WETLAND CLASSIFICATION AND ENVIRONMENTAL MONITORING IN THE PEACE-ATHABASCA DELTA USING LANDSAT DIGITAL DATA

By

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WETLAND CLASSIFICATION AND ENVIRONMENTAL
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USING LANDSAT DIGITAL DATA

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ABSTRACT

Through the use of LANDSAT digital data and automated image classification techniques, habitats of the Peace-Athabasca Delta region in northeastern Alberta were classified, and mapped, a number of change detection techniques evaluated, and the potential of using LANDSAT digital data in a long-term monitoring program assessed.

The General Electric Image 100 Multispectral Image Analysis system was used to conduct a supervised classification for a 1200 Km^2 test site centered on Mamawi Lake at the east end of the Delta complex. To provide optimum opportunity for detecting change and for testing the classification of habitats under differing conditions, two images, one with normal water levels (August 1, 1976) and one with above normal water levels (August 26, 1973), were selected for analysis. A total of eight habitats was identified for the 1976 data and seven for the 1973 date.

Classification accuracy of the 1976 habitats was considered excellent when compared with available ground reference data. Although ground reference data were not available for 1973, classification results are considered good. Spatial filtering of the classified scenes was found to improve the visual quality of the images, although only marginal improvements in classification accuracy resulted.

The classified scenes were found to be useful in delineating major topographic subdivisions within the Delta. These subdivisions can be used to identify areas most susceptible to change. Using an image registration technique, the 1973 and 1976 scenes were overlayed and two change detection

analyses carried out. These were ratioing and post-classification change detection. Ratioing was found to be a relatively fast and simple method for determining the areal extent of flooding and areas of major vegetation change. Post classification change detection was carried out for the entire study area as well as 1/2 and 1/8 areas. The technique was found to be useful in identifying the nature of change, although further research is required before an evaluation of the absolute values generated in the analyses can be fully assessed.

It is anticipated that when extrapolated over the entire 37,500 Km^2 area of the Delta, the use of digital LANDSAT data will provide a relatively low cost and yet effective means of maintaining a current habitat map of the region, as well as providing an effective method for detecting and monitoring environmental change.

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CHAPTER 1

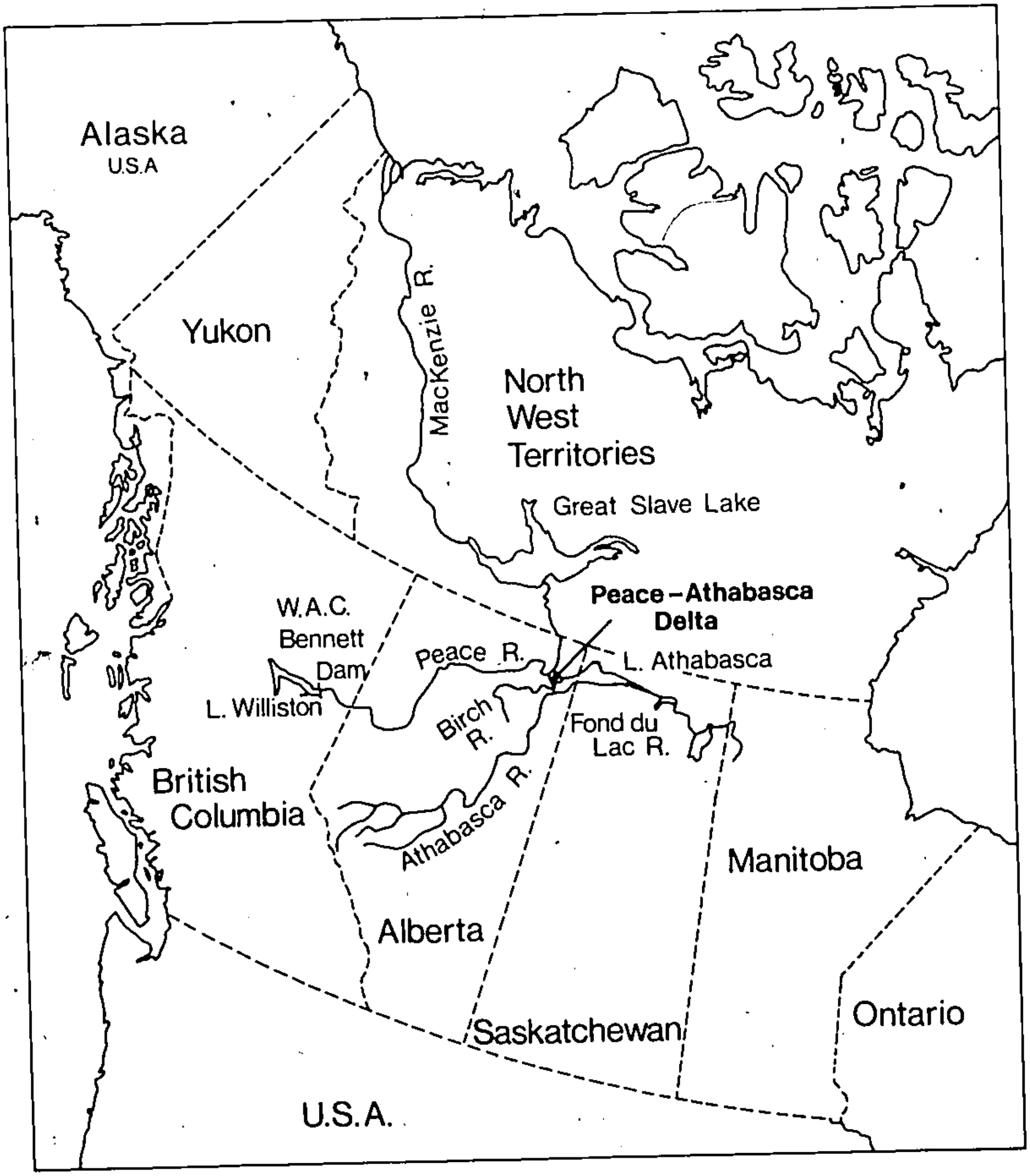
INTRODUCTION

1.1 Purpose of the Study

The Peace Athabasca Delta is a dynamic, complex wetland environment which has recently attracted considerable interest from the general public and the scientific community. Attention was focused on the region after 1968 when several years of abnormally low water levels occurred. This was due to the filling of the Williston Lake Reservoir behind the W.A.C. Bennett hydro-electric power dam on the Peace River in northern British Columbia (Figure 1.1). The volume of flow in the Peace River, was substantially reduced, thereby affecting the ecology of the delta. Significant and alarming changes in habitats occurred and the traditional role of the delta as a valuable ecological region for migrating, breeding and nesting waterfowl was threatened.

Studies were initiated by the governments of Alberta and Canada to examine the characteristics of the new flow regime and to determine ways of mitigating its effects. Although the results of these studies were subsequently published (Peace-Athabasca Delta Project Group, 1973) and recommendations regarding water level control structures put into effect, the inescapable fact remains that a major and ecologically important northern ecosystem has been irrevocably altered. In spite of subsequent remedial measures, the natural character of the delta remains in jeopardy (Cordes and Pearce, 1977). As a result, management of the delta's resources is now an important consideration and a long term environmental

Figure 1.1 General location of the Peace-Athabasca Delta region. The Delta is located approximately 1,120 Km downstream from the W.A.C. Bennett dam.


Alaska
U.S.A
Yukon
MacKenzie R.
North
West
Territories
Great Slave Lake
Peace-Athabasca
Delta
W.A.C.
Bennett
Dam
Peace R.
L. Athabasca
L. Williston
Birch
R.
Fond du
Lac R.
British
Columbia
Athabasca R.
Manitoba
Alberta
Saskatchewan
Ontario
U.S.A.

monitoring program is essential.

Much of the region lies within the confines of Wood Buffalo National Park. Thus, responsibility for the establishment of a monitoring program rests with the Federal Government. In 1974 a program was established to monitor the effects of the new hydrologic regime on the vegetation communities in the delta. The basis for the program is field study involving detailed ground sampling along pre-selected transects considered representative of the various habitats in the delta (Cordes, 1975). Large scale 70 mm colour infrared photography is used to aid mapping along each transect. Early studies by Dabbs (1971) and Dirschl *et al* (1974) had demonstrated that through the use of small scale (1:37,000) and large scale (1:7,000) aerial photos combined with detailed ground sampling, vegetation communities in the delta could be effectively mapped and classified. To map and classify the entire delta, however, at such scales and on a regular basis would require a considerable investment in both human and material resources.

It is suggested, however, that digital LANDSAT satellite data offers a possible method for mapping, classifying and monitoring the delta's resources. Although long touted as a potentially useful system for environmental monitoring (Sayn-Wittgenstein and Aldred, 1976; Thie and Wachmann, 1974) few serious attempts have been made to fully incorporate LANDSAT into an operational monitoring program. The frequent and repetitive coverage and the relatively low data acquisition costs to users combine to make LANDSAT an ideal data acquisition vehicle for such a task.

This thesis is in part, a contribution to the continuing requirement of the National Parks Branch for an effective and yet cost-conscious monitoring program in the delta. The objective of the study is to determine what role digital LANDSAT data might play in any future mapping, classification and monitoring program in the Peace-Athabasca Delta by:

(a) evaluating the effectiveness of digital LANDSAT data in mapping and classifying habitat types, and

(b) evaluating the potential for change detection, and hence the monitoring capabilities of digital LANDSAT data.

1.2 Description of the Study Area.

The Peace-Athabasca Delta is located on the west end of Lake Athabasca and lies between 58°15' and 58°50'N and by between 110°40' and 112°30'W (Figure 1.2). Approximately 4,000 km^2 in area, it represents one of the world's largest freshwater deltas.

Following deglaciation approximately 10,000 years B.P., glacial Lake Athabasca was formed and occupied a much larger basin than at present. Raised glacial lake beaches at the west end of Lake Claire (Figure 1.3) are evidence for this early condition. Since then, the Peace and Athabasca Rivers have deposited immense quantities of silt and other fluvial material into the western end of Lake Athabasca producing deltas which have subsequently coalesced to form the present Peace-Athabasca Delta (Bayrock and Root, 1971). The Peace Delta has currently reached a stage of development where deposition takes place only during periods of flood. In contrast, the Athabasca River continues to deposit a great deal of sediment in its delta and is actively extending its area. Currently a third, although much smaller delta (168 km^2), is building at the mouth of the Birch River on the west side of Lake Claire.

Occupying approximately 4% of the Lake Athabasca basin, the area

Figure 1.2 The 4,000 Km^2 Peace-Athabasca Delta located on the west end of Lake Athabasca.

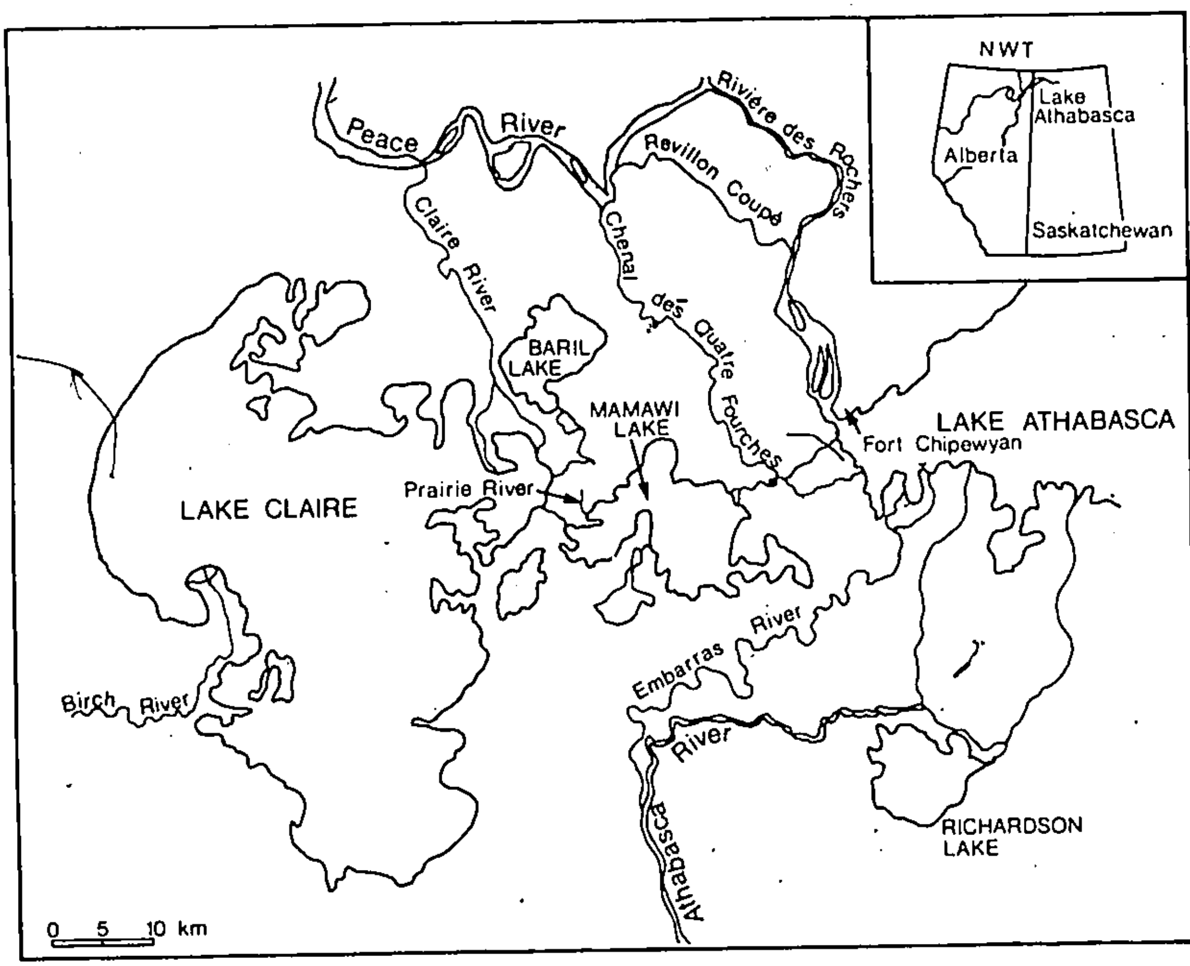

NWT
Lake Athabasca
Alberta
Saskatchewan
Peace River
Rivière des Rochers
Revillon Coupé
Claire River
Chenal des Quatre Fourches
BARIL LAKE
MAMAWI LAKE
LAKE ATHABASCA
Fort Chipewyan
Prairie River
LAKE CLAIRE
Embarras River
Birch River
Athabasca River
RICHARDSON LAKE
0 5 10 km

Figure 1.3 Raised glacial lake beach ridges near the west end of Lake Claire.

is characterized by several large but relatively shallow lakes (Claire, Mamawi and Baril). In addition, numerous perched basins and meandering stream channels are encountered. Relief in the delta is slight with the vegetation patterns reflecting minor differences in topography and moisture regime. During spring flood conditions, water from Lake Athabasca spills into the Delta inundating and recharging the lakes and perched basins with nutrient rich sediments. At the same time, the products of organic decomposition are flushed out of the system. Biologically rich and diverse, the region is an important international resource as a major habitat area for millions of migrating waterfowl. It also supports the world's largest herd of free-roaming bison and is an important hunting, trapping and fishing area for local residents.

A more detailed description of the study region and its major components is presented in Chapter 2 of the thesis.

1.3 Data Sources

During the period 1968-72, numerous ecological investigations were carried out in the region as scientists attempted to discover the effects of the new hydrologic regime of the Peace River on the ecology of the delta. These studies published by the Peace-Athabasca Delta Project group (1973) and the data acquired for the monitoring program established in 1974 provide the basic reference material used to support the analyses of LANDSAT data in this study. Remote sensing data obtained during the course of these studies and used in this investigation are listed in Table 1.1.

1.4 Pertinent Literature

1.4.1 Ecological Investigations

Table 1.1. Remote Sensing Imagery used for Habitat Classification and Change Detection in the Peace-Athabasca Delta.

Aerial Photography

Date	Scale	NAPL Reference	Film Type
1971	1: 60,000	A30340 15- 22	Aero colour negative (2445)
1975	1:100,000	A37177 119-122 A37180 14- 17	Colour Infrared (2443)
1975	1: 30,000	A37179 141-147 A37179 85- 89	Aero colour negative (2445)
1976	1: 7,000	Available only through Parks Canada, Prairie Region, Winnipeg.	Colour Infrared (70mm)

LANDSAT Analogue and Digital Data

Date	Frame Number	Bands
26 August 1973	10399-18104	4,5,6,7
1 August 1976	20557-17522	4,5,6,7

A substantial literature on the ecology of the Peace-Athabasca Delta is available and falls into three main time periods: pre-1950, 1968-72 and 1974-present. The pre-1950 period consists primarily of the accounts of Raup (1930, 1933, 1935, 1936, and 1946) who visited the area and undertook detailed studies on the vegetation, landforms and hydrologic relationships. Descriptions of the area prior to Raup occur mainly in the journals of early explorers and trappers who travelled through the region during the opening of Canada's Northwest (Fuller and LaRoi, 1971).

