 LANDSAT MSS color composite showing the quarter section grid of each of the study sites (Linear contrast stretch; Infrared B6 as red, Red B5 as green, Green B4 as blue).

Township 49-Range 9-W 4th Meridian   Township 51-Range 11-W 4th Meridian

Figure 1.2 LANDSAT MSS color composite images of 2 of the 4 townships in N.E. Alberta used as study sites (Image Date August 4, 1975; Infrared Band 6 as red, Red band 5 as green, Green Band 4 as blue; Linear contrast stretch approximate presentation scale 1:100,000).

Township 53-Range 10-W 4th Meridian Township 55-Range 7-W 4th Meridian

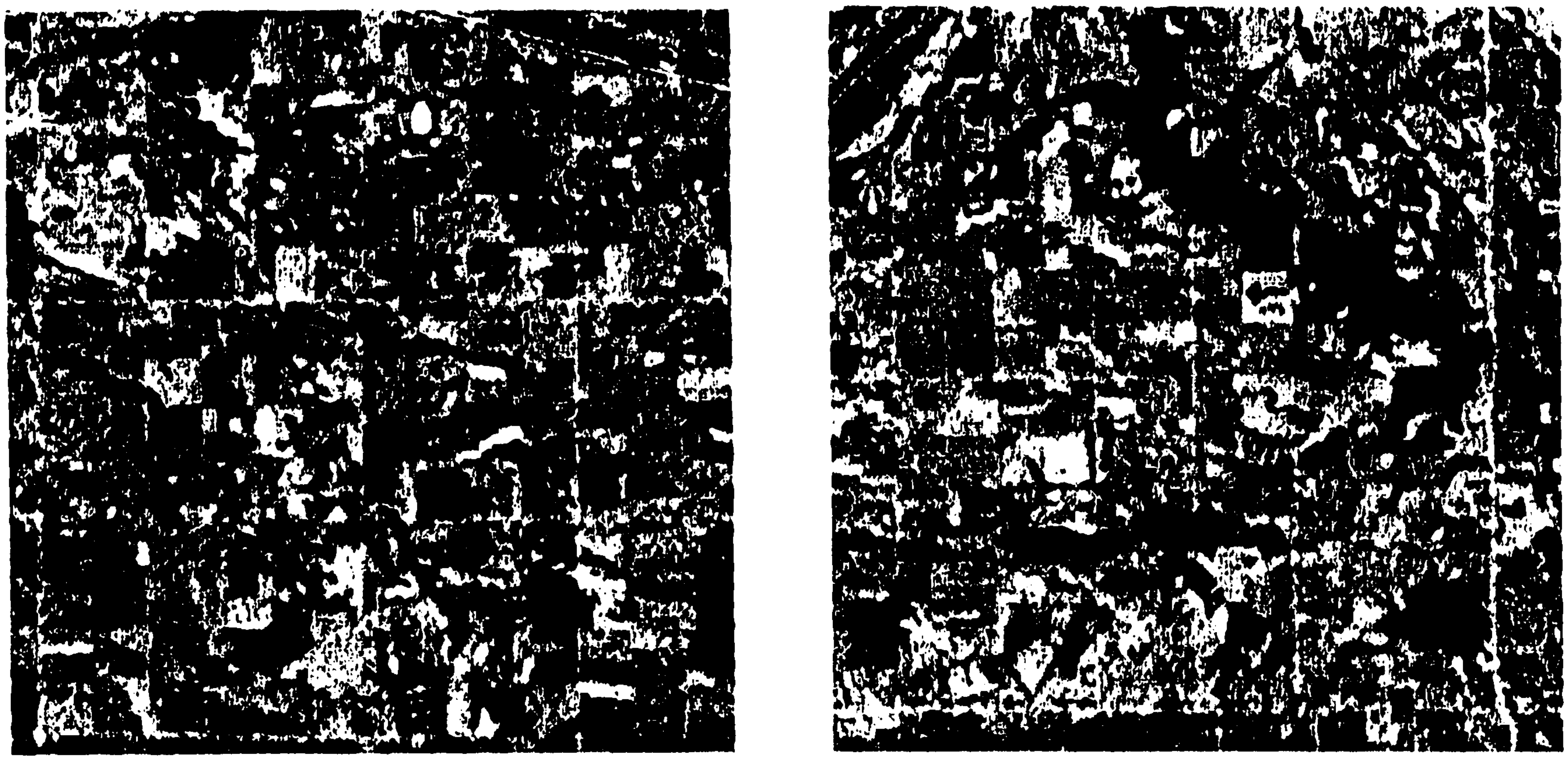

Figure 1.3 LANDSAT MSS color composite images of 2 of the 4 townships in N.E. Alberta used as study sites (Image Date August 4, 1975; Infrared Band 6 as red, Red band 5 as green, Green Band 4 as blue; Linear contrast stretch approximate presentation scale 1:100,000).

Township 49-Range 9-W 4th Meridian   Township 51-Range 11-W 4th Meridian

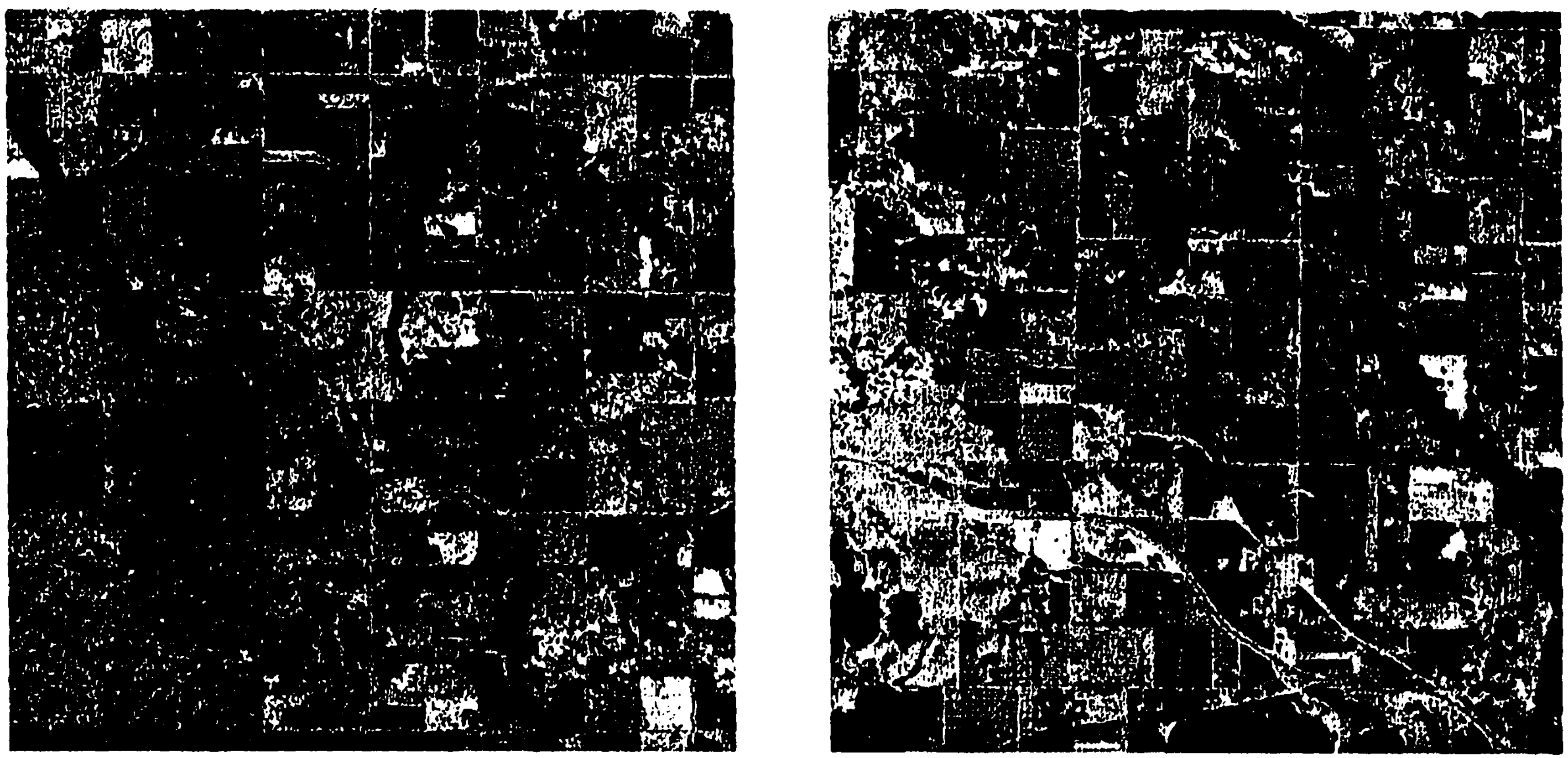

Figure 1.4 LANDSAT TM color composite images of 2 of the 4 townships in N.E. Alberta used as study sites (Image Date August 5, 1991; Infrared Band 4 as red, Red band 3 as both green and blue; Linear contrast stretch approximate presentation scale 1:100,000).

Township 53-Range 10-W 4th Meridian   Township 55-Range 7-W 4th Meridian

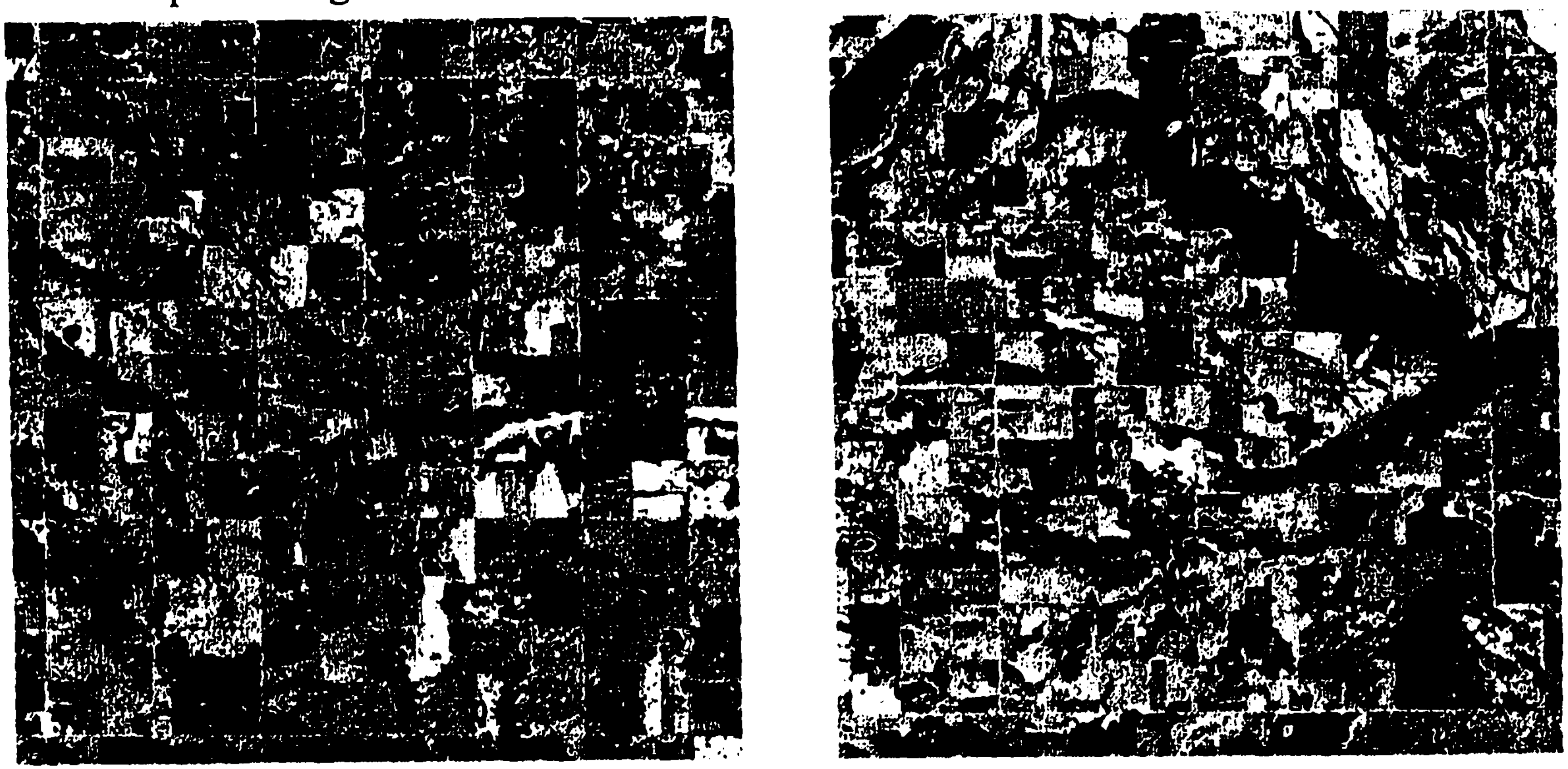

Figure 1.5 LANDSAT TM color composite images of 2 of the 4 townships in N.E. Alberta used as study sites (Image Date August 5, 1991; Infrared Band 4 as red, Red band 3 as both green and blue; Linear contrast stretch; approximate presentation scale 1:100,000).

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CHAPTER 2: Review of Literature and Image Analysis Methods

2.1 Introduction

Soil erosion by water is considered one of the processes that is significantly responsible for the degradation of soils in many areas around the world. It is the most widespread kind of soil degradation and is found in all parts of Canada (Standing Committee on Agriculture, Fisheries and Forestry 1984).

For a period of time it was thought that wind erosion was the major factor of erosion in Alberta (Tajek et al. 1985), and little attention was given to water erosion. Howitt (1989) has reported the loss of great amounts of soil caused by water erosion in East-central Alberta. He also encouraged the adoption of soil conservation practices in this area to reduce soil erosion. Signs of water erosion were also reported in all parts of Alberta including the Brown Soil Zone (Tajek et al. 1985).

The reduction of soil erosion caused by water may be accomplished by first understanding the factors influencing the rate of erosion, and then trying to reduce their contributions to the erosion process. According to the USLE, the erosion of soil by water depends on the rainfall intensity, slope, the erodibility of soil, the crops or vegetation cover, and the management and conservation practices (Larson 1983). Of these, information on land cover and management practices may be derived from satellite data. Information on field size may also be derived from satellite data. Troeh et al. (1980) reported that the small size of cultivated fields in the early days of agriculture was a factor in reducing soil erosion. Later Dumanski et al. (1986) reported that expanding field size was one of the factors that has led to the deterioration of soil quality in Canada. In Alberta the average farm size in 1991 was 365 ha, the second largest in the country (Dumanski et al. 1994).

2.2 LANDSAT Satellite Data

The imagery available for this research were provided by two types of sensors on the LANDSAT-2 and LANDSAT-4 satellites. Some of the important characteristics of the sensors used, their platforms, and the major differences between them are highlighted in the following overview.

LANDSAT-2

The satellite launched in January 1975 and decommissioned in February 1982, was in a sun-synchronous, near polar orbit, with a nominal altitude of 900 km and a temporal resolution of 18 days (Lillesand and Kiefer 1994). The main sensor on LANDSAT-2 was the Multispectral Scanner (MSS), which is still operating in the current LANDSAT's 4 and 5. The MSS is an optical mechanical line scanner, which records the solar radiation reflected from the Earth's surface in four spectral channels of wavelengths of 0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 µm, covering a swath of 185 km wide and a ground resolution cell size of 79 X79 (Lillesand and Kiefer 1994).

LANDSAT-4

The major difference in the orbital characteristics between this satellite and LANDSAT -2 is the lower altitude of 705 km and the improved temporal resolution of 16 days repeat coverage. Along with the MSS, this platform carries a Thematic Mapper (TM). The MSS in this platform is almost identical to that previously described. The data used from this satellite in this study were recorded by the TM sensor. The TM provides an improved spectral resolution as a result of adding more narrow spectral bands compared to the ones used in MSS, allowing more sensitivity to discriminate features on the ground, such as the seperability of man-made features, vegetation species, water, and soil features (Salomonson and Koffler 1983). Also the radiometric resolution has improved to eight bit data (Vs. six bit for the MSS) and the spatial resolution to 30 m for the optical channels. More details on the TM specifications can be found in Engel and Weinstein (1983). The improved attitude stability of the platform has aided in enhancing the geometric properties of the produced imagery (Welch and Usery 1984).

2.3 Related Work

The review of the related work will include two areas; research conducted using satellite imagery for monitoring land resources management, and work carried out in the detection of field boundaries and other linear features. A review of the methods used, and the rationale behind applying them are discussed in section 2.4.

2.3.1 Land Resources Management

The tremendous potential of LANDSAT imagery for monitoring land resources management through land cover identification is well documented in the literature. This is particualrly true for agricultural areas. Zhuang et al. (1991) have reported the successful use of LANDSAT TM data to determine the type and amount of crop residues on the surface of cultivated soils over a large area. Green et al. (1994) among others, have used LANDSAT TM data to detect and monitor land cover, and also measure the change over a period of time. In Alberta, Crown et al. (1994) have used LANDSAT MSS and TM data to inventory and monitor surface cover as an indication of the adoption of soil conservation management practices. Also Smith et al.(1995) have used TM visible-infrared data for monitoring land under various agricultural practices. McNairn and Protz (1992) used TM data to map crop residue cover in Ontario, using simple, easy to implement linear model that defines the relationship between reflectance values and different percent residue cover. Van Deventer et al. (1997) used LANDSAT TM data to distinguish between conventional and conservation tillage through classifying agricultural management practices and soil properties in Ohio, they concluded that remotely sensed tillage information could be used as an input for soil erosion modeling . All this work relates to that reported by Jurgens and Fander (1993) who used LANDSAT TM data to determine the land cover factor in the USLE in a study to asses the long-term soil erosion for a small area. They also reported that their future work would include the development of a procedure to determine the slope length factor in the USLE. In a study to determine the critical periods of water erosion for different crops in southern Quebec, Cyr et al. (1991) used multitemporal satellite imagery to improve the monitoring of cover types.

DeGloria et al. (1986) used a manual interpretation approach of film products of LANDSAT MSS color composites to map and monitor the spread of conservation tillage practices in the central coast region of California over a period of five years. They have pointed to the importance of multidate imagery, and in their study at least two images per year were required to optimize the interpretation of tillage practices. Leek and Solberg (1995) assembled a monitoring system from several sources of remotely sensed data to monitor soil management practices in Norway and relate them to soil erosion. Pickup and Chewings (1988) presented a method to forecast the spatial distribution of soil erosion and deposition. The MSS data were used to derive stability index values based on the kind of soil cover that would allow the mapping of erosion and deposition, then a model was used to locate areas of potential degradation. Palylyk (1991) also identified areas of soil erosion risk by studying changes in land cover using multidate MSS imagery.