Beginning in 1968 and continuing until 1972, studies of the effects of low water levels in the delta were undertaken initially by the Canadian Wildlife Service (Dabbs, 1971 and Dirschl, 1970 [a] and [b]) and later by the Peace-Athabasca Delta Project Group (1973). These studies provide a large volume of literature on the biotic and abiotic relationships in the area. Most importantly, the studies document the major successional trends which occur in the area under normal hydrologic conditions as well as periods of prolonged flooding or drying. Recommendations regarding the restoration of water levels in the delta were made (Peace-Athabasca Delta Project Group, 1972) and subsequently effected.

In 1974, Parks Canada initiated an environmental monitoring program designed to provide detailed information on changes in the vegetation following implementation of the remedial measures (Cordes, 1975). This program continued to 1978 when a temporary halt in the program occurred due to government fiscal restraint programs and the need to evaluate the longer term monitoring needs and strategies. Results of the Peace-Athabasca Delta Project Group studies and the more recent studies by Cordes (1975), Cordes and Strong (1976) and Cordes and Pearce (1977) are essential to understanding the present study and as such are reported separately and in more detail in Chapter 2.

1.4.2 Change Detection using LANDSAT Digital Data

A review of the literature reveals that although a number of studies using LANDSAT digital data have been carried out to demonstrate its utility for mapping wetland environments (Carter *et al*, 1973; Carter and Schubert, 1974; Carter, 1976 [a] and [b]; Cartmill, 1973; Frazier *et al*, 1973; Klemas *et al*, 1973; Seevers *et al*, 1973; Wobber and Anderson, 1973; Wickware, 1979; Cowell *et al*, 1979; Weismiller *et al*, 1977) few, if any, have attempted to demonstrate the feasibility of using this data in an environmental change detection program (Rubec, 1978).

Although a variety of change detection techniques has been developed, the majority of studies to date have concentrated on land-use changes in or near urbanizing areas (Wilson *et al*. 1976; Atlantic Regional Commission, 1977; Ellefsen and Peruzzi, 1976).

Change detection in wetland environments has for the most part been undertaken using conventional remote sensing techniques (Eitel, 1974). A more recent study by Weismiller *et al*., (1977) did however utilize LANDSAT digital data in a study of change detection in coastal zone environments. Four techniques for detecting change were designed for evaluation purposes: (1) post-classification comparison change detection, (2) delta data change detection, (3) spectral temporal change classification and, (4) layered spectral temporal change classification. The post-classification technique was considered the most reliable and results from the other techniques were evaluated against this method. A more detailed discussion of change detection techniques is provided in Chapter 5.

1.5 Outline of the Thesis

The foregoing provides a brief introduction to the background and purpose of the present study.

Pertinent information on the ecological relationships operative in the delta is considered in Chapter 2. This discussion is important as it provides the necessary background to understand the analysis and results presented in this study.

Chapters 3, 4, 5, and 6 form the main body of the thesis. Chapter 3 outlines the methods and techniques used for the analysis and interpretation of the LANDSAT data, the digital classification and the change detection techniques. Chapter 4 details the results obtained using supervised digital classification methods while Chapter 5 presents the results obtained using the ratioing and post-classification change detection techniques. Chapter 6 provides a brief discussion of the salient and important points while relating them to the objectives of the study. The final chapter summarizes the findings of this study and provides recommendations concerning the role that digital LANDSAT data and automated image classification techniques can play in a future monitoring program for the Peace-Athabasca Delta.

CHAPTER 2

HYDROLOGIC AND VEGETATION PROCESSES

2.1 Introduction

The Peace-Athabasca Delta ecosystem is dynamic and complex. A general knowledge of the major forces and ecological relationships that are encountered is, however, important for this study. The purpose of this chapter is to familiarize the reader with the essentials relating to the past and current hydrologic regime, the vegetation communities and their relationships to the landforms. The successional trends in these communities under differing hydrologic conditions are also discussed.

2.2 Hydrologic Characteristics

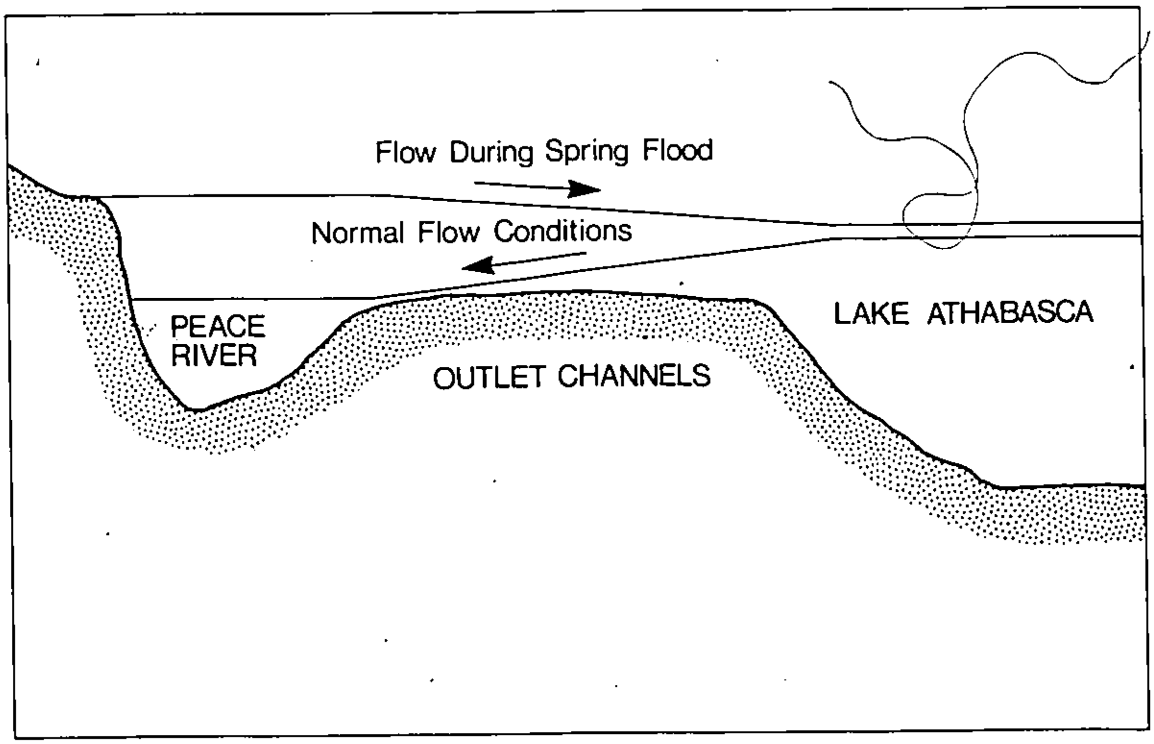
2.2.1 Natural Regime

The biological importance of the delta results from a unique hydrological relationship between Lake Athabasca, the Peace and Athabasca Rivers, their tributary channels and the numerous perched basins throughout the area. Each spring until 1969, the rising flood waters on the Peace River created a hydrologic dam preventing the outflow channels of Lake Athabasca and the delta from flowing into the Peace River. The hydrologic dam, in effect, caused the waters to flow back into Lake Athabasca, thereby forcing the lake waters to rise rapidly and ultimately reach sufficient elevation above sea level to flood into the delta. This resulted in a recharge of the lakes and perched basins (Figure 2.1).

2.2.2 Modified Regime

As a result of concern about the ecological effects of lower water

Figure 2.1 Schematic diagram of water flow in the outlet channels of the Peace-Athabasca Delta. (Source: Bennett 1971).


Flow During Spring Flood
Normal Flow Conditions
PEACE RIVER
OUTLET CHANNELS
LAKE ATHABASCA

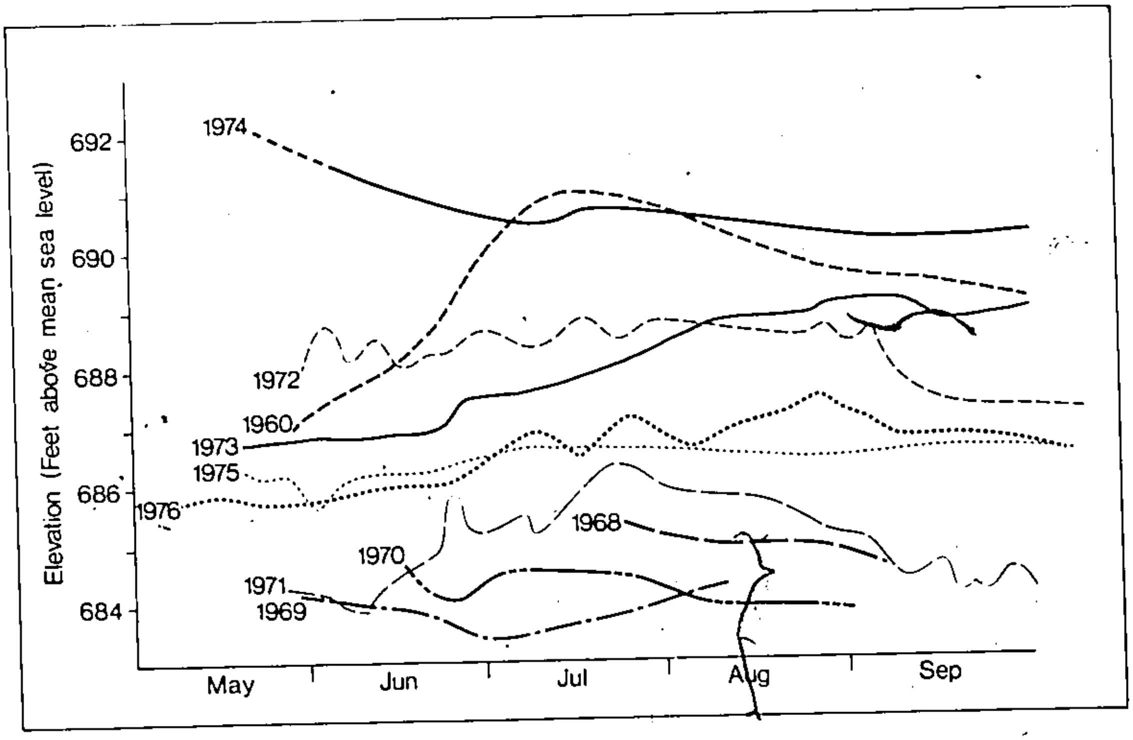
levels on the Peace River resulting from construction of the W.A.C. Bennett dam, and until a permanent remedial structure could be built, a temporary rockfill weir was constructed on the western arm of the Quatre Fourches Channel (Figure 2.2). This weir, built to an elevation of 688.5 feet (209.9 meters) a.s.l. was completed in the spring of 1972 and was designed to hold water in the delta, thereby improving water levels. As a result of overbank flooding from the Peace River due to ice jamming and the impact of the weir, water levels in 1972 approached normal peak summer levels (Figure 2.3). Although Lake Athabasca levels began dropping, as is normally the case during August and September, lakes in the delta were held near their summer maximum (688.1 feet/209.7 meters a.s.l.) by the weir. In the spring of 1973, ice jam flooding resulted in damage to the weir, which was subsequently rebuilt to an elevation of 694 feet (211.5 meters) a.s.l. (Cordes, 1975). By the end of August, water levels in the delta had reached 689 feet (210 meters) a.s.l. (Figure 2.3). In the spring of 1974, with water levels already 1.2 - 1.5 meters higher than normal, flooding increased water levels a further 0.8 meters to reach a peak of 691.09 feet (210.6 meters) a.s.l. After three years of successively high water levels, the Quatre Fourches weir was finally removed in the fall of 1974 and water levels declined until April 1975. During 1975, water levels were lower (Figure 2.3), reaching a summer maximum of 687 feet (209.4 meters).

In 1976 the Little Rapids weir on the Riviere Des Rochers was completed (Figure 2.4). The weir, located on the principal outlet from Lake Athabasca, was recommended by the Peace-Athabasca Delta Project Group as a means of counteracting the effects of reduced Peace River flows,

Figure 2.2 Temporary rockfill weir on the western arm of the Quatre Fourches Channel. Weir was initially constructed in spring of 1972 and was finally removed in the fall of 1974. (Source: L. D. Cordes).

Figure 2.3 Recorded water levels, Mamawi Lake 1968-1976.

(Source: Cordes and Pearce 1977).



Elevation (Feet above mean sea level)
692
690
688
686
684
1974
1972
1960
1973
1975
1976
1970
1971
1969
1968
May
Jun
Jul
Aug
Sep

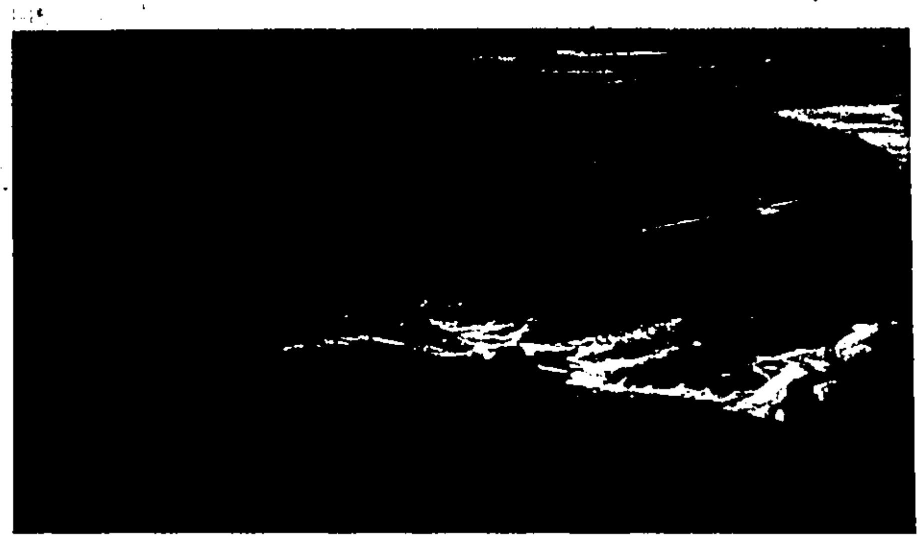


Figure 2.4 Permanent weir at the Little Rapids site on the Rivière des Rochers.

thereby helping to restore 'normal' hydrological conditions to the delta. Relatively stable water levels (Figure 2.3) characterized 1976, although, as in 1975, levels were still 0.8 meters below the long term mean maximum. Similar conditions persisted into 1977, although spring to late summer water levels were approximately 0.3 and 0.6 meters higher than in 1975 and 1976 respectively.

Cordes and Pearce (1978, p. 25) in comparing the present water regime with that for a 'normal' year, summarize the major differences as follows:

(1) "Water level amplitudes over the growing season are 2.4' [0.7 meters] lower than were experienced under the 'normal' regime, although levels in the late summer and on are now 2'-2.5' [0.6-0.8 meters] higher and are being maintained for a longer period".

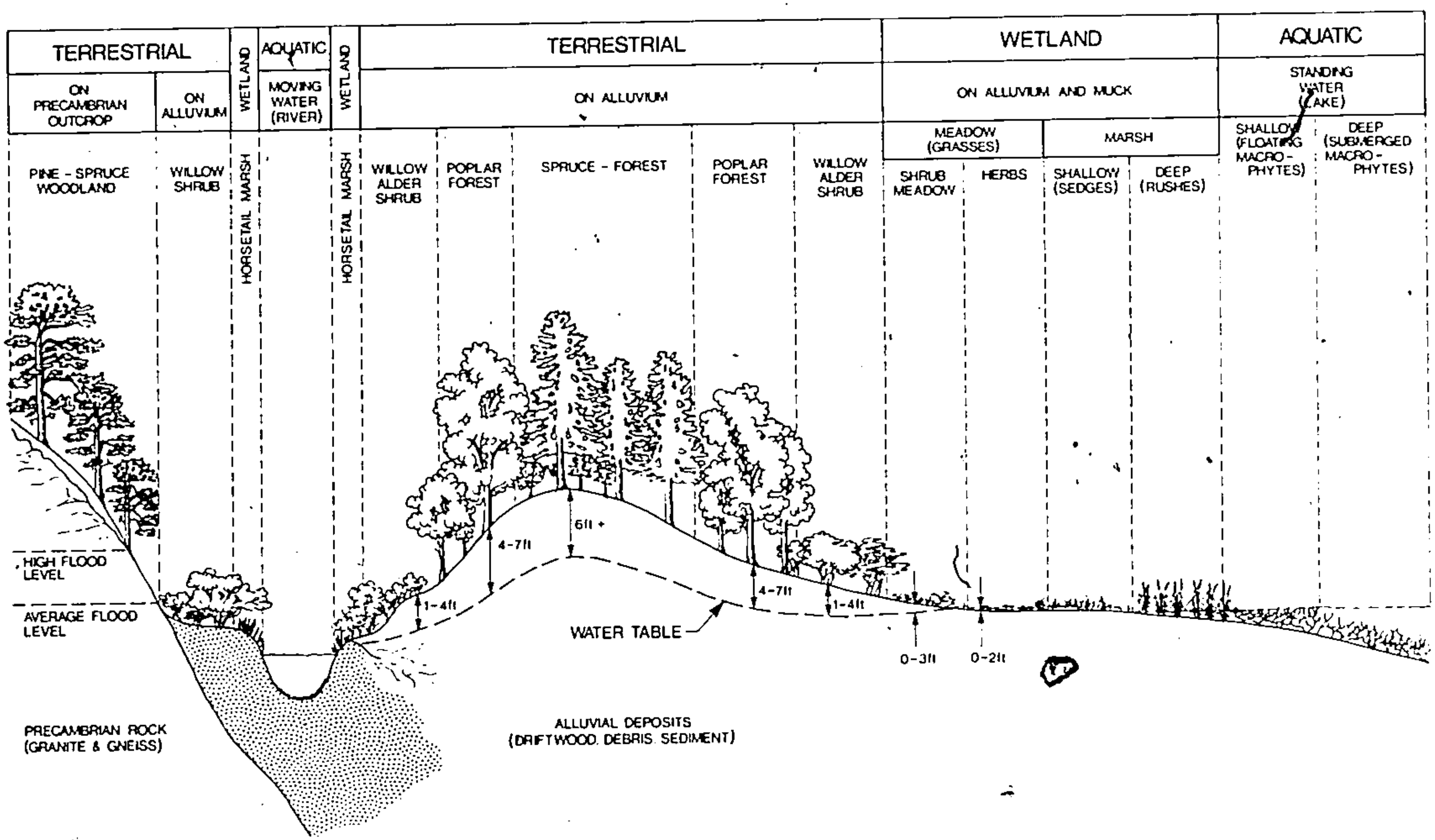
(2) "The summer peaks of 690' [210.3 meters] under the 'normal' regime which served to flood most of the perched basins are not now being attained".

2.3 Vegetation Characteristics

Although relief in the delta is slight, the vegetation patterns reflect minor differences in topography and moisture regime. The floods and associated fluctuating water levels described earlier are, in fact, primarily responsible for the vegetation patterns or habitats observed in the delta. Changes in the hydrologic regime result in ecological adjustments within the delta (Dirschl, 1972).

Figure 2.5 is an idealized cross-section which illustrates the broad relationships between the vegetation and the major landforms.

Figure 2.5 Diagrammatic profile of habitat relationships to landscape position. (Source: Fuller and La Roi 1971).


TERRESTRIAL
ON PRECAMBRIAN OUTCROP
ON ALLUVIUM
WETLAND
AQUATIC
MOVING WATER (RIVER)
WETLAND
TERRESTRIAL
ON ALLUVIUM
WETLAND
ON ALLUVIUM AND MUCK
AQUATIC
STANDING WATER (LAKE)
PINE - SPRUCE WOODLAND
WILLOW SHRUB
HORSETAIL MARSH
HORSETAIL MARSH
WILLOW ALDER SHRUB
POPLAR FOREST
SPRUCE - FOREST
POPLAR FOREST
WILLOW ALDER SHRUB
MEADOW (GRASSES)
MARSH
SHRUB MEADOW
HERBS
SHALLOW (SEDGES)
DEEP (RUSHES)
SHALLOW (FLOATING MACRO-PHYTES)
DEEP (SUBMERGED MACRO-PHYTES)
HIGH FLOOD LEVEL
AVERAGE FLOOD LEVEL
1-4ft
4-7ft
6ft +
4-7ft
1-4ft
0-3ft
0-2ft
WATER TABLE
PRECAMBRIAN ROCK (GRANITE & GNEISS)
ALLUVIAL DEPOSITS (DRIFTWOOD, DEBRIS, SEDIMENT)

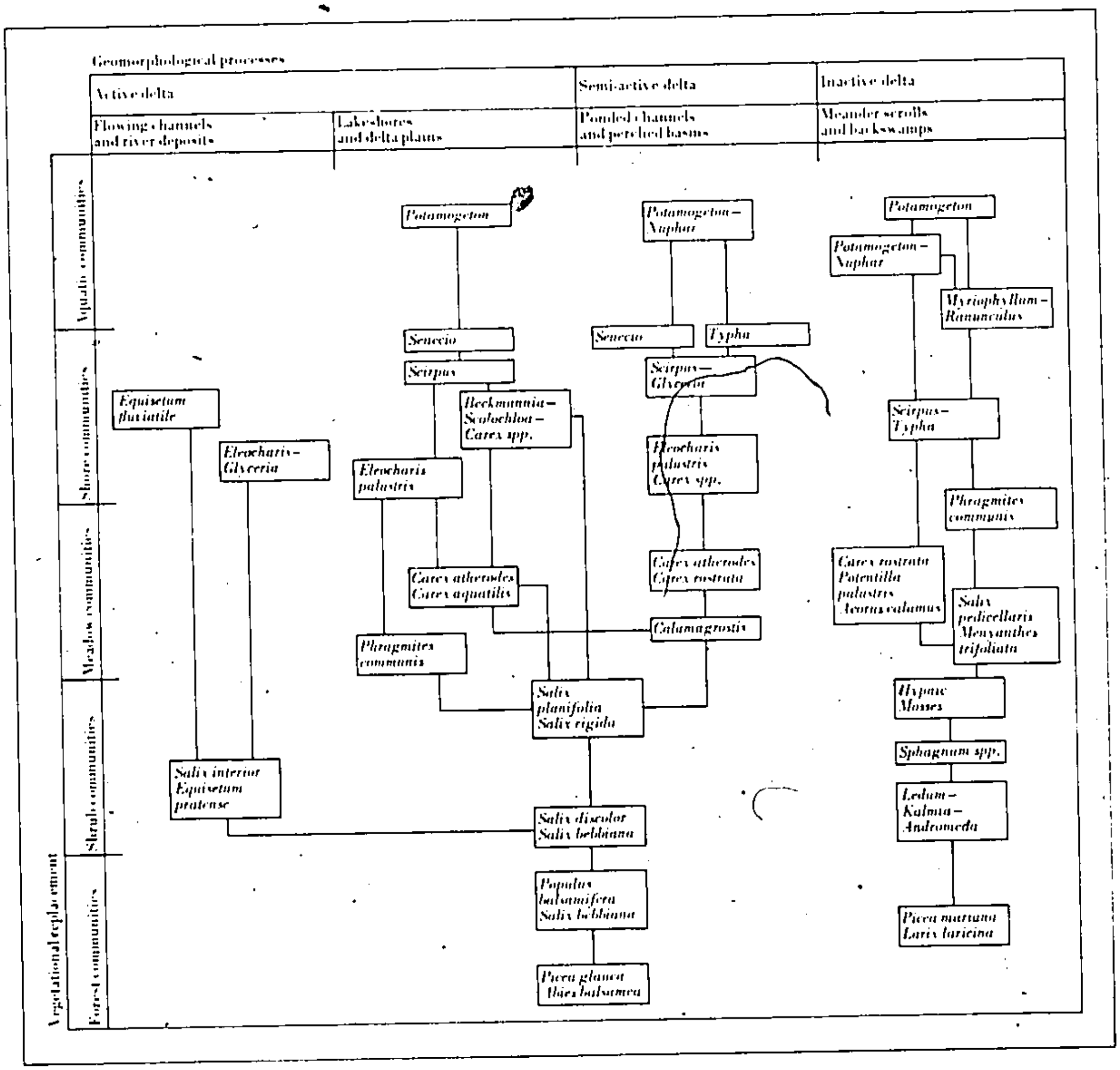
2.3.1 Vegetation Succession

The actual occurrence and extent of each habitat type depends, of course, on its landscape position and the state of the hydrologic regime over a period of time. Periods of prolonged flooding, as well as prolonged drying, have occurred naturally in the delta. The new regime, however, as established by the W.A.C. Bennett dam, has effectively "dampened" this normally fluctuating regime. An understanding of plant succession is therefore necessary, if accurate prediction of vegetation response to changing water levels is to be made. Dirschl *et al.* (1974) provided a relatively detailed schematic of successional trends for plants in the delta under 'normal' conditions (Figure 2.6). A simplified model depicting successional trends expected under either prolonged flooding or declining water levels was prepared by the Peace-Athabasca Delta Project Group (1973) to predict the habitat types in the delta resulting from either condition (Figure 2.7). This latter diagram is of particular importance since the change detection aspects of this thesis examine conditions following a number of years of prolonged flooding.

2.4 Habitat Classification

One of the major objectives in this study is to develop an ecologically sensitive classification of habitat types in the delta. In developing the classification system for use with LANDSAT data and to make it as compatible as possible for integration into a classification system using other remote sensing techniques, the classification system initially developed by Dabbs (1971) and Dirschl *et al.* (1974), and later adopted and modified by Cordes (1975) for his monitoring studies in the delta, has been followed as closely as possible.

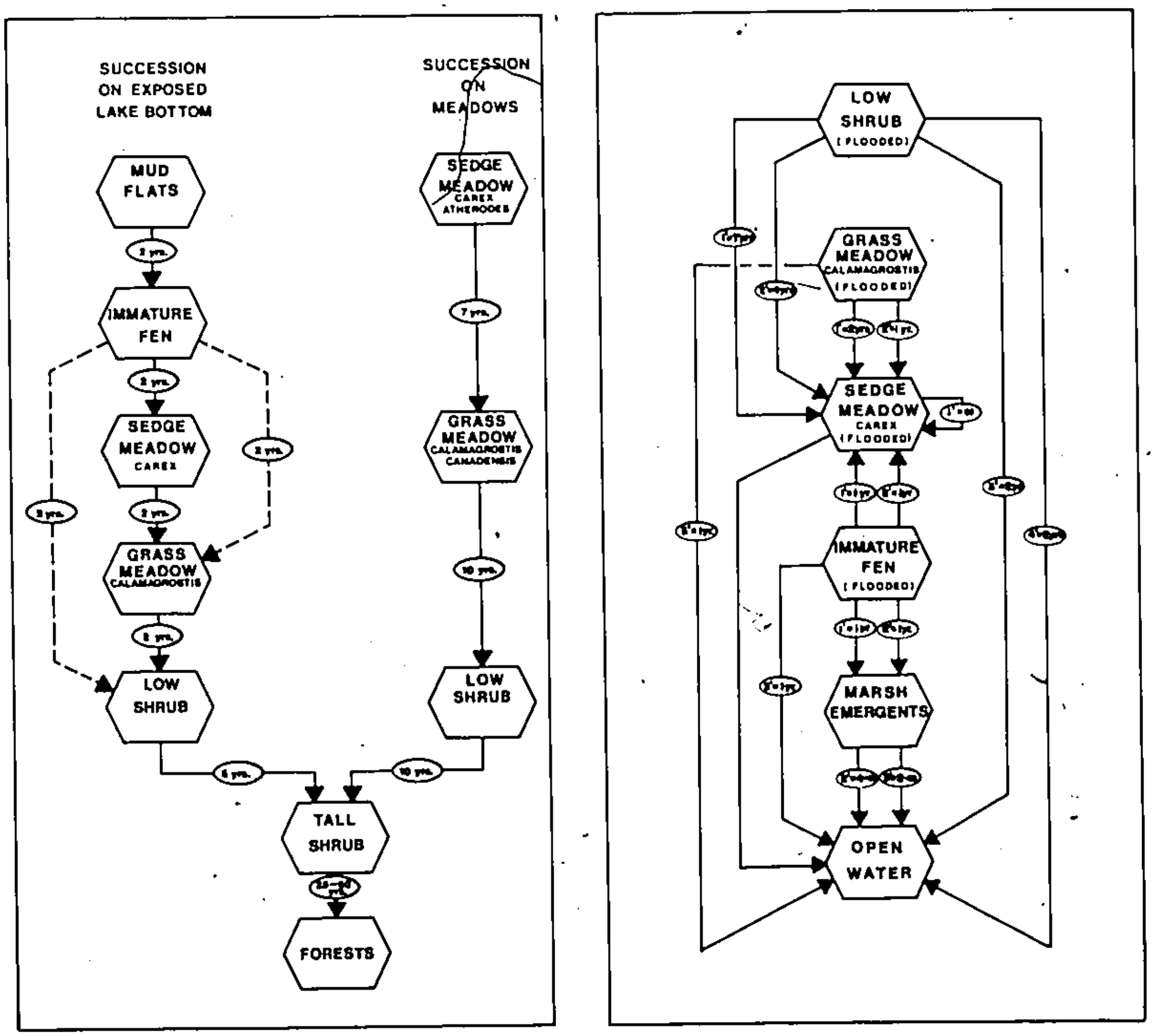
Figure 2.6 Outline of plant successional trends in the Peace-Athabasca Delta (Source: Dirschl *et al.* 1974).



Geomorphological processes
Active delta
Semi-active delta
Inactive delta
Flowing channels and river deposits
Lakeshores and delta plains
Ponded channels and perched basins
Meander scrolls and backswamps
Aquatic communities
Shore communities
Meadow communities
Shrub communities
Forest communities
Vegetational replacement
Potamogeton
Potamogeton–Nuphar
Potamogeton
Potamogeton–Nuphar
Myriophyllum–Ranunculus
Senecio
Scirpus
Senecio
Typha
Scirpus–Glyceria
Equisetum fluviatile
Beckmannia–Scolochloa–Carex spp.
Eleocharis–Glyceria
Eleocharis palustris
Eleocharis palustris Carex spp.
Scirpus–Typha
Phragmites communis
Carex atherodes Carex aquatilis
Carex atherodes Carex rostrata
Carex rostrata Potentilla palustris Acorus calamus
Salix pedicellaris Menyanthes trifoliata
Calamagrostis
Phragmites communis
Salix planifolia Salix rigida
Hypnic Mosses
Sphagnum spp.
Salix interior Equisetum pratense
Ledum–Kalmia–Andromeda
Salix discolor Salix bebbiana
Populus balsamifera Salix bebbiana
Picea mariana Larix laricina
Picea glauca Abies balsamea

POOR COPY

Figure 2.7 Successional trends expected under conditions of declining water levels (left diagram) and prolonged flooding (right diagram). (Source: Peace-Athabasca Delta Project Group 1973).


SUCCESSION ON EXPOSED LAKE BOTTOM
MUD FLATS
IMMATURE FEN
SEDGE MEADOW
CAREX
GRASS MEADOW
CALAMAGROSTIS
LOW SHRUB
SUCCESSION ON MEADOWS
SEDGE MEADOW
CAREX ATHEROOES
7 yrs.
GRASS MEADOW
CALAMAGROSTIS CANADENSIS
10 yrs.
LOW SHRUB
10 yrs.
TALL SHRUB
FORESTS
LOW SHRUB (FLOODED)
GRASS MEADOW
CALAMAGROSTIS
(FLOODED)
SEDGE MEADOW
CAREX
(FLOODED)
IMMATURE FEN
(FLOODED)
MARSH EMERGENTS
OPEN WATER

On the basis of these detailed studies of plant successional trends, and through the use of remote sensing imagery and different mapping scales, two levels of landscape classification for the delta have been developed. The classification for mapping the area at a scale of 1:37,000 is presented in Table 2.1 while in Table 2.2 the classification used for mapping the study area at a scale of 1:10,000 shown. The more detailed classification (Table 2.2) is used by Dirschl *et al.* (1974) and Cordes (1975) at the field transect mapping level. A summary of the classification used by Cordes *et al.* (1977) is provided in Table 2.3.

Table 2.1. Classification for Mapping Habitats in the Peace-Athabasca Delta at the Scale of 1:37,000. (Source: Dirschl *et al.*, 1974.)

LANDSCAPE TYPE	CLASS
	Terrestrial Community Types:
Delta	Coniferous forest
	Deciduous forest
	Tall shrub: 3-6 m
	Low shrub: <3 m
	Fen: predominantly graminoids, may contain a few scattered low shrubs
	Immature fen: scattered low plants on newly colonized mudflats
Precambrian outcrop	Forest
	Grassland
	Water Body Types:
Water channel	Flowing stream and river
	Intermittent stream
	Abandoned stream bed and meander scroll
Standing water	Freely drained: deep and open
	Freely drained: shallow open with emergent vegetation
	Restricted drainage: open with emergent vegetation
	Severely restricted drainage: open with emergent vegetation

Table 2.2. Land Facet-Vegetation Type Classification for Mapping of Field Transects at the Scale of 1:10,000 in the Peace-Athabasca Delta. (Source: Dirschl *et al.*, 1974.)