The emphasis is therefore been placed on the relationship between land cover and soil erosion risk. However, field size and shape may also be factors and their study would require an initial delineation of field boundaries.

2.3.2 Detecting Linear Features

The literature on the delineation of field boundaries from satellite imagery and other remotely sensed data is very scarce. In a study to determine the feasibility of measuring agricultural fields from satellite data, Cihlar (1988) used a manual, visual image analysis approach to define field boundaries for agricultural measurements from LANDSAT TM and SPOT High Resolution Visible data. His method included enhancements of the imagery for a better visual perception of boundaries, and then manually drawing of the field boundaries. Moussa (1994) also used a manual approach for the delineation of agricultural land boundaries, by means of ground points from multitemporal aerial photographs.

Cheng et al. (1992) reported on a prototype image processing software, developed by NASA, to automate the boundary delineation procedure of agricultural lands to replace the manual approach used in the National Agriculture Statistics Services. Some manual digitization was still needed in their procedure.

Other work has been performed on the automation of detecting other linear features and edges. Ton et al. (1989) have proposed an automated method for the detecting and labeling of roads from LANDSAT TM data using different roads sharpening operators that work in eight directions. In their study, detection of roads was performed to utilize them as an ancillary data for the detection of oil/gas pads. Grouch (1982) also presented a similar procedure. Geologists have also used similar approaches, based on various filtering techniques, for detecting linear features. Qari (1991) showed that edge enhancement was achieved by high-pass filtering, emphasizing higher spatial frequency data, using a convolution operation to increase contrast of lineaments. He also reported the usefulness of the resultant filtered image in constructing remotely sensed lineament maps. Al-Hinai et al. (1991) used various spatial filters to enhance fine details of sand dunes in LANDSAT TM imagery.

Jacobberger (1988) used a directional filter on TM data to permit detailed mapping of the geomorphology of the old Niger river system. Blondel et al. (1992) applied an adaptive filter that computes gradient in eight directions to track geological lineaments in RADAR imagery. Nevatia and Babu (1980) have discussed a technique for extracting linear features, based on convolution with a number of edge masks, thinning, and thresholding. Mah et al. (1995) have used edge enhancing filters with different illumination directions to analyze lineaments in LANDSAT TM imagery. Also Moore and Waltz (1983) presented an automated, and objective procedure based on diagonal convolution filtering to produce maps of geological lineaments with little noise.

Burgess (1993) has demonstrated an automated procedure for detecting ships and their wakes in LANDSAT and SPOT imagery. Her procedure was based on the use of a series of masking and filtering techniques.

Pedologists also used image analyses techniques on spectral data to describe the geometry of soil microstructures as shown on soil thin sections. Ringrose-Voase and

Bullock (1984) developed a system to discriminate soil micro structure in digital imagery, Ringrose-Voase (1987) has classified soil structures to shape classes using shape and size parameters. Protz et al. (1992) noted the difficulties associated with identifying soil structures visually and reported that image enhancement techniques provide better results in identifying and mapping theses structures. Murphy et al. (1977a) used parameters such as area, perimeter, and number of voids to characterize soil voids using image analyses techniques, and then applied them in a later study to describe them (Murphy et al. 1977b). Sweeny et al. (1992) used spectral images to identify 15 individual pedological features, among which were void space, mottles, and skeletal grains, and to delineate their boundaries.

From the previous review, it could be concluded that LANDSAT imagery were used successfully for related research on detecting linear features and mapping other conservation practices. This thesis discusses an automated procedure for the extraction of field boundaries and applies it to assess the changes in field geometry, for which the LANDSAT imagery is considered very well suited.

2.4 Methods of Analyses

In this section, a discussion of the image analysis techniques and the procedure used for detecting the change in geometry are presented. Also included is the rationale for choosing specific methods, as supported from the literature.

Generally there are two types of digital image analysis, one is involved with enhancing the images, such as contrast enhancing, color compositing, and spatial filtering. Basically they are performed for direct human visual interpretation. The second type is performed by applying quantitative rules to automatically extract features using computers, for example classification (Duggin and Robinove 1990).

To produce the desired maps that portray the field boundaries from the digital data, several techniques of digital image analysis of both approaches were performed throughout the study as illustrated in Figure 2.1.

2.4.1 Digital Image Enhancements

Various image processing techniques have been developed for the purpose of enhancing remotely sensed data. These techniques alter the data to improve their interpretability by increasing the separability between the features in the imagery. They are either point or local operations (Jensen 1996). Point operations such as contrast manipulation change the pixel's Brightness Values (BVs) without regarding the neighboring pixels. Local operations on the other hand, change the pixel's BV according to the context of the BVs of the surrounding pixels. An example of this type of operation would be the spatial filtering. As these techniques are applied mainly to improve visual appearance, the success of their application is judged subjectively by their suitability to the analyst (Wang et al. 1983, Jensen 1996, and Campbell 1987).

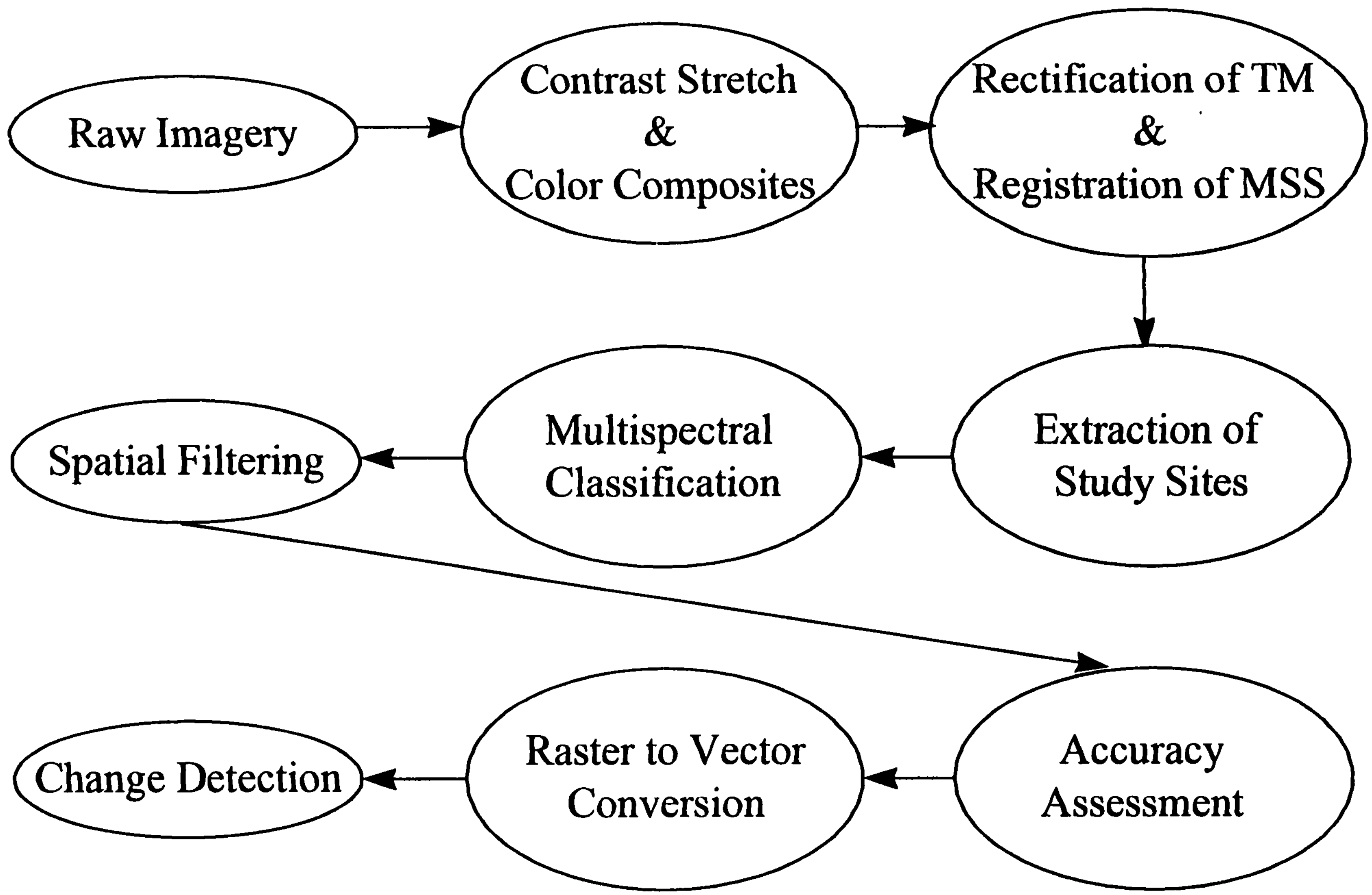

Figure 2.1 Flow chart of the steps followed to identify and verify boundaries from satellite imagery for assessing change in field geometry.

2.4.1.1 Contrast Stretch

A satellite image is comprised of a series of BVs, each representing the relative intensity of the reflection from the corresponding ground cell in a specific spectral band. An elaboration on the characteristics of digital imagery can be found in Schowengerdt (1983). Contrast refers to the range of the BVs present in the image. It is common for the BVs collected from the remote sensor to fall within a narrow range, which in turn leads to a low contrast image. Floyd (1987) and Hummel (1977) reported that this is partly due to the nature of the features being sensed having low contrast, and partly due to the sensitivity of the system response that is designed to record a much broader range of BVs than is usually present in a scene. Contrast enhancement is a point operation performed to increase the contrast of the displayed imagery by expanding the narrow range that the BVs occupy, over the entire range of BVs that the display device can offer. This transformation could be linear or nonlinear. Non-linear techniques include piecewise, histogram equalization, square root curve, and infrequency enhancements (PCI 1996). The linear stretch uniformly redistributes the original BVs over the whole dynamic range of the display (0 - 255). The lowest BV in the original image is assigned to 0 and the highest to 255, and the rest of the pixels are redistributed linearly between them (Jensen 1983). Linear enhancement is best applied to images having a normal or near normal histogram (Jensen 1996). Wang (1983) advised the trial and error procedure in applying such techniques to obtain the results that are best suited for the analyst's purpose. For this study, the objective of applying this enhancement was to maximize the visual detectability of different cover types present in the scene. Rohde et al. (1978) reported that the analyst's intent for the application, knowledge of the area, and the nature of the area, altogether control the type of the contrast enhancement algorithm and its degree of application that would provide the optimum results.

2.4.1.2 Color Composites

In traditional black and white photography, a color composite can be prepared through a process known as "Additive Color Viewing". The three primary colors of visible light (red, green , and blue) are transmitted through black and white positive film transparencies, all of the same scene, but in different spectral bands, and in registration with one another. The degree of produced enhancements can be adjusted by altering the combinations of the filters (Estes et al. 1983).

In a similar manner, using digital imagery, each band of the data can be assigned to any of the available red, green, or blue guns in the display to create different color composites. The images were displayed as false color infrared composites that simulate the color presentation observed on color infrared photography, which is the traditional representation used for interpreting vegetation and soil information.

2.4.2 Preprocessing and Geometric Correction of Remotely Sensed Data

Image preprocessing includes the techniques that are applied initially to the data to compensate for any undesirable characteristics produced during the acquisition of the imagery, like the removal of noise, geometric corrections, and radiometric corrections (Short 1982). The specific preprocessing operations depend on the type of sensor acquiring the data, as these distortions are introduced by the specific sensor system.

Geometric Corrections : Satellite data contain both systematic and non-systematic distortions (Richards 1986, and Van Wie and Stein 1977). Systematic errors in LANDSAT data are due to the non-linearity of the velocity of the scanning mirror, the panoramic view of the earth, the forward motion of the satellite, and the rotation of the earth during imaging (Bernstein 1983).

Commercially available LANDSAT data have most of the systematic distortions removed. The further rectification of the imagery involved in this study to a map projection is essential to identify the geographical locations of the study sites and also to orient within each of them. It was also of great importance to register the two different dates of imagery to allow for comparison and detection of changes in the actual field boundaries. Michaelis (1988) pointed to the necessity of the rectification in serious remote sensing research in general and Jensen (1996) also pointed to its importance, specifically in the field of Earth Sciences. Both Bernstein (1983) and Wolfe et al. (1982) reported the importance of image rectification in studying images acquired from different dates and sensors. It was realized that errors due to image rectification and registration must be minimized in this study as the data were from different satellites. Therefore, geometric corrections were conducted to correct for the non-systematic errors. Such distortions are due to changes in the platform's velocity, altitude, and attitude.

The most widely used technique for rectification is performed by establishing mathematical relationships between some pixels in the image and their location on Earth (Ford and Zanelli 1985). These points are Ground Control Points (GCPs). The GCPs are features which can be seen in the image and whose geographic location can be defined from a map (Van Wie and Stein 1977). The geometric correction is performed in two steps, the first is to develop the transformation by means of GCPs to model the relationship between the geometry of the image and the geometry of a map. The second, is the establishment of the new grid of pixels with no BVs, that conforms to the map projection, and then to fill this grid with BVs that are derived from the original image (Friedmann et al. 1983). The accuracy of the corrected image depends directly on the accuracy, the number, and the distribution of the GCPs (Ford and Zanelli 1985, Bernstein 1983).

The optimal distribution of the GCPs is one which is uniform over the entire image (Shlien 1979). Although Novak (1992) reported that the more control points available the more accurate the result of the rectification, this may depend on the kind of image data used, their geometric characteristics, and the accuracy with which GCPs can be located. Ford et al. (1978) as cited by Ford and Zanelli (1985) showed that the GCPs mean-squared error is inversely proportion to the number of GCPs. Almost all of the GCPs used in this study were road intersections, as there was sufficient number of them running north-south and east-west, and were well distributed all around the center and the edges of image to assure good registration. Other features like field boundaries, or edges of water bodies were avoided as their locations are subject to change over time.

The TM image from 1991 was chosen to be rectified to a map because of its higher quality (almost completely free from clouds) and its relatively small pixel size that allowed more accurate location of the GCPs. Welch and Usery (1984) stated that among other factors the spatial resolution of the data is the most important for accurately locating the GCP. The MSS image was then registered to the rectified TM image.

Resampling is the process of estimating the values of pixels (BVs) on the newly constructed grid (Shlien 1979) after their corrected position had been determined. Several methods can be used to calculate the new BV of the pixel, by either shifting the original samples or by interpolating between them. These methods and their effects on the geometric and the radiometric characteristics of the imagery are discussed briefly below.

Nearest Neighbor : This is the simplest procedure of resampling. The BV of the pixel that has its center nearest the point located in the image, is transferred to the corresponding grid location in the output image (Shlien 1979). This method avoids alteration of the original input pixel value, and because of that, it is the most preferred by Earth scientists (Jensen 1996). For the same reason, it is recommended if the new image is to be classified. On the other hand, Shlien (1979) showed that the positional error between the assigned value and the real one is maximum. This method introduces a spatial shift error, such that the local geometry may be inaccurate by up to $2^{1/2}$ of the instantaneous field of view

(Billingsley 1983). In a study to define resampling in detail, and to compare different resampling methods, Simon (1975) showed that the nearest neighbor causes deletion or replication of image samples and positional errors of up to +/- 1/2 pixel, in MSS data. This could significantly degrade change detection performance.

Bilinear Interpolation: In this method, output pixel values are assigned by interpolating the BVs for the four integral nearest pixels that surround the desired position (Gonzalez and Woods 1992). A new BV is computed and the closer the pixel is to the desired position, the more weight it will have in the computation. This process has a smoothing effect on the resampled image (Shlien 1979). Atkinson (1984) in a study to investigate the effects of different resampling algorithms, reported that this smoothing is a result of the truncation of intensity peaks and that the introduced blurring was a function of the distance of the resampled pixels from the original sampling sites. If the resampling sites coincide with the sampling sites there is no amplitude attenuation of high spatial frequencies. The alteration of the BVs constitutes a problem in spectral signature analysis, and because of this, it is often performed after image classification has been completed. The resulting image has approximately 1/4 the mean squared resampling error of the nearest neighbor (Billingsley 1983).

Cubic Convolution : Values are assigned to output pixels in a similar manner as the bilinear interpolation, except that the weighted values of the 16 input pixels surrounding the desired location are used. This method also alters the original gray levels of the original image, but according to Billingsley (1983) it has a mean-squared resampling error about 1/3 that of bilinear.

By comparing the registration of two scenes of the same area using nearest neighbor sampling and cubic convolution, Simon (1975) reported that errors inherent in low-order resampling methods were apparent. Schowengerdt (1983) showed that the smoothing effect that is associated with the bilinear interpolation is avoided in the cubic convolution. Etheridge and Nelson (1979), from a study to determine some of the effects of the three resampling methods, reported that the nearest neighbor resampled data were the most efficient in preserving the original shapes and the data values of the land covers involved in their study. Also peaks and valleys were smoothed by the application of bilinear interpolation and exaggerated by cubic convolution.

In this study, the main concern was to achieve the best possible registration for change detection even at the expense of some alteration in BVs. Although computationally demanding, the cubic convolution algorithm was applied to resample the images.

2.4.3 Image Classification

Lillesand and Kiefer (1994) defined classification as the process that assigns the pixels in the image to classes. For each pixel in the image, there is a BV recorded in each of the spectral bands used. The set of BVs of a pixel for all the channels defines its spectral signature relative to the rest of the pixels. Multispectral classification analyzes the spectral signatures, and assigns the pixels that are more similar to one another to a specific class (Floyd 1987). There are two approaches for digital image classification; "Supervised" and "Unsupervised". The basic difference between the two procedures is in the training stage to develop the spectral signatures for the classes. In the supervised approach the analyst must identify the training areas that belong to each informational class in the image. Unsupervised approach on the other hand, proceeds with only the minimal interaction with the analyst in defining spectral classes. The analyst makes decisions regarding the data to be studied, the algorithm to be applied, some statistical parameters, and the number of classes to be extracted, but the spectral classes are defined on a statistical basis. A knowledge of the area is required to interpret the meaning of the resulting classes from this procedure (Strahler 1980).