I. ACTIVE DELTA

Point Bar and Levee (IA)

Equisetum
Eleocharis-Glyceria
Salix interior
Salix-Alnus
Betula
Populus
Picea

Lakeshore and Delta Plain (IB)

Potamogeton
Sparsely vegetated mudflat
Senecio
Scirpus
Eleocharis-Carex
Beckmannia-Scolochloa-Carex
Carex
Salix-Carex
Calamagrostis
Phragmites

II. SEMIACTIVE DELTA (perched basin and backslope of levee)

Potamogeton-Nuphar
Typha-Scirpus
Senecio
Equisetum
Scolochloa
Eleocharis-Carex
Carex
Calamagrostis
Salix

III. INACTIVE DELTA

Backswamp (wet depression) (IIIA)

Potamogeton-Nuphar-Myriophyllum
Scirpus-Typha
Phragmites
Equisetum-Acorus
Carex-Potentilla (floating mat)
Salix-Menyanthes (floating mat)

Meander Scroll (dry channel) (IIIB)

Carex
Calamagrostis
Salix
Betula

Precambiran Outcrop (IV)

Populus-Picea
Juniperus
Stipa-Artemisia

Table 2.3. The Classification System used by Cordes (1975) for Detailed Vegetation Monitoring Studies in the Peace-Athabasca Delta.

I. ACTIVE DELTA

Point Bar and Levee

E-G/1	*Eleocharis-Glyceria*
Sa/1	*Salix interior*
Sa-A/1	*Salix-Alnus*
Po/1	*Populus*
Pi/1	*Picae*

Lakeshore and Delta Plain

Sc/1	*Scirpus*
Sp/1	*Sparganium*
S/1	*Scolochloa*
S-C/1	*Scolochloa-Carex*
S-C-Sa/1	*Scolochloa-Carex-Salix*
E-C/1	*Eleocharis-Carex*
Eq/1	*Equisetum*
C/1	*Carex*
Ph/1	*Phragmites*
Sa-C/1	*Salix-Carex*
Se/1	*Senecio*
if/1	Immature Fen
Cal/1	*Calamagrostis*

OPEN WATER

Wf	Freely drained
Wr	Restricted drainage

II. SEMIACTIVE DELTA

P-N/2	*Potamogeton-Nuphar*
Sc/2	*Scirpus*
Sp/2	*Sparganium*
S/2	*Scolochloa*
S-C/2	*Scolochloa-Carex*
E-C/2	*Eleocharis-Carex*
Eq/2	*Equisetum*
C/2	*Carex*
Sa-C/2	*Salix-Carex*
Se/2	*Senecio*
if/2	Immature fen
Cal/2	*Calamagrostis*
Sa/2	*Salix*

III. INACTIVE DELTA

P-N-R/3	*Potamogeton-Nuphar-Ranunculus*
Sc-T/3	*Scirpus-Typha*
Eq-Ac/3	*Equisetum-Acorus*
C-Pt/3	*Carex-Potentilla*
C/3	*Carex*
Sa-M/3	*Salix-Menyanthes*
Sa/3	*Salix*

IV. PRECAMBIRAN OUTCROP

Po-Pi/4	*Populus-Picea*

OTHER

Svm	sparsely vegetated mudflats
d	Disturbed areas

CHAPTER 3

METHOD OF ANALYSIS

3.1 Selection of Imagery

As discussed in Chapter 1, the study has two objectives. These are to map and classify habitat types in the delta and to determine whether or not changes in these habitat types can be monitored using LANDSAT digital data and automated image analysis techniques. Although the first objective can be satisfied using single date classification, achievement of the second requires at least two dates for which data are available.

To provide optimum opportunity for detecting change and for testing the classification of habitat types in the delta under differing ecological conditions, it was decided to select one image with 'normal' and one with 'abnormal' conditions. Selection of the image with normal conditions was felt to be important, as it was hoped that the resultant classification could be used as 'baseline' information against which other conditions could be measured.

LANDSAT scene, 20557-17522, recorded on August 1, 1976 was selected as the one best representing 'normal' ecological conditions under the new hydrologic regime (Cordes and Pearce, 1977). On this date, water levels in the delta were approximately 686.84 feet (209.3 meters) (Water Survey of Canada, 1977), a substantial reduction from those experienced during the period 1972-74 (Figure 2.3).

LANDSAT scene 103399-18104 obtained on August 26, 1973 was selected as best representing 'abnormal' conditions in the delta. As discussed in Chapter 2, water levels had been higher in the delta since 1972, but not so high as to completely inundate the area. Extreme flood conditions were experienced in 1974 making the use of imagery from this year unsuitable. Figure 3.1 shows the south shore of Mamawi Lake under extreme flood conditions during 1974. Under such conditions, a visual interpretation of LANDSAT imagery is sufficient to assure the observer that significant change has occurred.

As a result of the on-going vegetation monitoring program in the delta, detailed ground knowledge in the form of transect data and 70 mm colour infrared phototography was available for developing the 1976 'baseline' classification. Ground data were not, however, available for 1973. This created a situation where an evaluation of the classification had to be more subjective in nature than for the 1976 results.

3.2 Mamawi Lake Test Site

Because of the large size of the delta, an area considered representative of the major habitat types was selected for detailed analysis. The 1,200 km^2 test site is centered on Mamawi Lake at the east end of the delta complex (Figure 3.2). Specific considerations in selecting the test site included the availability of:

(1) previously prepared maps of all or parts of the test area;

(2) detailed data from at least five transects. These transects, studied initially by Dabbs in 1971 and more recently by Cordes and Pearce (1977), are shown in Figure 3.3;

(3) 70 mm colour infrared (1:7,000 scale) photography for these

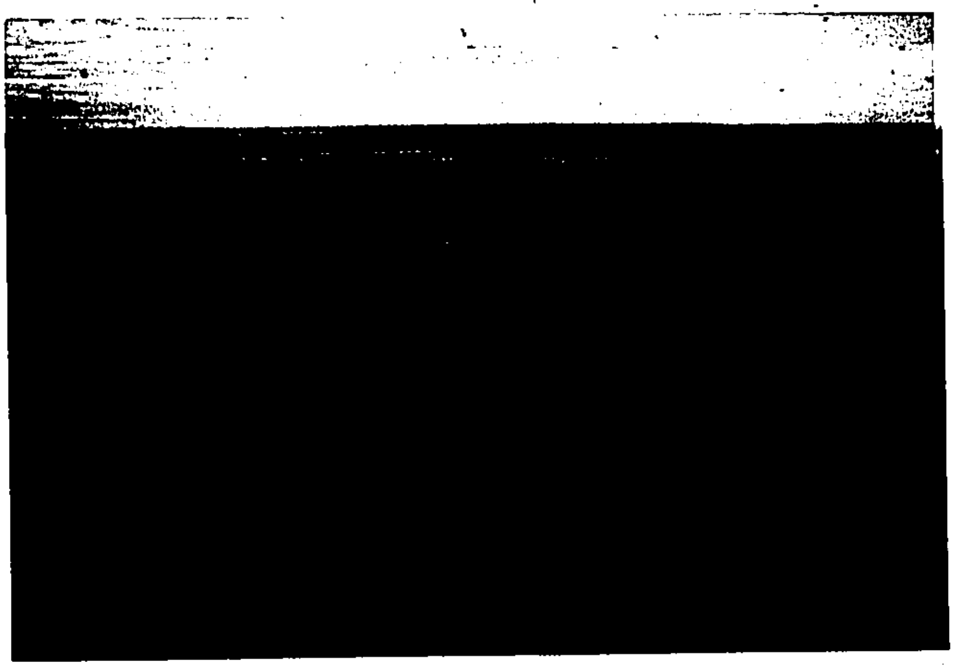
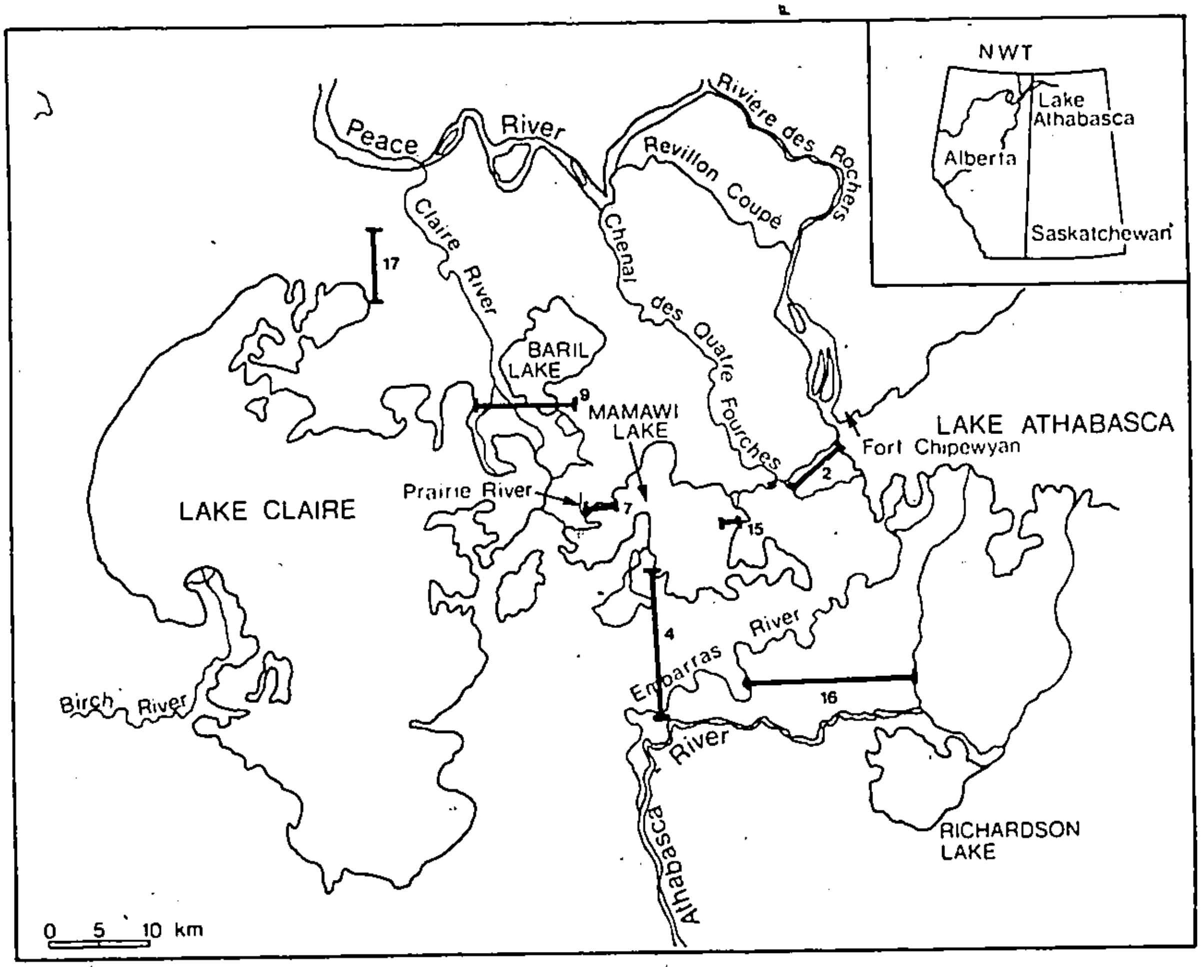


Figure 3.1 South shore of Mamawi Lake during flood conditions, 1974.

Figure 3.2 The 1,200 Km Mamawi Lake Test Site near the east end of Lake Athabasca. The townsite and airport of Ft. Chipewayn are located near the top right hand position of the figure.

Figure 3.3 Location of the various transects used initially by Dabbs in 1971 and later by Cordes for detailed vegetation monitoring studies in the Delta.


NWT
Lake Athabasca
Alberta
Saskatchewan
Peace River
Rivière des Rochers
Revillon Coupé
Chenal des Quatre Fourches
Claire River
BARIL LAKE
MAMAWI LAKE
LAKE ATHABASCA
Fort Chipewyan
LAKE CLAIRE
Prairie River
Birch River
Embarras River
Athabasca River
RICHARDSON LAKE
17
9
7
2
15
4
16
0 5 10 km

transects. The photography was able to be used in the selection of training (calibration) sites and in the analysis of the classification accuracy.

3.3 Analysis Procedures

3.3.1 Scene Classification

Digital analysis was carried out using the General Electric Image 100 Multispectral Image Analysis System located at the Canada Centre for Remote Sensing (CCRS) in Ottawa. Operators for the system were provided by CCRS. Details on the Image 100 system are available elsewhere and need not be repeated here (Goodenough and Shlien, 1974).

There are two basic methods of classification on the Image 100 system. Although both techniques were tested in this study, only the results of the supervised classifications, which proved to be the more successful, are reported in this thesis.

Supervised classification was carried out separately for each of the two selected dates. In developing the signature file for each scene, care was taken to ensure that a minimum of 50 pixels for each habitat type was selected. Training sites were pre-selected using the detailed ground transect data from Cordes (1975) and Cordes and Pearce (1977). Selected sites were marked on 1:30,000 scale colour air photos and referred to during the classification. Output displays and data from the Image 100 classification procedures included:

-35 mm colour slides of the classified test site which were obtained by photographing the Image 100 display monitor;

-1:125,000 scale binary theme prints (individual themes);

-1:50,000 scale alpha-numeric theme prints (all themes printed in a composite map);

-1:250,000 scale Electron Beam Image Recorder (EBIR) theme prints;

-various statistics for the classified scenes which are used during the classification and during further analysis of the classified scenes.

3.3.2 Scene Filtering

Following classification, each of the scenes was filtered using 3 x 3 weak and 3 x 3 strong filtering algorithms (Goldberg, 1975). This procedure is normally carried out to decrease the number of misclassified pixels and/or to decrease or 'smooth' the texture of the classifed scene (Schubert, 1978). Texture in any area of a scene generally results from the presence of small numbers of pixels of a different cover class from the majority class, or as a result of a highly variable cover (Schubert, 1978).

3.3.3 Scene Registration and Overlap

Prior to studying change detection between 1973 and 1976, it was necessary to overlay and register the two scenes as accurately as possible. Using procedures outlined by Shlien (1978), the two scenes were registered. This was done as accurately as possible since misregistration can result in erroneous detection of change. To simplify and improve the registration, the test site was divided in half. The same halves from the two scenes were then displayed simultaneously on the monitor. Twenty-five matching ground control points in areas that did not change between dates of images were then selected for carrying out the registration.

3.3.4 Ratioing

One of the simplest and quickest methods of change detection is ratioing (Wilson *et al.* 1976). Using bands 5 and 7 a preliminary attempt was made to determine areas of significant change between 1976 and 1973. The ratioing algorithm on the Image 100 does not permit statistics or other paper outputs to be generated. Colour 35 mm slides, however, were taken of the results displayed on the Image 100 monitor. These results were used only as a qualitative aid in evaluating change.

3.3.5 Post-Classification Change Detection

The change detection analysis used in this study is similar to methods described by Weismiller *et al.* (1977) and Rubec (1978). The method involves overlaying each theme from one year with each theme of the other. Compared on a class by class basis, the nature, location and amount of changed and unchanged area can be identified (Rubec, 1978).

Using preliminary results, it was observed that certain areas in the test site had undergone more extensive change than other areas. Three levels of change detection statistics and classification maps were therefore produced:

(a) statistics for the entire Mamawi Lake Test site

(b) statistics for 1/2 areas; and

(c) statistics for 1/8 areas

Results of the classification and change detection procedures are presented in subsequent chapters.

CHAPTER 4

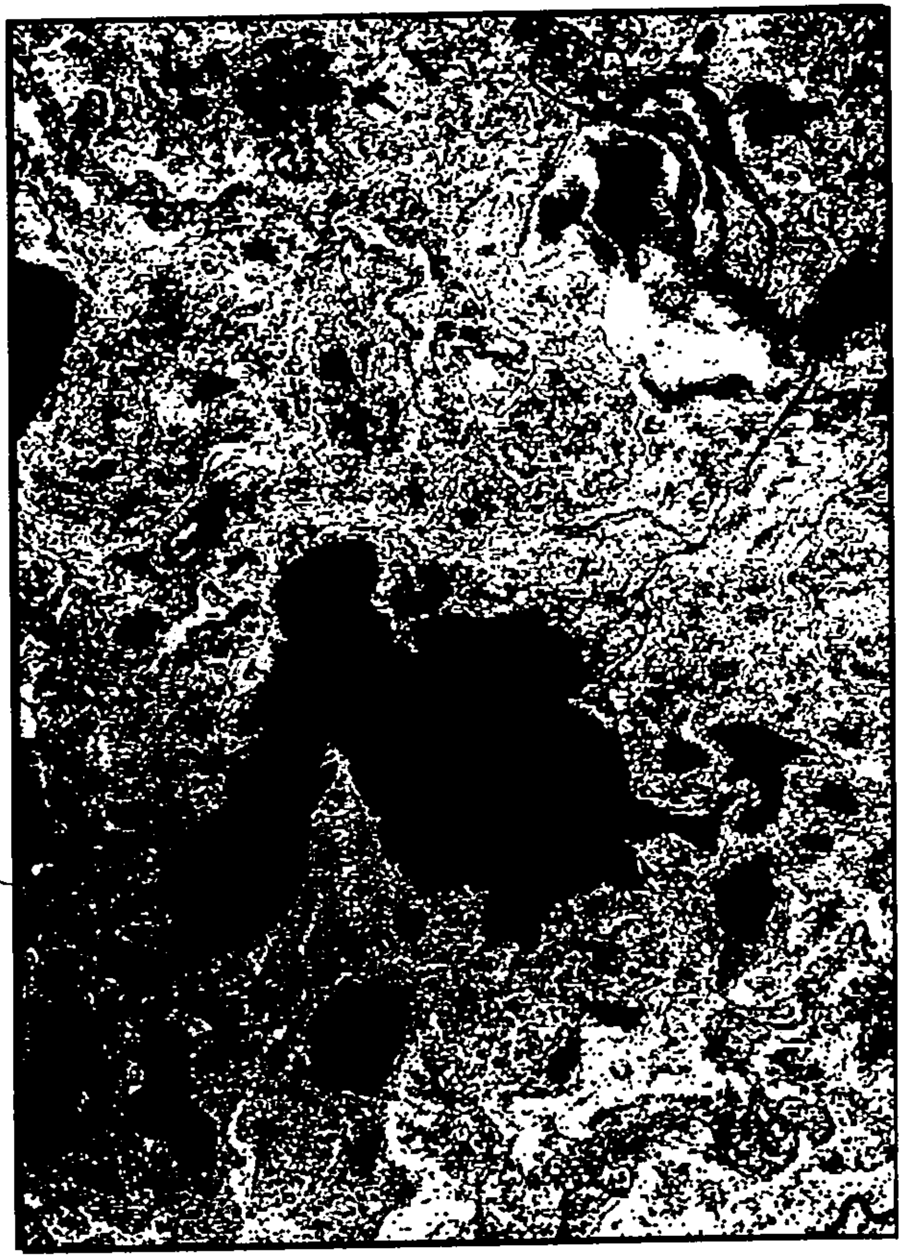
SUPERVISED CLASSIFICATION

4.1 Introduction

All change detection techniques, with the exception of ratioing, rely on the generation of spectrally classified scenes. As such, the quality of the change detection is dependent, in large measure, on the accuracy of the classifications. The purpose of this chapter is to present the results of several digital classifications, including an assessment of their accuracy, undertaken with the 1973 and 1976 LANDSAT data of the Peace-Athabasca Delta.

4.2 Supervised Classification: 1976

Following procedures outlined by Economy *et al.* (1974) and Howarth (1976), supervised classification was carried out first on the 1976 scene. Training sites were selected using 1:60,000 scale 70 mm colour infrared photography obtained during July, 1976. Various habitats were identified on the imagery and confirmed using the transect data of Cordes and Pearce (1977). A minimum of 50 pixels for each habitat was using during the training. A total of eight themes (the maximum number available for display at one time on the Image 100) was produced using the supervised classification program. The results are displayed in Figure 4.1. Habitat descriptions for each theme follow and are in sequence from habitats occupying the lowest topographic positions to those occupying the highest positions in the landscape.



LANDSAT THEMATIC MAP

MAMAWI LAKE

1976

Supervised Classification
(unfiltered)

EBIR Colour	Theme No.	Habitat Description	Km^2	% Area
Green	1	Open Turbid Water	153.6	12.6
Purple	3	Less Turbid Open Water	141.9	11.6
Yellow	4	*Scolochloa*/ *Scolochloa*-*Carex*	85.6	7.0
Orange	2	Wet *Carex* Fen	123.1	10.1
Mauve	7	*Carex*/ *Calamagrostis* Fen	141.2	11.6
Pink	5	Shrub-Fen	159.8	13.1
Blue	6	*Salix*-*Alnus*-*Populus*	191.1	15.6
Brindle	8	*Picea*/ *Populus*	25.8	2.1
Black	9	Unclassified	——	16.3

Figure 4.1

(1) Green

The green pixels represent areas of open turbid water and occupy 12.6% of the test area. The class is, in fact, a combination of one large class and several small classes which were spectrally distinct as a result of variations in turbidity. The variation is apparent not only on the aerial photos, but also on the analogue LANDSAT scene. Major rivers and streams are also included in this class.

(2) Purple

The purple pixels represent areas of less turbid open water and occupy 11.6% of the test site. Also included in this class are a number of emergent aquatic vegetation species. As seen in Figure 4.1, this habitat occurs along the shorelines and in protected embayments of large freely drained, open water bodies. These pixels also represent the shallower, smaller open water bodies and perched basins.

(3) Yellow

The area represented by the yellow pixels is the '*Scolochloa*/*Scolochloa*-*Carex*' fen habitat (Figure 4.2). Following several years of continuous flooding, *Scolochloa* generally replaces the *Carex* and *Calamagrostis* fen species. Although 1976 water levels were, in general, significantly reduced from 1974, some levels remained relatively high in the lower basins and the *Scolochloa* persisted, although some regrowth of *Carex* has undoubtedly occurred. Immediately following flooding, and where a dramatic reduction in water levels occurs, the *Scolochloa*/*Scolochloa*-*Carex* may develop in a 'sparsely vegetated mudflat' or 'Immature fen' habitat. If water levels are only reduced and not entirely eliminated, it might be expected that the *Scolochloa* habitat would succeed

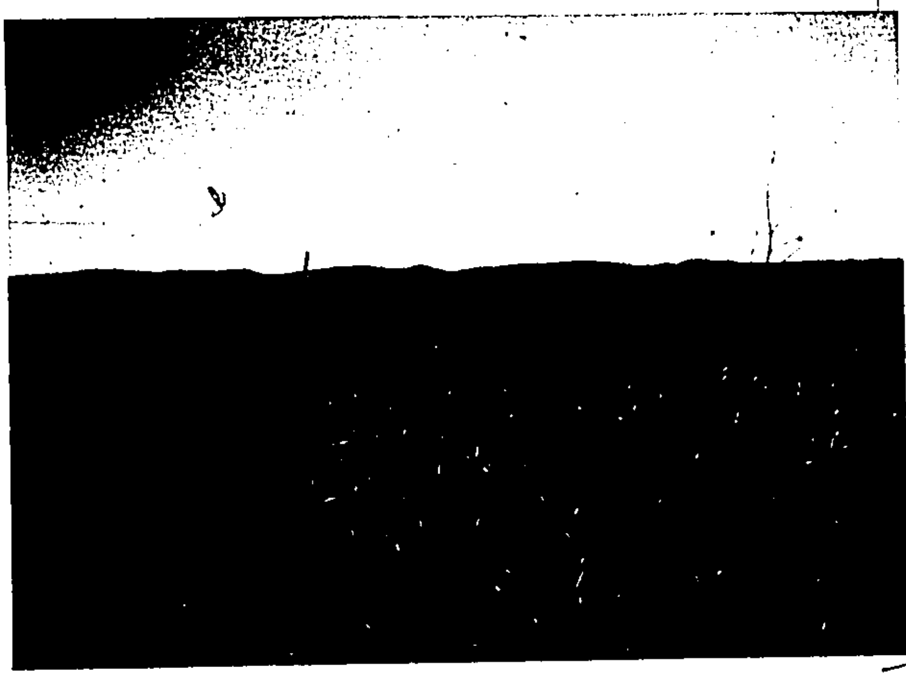


Figure 4.2 The *Scolochloa*/*Scolochloa*-*Carex* fen habitat. (Source: L. D. Cordes).

to the Wet *Carex* fen.

(4) Orange

The habitat Wet *Carex* fen (Figure 4.3) is represented by the orange pixels. Occurring on a low, yet relatively higher landscape position and with better drainage conditions than the *Scolochloa* fen, the *Carex* fen usually experiences only light flooding, or else the water table remains near the ground surface (Cordes and Pearce, 1977). The majority of this habitat is situated on the Lakeshore and Delta Plain of the active delta with some occurrence in perched basins of the semi-active delta.

(5) Mauve

The mauve pixels represent the major fen class *Carex/Calamagrostis* (Figure 4.4). This habitat occurs on a moist to wet substrate. It is not submerged for much of the growing season and therefore occupies a slightly higher and drier position on the landscape than the Wet *Carex* fen. During digital classification, although every attempt was made to separate the *Carex* from the *Calamagrostis*, no reliable result could be achieved. Together, however, the two species form a coherent and reliable class.

(6) Pink

The pink pixels represent areas with relatively higher positions on the landscape and are classified as Shrub-Fen (Figure 4.5). The shrubs are dominately *Salix* spp. with some *Alnus*. Interspersed with the shrubs are pockets of fen, dominated by *Calamagrostis* on the drier sites and *Carex* on the moister sites. This habitat is the first to replace the *Calamagrostis* on the backslope of levées and in the older perched basins, the latter having been in-filled with organic material, thereby improving the drainage conditions.

Figure 4.3 The wet *Carex* fen habitat occurs mainly on the Lakeshore and Delta Plain. Bison tracks are clearly visible in the photograph. (Source: L. D. Cordes).

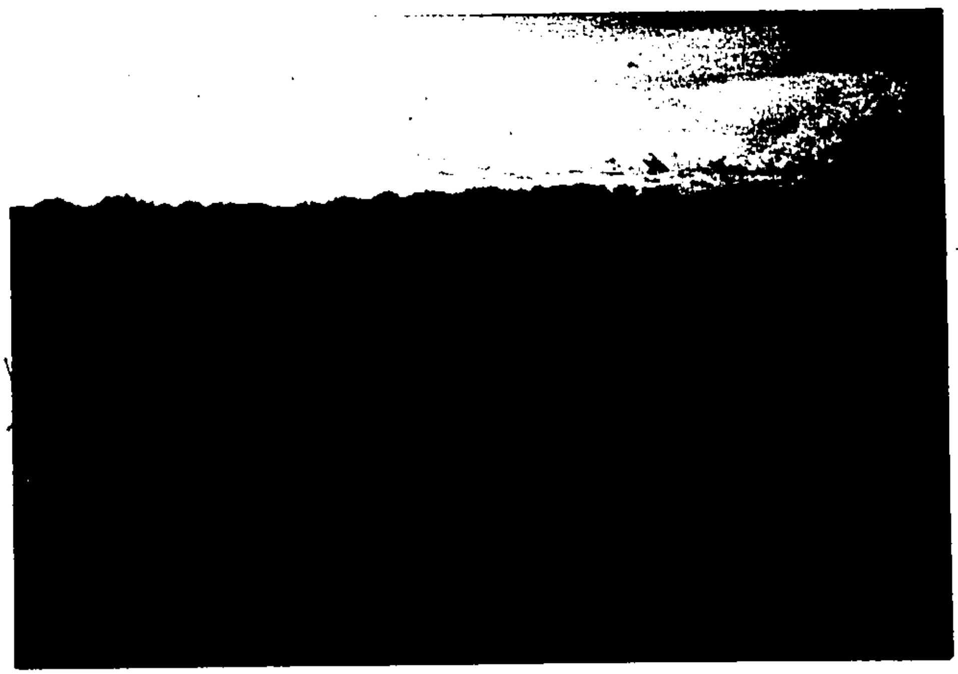


Figure 4.4 The *Carex*/*Calamagrostis* fen habitat. Difficulty was experienced in spectrally separating the *Carex* and *Calamagrostis* fen species. (Source: L. D. Cordes).

Figure 4.5 The Shrub-Fen habitat. Occurs on levée backslopes and in older parts of the Delta. *Salix* and *Alnus* dominate in this habitat.

(7) Blue

The blue pixels represent the habitat *Salix-Alnus-Populus* (Figure 4.6). This class occurs along the higher and better drained levées and in the older parts of the delta. In these landscape positions, the habitat is less subject to flooding and is therefore relatively stable.

(8) Brindle

The habitat *Picea-Populus* is represented by the brindle pixels (Figure 4.7). As might be expected, this is the smallest of the habitat classes only occurring along major river levées and on the few scattered Precambrian rock outcrops at the east end of the Mamawi Lake test site. The dominant tree species are white spruce (*Picea glauca*), balsam poplar (*Populus balsamifera*) and white birch (*Betula papyrifera*).

(9) Black

The pixels that remain unclassified (16.3%) are left black, as can be seen on Figure 4.1. The relatively high percentage of unclassified pixels is not surprising in a complex environment such as the Peace-Athabasca Delta. Such environments tend to create the opportunity for a larger number of border or boundary pixels to occur than in a simpler environment. The boundary pixels result from the ground resolution of LANDSAT where the smallest area that can be recorded is 58 m x 79 m. In boundary situations, e.g. land and water, a pixel may include both categories and may therefore remain unclassified. Alternatively, as Howarth (1976) has suggested, the intensity values for that pixel, which result from a combination of the two surfaces, may lead to the pixel being incorrectly assigned to a class. Unless an area is uncommonly homogeneous, this situation is likely to occur throughout the area being classified.

Figure 4.6 The *Salix-Alnus-Populus* habitat which occurs along the higher and better drained levées in the Delta.

Figure 4.7 Precambrian rock islands in the east end of the Delta complex. *Picea-Populus* habitat provides the dominant tree cover. This habitat class also occurs along major river levées.

Although many of the unclassified pixels can be accounted for in this manner, an examination of the classified scene reveals a number of areas where blocks of unclassified pixels occur. This suggests that a unique habitat or habitats remain unclassified.

One major class not identified was the 'Immature Fen - Sparsely Vegetated Mudflats'. Many of the unclassified pixels, particularly those in blocks, in fact represent this habitat. It occurs along lakeshores and the edges of perched basins which are flooded each year but experience drawdown. Normally of minimum areal extent, the habitat is now somewhat more extensive. This results from the recent prolonged flooding, which led to extensive growth of *Scolochloa/Scolochloa-Carex*. With drawdown and hence drier conditions, the *Scolochloa/Scolochloa-Carex* habitat is reduced to a mat of decaying reeds (Figure 4.8) or to a sparsely vegetated mudflat (Figure 4.9).

A summary of the major habitats identified in the LANDSAT analysis is presented in Table 4.1.

4.2.1 Assessment of Digital Classification Accuracy

To evaluate the accuracy of the digital classification and hence its usefulness for mapping and monitoring habitats in the delta, two separate evaluations were undertaken. First, a measure of the classification accuracy was desired which would not simply be a measure of the internal statistical accuracy of the classification normally generated by a confusion matrix (Shlien and Goodenough, 1973). To gain an impression of the ecological accuracy of the classification, 78 pixels were selected by overlaying a 34 x 20 pixel grid onto a 1:50,000 scale alpha-numeric print (Figure 4.10) and selecting the pixel on each corner of the grid.