In this study, rather than having to extract the boundaries from an unclassified image in which the pixels have continuous gray level values, image classification was performed to produce uniform areas, and thus remove the subtle, gradual changes in BVs which would have made it difficult to extract the desired boundaries. Detecting the boundaries in unclassified imagery would be very tedious, and would create edges far in excess of the ones of interest. Also, one of the concerns was the use of MSS data, being the only available satellite data for the 1970's with the ground resolution of 79X79 m. This poorer spatial resolution data may not be as efficient as the TM data in delineating the boundaries if the extraction was carried out directly on the unclassified data.

Problems of identifying field boundaries using MSS data alone have been reported. Reichert and Crown (1984) pointed to the poor resolution of the MSS system in defining field boundaries relative to the narrow widths of fields in their study in southern Alberta. Also Grunblatt (1987) reported significant modulation loss (the ability of the sensor to transfer spectral variations in the intensity of reflected radiation) of the MSS system at a boundary. Detailed information on the relationship between the spectral, radiometric, and spectral resolution of MSS and the ability to discriminate cover types can be found in Acevedo et al. (1984).

For this study, the objective is to distinguish the boundary between different cover types, without emphasizing the identity of each cover. One would speculate that it would have been more suitable to adopt the unsupervised classification approach and avoid the training stage. A number of iterations of unsupervised classification, with different parameters, were applied initially but the resulting spectral classes did not consistently match the landuse classes and field areas, when compared to the known cover types from field studies and as observed on the color composites and aerial photographs. Spectral classes are groups of pixels that are uniform with respect to their several spectral channels. In a thorough discussion of spectral and informational classes Richards and Kelly (1984), noted the importance of producing spectral classes that correspond to informational classes of interest. Of importance to this study was the uniformity of spectral classes over field areas for boundary identification, rather than an identification of the spectral variability within a field.

There are often several spectral subclasses within cultivated fields of one cover type. The application of the unsupervised approach, in some cases, would identify the detailed spectral structure of the data and produce a number of classes within fields that would confuse the identification of the actual boundary.

2.4.3.1 Training Stage

The production of an effective classification depends heavily on the appropriate derivation of the spectral classes. In a study performed on the application of different classification schemes for an agricultural area, Hixson et al. (1980) concluded that the selection of training areas is more important than the choice of the classifier's algorithm as the choice of classification algorithm made relatively little difference in the accuracy of differentiation between cover types if compared to the differences obtained using different sets of training areas. For training areas to be a homogeneous samples of the corresponding class, and also account for the class's variability, two factors were taken into account when choosing the training areas, their size and their number.

For this study, a set of training areas for each class was established, based on a ground truthing field visit, which was carried out in August 1996, and black and white panchromatic aerial photographs with scales of 1:31,680 (1975) and 1: 20,000 (1991). These were acquired during the same years as the satellite images and were used as references to verify the representation of the different general land cover classes observed in the satellite imagery.

The size of the individual training areas varied according to heterogeneity of the land cover in a field. Agricultural fields in this region range in size from a few hectares to an entire quarter section (63 ha). Joyce (1978) recommended that training areas be at least 4 ha in size at the absolute minimum, and a maximum of a 65 ha, for MSS data. For the TM data, the general rule as reported by Jensen (1996), was that for each class, the number of pixels of training data should be greater than ten times the number of bands used for classification.

The number of training areas also depended on the diversity of each cover type. An increased number of training areas would be required as the diversity of the cover increases. To accommodate this diversity in generating signatures. Swain and Davis (1978) reported that from 10 to 100 pixels per feature are typically needed to establish the statistical parameters for the classifier.

2.4.3.2 The Classification Algorithm

The Maximum Likelihood Classifier was chosen to be applied for all the study segments. The Maximum Likelihood classifier is the most accurate parametric computer classifier (Mausel et al. 1990). It is also the most common method used with remotely sensed imagery in general (Richards 1986), and specifically for land use / land cover applications (Huang and Mausal 1994). The classifier estimates the means and the variances of the classes, from the pixels in the available training areas, and then estimates the probabilities for each pixel to be a member of each of the classes. Each pixel is then assigned to a class with the highest probability (Strahler 1980).

The histograms of the training areas were studied and found to be Gaussian in nature indicating the "purity" of the training sites which fulfilled the requirements for this parametric classifier (Jensen 1996). Lillesand and Kiefer (1994) reported that the major disadvantage of this algorithm is that it is computationally demanding, especially if either a large number of channels are to be used, or a large number of classes are to be produced. In this study three bands were available for the TM data and four for the MSS data, and from six to nine spectral classes were produced. A forced type of the classifier was used meaning that each pixel in the image had to be assigned to a class, leaving none unclassified. In the normal case, pixels would only be assigned to a class if they fell within its Gaussian threshold. This "forcing" was performed to avoid the problem of unclassified mixed pixels on the boundaries, especially for the MSS with its coarse spatial resolution. The precise geographic location of the boundary would be of interest but could only be expected to be within the resolution cell size of the satellite data and the resampling procedures employed.

2.4.4 Edge Detection

Edges, as defined by Davis (1975) are boundaries between regions of different relatively constant gray level values. Unlike contrast enhancements, edge detection is a local operation in which the pixels' values in the original image are modified, based on the BVs of the surrounding pixels, to increase the gray level difference between the edge pixels of the object and its neighbors (Wang 1983). Edge enhancement operations can be conducted either directly to the image data by means of spatial domain techniques, or on the Fourier transformation of the image. The latter allows more specific filtering options to be done more conveniently than on the spatial domain (Richards 1986). Duggin and Robinove (1990) reported that the convolution in the spatial domain is used more frequently. Most of the edge enhancements procedures can be performed using either set of techniques, and the option of using one of them is influenced by many factors including the availability of the software, and the familiarity with the method (Richards 1986). According Richards 1986 the methods of detecting edges in the spatial domain basically include :

1) Convolution using edge detection kernels, these are operators of defined constants.
2) Calculating derivatives such as Sobel, Prewitt, and Roberts filters, as discussed by Pratt (1991).
3) Subtracting low-passed filtered image from its original.

The technique used in this research was filtering in the spatial domain. Two methods were considered initially for the extraction of boundaries and were tested in this study, the use of templates and the use of derivatives. The Sobel and Prewitt 3X3 gradient filters (Pratt 1991) were applied initially. The result of their trial application was observed to be the production of too many discontinuous line segments that did not define the boundaries of the fields completely. Therefore the extraction was performed by a two-step spatial filtering procedure using Median and Laplacian filters discussed below.

Spatial Filtering : This is a local operation, in which the BV of a pixel is altered according to its relationship with the BVs of the pixels covered by the filter's kernel. Jensen (1996) defined the spatial frequency as the number of changes in BVs per unit distance for a given part in the image. The interest in this study was in the identification of areas of high spatial frequency, where there was an abrupt change in the gray level value. These would be the boundaries between different land covers. The concept was to first smooth the classified imagery to reduce the scattered noise within the fields by means of Median smoothing filters without loosing the edges between different parcels of lands. The boundaries were then extracted using non-directional high-pass filtering by which a kernel of certain coefficients and size moves all through the image, where the pixel in the middle of the kernel is adjusted by multiplying each coefficient by the corresponding original BV and summing the results (Lillesand and Kiefer 1994).

2.4.5 Data Conversion

Vector and raster are two data models that can be used to represent spatial data. In the vector data model, the real world is represented by three entities; points, lines, and polygons. In the raster model the space is represented by a regularly divided grid of cells. Each cell holds a value that provides information about the corresponding ground area Aronoff (1995). According to Lunetta (1991) the raster to vector conversion can introduce some errors to the nature of the detected boundaries, the size of this error depends on the algorithm used in the conversion process, the complexity of the features, and the size and the orientation of the cells in the raster format.

The resultant maps of boundaries were converted from the raster to the vector data model. This was performed for two reasons; first, to produce a data layer of the boundaries that can be overlain on the original color composite from the same date, to allow a visual assessment of the success of the extraction procedure. Also the boundaries from one date could be overlain on top of the other date of imagery, which would allow a visual assessment of the change in field boundaries. Secondly, the raster to vector conversion would facilitate the quantitative assessment of the change in geometry of the fields using polygon geometry parameters or characteristics. A GIS could provide data, such as perimeter length and area of polygons which could be also used to establish a parameter that can describe shapes.

The ARC/INFO version 7.0 GIS software package was chosen because of the accuracy in its raster to vector conversion process. Its algorithm does not vectorize the outer edges of the pixel but takes the points in the middle of the pixels instead, and the analyst can interactively snap lines together to produce perfectly closed polygons (Martin 1997 personal communication).

2.4.6 Change Detection

The remote sensing change detection as described by Mouat et al. (1993) is the process of detecting and evaluating differences of surface phenomena over a period of time. Traditional techniques of change detection analysis include composites of different dates, differenced and ratioed images, Principal Components Analysis, and post-classification comparisons (Mouat et al. 1993, Milne 1988).

In this study, the interest was in detecting and assessing the temporal changes in field geometry. The above techniques were not applicable as they did not quantify changes in geometry, only cover types, and a slight misregstration in boundaries could affect the analysis using such procedures. In a study to integrate remotely sensed data with vector GIS data, Mattikalli (1995) reported that these techniques operate on a pixel by pixel basis and are not valid for vector data sets.

Two approaches were followed to investigate whether or not there had been changes in the geometry of the fields involved. First, a visual assessment was made by overlying the resulting boundary polygons from the 1975 image onto the corresponding 1991 false color composite image of the same area. Second, a numerical assessment was conducted between the two dates of imaging for each study area using many parameters including: the total number of polygons, the total length of polygon perimeter, and the average size of the polygons or fields. All can provide an indication of whether or not a serious fragmentation has happened. Finally, a non-parametric analysis of variance was performed on those data to test for the significance of change between the two dates. The visual overlay was then used to describe the nature of any changes.

The parameters chosen for the statistical test were area, perimeter, and shape index. The shape descriptor, given as Edge / 2 $\sqrt{Area * \pi}$, basically provides information about the elongation of an object, as it deviates from a disk shape. It is least for circular shapes, greater as the shape deviates to rectangular shapes, and greatest for elongated objects and shapes with long perimeter. This index is used by urban geographers to describe spatial structures (Haggett and Chorley 1977). Similar shape descriptors are used by landscape ecologists to describe changes in landscape patterns and shapes of patches (Dunn et al. 1990, Forman and Godron 1986).

The addition of information on field boundaries, and therefore field size and shape to information on land cover would provide a more complete analysis of landscape changes as related to soil conservation or erosion risk. The results of the application of specific methods to detect boundaries and on analysis of their changes are presented in Chapter 3.

2.5 References

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Chapter 3 :

Detecting Field Boundaries Using LANDSAT MSS and TM Data and Assessing Changes in Field Geometry in Northeastern Alberta.

3.1 Introduction

The Parkland Agricultural Research Initiative (PARI) was a program designed for testing and validating soil and water conservation practices and encourage their adoption in the Parkland area (Lindwall 1995). The research conducted in that program, had concentrated on the study of the adoption of management practices that are directly related to land cover and land use. Changes in the fields' sizes and geometry were not considered as conservation practices assessed in the PARI project. The changes in field geometry may be of great importance in the northeastern part of Alberta and the Parkland area, and information on these changes over a long period would complete the picture of the adoption of conservation practices.

Since the launch of the first LANDSAT satellite, the data provided have been used extensively in various aspects related to the Earth's renewable resources monitoring, planning, and management. The successful use of LANDSAT data for mapping land use/cover, land degradation, and soil classification and surveys is well documented.

Moreover, among others, Crown et al. (1994), Zhuang et al (1991), Van Deventer (1997) McNairn and Protz (1992) and DeGloria et al. (1986) all have demonstrated specifically that soil conservation practices can be identified and monitored using LANDSAT data.

While the data on field boundaries could be important in erosion studies and other managerial inventory purposes (Whiting and Heyland 1988, Benjamin 1987), there has been a general scarcity in the literature regarding the extraction of such information from satellite data. Cihlar (1988) used a manual visual image analysis approach to define field boundaries for agricultural measurements from LANDSAT and SPOT data. Cheng et al. (1992) reported on a prototype image processing software to automate the boundary delineation procedure of agricultural lands to replace the manual approach used. Some manual digitization was still needed in their procedure.

As a part of the PARI program, the study described here, was an attempt to utilize LANDSAT TM and MSS image data to detect field boundaries. The main goal of this study was to investigate whether or not there have been changes in field geometry, in study areas located in Northeastern Alberta, and to assess these changes over a period of 16 years. This would add to the picture of the adoption of different land management practices. The manual approach of delineating field boundaries is tedious, expensive, and labor intensive (Cheng et al. 1992). Therefore one of the objectives in this study was to perform the delineation process in an automated manner, and introduce guidelines for this procedure. Similar techniques, based on spatial filtering have been widely used to delineate other linear features such as roads (Ton et al. 1989, Grouch 1982). In the field of geology, Qari (1991), Al-Hinai (1994), Nevatia and Babu (1980), Mah et al. (1995), and Moore and Waltz (1983) used filtering technique-based procedures, in studying linear geological structures. The procedure introduced here is based on the use of a sequence of image analysis techniques, in which spatial filtering constitutes the core procedure utilized.

3.2 Study areas

The study areas were located in the Parkland region of Northeastern Alberta, where other related studies on the adoption of soil conservation practices were carried out

(Crown et al. 1994). Four study sites were chosen, each is 10 X 10 km in size, corresponding to a Township. The topography was considered in choosing the segments, as the size and the geometry of the field is assumed to be determined partly by relief conditions. Some of study areas were contained in nearly level relief areas, where it is assumed that the fields were relatively large and rectangular. Small fields were anticipated in other study sites of more rugged topography. The study sites also contained different soil types, which may influence the size of fields as farmers are aware of the erosion potential of some soils. A brief description of these study sites was provided in chapter 1.

3.3 Materials and Methods

The procedures followed are illustrated in Figure 2.1. Specific details of each of the steps taken are included in the following discussion. These details are augmented by the general discussion of methods in Chapter 2.

3.3.1 Image Data Acquired

Two dates of satellite imagery were selected for this study, LANDSAT-2 MSS data were used to represent the period of 1975, LANDSAT-4 TM data for the 1991 period. Both data were obtained as full scenes; Track 41 Frame 23 for the TM, and Track 44 Frame 23 for the MSS. For the TM data only channels 3 (0.63-0.69) μm, 4 (0.76-0.90) μm, and 5 (1.55-1.75) μm where available, for the MSS bands 4 (0.5-0.6) μm, 5 (0.6-0.7) μm, 6 (0.7-0.8) μm, and 7 (0.8-1.1) μm. These images were selected from the available PARI imagery based on their quality, as both were almost clouds free, although the TM data had tiny amount of cumulus clouds along the eastern most edge of the image. Also one great advantage was that the two images were almost from the same day of the year, August 4th 1975 for the MSS and August 5th 1991 for the TM. This would be expected to minimize changes due to the phenological status of the plants, depending on the climatic conditions and seeding date. Black and white panchromatic aerial photographs with a scale of 1 : 31,680 and 1: 20,000 taken on September 9th 1975 and July 13th 1991 respectively were also used.

3.3.2 Digital Image Processing

The images were displayed as color composites in which, for the MSS data, bands 6 (Near-Infrared), 5 (Red), and 4 (Green) were projected as R, G, B, respectively to simulate a CIR representation. For the TM data, since there was no green band available and knowing the spectral response of vegetation, a similar color composites was created by assigning the channels TM 4 (Near-Infrared) to the red gun, and the TM 3 (Red) to both the green and the blue. For visual presentation the spectral bands were displayed with a linear contrast stretch. Wang (1983), Jensen (1996) and Campbell (1987) reported that the success of the application of enhancements techniques that are applied mainly to improve visual appearance, is judged subjectively by their suitability to the analyst.

The images from the two dates were to be registered to each other for the change detection to follow. A network of 57 points ground control points (GCPs) were selected to rectify the raw 1991 TM data to a Universal Transverse Mercator (UTM) map projection (Appendix 5.2). The GCPs were selected from the National Topographic Series 1:50,000 map sheets, at locations that could be accurately identified in both the map and the image, mostly road intersections. The residual error plot of these points was used to identify points that were the least accurately positioned and they were replaced by new points until residual errors of less than 0.25 pixels were obtained. The spatial interpolation of the TM scene was conducted with a third order polynomial using the cubic convolution method (Billingsley 1983), with the pixels resampled to a size of 25 X 25 m. This would allow registration with other types of data such as available digital elevation models, and for convenience would also result in an even number of pixels in a 10 km distance.

The MSS image was registered to the rectified TM scene. This was performed by displaying both images and choosing 25 common GCPs that appeared in both images. The MSS data were then resampled to the same output pixel size as the TM data using the same cubic convolution method and third order polynomial.

Image classification for each study sites was based on a set of training areas for each class, established by delineating solid polygons interactively on the screen around the desired areas. The linear contrast stretch enhanced the spectral variations between areas having poor vegetative cover (fallow fields with varying levels of crop residue) the most without affecting the contrast of other cover types (green crops, treed areas, and water bodies). This step has enhanced the detailed variations in the scene and made subtle differences between different cover types more readily distinguishable for visual analysis. The color composites provided the most recognizable discrimination between vegetated and non-vegetated areas. This is attributed to the fact that this color presentation is common and image analysts are very comfortable identifying agricultural cover types with this representation.

The ground truthing field visit, which was carried out in August 1996, and the black and white panchromatic aerial photographs were used as references to verify the representation of the different general land cover classes observed in the satellite imagery. The number and the size of the training areas depended on the diversity of each cover type, both were increased as the diversity of the cover increased.

Training areas of not less than 50 pixels were chosen in the middle of the cover type, boundaries and mixed pixels were avoided. Separate sets of signatures for each township were generated for each cover type using all the available channels. After the selection of the training areas, signatures were created comprised of spectral band means and 3 standard deviations, and an equal *a priori* probability for all the class (PCI 1996).

Then a "forced" Maximum Likelihood Classifier was applied (PCI 1996), and pseudo color tables were created to portray the classified imagery.

The Classified images were subjected to a median-filter using 5X5 kernel. Using this filter, the central pixel's value is altered to the median value of the pixels covered by the kernel (Pratt 1991). A high pass 3X3 Laplacian filter, given as:

$$\begin{matrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{matrix}$$

was then applied to the median-filtered imagery to highlight the boundaries.