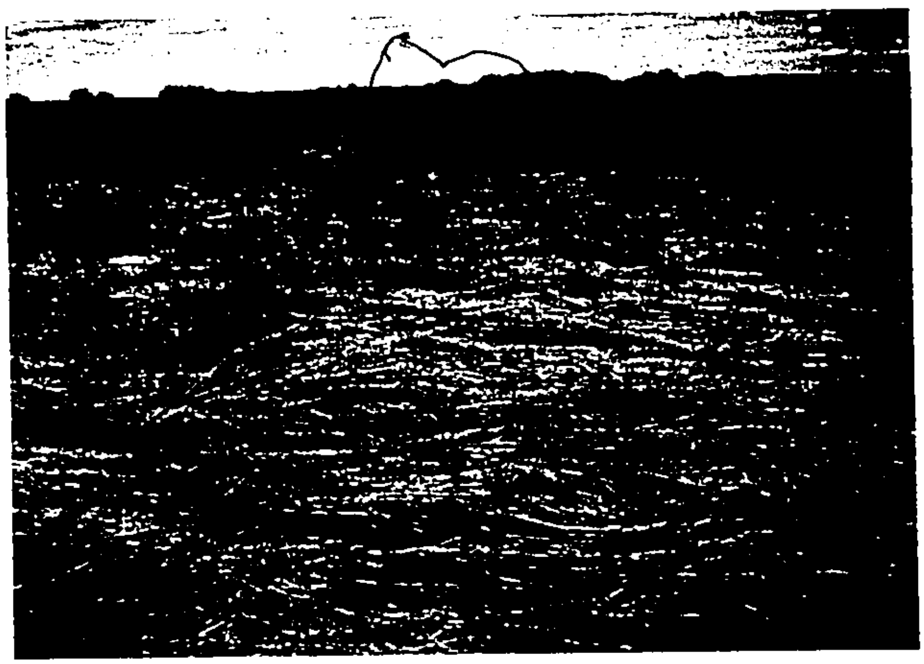


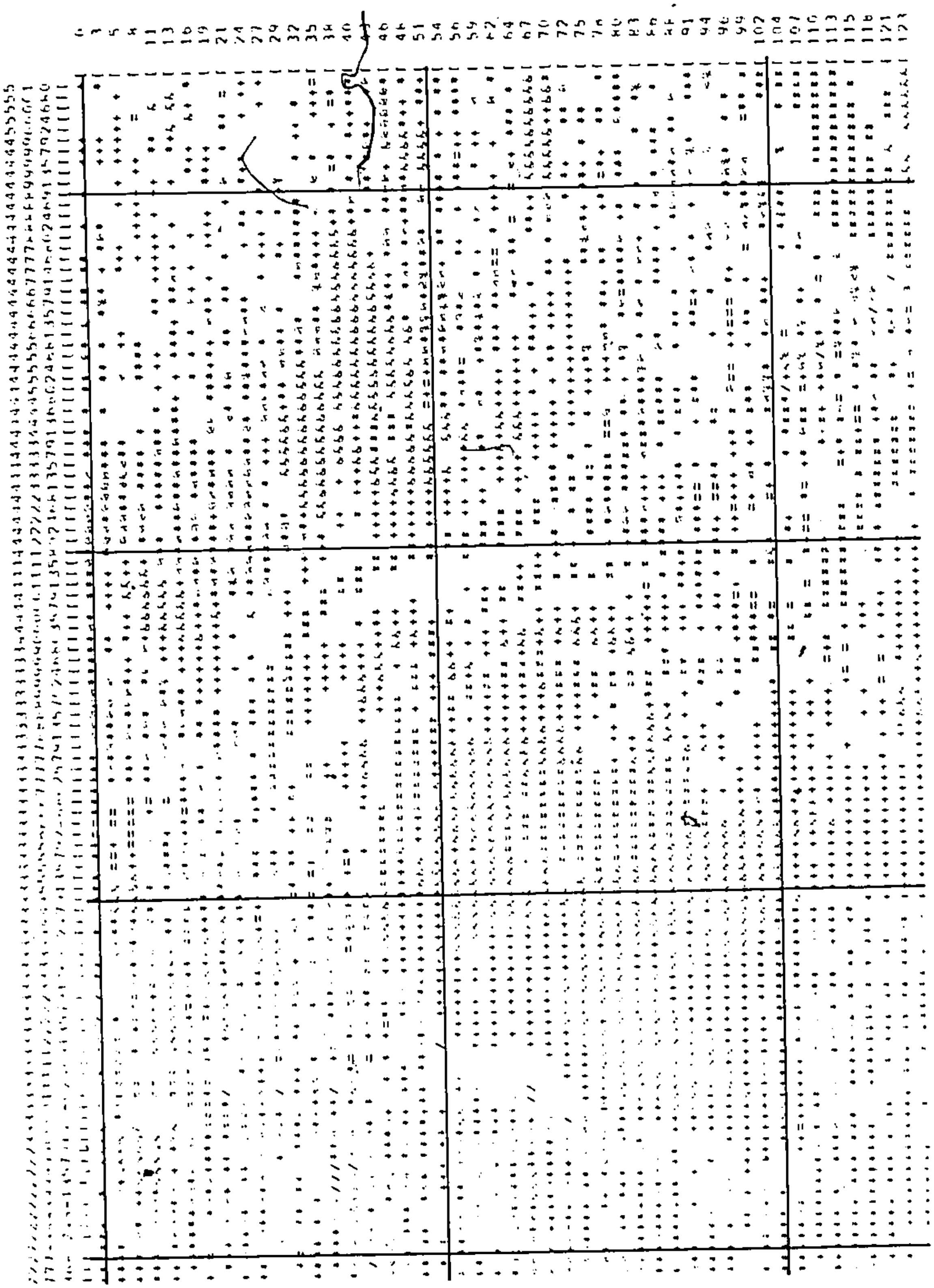
Figure 4.8 A decaying mat of *Scholochloa* reeds following reduced water levels. (Source: L. D. Cordes).

Figure 4.9 *Senecio congestus*, a pioneer species in the sparsely vegetated mudflats habitat. (Source: L. D. Cordes).

Table 4.1 Names and Descriptions of Major Habitats in the Peace-Athabasca Delta Identified using 1976 Digital LANDSAT data.

Habitat Class	Description
Turbid Open Water	Flooded area generally devoid of emergent vegetation.
Less Turbid Open Water	Flooded area, often with emergent vegetation (*Scirpus* spp.). It is found in protected embayments of larger lakes and in smaller perched basins.
Scolochloa/Scolochloa-Carex	Inundated area with erect, living vegetation whose normal habitat requires continual flood inundation (*Scolochloa/Scolochloa-Carex* group most frequently occurring community). Wetter *Carex* meadows also occur.
Wet *Carex* Fen	Inundated area with lower water levels than in the *Scolochloa/Scolochloa-Carex* communities. Some *Scholochloa* may also occur, however. Growth is moderately dense and semi-vigorous.
Carex/Calamagrostis Fen	Dense vigorously growing *Carex/Calamagrostis* on sites less wet than those of the wet *Carex* meadows. Vigorously growing immature fen species may also occur in this class.
Shrub Fen	Area dominated by *Salix* shrubs, *Calamagrostis* meadows and drier *Carex* meadows.
Salix-Alnus-Populus	Areas dominated by tall deciduous shrubs (*Salix/Alnus*) and/or tree species (*Populus*). Usually occur along well drained river levées, Precambrian rock outcrops or older better drained areas of the delta.
Picea-Populus	Areas dominated by ~~coniferous~~ forest species of white spruce and balsam fir. Balsam poplar ~~and~~ white birch are scattered throughout.

Figure 4.10 A portion of the 1:50,000 scale alpha-numeric print showing part of the 34 x 20 pixel grid used for evaluating the classification accuracy of the 1976 scene. A total of 78 pixels were identified by selecting pixels on each corner of the grid.



Poor Copy

The computer-generated classification for each of these 78 pixels was then compared with normal colour and colour infrared air photos obtained for the delta in 1975 (Table 1.1). An accuracy matrix was prepared (Table 4.2) which shows the actual pixel counts, and their 'true' class as identified from the air photos. Classification accuracy was generally excellent with perhaps two exceptions; namely, the *Scolochloa/Scolochloa-Carex* and *Salix Alnus-Populus* classes. In both cases, confusion seems rather widespread. Although this was recognized during the digital classification it was not possible to improve the results. Finally, because the *Picea-Populus* is a relatively small habitat class, no pixels in this category were actually selected. It is known from visual inspection, however, that minor confusion exists between this class and the Less Turbid Open Water class.

The second method of evaluating the classified scene was by comparing the digital results with those obtained by the Peace-Athabasca Delta Project Group (1973) and by Cordes and Pearce (1977). Using data from Cordes and Pearce (1977) Table 4.3 was prepared. As the classification categories generated using LANDSAT differed from the ones prepared by the Peace-Athabasca Delta Project Group (1973) and by Cordes and Pearce (1977), some generalization of their data was necessary to make a comparison. From the tabular results, it would appear that a good correlation between the digital LANDSAT classification and the other classifications was achieved. It should perhaps be noted here as well that the statistics for the Peace-Athabasca Delta Project Group (1973) and for Cordes and Pearce (1977) are based on the percentages of habitats encountered along the survey transects (Figure 3.6). While the transects may include

Table 4.2 Accuracy Matrix Comparing a Digital Pixel Count Obtained from the Classified LANDSAT Scene ("Chosen Class") with the "True Class" Identified by Photointerpretation.

True Class	Chosen Class								
	Open Turbid Water	Less Turbid Open Water	*Scolochloa/ Scolochloa-Carex*	Wet *Carex* Fen	*Carex/ Calamagrostis* Fen	Shrub Fen	*Salix-Alnus-Populus*	*Picea-Populus*	Unclassified
Open Turbid Water	11	0	0	0	0	0	0	0	0
Less Turbid Open Water	0	10	1	0	0	0	0	0	0
Scolochloa/Scolochloa Carex	0	2	6	1	0	1	1	0	2
Wet *Carex* Fen	0	0	0	3	0	0	0	0	2
Carex/Calamogrostis Fen	0	0	0	0	9	0	0	0	1
Shrub Fen	0	0	0	0	0	8	2	0	3
Salix-Alnus-Populus	0	0	1	1	0	3	8	0	1
Picea-Populus	0	0	0	0	0	0	0	0	1

Table 4.3 Comparison of the Percentages of Areas Occupied by Different Habitats, According to Three Studies

Habitat Class	Percent Area		
	P.A.D. Group (1970)	Cordes and Pearce (1977)	LANDSAT (1976)
Mixed Forest	.9	.9	2.1
Tall Shrub	25.0	23.6	16.3
Low Shrub	9.5	10.0	13.2
Shrub Fen *Carex* *Calamagrostis* *Scolochloa*	32.3	33.2	29.1
Open Water (includes *Scirpus*)	15.6	21.3	24.5

representative habitats for the delta, there is some question as to whether the overall habitat mix on these transects is, in fact, representative (Cordes, Pers. Comm.). Some of the differences in classification results may be attributed to this possible source of error.

4.3 Supervised Classification: 1973

Once 'baseline' conditions and habitats were established for 'normal' water level conditions, digital classification of habitats under flooded conditions was undertaken. Results of the classification are presented in Figure 4.11. The digital classification scheme is similar to the one developed for normal conditions. Because of high water levels particularly in the lakeshore and delta plain and in the perched basin physiographic areas, it was difficult to separate flooded habitats from the Shrub-Fen and *Salix-Alnus-Populus* habitat classes. A relatively large number of unclassified pixels (16.6%) also remained after the digital classification. In this instance, however, most of the unclassified pixels that occur in 'blocks' are those of the Tall Shrub habitat type identified by Dabbs (1971) (Figure 2.8). This habitat class occurs on older parts of the delta and along levées and levée backslopes. An examination of Figure 4.11 clearly reveals this situation.

4.4 Effects of Filtering on the Classifications

Due to the fixed pixel size (57 m x 79 m), the only method of generalizing the data is to apply a filtering algorithm. Several different degrees of filtering are available on the analysis system at CCRS, including a 3 x 3 weak and 3 x 3 strong filter. Both filters were used on the classified scenes for 1973 and 1976. Results are presented in Figures 4.12, 4.13, 4.14 and 4.15. These results are summarized for the

LANDSAT THEMATIC MAP

MAMAWI LAKE

1973

Supervised Classification (unfiltered)

EBIR Colour	Theme No.	Habitat Description	Km^2	% Area
Green	1	Open Turbid Water	145.0	11.9
Purple	3	Less Turbid Open Water	151.0	12.4
Orange	2	*Scolochloa*/ *Scolochloa*-*Carex*	32.8	2.7
Blue	6	Fen-*Salix*/ Fen/*Salix*-*Alnus*-*Populus*	433.1	35.4
Pink	5	*Carex*/ *Calamagrostis* Fen	157.3	12.9
Mauve	7	Wet *Carex* Fen	70.4	5.6
Brindle	8	*Picea*/ *Populus*	29.6	2.4
Black	-	Unclassified	——	16.6

Figure 4.11

LANDSAT THEMATIC MAP

MAMAWI LAKE

1976

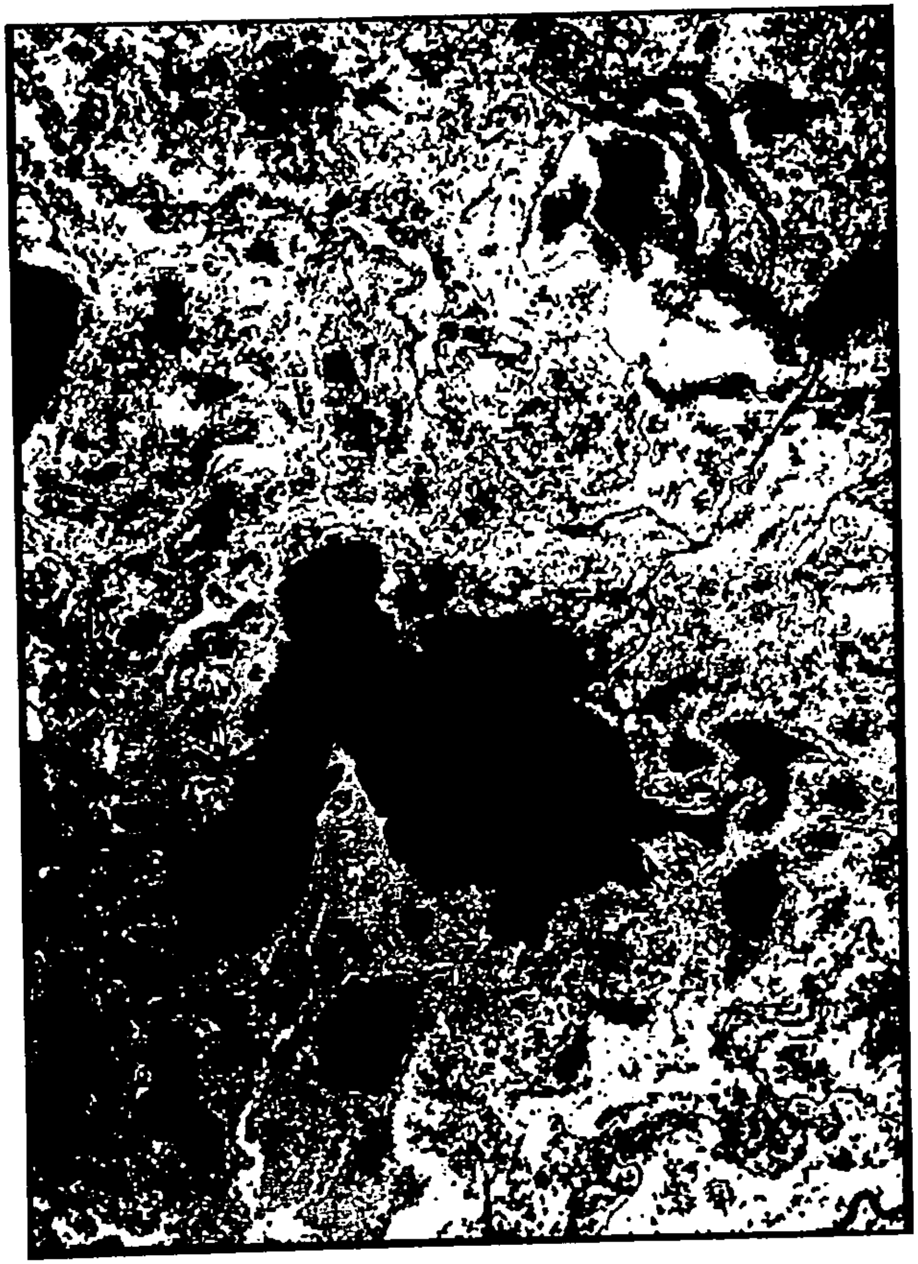
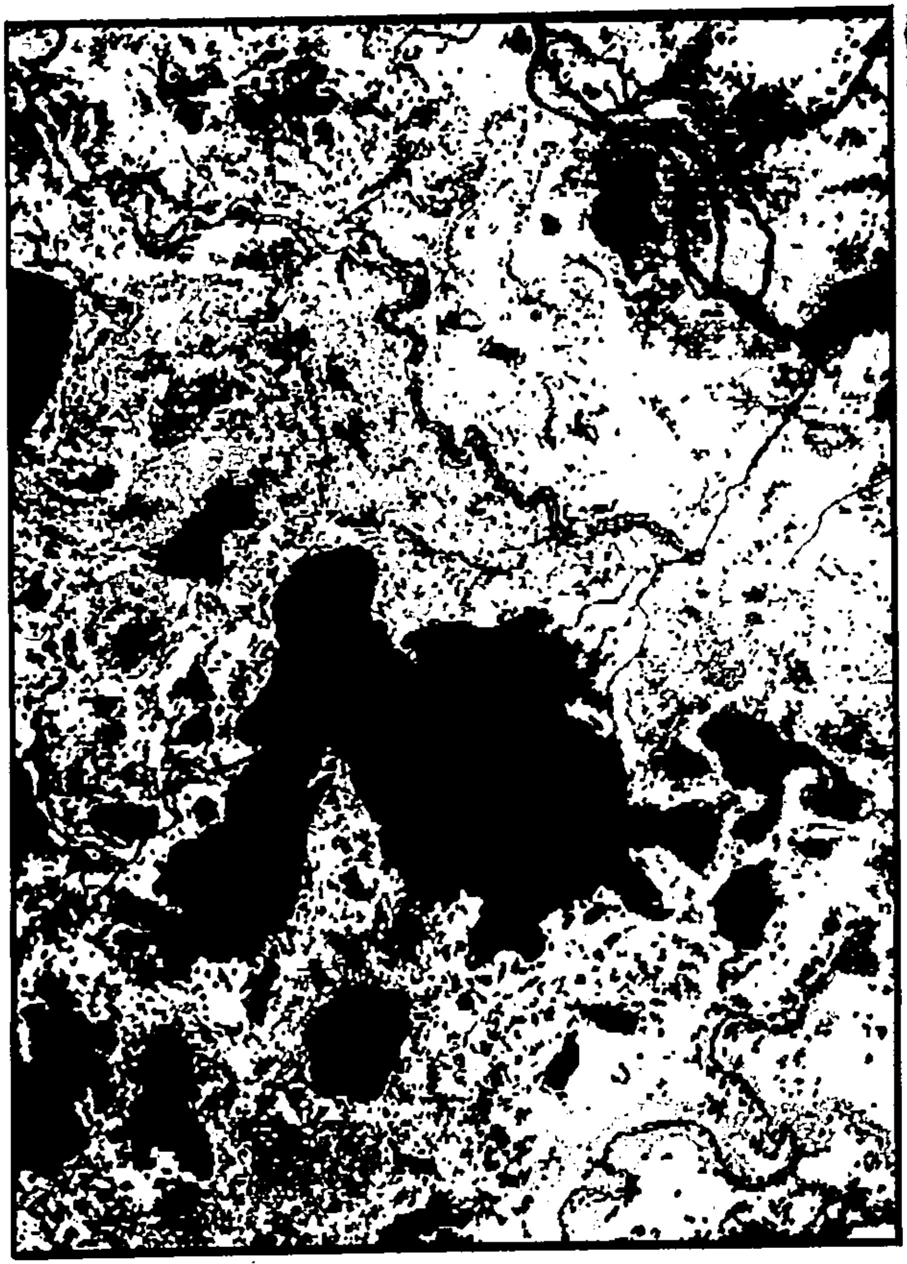


Figure 4.12

Supervised Classification
3x3 Weak Filter

EBIR Colour	Theme No.	Habitat Description	Km^2	% Area	% Change
Green	1	Open Turbid Water	153.7	12.6	+ .01
Purple	3	Less Turbid Open Water	145.3	11.9	+ .28
Yellow	4	*Scolochloa*/ *Scolochloa*-*Carex*	83.9	6.9	- .15
Orange	2	Wet *Carex* Fen	124.5	10.2	+ .09
Mauve	7	*Carex*/ *Calamagrostis* Fen	146.7	12.0	+ .44
Pink	5	Shrub-Fen	160.9	13.2	+ .09
Blue	6	*Salix*-*Alnus*-*Populus*	199.5	16.3	+ .69
Brindle	8	*Picea*/ *Populus*	24.6	2.0	- .10
Black	9	Unclassified	——	15.0	-1.37



LANDSAT THEMATIC MAP

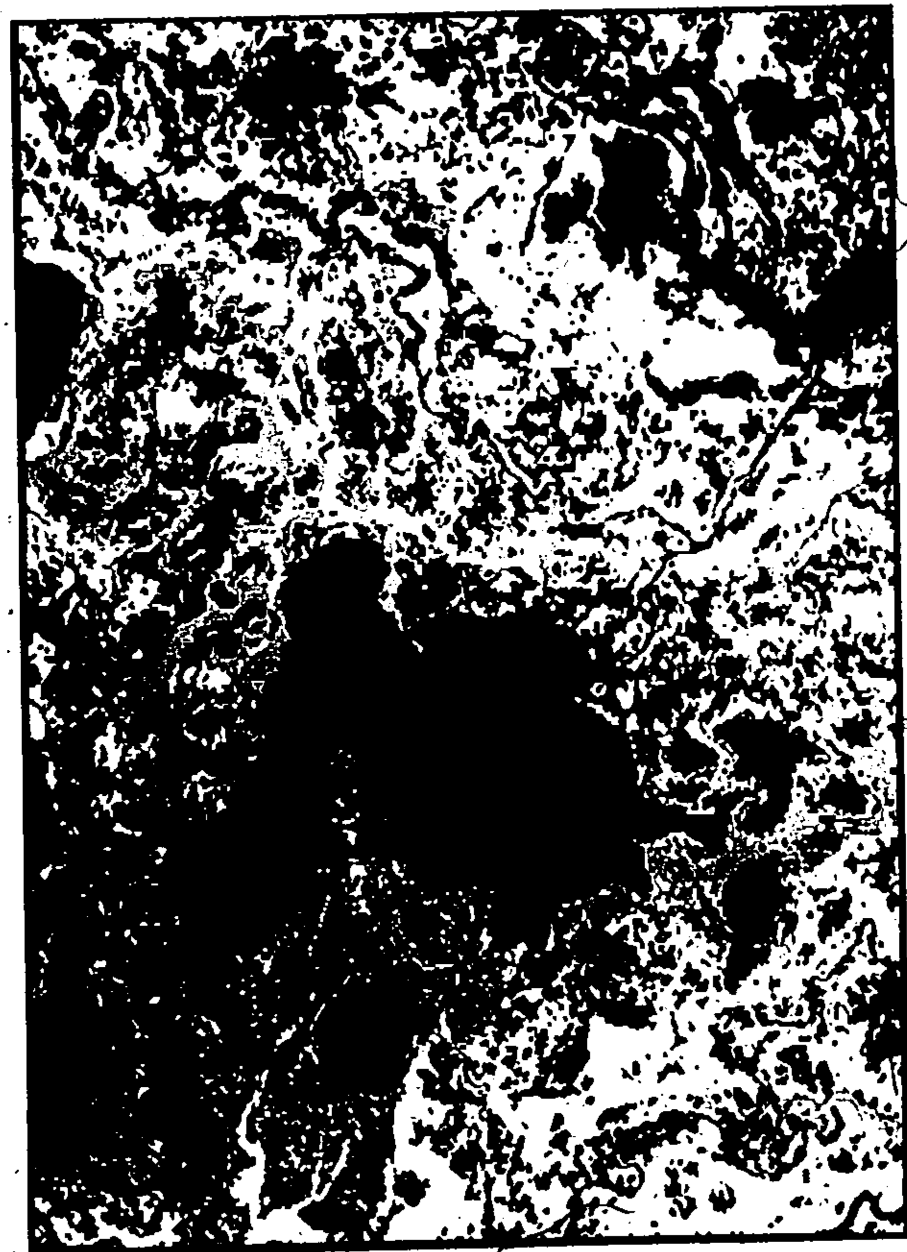
MAMAWI LAKE

1973

Supervised Classification
3x3 Weak Filter

EBIR Colour	Theme No.	Habitat Description	Km^2	% Area	% Change
Green	1	Open Turbid Water	145.5	11.9	+ .04
Purple	3	Less Turbid Open Water	150.9	12.4	0.0
Orange	2	*Scolochloa*/ *Scolochloa*-*Carex*	28.4	2.3	- .35
Blue	6	Fen-*Salix*/ (flooded) Fen (flooded)/ *Salix*-*Alnus*-*Populus* (not-flooded)	471.0	38.5	+3.1
Pink	5	*Carex*/ *Calamagrostis* Fen	159.4	13.0	+ .17
Mauve	7	Wet *Carex* Fen	71.4	5.8	+ .08
Brindle	8	*Picea*/ *Populus*	27.2	2.2	- .20
Black	-	Unclassified	——	13.8	-2.84

Figure 4.13



LANDSAT THEMATIC MAP

MAMAWI LAKE

1976

Supervised Classification
3x3 Strong filter

EBIR Colour	Theme No.	Habitat Description	Km^2	% Area	% Change
Green	1	Open Turbid Water	155.1	12.7	+ .13
Purple	3	Less Turbid Open Water	151.9	12.4	+ .82
Yellow	4	*Scolochloa/ Scolochloa-Carex*	76.6	6.3	- .74
Orange	2	Wet *Carex* Fen	120.9	9.9	- .18
Mauve	7	*Carex/ Calamagrostis* Fen	159.3	13.0	+1.48
Pink	5	Shrub-Fen	160.8	13.2	+ .08
Blue	6	*Salix-Alnus Populus*	209.0	17.1	+1.46
Brindle	8	*Picea/ Populus*	23.3	1.9	- .20
Black	9	Unclassified	——	13.5	-2.85

Figure 4.14

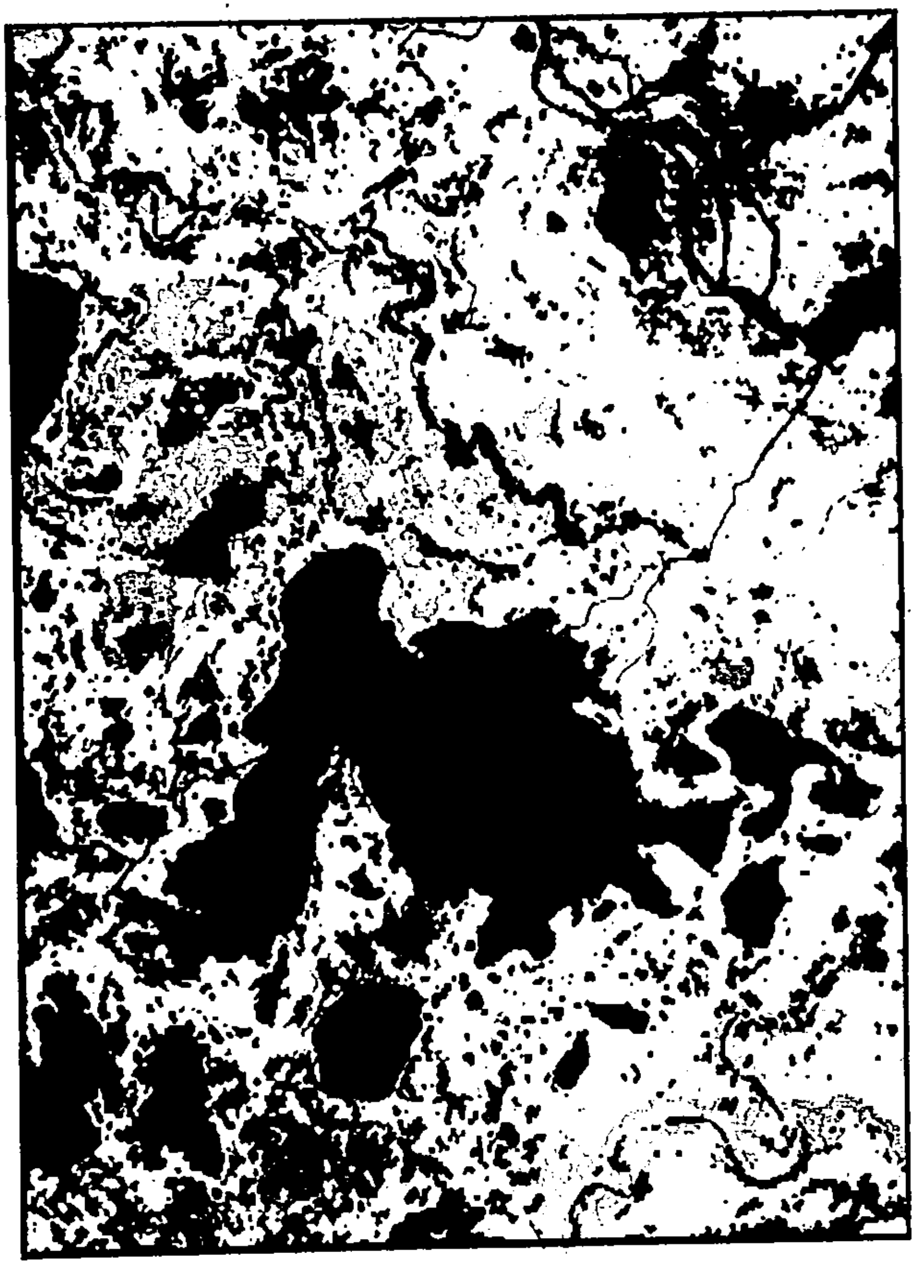


Figure 4.15

LANDSAT THEMATIC MAP

MAMAWI LAKE

1973

Supervised Classification
3x3 Strong filter

EBIR Colour	Theme No.	Habitat Description	Km^2	% Area	% Change
Green	1	Open Turbid Water	147.5	12.1	+ .2
Purple	3	Less Turbid Open Water	152.0	12.4	+ .09
Orange	2	*Scolochloa/ Scolochloa-Carex*	23.6	1.9	- .75
Blue	6	Fen-*Salix*/Fen/ *Salix-Alnus-Populus*	496.0	40.6	+5.16
Pink	5	*Carex/ Calamagrostis* Fen	160.2	13.1	+ .24
Mauve	7	Wet *Carex* Fen	74.6	6.1	+ .34
Brindle	8	*Picea/ Populus*	25.3	2.1	- .35
Black	-	Unclassified	——	11.7	-4.93

readers' convenience in Table 4.4, 4.5 and 4.6.

The most obvious effects of the filtering are to smooth the texture of the classified scene by eliminating isolated pixels and reassigning boundary pixels. Although visually more appealing, there are no appreciable improvements in classification accuracy.

4.5 Conclusion

Results presented in this chapter demonstrate the feasibility of using digital LANDSAT data for classifying and mapping major habitats in the Peace-Athabasca Delta. The independent generation of two accurately classified scenes is also an essential first step in the conduct of a quantitative change detection analysis. Results of the change detection analysis are presented in the following chapter.

Table 4.4 Summary of Classes for 1973 and 1976, 3 x 3 Weak Filter Statistics

Habitat Class	No. Pixels		Km^2		Percent Area	
	1976	1973	1976	1973	1976	1973
Turbid Open Water	32,980	31,217	153.720	145.502	12.58	11.91
Less Turbid Open Water	31,173	32,377	145.297	150.909	11.89	12.35
Scolochloa/Scolochloa-Carex	17,991	6,096	83.856	23.413	6.86	2.33
Wet *Carex* Fen	26,720	15,319	124.542	71.402	10.19	5.84
Carex/Calamagrostis Fen	31,466	34,189	146.663	159.355	12.00	13.04
Fen-*Salix*/Fen/*Salix-Alnus Populus*	---	101,032	---	470.910	---	38.54
Shrub Fen	34,519	---	160.893	---	13.17	---
Salix-Alnus-Populus	42,812	---	199.547	---	16.33	---
Picea-Populus	5,280	5,825	24.610	27.150	2.01	2.22
Unclassified	---	---	---	---	14.97	13.77

Table 4.5 Summary of Classes Produced for 1973 and 1976, 3 x 3 Strong Filter Statistics

	Classification Statistics					
	No. Pixels		Km^2		Percent Area	
Habitat Class	1976	1973	1976	1973	1976	1973
Turbid Open Water	33,283	31,635	155.132	147.451	12.70	12.07
Less Turbid Open Water	32,583	32,602	151.869	151.958	12.43	12.44
Scolochloa/Scolochloa-Carex	16,436	5,053	76.608	23.552	6.27	1.93
Wet *Carex* Fen	25,947	15,995	120.939	74.553	9.90	6.10
Carex/Calamagrostis Fen	34,171	34,360	159.271	160.152	13.04	13.11
Fen-*Salix*/Fen/*Salix-Alnus-Populus*	---	106,423	---	496.038	---	40.60
Shrub Fen	34,502	---	160.814	---	13.16	---
Salix-Alnus-Populus	44,832	---	208.962	---	17.10	---
Picea-Populus	5,004	5,428	23.324	25.300	1.91	2.07
Unclassified	---	---	---	---	13.49	11.68

Table 4.6 Summary of Filtering Algorithms on Classification Results

Habitat Class	Percent Area 1976 Unfiltered	1976 3x3 Weak	1976 Δ*	1976 3x3 Strong	1976 Δ	Percent Area 1973 Unfiltered	1973 3x3 Weak	1973 Δ	1973 3x3 Strong	1973 Δ
Turbid Open Water	12.57	12.58	(+.01)	12.70	(+.13)	11.87	11.91	(+.04)	12.07	(+ .2)
Less Turbid Open Water	7.01	6.86	(-.15)	6.27	(-.74)	12.35	2.33	(-.35)	1.93	(-.75)
Wet *Carex* Fen	10.08	10.19	(+.09)	9.90	(-.18)	5.76	5.84	(+.08)	6.10	(+.34)
Carex/*Calamagrostis* Fen	11.56	12.00	(+.44)	13.04	(+1.48)	12.87	13.04	(+.17)	13.11	(+.24)
Fen-*Salix*/Fen/*Salix-Alnus-Populus*	---	---	---	---	----	35.44	38.54	(+3.1)	40.60	(+5.16)
Shrub Fen	13.08	13.17	(+.09)	13.16	(+.08)	---	---	---	---	---
Salix-Alnus-Populus	15.64	16.33	(+.69)	17.10	(+1.46)	---	---	---	---	---
Picea-Populus	2.11	2.01	(-.10)	1.91	(-.20)	2.42	2.22	(-.20)	2.07	(-.35)
Unclassified	16.34	14.97	(-1.37)	13.49	(-2.85)	16.61	13.77	(-2.84)	11.68	(-4.93)

*Δ indicates the differences in means between the two years.