The resultant maps of extracted boundaries were converted from raster to vector data format. This was performed firstly in PCI to use the resulting layer for overlaying purposes over the same, and the opposing data to allow the visual analysis, and for the accuracy assessment process as well. Secondly, it was performed in ARC/INFO for the numerical analysis.

3.3.3 Accuracy Assessment of the Extraction Procedure

The Township 55-Range-7 W 4^{th} study site was chosen to test the accuracy of the extraction procedure as it included the greatest variability in land cover classes (Crown & Klita 1997). The accuracy assessment procedure was adapted from the Confusion Matrix (Congalton 1991) widely used in assessing the accuracy of classifying remotely sensed data. The aerial photographs, from the same year, but one month difference from the satellite images, were used as the source of ground truth for the field boundaries.

With the imagery loaded as color composites, linearly enhanced, the vector layer containing the extracted boundaries, and also a vectorised grid, showing the sections of the township were overlain to facilitate locating the fields. All treed areas and water bodies were detected in both kinds of imagery, so only fields were accounted for in the accuracy of the extraction process. The fields were counted from the aerial photograph and compared to their location in the imagery.

A definition of a field was constructed to assure the consistency of identifying fields in the photographs. A "field" was one continuous cover type identified by the same gray level tone that is different than the adjacent land parcels. Parcels of land having the same cover or similar gray level tone, but separated by an observed physical boundary in the photograph such as treed areas or a road, were counted as different fields. Not all polygons were fields, as polygons also included other features such as lakes. This could introduce some error into the results if all boundary changes were assumed to be associated with agricultural fields. The changes in such features were non-significant given the small number of these features compared to the numbers of agricultural fields per study area and the anticipated changes to be considered.

3.3.4 Raster to Vector Conversion

The resultant maps of boundaries were converted from the raster to the vector data format. This was performed for two reasons; firstly, to produce a data layer of the boundaries that can be overlain on the original color composite from the same date, to allow a visual assessment of the success of the extraction procedure. Also the boundaries from one date could be overlain on top of the other date of imagery, which would allow a visual assessment of the change in field boundaries. Secondly, the raster to vector conversion would facilitate the quantitative assessment of the change in geometry of the fields using polygon geometry parameters. A GIS could provide data, such as perimeter length and area of polygons which could subsequently used to establish a parameter that can describe shapes.

For the quantified analysis of changes in geometry, the maps of boundaries were exported to ARC/INFO 7.0 GIS software package to :

1) Snap the polygons to ensure that they were perfectly closed, enabling construction of polygon topology.

2) Compute the area and perimeter of each polygon.

The raster to vector conversion was accomplished using the GRIDLINE command with "no filtering", "no thin", and "round options" specified (ARC/INFO 1995) The polygons were snapped by extending any dangling lines to two pixels at first, then manually snapping the rest using an interactive MOUSECLEAN AML. Topology was then built using the CLEAN command. Polygons were automatically labeled with the command CREATLABELS. Polygons less than 0.8 ha in size were discarded, as they were most probably not fields but small depressional and wet areas within fields. Finally, a list of the areas and the perimeters of the polygons for each township was obtained.

The parameters chosen for the statistical test were area, perimeter, and shape index. The shape descriptor, given as Edge / 2 $\sqrt{Area * \pi}$ (Haggett and Chorley 1977), basically provides information about the elongation of an object, as it deviates from a disk shape. It is least for circular shapes, greater as the shape deviates to rectangular shapes, and greatest for elongated objects and shapes with long perimeter.

3.3.5 The Statistical Analysis

A non-parametric one-way analysis of variance (ANOVA) was chosen to test for a statistically significant difference among the means for each of the parameters. The "year" was the only criterion for classifying the data where year 1 = 1975 and year 2 = 1991. The null hypothesis for each parameter was that the population means were not different in both dates. The alternative hypothesis was that there were differences in both cases, for each township. The hypotheses can be expressed as follows:

Hypotheses:

$H_{o1} : \mu_{A75} = \mu_{A91}$ $\qquad$ $H_{A1} : \mu_{A75} \neq \mu_{A91}$

$H_{o2} : \mu_{E75} = \mu_{E91}$ $\qquad$ $H_{A2} : \mu_{E75} \neq \mu_{E91}$

$H_{o3} : \mu_{s75} = \mu_{s91}$ $\qquad$ $H_{A3} : \mu_{s75} \neq \mu_{s91}$

Where, A, E, and S are area, edge, and shape index respectively.

The parameter data including polygon's area, perimeter, and shape index, were exported to the statistical package SAS 6.1. A non-parametric one way ANOVA was conducted (npar1way program). The non-parametric ANOVA was chosen as the assumptions are less restrictive than a parametric ANOVA, concerning the normality of the distribution of the data, and the chance of its improper use is small (Daniel 1990).

The study was conducted in the Spatial Information Systems Laboratory, Dept. of Renewable Resources, University of Alberta, with some field ground truthing carried out in early August 1996, the same time of the year as the imaging, to identify the cover types in the imagery. The image processing techniques were performed using the PCI Version 6.0 image processing software package (PCI 1996) installed on a UNIX operating system workstation; IBM RS/6000. The ARC/INFO 7.0 GIS software package was installed on a SUN Sparc10 workstation. This software was used for processing the vector results, and the production of the perimeter and area information. The statistical analyses were performed using the statistical package SAS 6.1.

3.4 Results and Discussion

The result of the various steps in the study (Figure 2.1) are presented in the order in which they were performed.

3.4.1 Geometric Corrections

The total Residual Mean Square Error (RMSE) of all the GCPs for the MSS data was (11.06 , 10.27) m, for the TM it was (8.4 , 5.4) m for the X and Y direction. A report summarizing the RMSE for all the GCPs for both dates of imaging, and their residual plot are included in (Appendices 5.1 and 5.2). Welch and Usery (1984) reported that the representative RMSE in the X and Y directions of +/- 25 and +/- 55 m for the TM and MSS data, respectively are compatible with the US National Map Accuracy Standards for cartographic products of 1:80,000 to 1: 180,000 scale.

It should be noted that perfect registration of the two types of imagery used may not be possible. This is due to the differences in platforms (LANDSAT-2 Vs LANDSAT-4), with their different track center and coverage areas, and also due to the differences in the ground resolution cells of the TM and MSS imaging systems.

Decreasing the size of the cells by resampling in the MSS reconstructed grid resulted in a less distinct image appearance than the original imagery since the radiation recorded by an Instantaneous Field of View that created an 80X80 m resolution on the ground is now represented by 25X25 m pixel in the image.

3.4.2 Image Classification

The desired goal of generating homogeneous parcels of land with maximum gray level difference between them was achieved by classifying the imagery. If the detection process were to be conducted on the unclassified imagery, there would have been many internal "boundaries" due to spatial variations in fields as well as the external boundaries of interest, and thus the number of "boundaries" would have exceeded their real number. This was suspected to occur because of the observed heterogeneity within the fields due to drainage differences and crop residue management practices (Figure 3.1). It would have also made it very difficult to locate boundaries accurately for the MSS data in particular. This would be due to the relatively coarse spatial resolution, boundaries are less distinct in this kind of imagery, and they are also comprised of a wider area of mixed pixels. However, the coarse spatial resolution resulted in more apparent homogeneity within the fields. The classification forced mixed pixels at the sides of the fields to join either class and form a boundary, hence reduced the width of the boundary, otherwise these mixed pixels would have caused confusion in defining the location of the boundaries. The number of spectral classes produced based on observed colors or color patterns in the color composite images, are shown in Table 3.1. These classes represent areas of bare soil, various levels of vegetation cover and water bodies. The degree of variation within a study site would dictate the number of classes required for complete classification.

Township		Number of Spectral Classes
49 Range-7 W 4th	MSS	9
	TM	8
51 Range-11 W 4th	MSS	8
	TM	8
53 Range-10 W 4th	MSS	7
	TM	9
55 Range-7 W 4th	MSS	6
	TM	8

Table 3.1 Number of spectral classes for each study area.

One would speculate that it would have been more suitable to adopt the unsupervised approach to classification. A number of iterations of unsupervised classification, with different parameters, were applied initially but the resulting spectral classes did not match consistently the landuse classes and field areas, when compared to the known cover types from field studies and as observed on the color composites and aerial photographs. The choice of conducting a supervised approach to image classification has proved very useful to allow more accurate match between the spectral classes with the informational classes. An example of this would be the following case: if a parcel of land that was identified as one field from aerial photographs, but had two different spectral response in the imagery, due that one part was harvested and the other was not harvested they would have been put into two different classes and a boundary would have been detected between them later on in the process.

3.4.3 Spatial Filtering

The application of the Median filter to the classified imagery resulted in loss of internal variations within many of the fields (Figure 3.3 is an example) by eliminating the extraneous classified pixels. This type of filter, while smoothing the image and removing the isolated noise also preserved abrupt edges (Pratt 1991). The application of the Median filter has also added some blurring to the image due to the smoothing effect. The northern region of Alberta and the study area contain a great variation in land cover with patches of trees and poorly drained areas between and within fields. An understanding of this pattern has been shown to be important in the analysis of coarse resolution NOAA satellite data (Izaurralde 1989). This fact is believed to be responsible for the creation of many edges within the fields, more evident from the TM data than from the MSS data (Figures 3.4). Because of this high variability of the terrain, if the Median filtering step was not performed prior to the application of the high pass filter in the next step, many detailed areas within the fields would have been detected as boundaries. This would have made the visual analysis confusing and the quantitative analysis misleading. Smoothing is one of the steps involved in the traditional edge extraction process to reduce the variation which will cause false edges (Paine and Lodwick 1989).

The kernel used was 5X5 pixels, providing the most desired degree of smoothing over large areas without degrading the target boundaries (Figure 3.3). This kernel size could be adjusted to suit the degree of variation in the area. For example, smaller sizes would result in a lower degrees of smoothing, which could be needed in a less variable terrain. However, the use of a smaller kernel size of 3X3 in this study left too many pixels within fields (Figure 3.6). Cushnie and Atkinson (1985) in a study to compare the effects of various filtering on the reduction of internal variation within land cover categories, and the ability to preserve edges, showed that a 3X3 median filter produced less blurring of the boundaries but on the expense of reducing less internal noise than a 5X5 kernel. Although the use of a larger kernel size of 7X7 had produced "clean" fields (Figure 3.6), it caused distortion to the shapes of fields, small ones in particular. Also the ability to separate two adjacent fields having the same cover type with a narrow line of separation between them deteriorates, all these effects could be attributed to the increased blurring introduced by large kernels. Rosenfeld and Kak (1982) as cited by Cushnie (1985) showed that the extent of these effects depend on the size of the kernel used.

The application of the 3X3 Laplacian filter resulted in highlighting the boundaries between features and eliminating all the background information (Figure 3.4). The use of non-directional filters reduced the steps involved that otherwise would be prolonged had individual directional filters been employed. The size of the kernel was chosen to be small to relate to the nature of the width of the boundaries. The results of this stage were the desired raster maps of boundaries of fields and other features like rivers, lakes, and treed areas (Figure 3.4) that were converted to vector format and overlaid on the composite images.

LANDSAT MSS Data LANDSAT TM Data

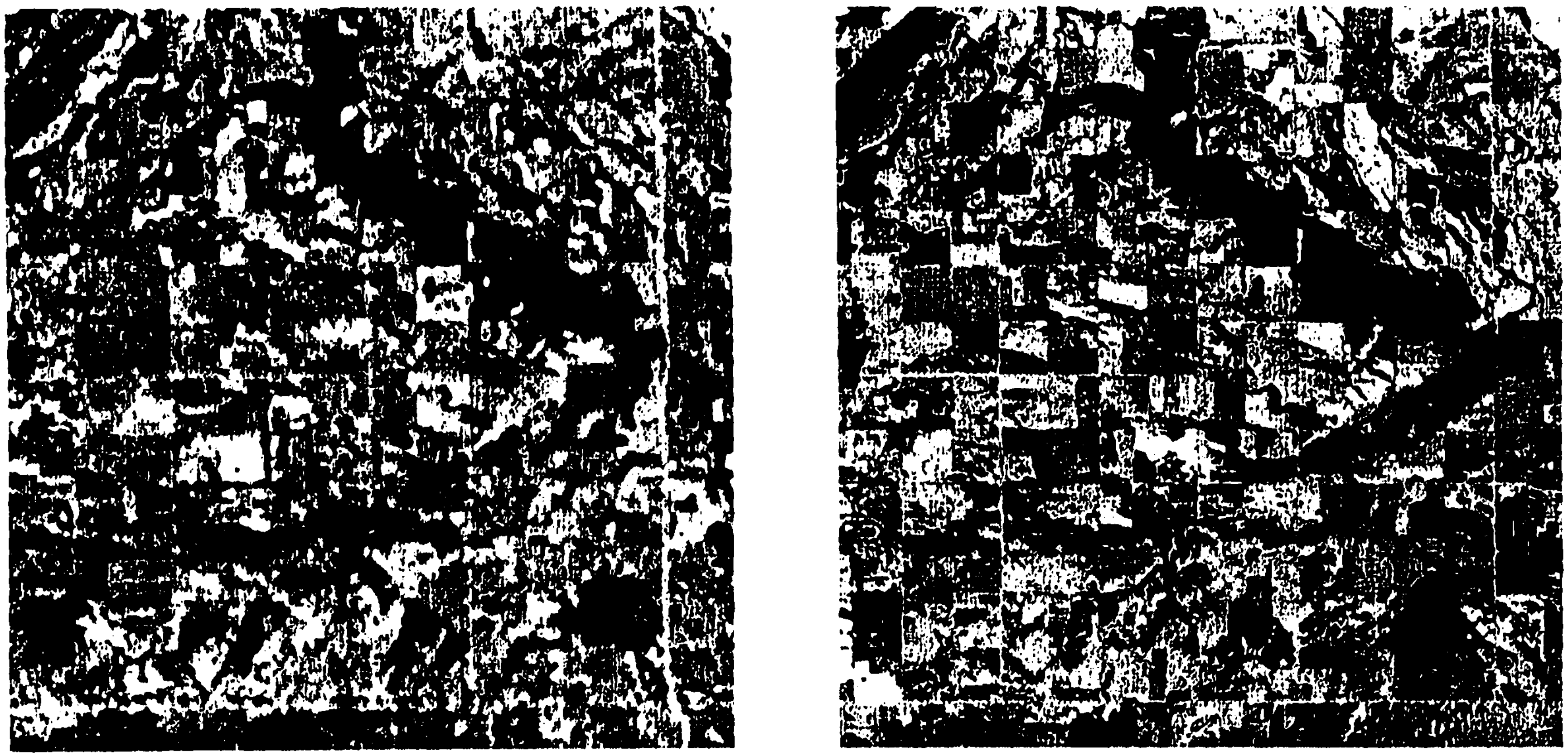


Figure 3.1 LANDSAT color composite images of study site T55-R7-W4th (MSS Date August 4, 1975, TM Date August 5, 1991; Linear contrast stretch; for the MSS, Infrared Band 6 as red, Red Band 5 as green, Green band 4 as blue; for the TM, Infrared Band 4 as red, Red band 3 as both green and blue; approximate presentation scale 1:100,000).

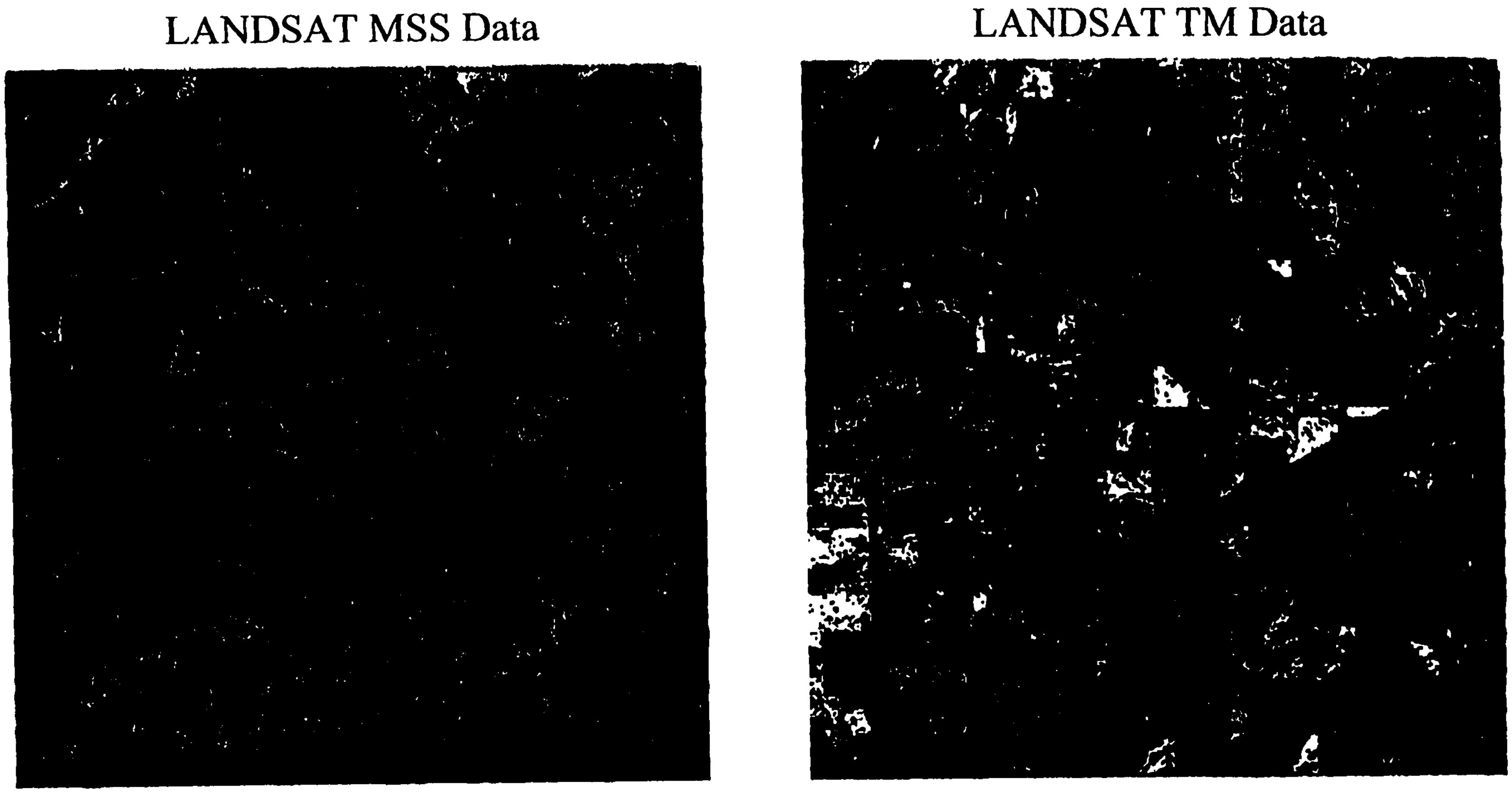


Figure 3.2 LANDSAT images of study site T55-R7-W4th after the supervised classification (approximate presentation scale 1:100,000).

LANDSAT MSS Data

LANDSAT TM Data

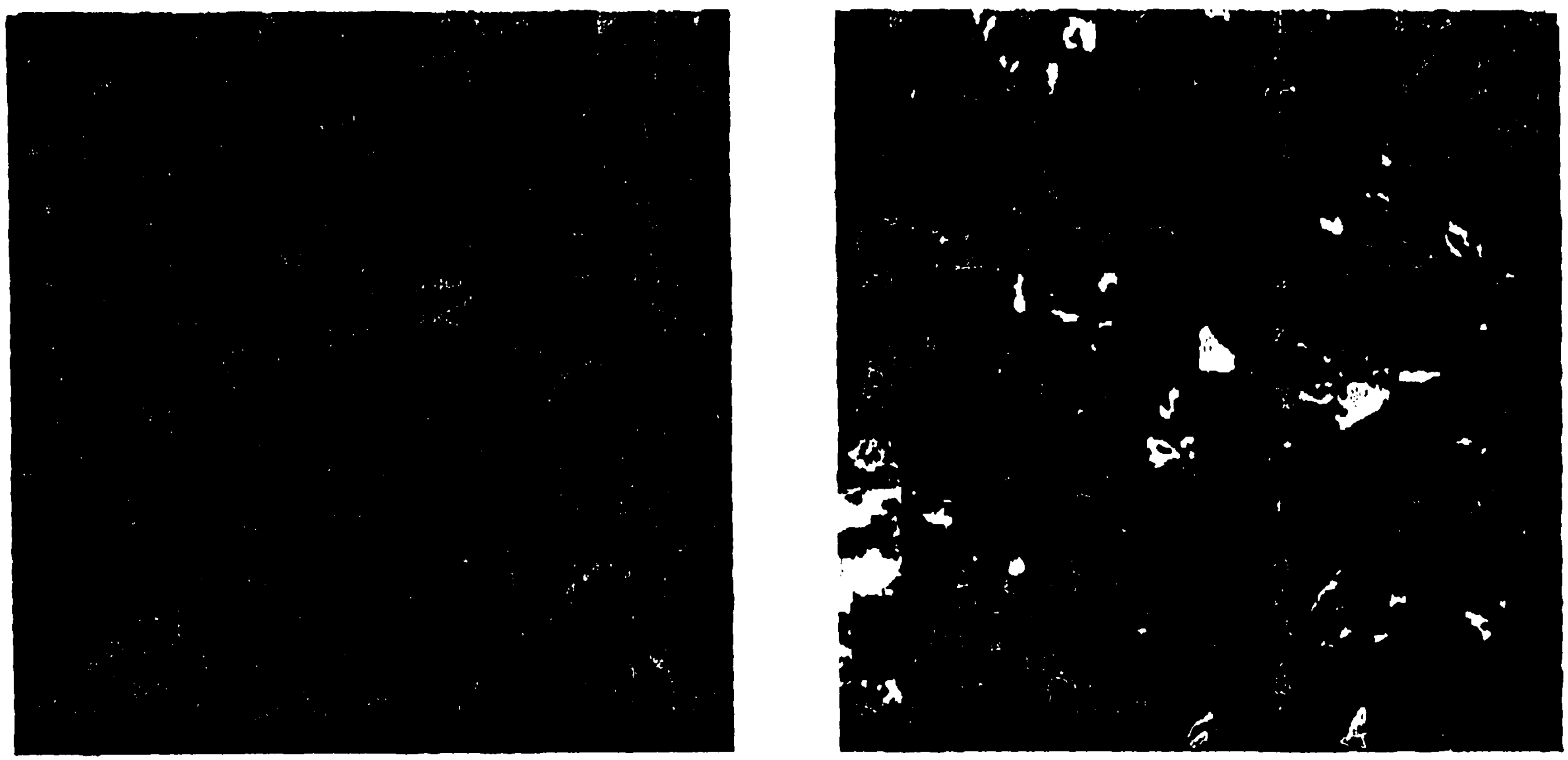


Figure 3.3 LANDSAT images of study site T55-R7-W4th after the supervised classification, followed by the application of the 5X5 Median Filter (approximate presentation scale 1:100,000).

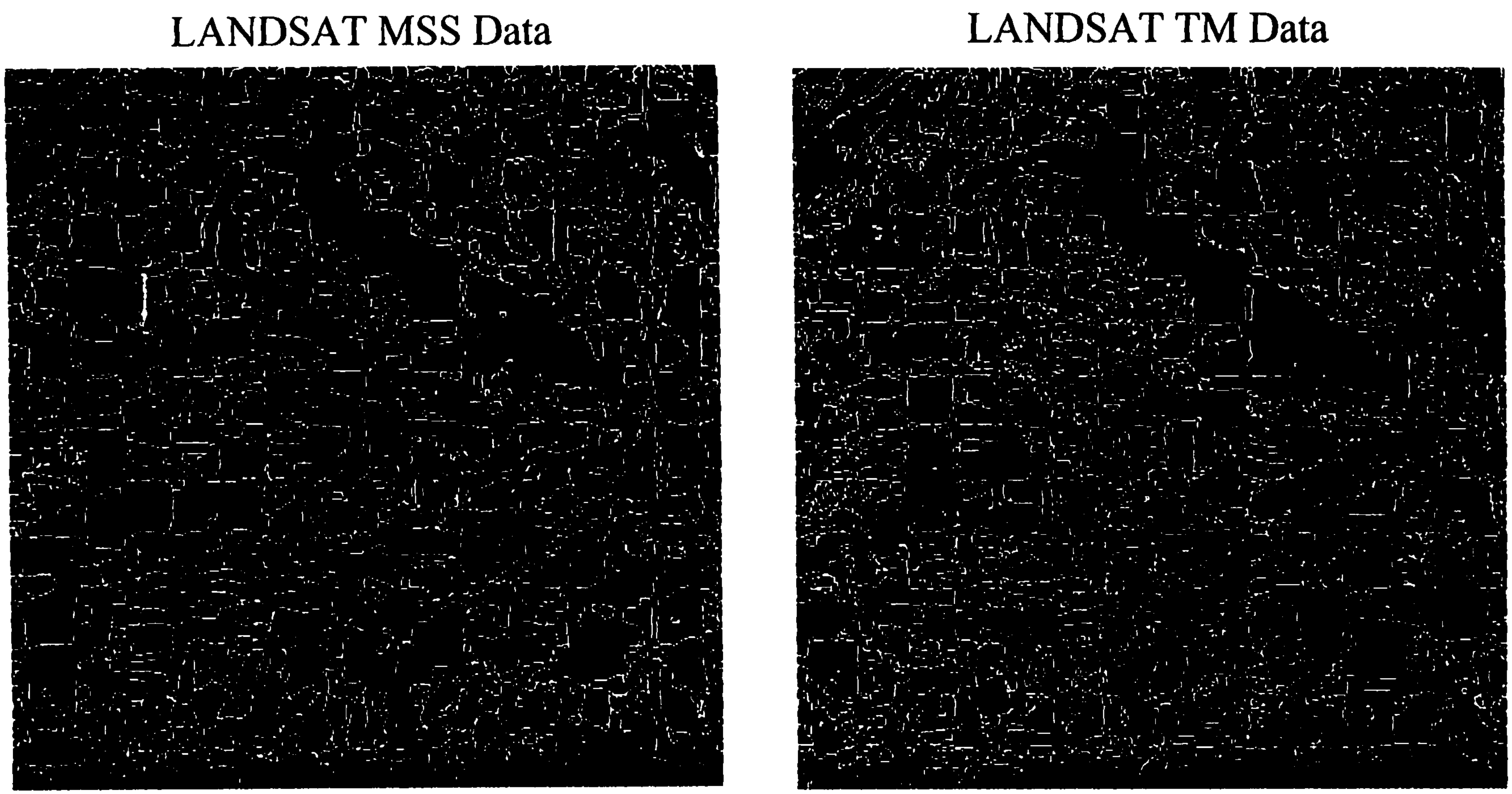


Figure 3.4 Maps of boundaries derived from LANDSAT images of study site T55-R7-W4th through the application of the 3X3 Laplacian filter on the classified-Median filtered imagery (approximate presentation scale 1:100,000).

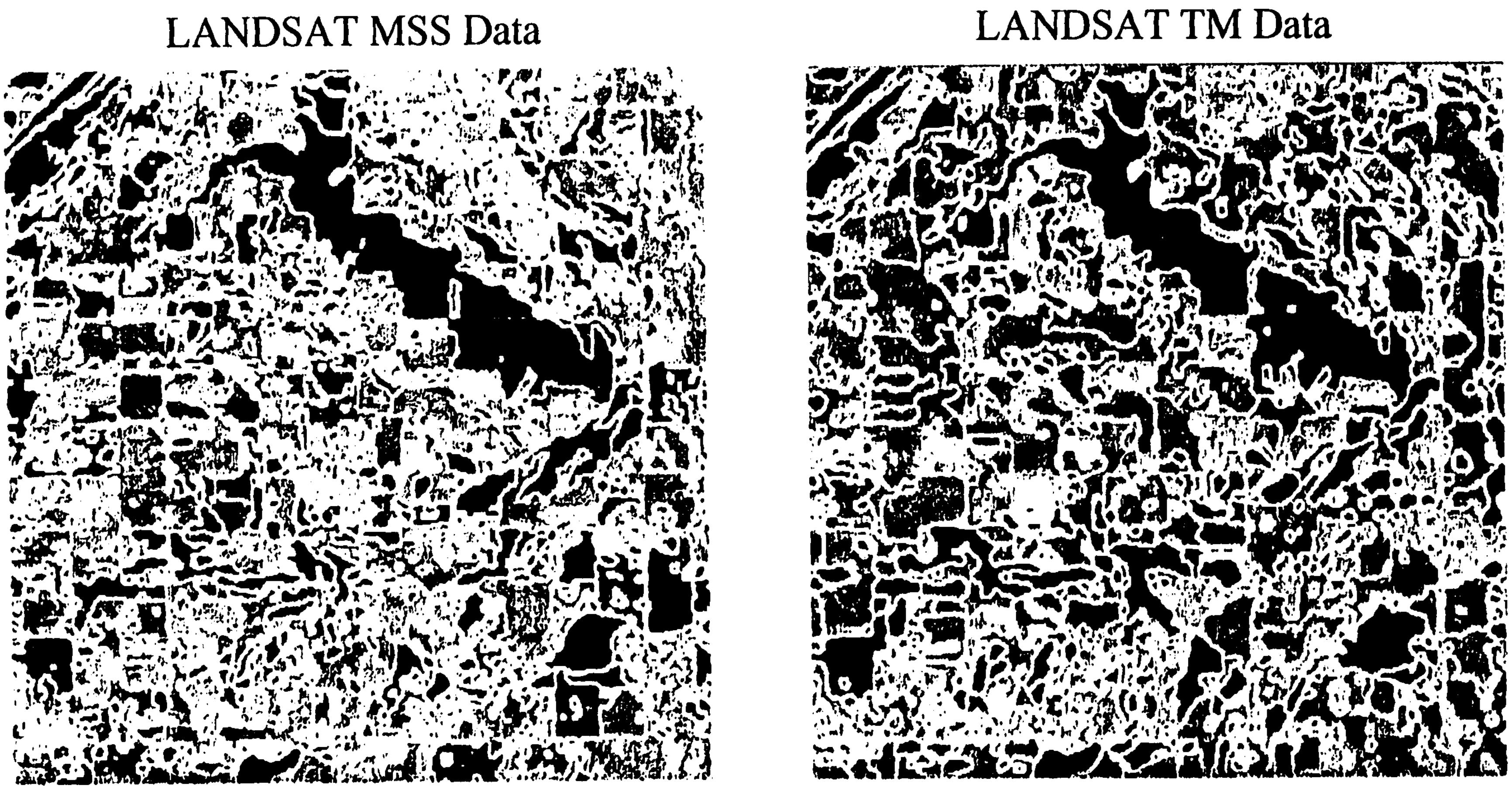


Figure 3.5 LANDSAT color composite images of study site T55-R7-W4th draped with the resultant vectors of the boundaries from the same date, vector width = 2 pixels (MSS Date August 4, 1975, TM Date August 5, 1991; Linear contrast stretch; for the MSS, Infrared Band 6 as red, Red Band 5 as green, Green band 4 as blue; for the TM, Infrared Band 4 as red, Red band 3 as both green and blue; approximate presentation scale 1:100,000).

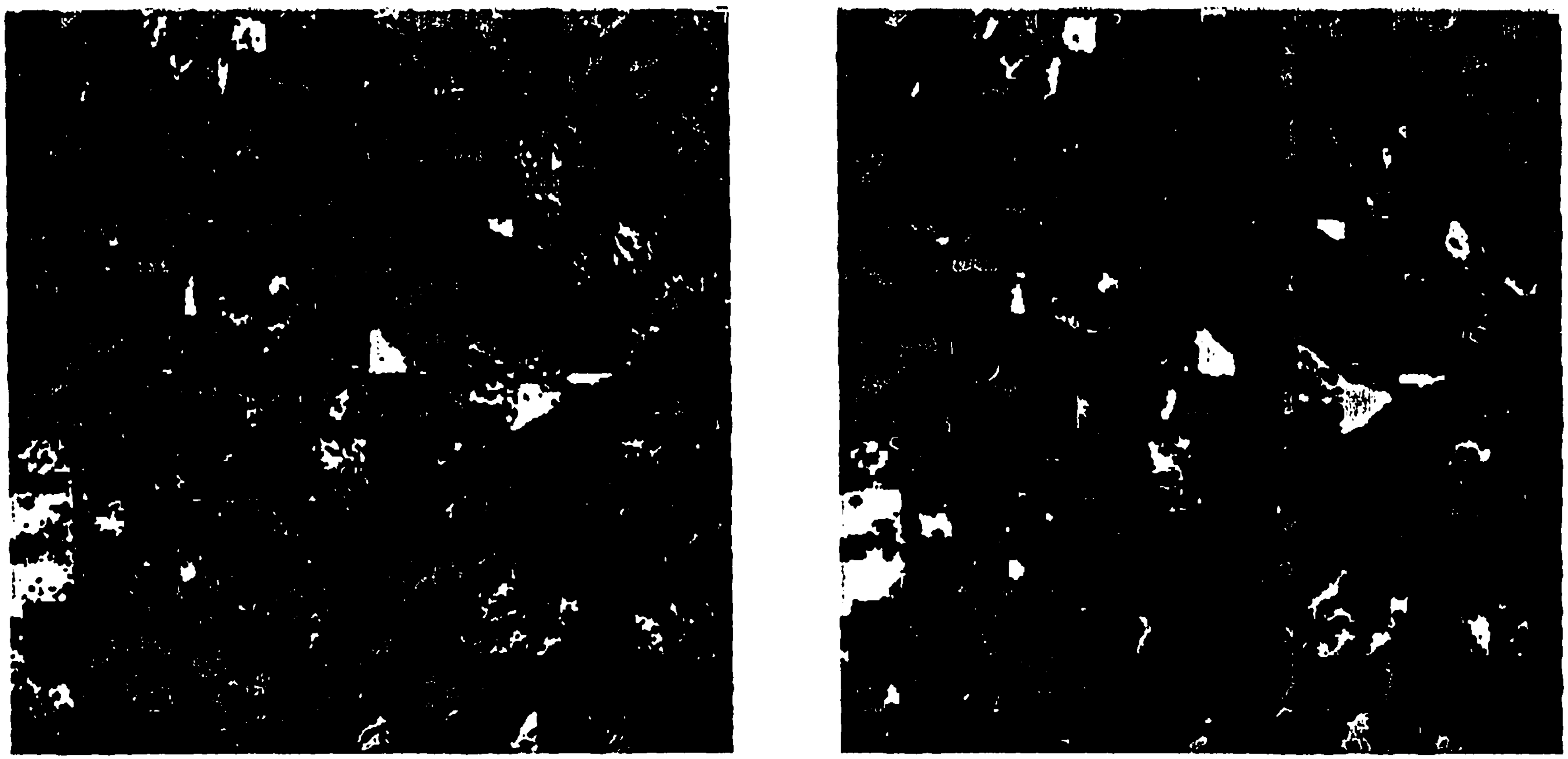


Figure 3.6 LANDSAT TM images of study site T55-R7-W4th after the supervised classification followed by the application of 3X3 (left) and 7X7 (right) Median filter (approximate presentation scale 1:100,000).

3.4.4 Accuracy Assessment

A visual analysis of the overlay results of the vectorized boundaries on top of the false color composites (Figure 3.5 and Figures 3.7-3.9) show that the boundaries are generally located in positions where they would be drawn by hand.

Based on the number of fields, the accuracy of extracting the field boundaries for the test segment was 92 % for the TM data and 88 % for the MSS (Tables 3.2 and 3.3). The higher accuracy obtained from the TM data could be attributed to its higher spatial and spectral resolution compared to the MSS. The edges between agricultural areas and treed areas or water bodies were all detected.

The boundaries that were not detected (errors of omission) were often boundaries between adjacent fields having a subtle difference of gray level tone. This would probably be the result of the same cover type but at a different stage of growth, with a relatively narrow physical line of separation, they were assigned to the same cover type during the classification stage and appear as one field. This lack of difference may have been reduced using multidate imagery in the same year.

On the other hand, errors of commission, the inclusion of delineated fields that were not observed on the aerial photographs, were noted in only a few cases (4 and 5 cases for MSS and TM, respectively). The boundaries that were present in the extracted maps that were not real boundaries of fields as observed on the photographs were often for sporadic areas of crops within fields that were at a different stage of growth than the rest of the field, discharge areas, or eroded areas.

Table 3.2 Accuracy of TM data as calculated for Township 55- Range-7 W 4th

Section	No. of extracted fields	No. of fields not extracted	Total no. of fields in the aerial photograph
1	5	0	5
2	6	1	7
3	15	1	16
4	10	3	13
5	15	1	16
6	12	1	13
7	10	0	10
8	14	2	16
9	10	0	10
10	7	4	11
11	9	0	9
12	13	0	13
13	8	1	9
14	8	1	9
15	10	0	10
16	15	1	16
17	9	1	10
18	5	0	5
19	5	1	6
20	9	1	10
21	12	0	12
22	12	1	13
23	6	0	6
24	5	0	5
25	13	0	13
26	9	0	9
27	4	0	4
28	13	0	13
29	10	1	11
30	8	1	9
31	9	2	11
32	10	1	11
33	5	0	5
34	12	1	13
35	8	1	9
36	13	1	14

Total Extracted = 344, Total fields in aerial photograph = 372, % Correct = 92 %

Table 3.3 Accuracy of MSS data as calculated for Township 55- Range-7 W 4th

Section	No. of extracted fields	No. of fields not extracted	Total No. of fields in the aerial photograph
1	4	1	5
2	6	2	8
3	8	3	11
4	10	1	11
5	9	3	12
6	11	1	12
7	10	0	10
8	9	1	10
9	8	1	9
10	7	0	7
11	10	2	12
12	8	1	9
13	7	1	8
14	10	2	12
15	12	1	13
16	12	0	12
17	7	4	11
18	6	1	7
19	10	0	10
20	11	2	13
21	11	1	12
22	11	2	13
23	9	1	10
24	10	0	10
25	10	1	11
26	10	1	11
27	5	0	5
28	10	1	11
29	10	1	11
30	9	4	13
31	8	1	9
32	11	2	13
33	6	0	6
34	8	0	8
35	10	1	11
36	12	1	13

Total Extracted = 325, Total fields in aerial photograph = 369, % Correct = 88 %

3.4.5 Changes in Geometry of Fields

The decision whether to accept the null hypothesis of no differences between the two population's means or the alternative hypothesis of a difference, was based on comparing the calculated F value (Fc) for each parameter, for all the townships, with the tabular F value (Ft) for 1 degree of freedom for the numerator, and more than 120 degrees of freedom for the denominator. The F tables are listed for a maximum of 120, and the degrees of freedom for the denominator were always more than 120. The Ft for $(1, \infty)$ degrees of freedom were 3.84 and 6.63 for 5% and 1 % probability levels, respectively. The results of the statistical analyses are summarized in Tables 3.4 to 3.7.

Statistical differences were evident in only two of the four studied townships for only two of the parameters tested. A statistically significant change in the shape index between 1975 and 1991 occurred in Township 49-Rang-9 W 4^{th}. The rest of the townships studied showed no significant statistical difference for any of the parameters between 1975 and 1991.

Tables 3.4 to **3.7** showing the results of the statistical analysis :

Parameter	Fc compared to Ft at 5% and 1% significance level	Acceptance of the null hypotheses H_o	Conclusion about the differences between the 1975 and 1991 parameter means
1. Area	0.656 < Ft	Accept the H_o	No differences
2. Perimeter length	0.084 < Ft	Accept the H_o	No differences
3. Shape index	3.77 < Ft	Accept the H_o	No differences

Table 3.1 Results of the statistical analysis for Township 53-Range-10 W 4th

Parameter	Fc compared to Ft at 5% and 1% significance level	Acceptance of the null hypotheses H_o	Conclusion about the differences between the 1975 and 1991 parameter means
1. Area	0.077 < Ft	Accept the H_o	No differences
2. Perimeter length	0.311 < Ft	Accept the H_o	No differences
3. Shape index	8.058 ** > Ft	Reject the H_o, and accept the H_A	Evidence of real differences

Table 3.2 Results of the statistical analysis for Township 49 Range 9 W 4th

Parameter	Fc compared to Ft at 5% and 1% significance level	Acceptance of the null hypotheses H_o	Conclusion about the differences between the 1975 and 1991 parameter means
1. Area	2.256 < Ft	Accept the H_o	No differences
2. Perimeter length	0.940 < Ft	Accept the H_o	No differences
3. Shape index	1.26 < Ft	Accept the H_o	No differences

Table 3.3 Results of the statistical analysis for Township 51-Range-11 W 4th

Parameter	Fc compared to Ft at 5% and 1% significance level	Acceptance of the null hypotheses H_o	Conclusion about the differences between the 1975 and 1991 parameter means
1. Area	0.012 < Ft	Accept the H_o	No differences
2. Perimeter length	0.300 < Ft	Accept the H_o	No differences
3. Shape index	8.605 ** > Ft	Reject the H_o, and accept the H_A	Evidence of real differences

Table 3.4 Results of the statistical analysis for Township 55-Range 7 W 4th

LANDSAT MSS Data

LANDSAT TM Data

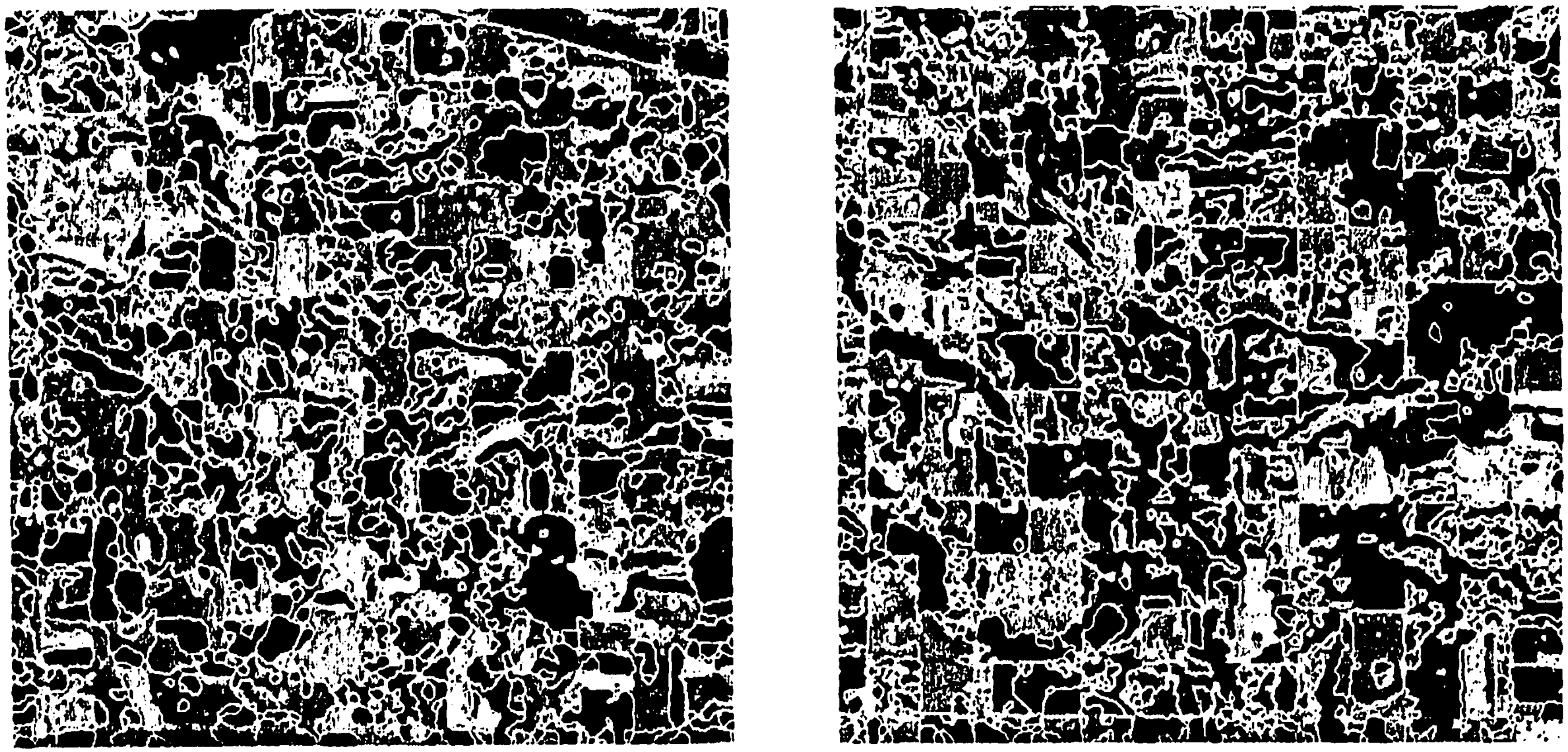


Figure 3.7 LANDSAT color composite images of study site T53-R10-W4th with the 1991 TM image draped with the vectors from the 1991 boundaries and the 1975 MSS image draped with the vectors from the 1975 MSS image (Linear contrast stretch; for the MSS, Infrared Band 6 as red, Red Band 5 as green, Green band 4 as blue; for the TM, Infrared Band 4 as red, Red band 3 as both green and blue; approximate presentation scale 1:100,000).

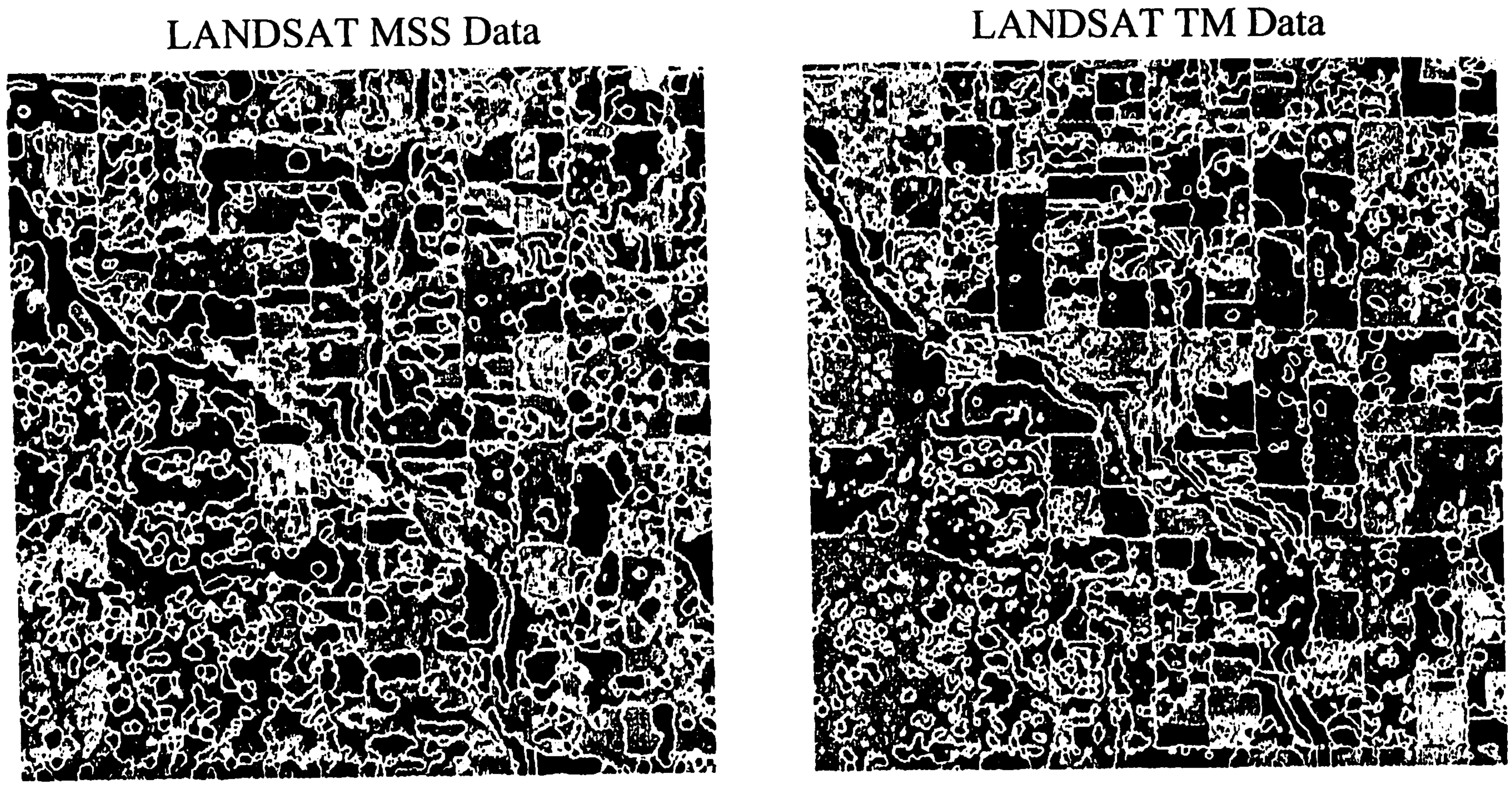


Figure 3.8 LANDSAT color composite images of study site T49-R9-W4th with the 1991 TM image draped with the vectors from the 1991 boundaries and the 1975 MSS image draped with the vectors from the 1975 MSS image (Linear contrast stretch; for the MSS, Infrared Band 6 as red, Red Band 5 as green, Green band 4 as blue; for the TM, Infrared Band 4 as red, Red band 3 as both green and blue; approximate presentation scale 1:100,000).

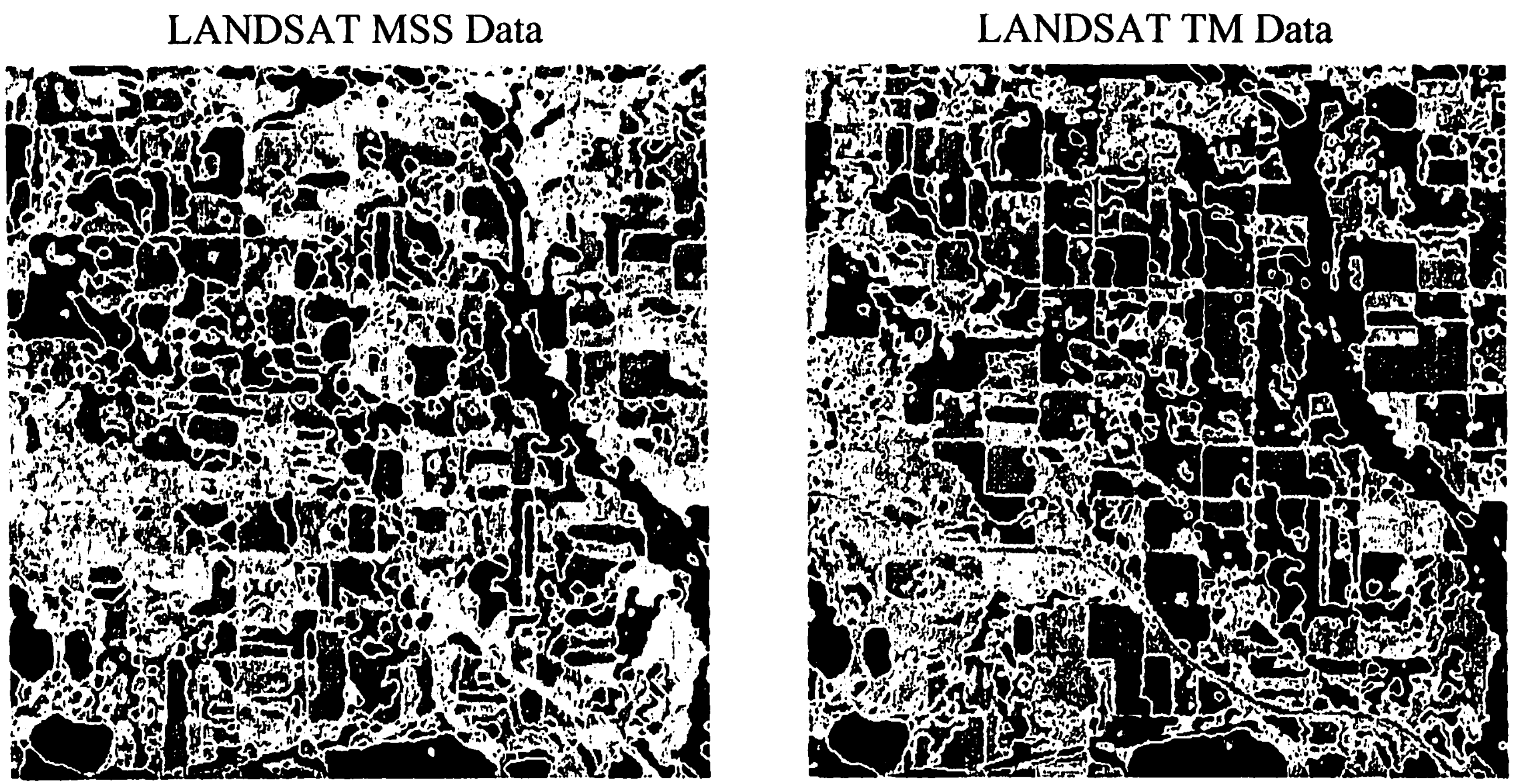


Figure 3.9 LANDSAT color composite images of study site T51-R11-W4th with the 1991 TM image draped with the vectors from the 1991 boundaries and the 1975 MSS image draped with the vectors from the 1975 MSS image (Linear contrast stretch; for the MSS, Infrared Band 6 as red, Red Band 5 as green, Green band 4 as blue; for the TM, Infrared Band 4 as red, Red band 3 as both green and blue; approximate presentation scale 1:100,000).

The general parameters of the average size of polygons, total length of perimeter, and number of polygons are given in Table 3.8. This may provide information on "fragmentation", as a result of changing the fields' sizes and geometry. For the two study sites, Township 55-Range-7 W 4^{th} and Township 49-Range-9 W 4^{th}, that showed significant statistical difference, histograms of the shape indices that illustrate this difference between 1975 and 1991 were generated (Figures 3.10 and 3.11). Examining these graphs along with a comparison with the overlay results (Figures 3.12 and 3.13) can provide an indication of the nature of the changes that have occurred.

Township		Number of polygons	Total length of perimeter (km)	Average size of polygons (ha)
49-R 9-W 4^{th}	1975	524	1072.5	18.14
	1991	510	1083.1	18.64
51-R 11-W 4^{th}	1975	563	1161.9	17.76
	1991	507	1099.7	19.72
53-R 10-W 4^{th}	1975	471	1049.4	20.14
	1991	502	1101.9	18.90
55-R 7-W 4^{th}	1975	486	1032.0	19.53
	1991	493	1086.2	19.25

Table 3.8 Changes in the general parameters tested.

1) Township 49-Range 9-W 4^{th}: The decreased number of polygons from 524 in 1975 to 510 in 1991, and the increased average size of the polygons (Table 3.8), indicates that some fields were merged together. The total length of the perimeters would therefore excepted to decrease. However, the total length of the perimeter increased, indicating that fields in 1991 had more complex shapes (more elongated, from Figure 3.10) associated with their larger average size to account for the increased total length of the perimeters. This conforms to the statistical results, that while the shape is different, the rest of the parameters have not changed significantly.

For this study area the major peak of the shape index of 1975 is approximately 1.09 - 1.17 (Figure 3.10), while for 1991, the major peaks are shifted to greater values. This is interpreted as the change in the geometry being towards less spherical to more elongated fields. However, from the overlay of the boundaries extracted from the 1975 image on the 1991 image (Figure 3.13), only few cases of elongated fields were identified visually. Also some of the small scattered patches where merged together.

2) Township 51-Range 11-W 4^{th} : The decrease in the total number of polygons from 563 to 507, the increased average size from 17.76 to 19.72 ha, accompanied by a decrease in the total length of perimeter (Table 3.8), indicate an amalgamation of fields. However, this change is not statistically significant (Table 3.6). Also, examining the overlay result (Figure 3.13) visually does not indicate a general pattern of change between the two dates, as fields remain relatively large and rectangular in 1991.

3) Township 53-Range 10-W 4^{th} : In 1991 the number of polygons had increased from 471 to 502, the total length of perimeter had increased, and the average size had decreased from 20.4 to 18.90 ha. All of these changes indicate that the fields in this township may have become more fragmented. This fragmentation is not statistically significant (Table 3.6), and a trend of change in the geometry could not be seen in the image overlay (Figure 3.13).

4) Township 55-Range 7-W 4^{th} : The total number of polygons increased from 486 to 493, and the total length of perimeter increased from 1032 to 1086.2 km, but the average size of polygons decreased slightly from 19.53 to 19.25 ha. All of these changes could indicate the possible fragmentation of fields. The statistical analysis of the changes in both the area and the perimeter are not significant, but the changes in the shape index are significant.

The shape of the histogram of the shape index for this township (Figure 3.11) shows that the major peak for 1975 was in the 1.13 -1.20 range, while the peak for 1991 was shifted towards the right at the 1.29-1.45 area. This may be indicating that the change in shape was also towards more elongated fields. Knowing that strip fields will have a much longer total perimeter compared to area than rectangular fields, this could indicate that the larger number of fields in 1991 were more elongated. From the overlay (Figure 3.12), some fields can be seen to have changed from a rectangular shape to L-shapes and some fields had become more elongated throughout the township.

The large sample of fields used in the statistical analysis may have manifested the slight differences in shapes that were to some extent apparent in the visual overlay. Also the parameters chosen to describe the shape may have been more sensitive to the amount of change than what was anticipated.

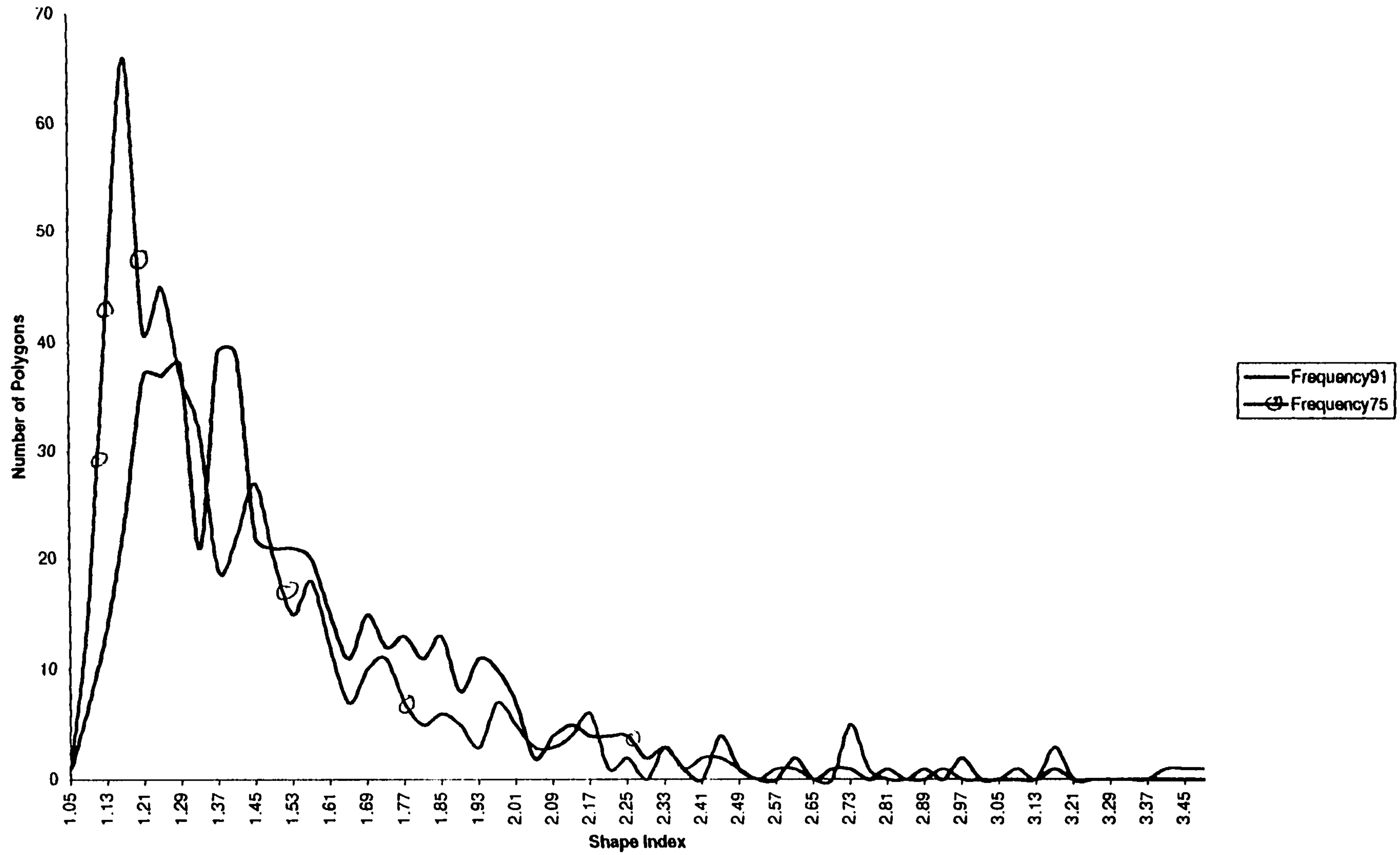


Figure 3.10, Histogram of shape index for T49 - R9 - W4th

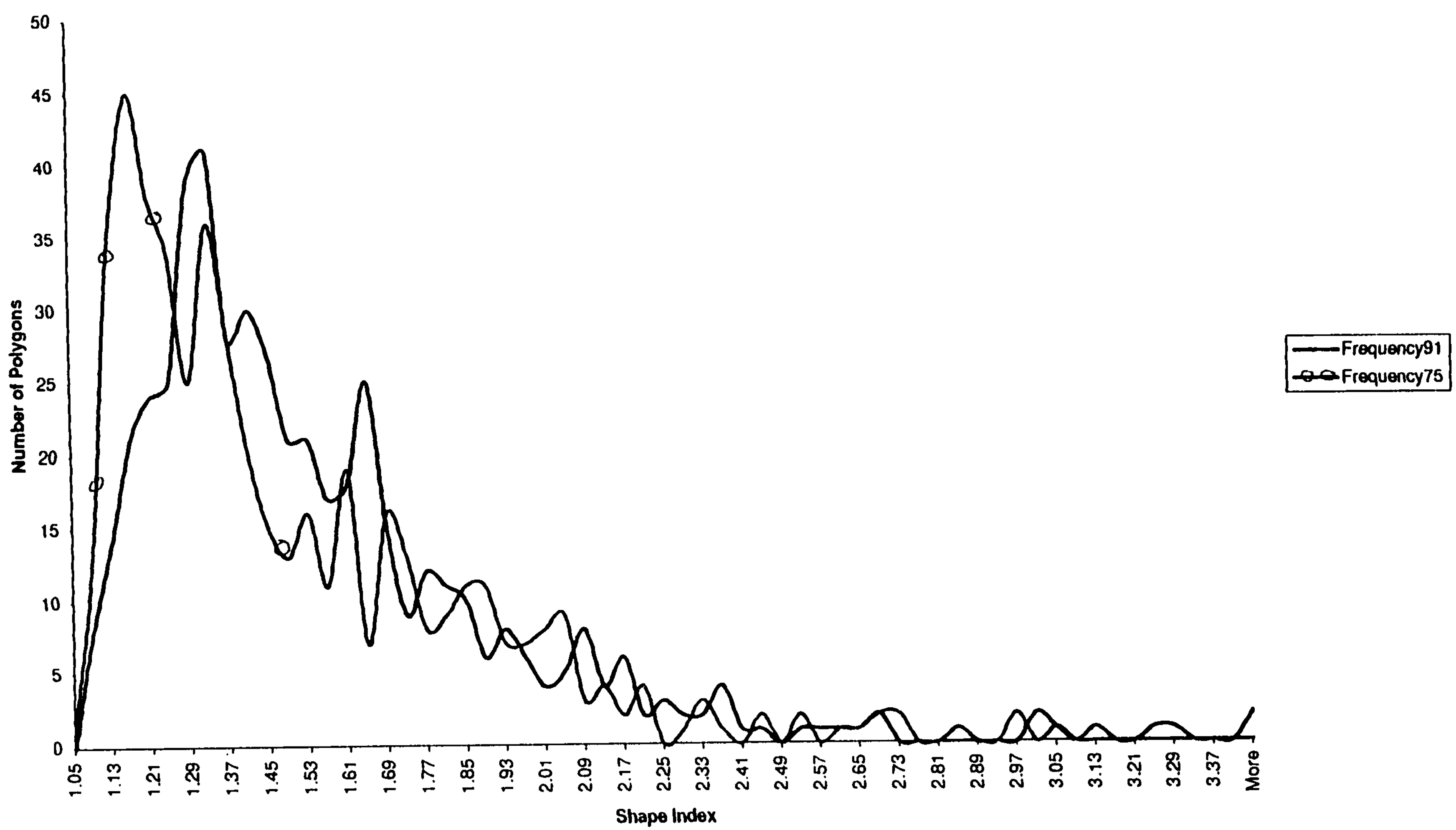


Figure 3.11, Histogram of shape index for T55 - R7 - W4th

Township 57-Range 7-W 4th Meridian

Township 53-Range 10-W 4th Meridian

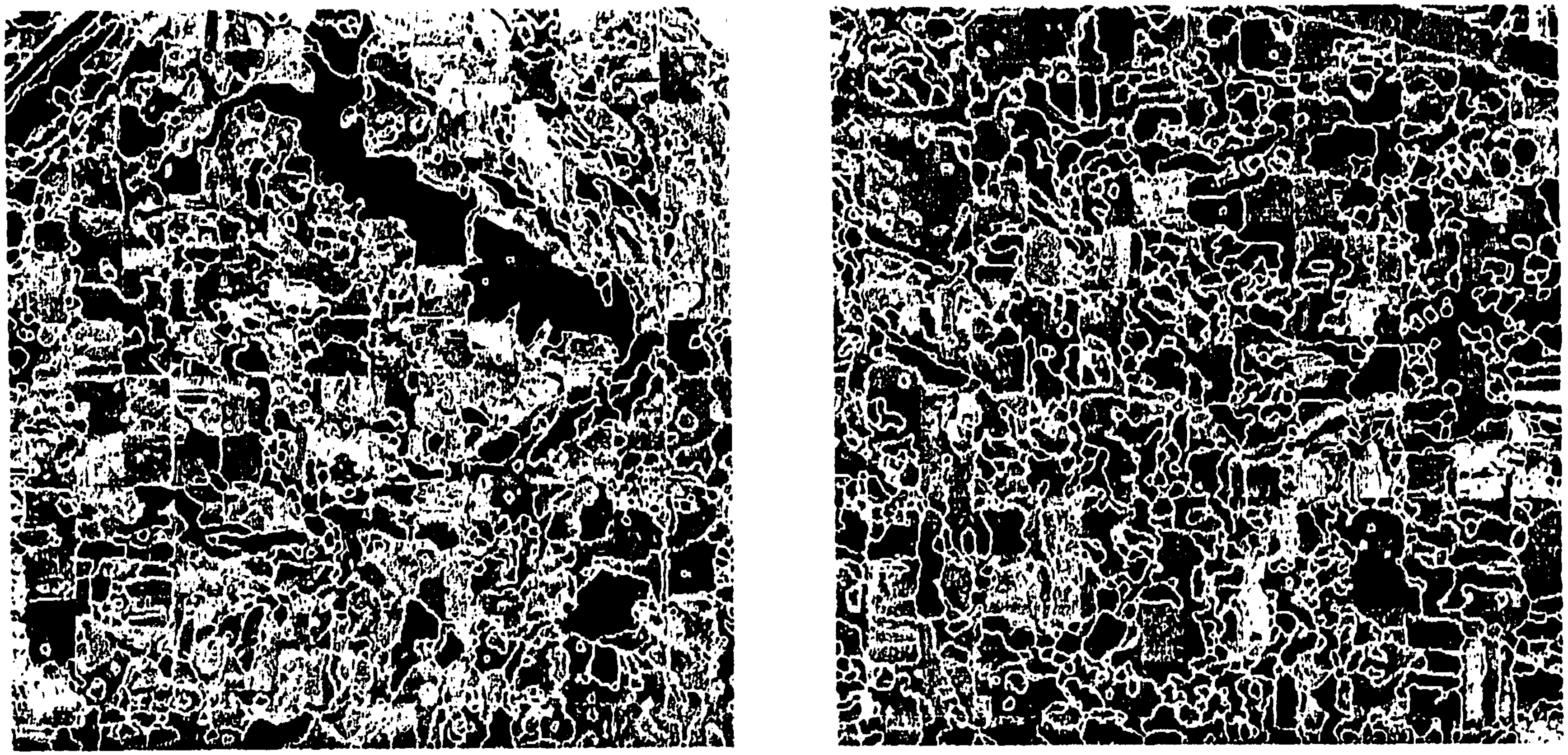
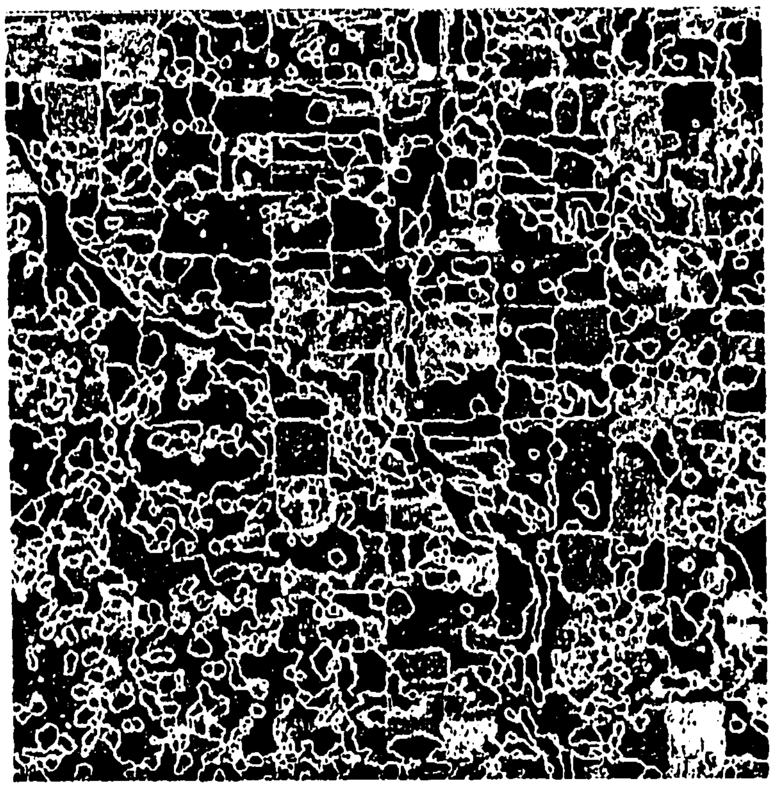


Figure 3.12 LANDSAT TM 1991 color composite images draped with the resultant vectors of the boundaries from the 1975 images, vector width = 1 pixels (Linear contrast stretch; Infrared Band 4 as red, Red band 3 as both green and blue; approximate presentation scale 1:100,000).

Township 49-Range 9-W 4th Meridian



Township 51-Range 11-W 4th Meridian

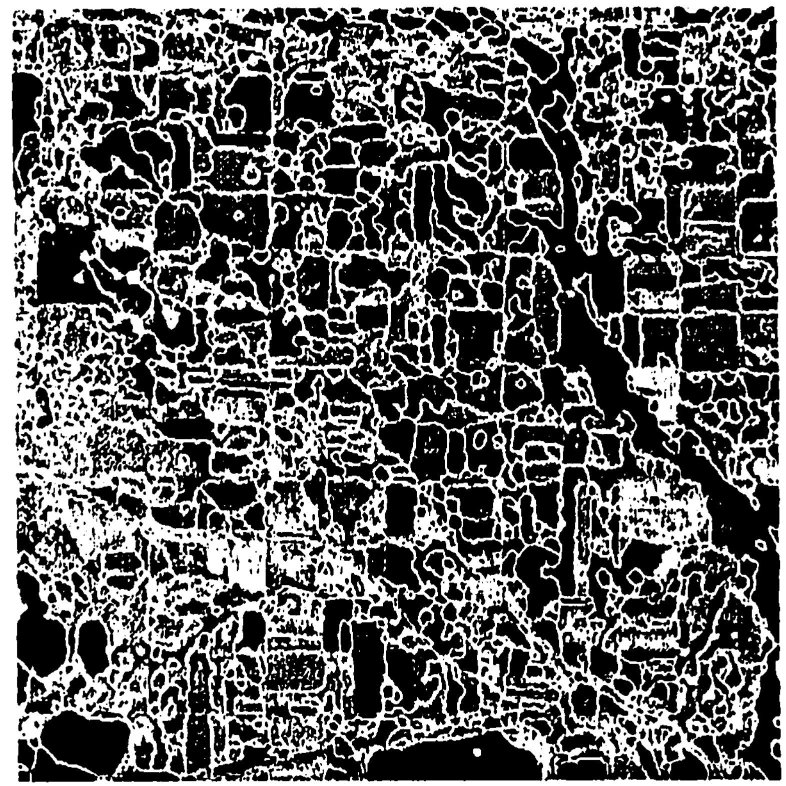


Figure 3.13 LANDSAT TM 1991 color composite images draped with the resultant vectors of the boundaries from the 1975 images, (Linear contrast stretch; Infrared Band 4 as red, Red band 3 as both green and blue; approximate presentation scale 1:100,000).

3.5 Summary and Conclusion

In this chapter, the use of LANDSAT MSS and TM data for the delineation of field boundaries was investigated. An approach for an automatic method for the extraction of field boundaries, based on the use of a sequence of image analysis techniques was introduced. This method, with minor modification could be suited for any other area.

The accuracy of the delineation procedure, based on the number of fields, was 88 %, and 92 % for the MSS and TM data respectively, these accuracies should be considered with the spatial limitations of the data used in mind. The higher accuracy produced from the TM data could be attributed to its higher spatial and spectral resolutions. An examination of the results of overlaying the produced maps of boundaries onto the original image, portrays how acceptable the results are visually. The resultant maps of the extracted fields were vectorized and used for visual and quantitative assessment of the change in the sizes and geometry of fields in four study sites in Northeastern Alberta.

Subtle changes in field geometry have occurred in two of the study sites, with this change being towards more elongation, or less spheroidal. From a practical point of view, there is no distinct trend of the change in shapes towards more elongated fields that can be meaningful in terms of a soil conservation practice, that is widely adopted in all the study areas. Even in the townships that showed statistical differences in some of the indices used, Township 49-Range-9 W 4^{th} the fields in the hummocky area in the south west of this township remain large and rectangular in shape, even though some merging of small patches together was observed. Daniel (1990) reported the importance of differentiating between the statistical and the practical importance, as the statistical test does not necessarily determine the practical significance, and only the analyst, knowledgeable of the area, is qualified to decide the practical significance. One of the things that should be considered is the large size of the sample used in the statistical analysis, that would reveal very small differences among the studied parameters (Daniel 1990). In this case a large number of fields or polygons were included (Table 3.8) so that relatively small differences in the parameters for individual fields may be highlighted.

The statistical analysis helped in quantifying the changes in the field geometry and in drawing the attention to slight changes, and to assist in describing their nature. Although there have been significant changes in this area of Alberta to land management and soil conservation practices that are manifested by changes in land cover (Crown and Klita 1997), there have not been associated changes in general field shape or size, based on the satellite data used.

3.5 References

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Chapter 4: Synthesis

4.1 Summary and Conclusion

This research was conducted to investigate the potential of using LANDSAT MSS and TM imagery data to delineate field boundaries within study sites in the Parkland region in Northeastern Alberta. Rather than manually delineating the boundaries, an attempt was made to automate the procedure. The resultant images of boundaries were used to monitor the temporal changes in field geometry. The procedure presented was based on the use of a sequence of image analysis techniques for both the human and machine interpretation. These included Multispectral classification, spatial filtering and other image enhancements.

The application of each of the digital enhancements, discussed in Chapter 2, provided useful and unique information. The linear stretch and color compositing have aided in the analyses by enhancing the visual discriminability between different cover types. The multispectral image classification reduced the heterogeneity of the land cover within fields. The spatial filtering reduced the variability within the classes, and was then employed to extract the boundaries between them.

The procedure described in this thesis provided a relatively simple and unbiased means for the delineation of field boundaries, if compared to manual digitizing. Remotely sensed maps of the extracted boundaries were constructed from both the raw TM and MSS image data on the level of a township. These results are encouraging for using such a method as a simple means for providing a GIS layer that could be incorporated in other kinds of studies.

Two types of analyses were conducted to estimate the change in the geometry of fields; the first involved the superimposition of the vectorized layers of field boundaries from 1975 onto the 1991 raster color composites to allow the visual assessment of the change. The second type included (a) the quantification of the change by means of parameters that describe the geometry of fields by means of comparing length field edges to their areas, and the description of fragmentation and (b) conducting a statistical analysis to investigate the significance of the change that has occurred. Histograms of the changed parameters were produced to portray the distribution of the available shapes in both dates of imaging.

The results of the visual analyses did not reveal a major change in the geometry of fields. The insignificant statistical changes between 1975 and 1991 in the most important parameters, area and perimeter, enforced the results of the visual analyses that there were no major changes to area and shape. Some statistically significant difference between the shapes of fields for Township-49 Range-9 W 4th and Township 55-Range-7 W 4th were detected, both were towards more elongated shapes, or less spheroidal (Figures 3.10, 3.11). In Township-49 Range-9 W 4th, merging of some internal sporadic patches into the field around them was noticed. This could be the result of the clearing, drainage, and seeding of small poorly drained areas in hummocky terrain to permanent cover. At the same time, a quarter section could be subdivided into 4 fields in 1975 and 3 in 1991 resulting in fewer fields, increased perimeter and increased area. In Township 55-Range-7 W 4th, some of the fields were observed to have more elongated shapes. These differences may be very subtle and were detected in the statistical analysis due to the large sample used that will manifest slight differences.

The fields in the MSS imagery were observed to have rounded corners, opposed to the sharper corners in the TM imagery. This may be attributed to the coarser spatial resolution of the MSS data. This may have also contributed to the statistical significance reported. Also the degree to which the shape index responds to very slight differences that may be finer than changes in agricultural fields may have affected the analysis.

The time window of imaging is assumed to be a very important factor in this study. Knowing the importance of crop calendar for this area, it might have been more suitable to obtain images in the beginning of the growing season, as a larger degree of spectral contrast could have been maintained in that early date, which can be attributed to the differences in spectral responses of the premature stage. As the season advances boundaries may become less distinct due to the growth of plants, especially if adjacent fields have the same type of cover and at the same growth stage, the absence of a considerable physical boundary between these fields also had aggravated this problem. Haas (1992), in a study to monitor rangelands using TM data, showed that the high reflectance of the vegetation late in the season, may overpower subtle spectral differences.

Various land management techniques in cultivation and tillage can play an important role in the reduction of erosion as they affect the rest of the factors involved in the process. The detail of the conservation methods depends on the local conditions of the area. Simms (1970) as cited in PFRA (1982) reported that no single conservation management practice is suitable for all situations, and that the adoption of a combination of several practices may optimize the control. In Alberta many conservation practices have been adopted to reduce the potential of soil erosion and to maintain soil quality. These include the use of rotational cropping, crop residue management, direct seeding, no till planting, stubble-mulch cropping, rock hedges, tree hedges, and grassed waterways (Dumanski et al. 1994). More details on the currently practiced conservation techniques in the Canadian Prairies can be found in Lindwall et al. (1994) and Larney et al. (1994).

4.2 Future Work

There are several directions for future work that could be performed based on this study. These are outlined in the following:

- It would be interesting to apply the same procedure used in this study to extract the field boundaries to a more complex terrain and investigate its robustness.
- The change in the orientation of the fields was not considered in our study, it might be useful to explore these changes, if any. This could be achieved by including some parameters that consider the orientation of the fields and incorporate this information with digital elevation models to investigate the changes in orientation relative to slopes magnitude and aspect.
- The time of imaging may have a substantial effect on the ability to separate different cover types, maybe it is worth while to explore the use of multidate images taken in different time of the year, this may aid in increasing the spectral seperability between

adjacent fields having the same cover type. Also information on land ownership might be included.

- The results suggests that defining the boundary might be influenced by the spatial resolution of the data used, it would be interesting to investigate the use of other types of data such as SPOT HRV with higher spatial resolution and consider higher locational accuracy as well.

- Apply the technique in non-agricultural areas, for example, this could include mapping forest clear-cutting, desertification in other areas of the world, changes in ecological boundaries, and changes in lake perimeters.

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Chapter 5: Appendices

Appendix 5.1 MSS Ground Control Points Report

Set 2 Units: UTM E000 Set 1 Units: PIXEL Number GCPs: 25

GCP's are ordered from worst to best residuals.

GCP No.	Set 2 GCP's (UTM E000)	Set 1 GCP's (PIXEL)	Residual (PIXEL)
8	(492200.4, 5969037.1)	(1422.1, 82.6)	(.52, -.25)
21	(414807.8, 5936142.2)	(264.4, 733.6)	(.41, .10)
11	(447561.3, 5883836.3)	(1057.6, 1260.4)	(.37, .16)
22	(410984.8, 5913761.3)	(301.3, 1016.8)	(-.32, -.16)
9	(449132.8, 5947939.1)	(790.0, 478.7)	(-.30, -.13)
25	(475788.3, 5811563.3)	(1866.2, 2042.5)	(.22, -.24)
12	(443310.2, 5849333.6)	(1143.1, 1691.5)	(-.32, -.06)
2	(507120.3, 5951626.6)	(1753.1, 244.9)	(-.29, .01)
17	(492781.2, 5945206.2)	(1540.4, 369.7)	(-.03, .28)
6	(543569.5, 5910149.2)	(2560.5, 628.5)	(.26, .09)
15	(423759.8, 5853686.3)	(792.8, 1702.7)	(.03, .24)
7	(545426.6, 5883882.8)	(2712.4, 940.6)	(-.02, -.22)
4	(514615.6, 5802646.9)	(2564.2, 2025.3)	(-.10, .18)
16	(508784.4, 5945184.4)	(1810.9, 317.4)	(-.17, -.06)
14	(432246.9, 5984490.6)	(338.0, 91.3)	(-.10, .12)
23	(416917.2, 5898507.8)	(471.8, 1182.3)	(.05, -.14)
20	(478384.8, 5862812.9)	(1674.7, 1414.4)	(-.14, .00)
1	(509496.9, 5909671.9)	(1985.9, 745.4)	(-.06, .09)
5	(559221.9, 5951659.4)	(2634.5, 74.5)	(-.08, .04)
10	(447177.3, 5920458.6)	(883.0, 818.0)	(.06, -.04)
18	(488415.6, 5909565.6)	(1630.0, 815.4)	(.03, .04)
13	(443388.3, 5967589.8)	(603.4, 259.6)	(-.05, .00)
3	(508604.7, 5854695.3)	(2223.4, 1414.3)	(.03, -.04)
24	(484837.1, 5951683.2)	(1376.6, 317.0)	(.03, -.01)
19	(488385.9, 5893307.8)	(1704.0, 1012.5)	(-.02, .01)

RMS=(.28, .18) .33

Appendix 5.2 TM Ground Control Points Report

Set 2 Units: UTM 12 U Set 1 Units: PIXEL Number GCPs: 57

GCP's are ordered from worst to best residuals.

GCP No.	Set 2 GCP's (UTM 12 U E000)	Set 1 GCP's (PIXEL)	Residual (PIXEL)
14	(388250.0, 5975775.0)	(679.1, 1003.0)	(.31, -.06)
59	(415625.0, 5855350.0)	(2557.0, 4667.3)	(.28, .12)
55	(483200.0, 5945275.0)	(4000.5, 1202.5)	(.29, -.08)
57	(486750.0, 5893300.0)	(4543.6, 2853.4)	(.06, .28)
46	(506925.0, 5958075.0)	(4661.7, 593.0)	(.10, -.26)
48	(529800.0, 5910350.0)	(5794.8, 1945.9)	(-.22, -.12)
45	(508900.0, 5941925.0)	(4858.7, 1098.3)	(.16, -.18)
64	(445300.0, 5987575.0)	(2426.8, 150.5)	(-.07, .21)
16	(399750.0, 5981950.0)	(999.8, 708.6)	(-.22, .04)
28	(436325.0, 5893825.0)	(2909.4, 3253.5)	(-.02, .22)
60	(414900.0, 5835850.0)	(2693.4, 5302.2)	(.11, -.18)
58	(453075.0, 5846425.0)	(3840.8, 4646.2)	(-.21, -.03)
63	(459000.0, 5874125.0)	(3804.4, 3702.6)	(-.18, .11)
5	(378175.0, 5937300.0)	(670.8, 2328.5)	(.09, -.19)
54	(376500.0, 5856200.0)	(1284.2, 4961.4)	(-.08, -.18)
20	(449000.0, 5939075.0)	(2946.1, 1685.6)	(-.01, -.19)
61	(515050.0, 5861125.0)	(5724.5, 3658.7)	(-.18, .05)
44	(518725.0, 5932250.0)	(5255.8, 1329.8)	(-.15, -.11)
15	(425450.0, 5965150.0)	(1969.8, 1038.4)	(-.11, .14)
34	(512200.0, 5836575.0)	(5835.4, 4474.9)	(.09, -.15)
10	(359259.0, 5876125.0)	(562.5, 4460.3)	(-.15, .08)
18	(456500.0, 5971250.0)	(2923.5, 584.4)	(.12, -.12)
11	(359250.0, 5846900.0)	(802.2, 5403.0)	(-.05, .15)
43	(531700.0, 5945300.0)	(5568.1, 801.5)	(.15, .03)
36	(492250.0, 5966200.0)	(4120.3, 452.2)	(-.10, .10)
38	(554800.0, 5956650.0)	(6221.5, 245.2)	(-.14, .03)
37	(545375.0, 5890300.0)	(6465.1, 2465.3)	(.13, .04)
62	(493900.0, 5861125.0)	(5040.1, 3833.8)	(-.13, .03)

53	(402550.0,	5852350.0)	(2158.7,	4871.6)	(.10,	-.08)
52	(410350.0,	5894325.0)	(2065.7,	3451.6)	(-.04,	-.13)
8	(377950.0,	5885300.0)	(1092.3,	4010.4)	(.13,	.03)
22	(443300.0,	5958400.0)	(2602.5,	1108.5)	(-.10,	-.09)
32	(495975.0,	5828550.0)	(5376.3,	4868.3)	(.12,	-.03)
7	(372775.0,	5900000.0)	(803.7,	3578.3)	(.00,	.12)
41	(539475.0,	5964750.0)	(5659.2,	109.9)	(.03,	.11)
25	(408550.0,	5949350.0)	(1553.7,	1688.4)	(-.11,	.03)
30	(450425.0,	5819100.0)	(3979.7,	5549.7)	(-.10,	.04)
49	(509500.0,	5903000.0)	(5199.0,	2351.4)	(-.07,	.07)
39	(545400.0,	5887000.0)	(6493.2,	2571.6)	(.09,	-.05)
50	(507950.0,	5880350.0)	(5336.1,	3096.3)	(.03,	.08)
26	(403475.0,	5878250.0)	(1975.7,	4027.7)	(.04,	-.08)
51	(411050.0,	5913750.0)	(1928.2,	2818.2)	(-.06,	.05)
56	(485150.0,	5912775.0)	(4331.3,	2236.8)	(.08,	-.02)
27	(449300.0,	5893500.0)	(3331.5,	3156.5)	(.05,	.04)
33	(495350.0,	5843450.0)	(5233.1,	4392.6)	(.03,	.04)
35	(484125.0,	5971800.0)	(3811.6,	338.5)	(-.04,	.04)
42	(565775.0,	5946725.0)	(6658.8,	475.2)	(-.02,	.05)
6	(379850.0,	5914400.0)	(913.9,	3054.7)	(-.05,	.01)
12	(352250.0,	5860100.0)	(467.4,	5034.6)	(.03,	-.01)
9	(369277.0,	5882300.0)	(836.2,	4178.6)	(.00,	-.02)
47	(511750.0,	5971050.0)	(4710.8,	134.8)	(.01,	.01)
23	(437475.0,	5926250.0)	(2679.4,	2195.6)	(-.01,	.00)
3	(390400.0,	5936800.0)	(1070.4,	2243.9)	(.00,	-.01)
24	(411575.0,	536400.0)	(1759.5,	2082.4)	(.00,	.00)
2	(376125.0,	595125.0)	(498.7,	1931.1)	(.00,	.00)
17	(464600.0,	597150.0)	(3187.9,	520.9)	(.00,	.00)
1	(3894450.0,	5959550.0)	(853.6,	1517.6)	(.00,	.00)

RMS=(.14, .13) .19

Appendix 5.3 Results of the ANOVA

Township 53 Range 10 W 4th

1. Analysis of Variance for Variable AREA
   Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			37616116541	57336263333
1	471	201475.806		
2	502	189034.067	F Value	Prob > F
			0.656	0.4182

2. Analysis of Variance for Variable EDGE
   Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			265646.682	3179039.57
1	471	2228.18486		
2	502	2195.12155	F Value	Prob > F
			0.084	0.7726

3. Analysis of Variance for Variable SHAPE
   Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			0.438290761	0.116257555
1	471	1.48065817		
2	502	1.52312749	F Value	Prob > F
			3.770	0.0525

Township 49 Range 9 W 4th

1. Analysis of Variance for Variable AREA
   Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			6370030147	82678697048
1	524	181416.985		
2	510	186381.539	F Value	Prob > F
			0.077	0.7814

2. Analysis of Variance for Variable EDGE
   Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			1537624.75	4948422.93
1	524	2046.75510		
2	510	2123.88712	F Value	Prob > F
			0.311	0.5774

3. Analysis of Variance for Variable SHAPE
   Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			1.26282422	0.148409850
1	524	1.44423664		
2	510	1.51413725	F Value	Prob > F
			8.509	0.0036

Township 51 Range 11W 4th

1. Analysis of Variance for Variable AREA
   Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			1.02624E11	45482348865
1	563	177616.936		
2	507	197230.572	F Value	Prob > F
			2.256	0.1334

2. Analysis of Variance for Variable EDGE
Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			2276965.85	2423038.90
1	563	2076.66586		
2	507	2169.05310	F Value	Prob > F
			0.940	0.3326

3. Analysis of Variance for Variable SHAPE
Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			0.126108919	0.100072553
1	563	1.47541741		
2	507	1.49715976	F Value	Prob > F
			1.260	0.2619

Township 55 Range 7 W 4th

1. Analysis of Variance for Variable AREA
Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			1881865296	1.580304E11
1	486	195295.794		
2	493	192522.832	F Value	Prob > F
			0.012	0.9131

2. Analysis of Variance for Variable EDGE
Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			1561088.27	5211837.09
1	486	2123.47595		
2	493	2203.34223	F Value	Prob > F
			0.300	0.5843

3. Analysis of Variance for Variable SHAPE
Classified by Variable YEAR

YEAR	N	Mean	Among MS	Within MS
			1.21956859	0.141721942
1	486	1.47119342		
2	493	1.54178499	F Value	Prob > F
			8.605	0.0034