CHAPTER 5

CHANGE DETECTION

5.1 Introduction

Environmental monitoring has as its objective the detection of change in land use/cover that occurs over a period of time. Conventionally, change detection has been accomplished by conducting locally based land surveys often supplemented by aerial photography. For large areas, such as the Peace-Athabasca Delta, such techniques have proven to be time consuming and expensive.

Before the use of LANDSAT digital data becomes operationally feasible, however, satisfactory techniques for change detection need to be developed and evaluated. At least three methods for change detection using the Image 100 have been developed. These three methods are: (1) ratioing, (2) classification and comparison of different dates, and (3) split screen classification (Wilson *et al.* 1976).

In ratioing, the simplest and quickest method of change detection on the Image 100, the intensity of reflected energy in one band of one LANDSAT scene is divided by the intensity in the same band of another scene. The data are compared on a pixel by pixel basis. Where the intensity of reflected energy is approximately the same in each scene, the result of the division is nearly 1 (Wilson *et al.* 1976). In this case land use/cover is assumed to have remained constant. Where change has occurred, the result of the division is different from 1. Results are subsequently displayed on the Image 100 monitor.

The classification and comparison of two different dates require the generation of two independently produced classifications. Results are overlayed and compared so that the areas and types of change can be identified. This technique is similar to the post-classification comparison change detection described by Weismiller *et al.* (1977).

Split screen classification involves the simultaneous (side by side) display on the monitor of the same area from two different dates. The areas are then classified as though they were part of the same scene. This method, the most time consuming of the three, requires visual analysis to detect changes and the use of numerous sub-scenes.

The previous chapter established the classification for each of the two years for which change detection is required. The purpose of this chapter is to present the results of the change detection procedures as carried out on the Image 100.

5.2 Change Detection in the Mamawi Lake Test Site: 1973-1976

5.2.1 Changes in Reflectivity

In addition to the need for two accurately classified scenes, the detection of change and hence the monitoring capability of LANDSAT is dependent on changes in the spectral characteristics of various habitats through time. The change may be brought about by (1) natural long-term succession, (2) a major perturbation (e.g. prolonged periods of low water or flood water levels), (3) phenological change, and (4) differences in atmospheric conditions.

Although reflectance characteristics of land/water surfaces are based on a number of factors, the more significant ones affecting those of the habitats in the delta include density and height of vegetation, percentage composition of species, vigor, background exposure and season of the year. As expected, Bands 6 and 7, which record reflectivity in the near-infrared region of the electromagnetic spectrum, were found to be most useful in distinguishing between habitat types (Table 5.1). In 1976, lowest reflectance values were recorded (Bands 6 and 7) for the two water classes, while the highest values identified the very vigorously growing *Carex/Calamagrostis* fen habitat. Of the vegetation-dominated habitats the *Picea-Populus* has the lowest mean reflectance value. This is not surprising since conifers generally have low reflectivity in the infrared region of the electromagnetic spectrum.

Reflectance values for habitats in 1973 demonstrate to some extent the effects of the prolonged period of low water levels prior to 1972. A comparison of Band 7 values for 1973 and 1976 shows that the increased moisture present in 1973 greatly improved the vigor of the *Carex* in the Wet *Carex* fen class (104.03 in 1973 and 87.14 in 1976). Some of the change, however, is undoubtedly due to higher residual water levels in several basins following the exceptionally high water levels of 1974.

Reduced vigor in the *Carex/Calamagrostis* habitat class as a result of the low water levels of 1968-71 is reflected in the low values for this class in 1973 (Table 5.2). Values in 1976 are much higher and result from an improvement in moisture conditions (Table 5.1). Increased growth of surface aquatics (*Potamogeton* and *Nuphar*) is evidenced by the higher reflectance values in the 1976 Open Turbid Water class. The increase in reflectance between 1973 and 1976 for the *Picea-Populus* habitat class is more difficult to explain. When training on this class

Table 5.1 Mean Reflectance Values in Each of the Four LANDSAT Bands Recorded by Habitat Class for 1976 and 1973.

Habitat Class	Mean Reflectance Values											
	Band 4			Band 5			Band 6			Band 7		
	1976	1973	Δ*	1976	1973	Δ	1976	1973	Δ	1976	1973	Δ
Open Turbid Water	44.78	40.29	-4.49	48.06	46.87	-1.19	37.25	22.91	-14.34	14.97	5.79	- 9.18
Less Turbid Open Water	28.21	25.28	-2.93	21.88	20.51	-1.37	19.86	11.01	- 8.85	11.93	4.29	- 7.64
Scolochloa/Scolochloa-Carex	29.23	32.13	+2.90	23.64	32.78	+9.14	46.64	48.66	+ 2.02	41.19	49.94	+ 8.75
Wet *Carex* Fen	33.27	34.31	+1.04	28.45	31.36	+2.91	83.91	86.81	+ 2.90	87.14	104.03	+16.89
Carex/Calamagrostis Fen	34.10	33.09	-1.01	28.00	33.19	-5.19	98.10	68.18	-29.92	107.53	78.36	-29.17
Shrub Fen/Fen/*Salix-Alnus-Populus*	-	29.12	-	-	27.55	-	-	46.18	-	-	49.76	-
Shrub Fen	31.12	-	-	25.76	-	-	68.20	-	-	69.72	-	-
Salix-Alnus-Populus	28.68	-	-	20.44	-	-	71.88	-	-	78.68	-	-
Picea-Populus	25.97	24.83	-1.14	17.59	18.97	+1.38	47.44	34.37	-13.07	49.26	37.20	-12.06

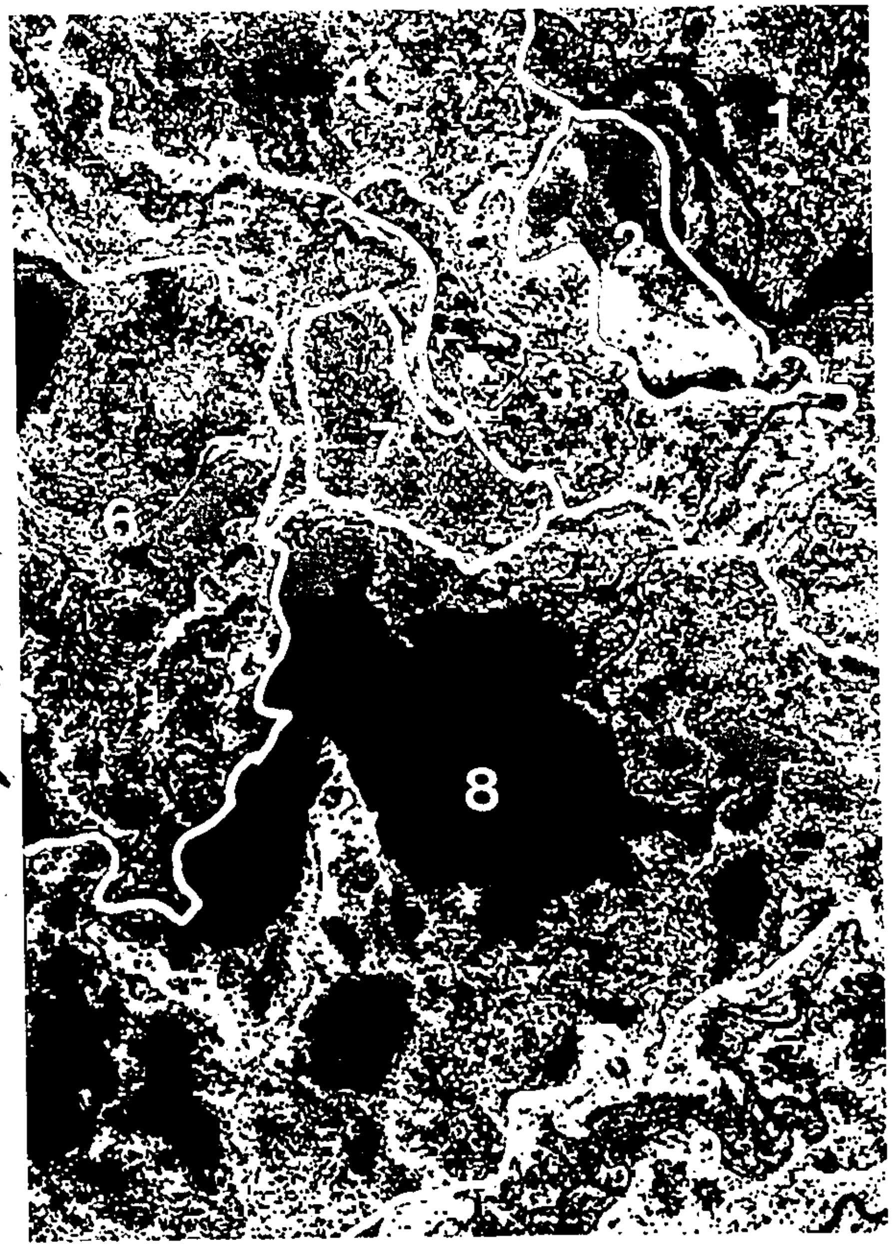
* Δ indicates the difference in means between the two years.

in 1976, a higher proportion of poplar and birch (which are interspersed throughout the white spruce) may have been picked up, thereby increasing the reflectivity of this class. The effects of flooding, particularly in the Lakeshore and Delta Plain habitats, served to reduce reflectivity in Bands 6 and 7. This resulted in habitat discrimination problems for 1973. The reflectance values in the infrared region for the *Scolochloa*/*Scolochloa-Carex* approximate the values of the fen-*Salix*/fen/*Salix-Alnus-Populus* class and are better discriminated in Bands 4 and 5. This suggests that under flood conditions habitat discrimination may, in fact, be improved using the visible portion of the spectrum (Bands 4 and 5) rather than the infrared portion (Bands 6 and 7).

5.2.2 Identification of Areas and Habitats Susceptible to Change

Prior to undertaking detailed change detection procedures, two generalized approaches to identifying areas and habitats most likely to experience change due to prolonged flooding were investigated. The first approach involved the delineation of topographic subdivisions in the Mamawi Lake Test Site using the 1976 classified scene (Figure 5.1). These subdivisions are made possible because of the orientation of the vegetation along topographic gradients, even where relief is low (Dabbs, 1971). The nine zones (Figure 5.1) represent generalized vegetation-hydrologic patterns and are useful in identifying areas (pixel classes) potentially important for monitoring. Zone 8, for example, is a large heterogeneous class of pixels occupying relatively low topographic positions on the Lakeshore and Delta Plain surrounding Mamawi Lake. The predominant habitats in this area are particularly sensitive to variation in the moisture regime and can be expected to reflect short term environmental

Figure 5.1 The Mamawi Lake Test Site with nine major habitat zones delineated. These zones represent generalized vegetation-hydrologic patterns interpreted from the 1976 digital classification results.


1
6
8

changes. Other zones, similar to Zone 8 (i.e. 2, 6 and 7), are also potential areas for monitoring change. Zones 1, 3, 4 and 9 however are dominated by more stable habitats such as the Shrub-Fen habitat and are therefore less likely to be good short term indicators of change.

The second approach to identifying areas of change involves overlaying data from the two years in the image analysis system and ratioing the various bands. The technique used for overlaying was described earlier in Chapter 3. Although the technique is more objective for the identification of areas of change, it still exhibits a major disadvantage in that the nature of the change cannot be determined. Two bands (5 and 7) were used in the analysis (Figures 5.2 and 5.3). Band 5, was expected to emphasize the areal extent of flooding (Bukata, 1973), whereas Band 7 was expected to emphasize differences in vegetation between the two years. Figure 5.4 is a colour composite of Figure 5.3. This colour enhanced image assists in the interpretation of the image by highlighting areas of major change. The flooded area around Mamawi Lake (displayed in red) is particularly evident in this image. The blue colour enhances the areas where change in vegetation has been most dramatic.

5.2.3 Post Classification Change Detection

Certain areas of the delta are more likely to undergo change than others. This is because of the complex nature of the habitats in the delta and their wide 'mix' over the entire area. For this reason, change detection results using the post classification technique were produced at three levels of detail; total area, 1/2 area, and 1/8 area. Levels 1 and 2 are mapped at 1:250,000 scale, whereas 1/8 area maps are produced at 1:125,000 scale.

Figure 5.2 Band 5 ratio of LANDSAT scenes E20557-17522 and E1399-18104. Areas of no change are gray, while increasing tones towards either the black or white ends of the gray scale indicate increasing change. In this figure, changes in water levels due to flooding are emphasized (brightest tones).

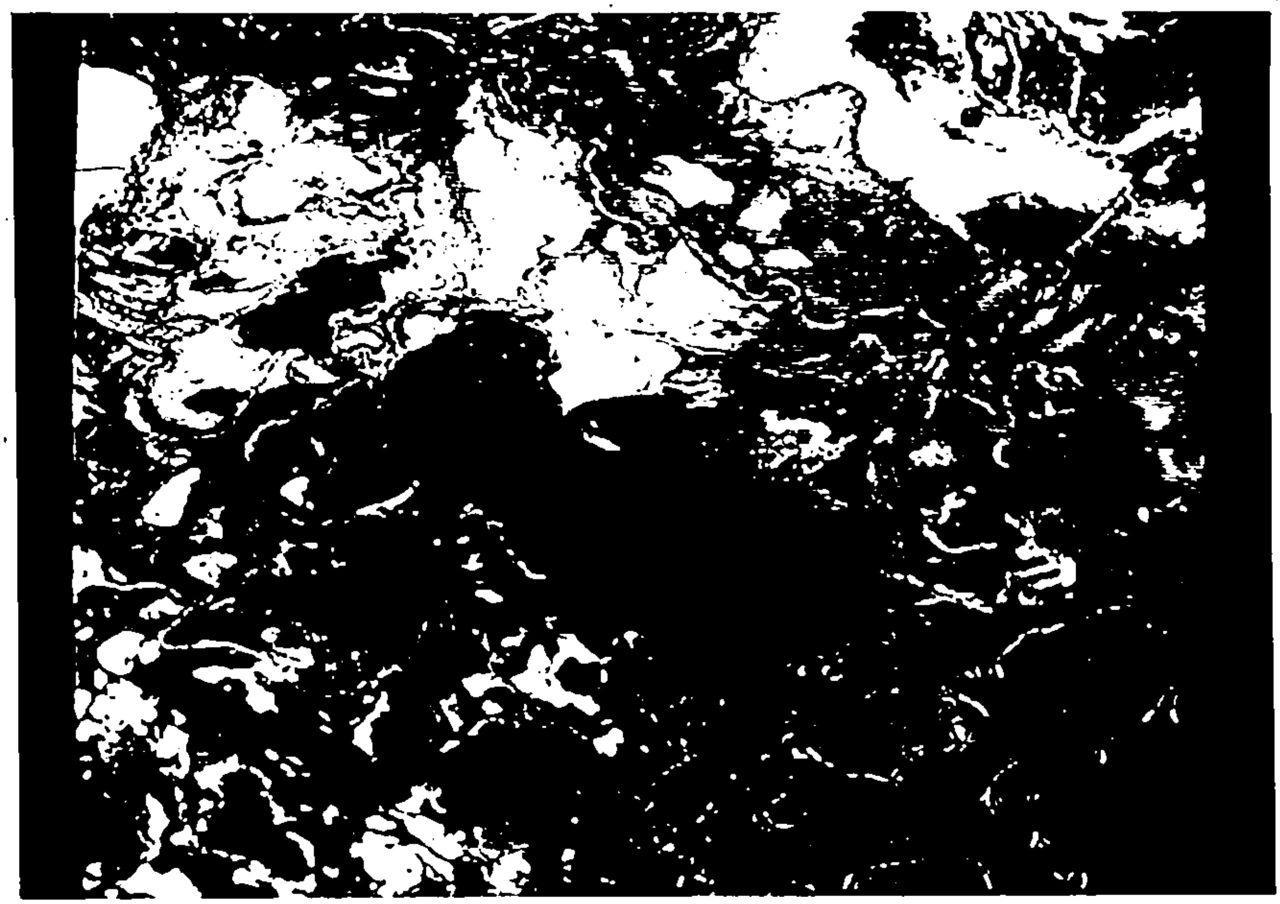


Figure 5.3 Band 7 ratio of LANDSAT scenes E20557-17522 and E1399-18104. In contrast to Figure 5.2, brightest tones emphasize changes in vegetation which result from the higher water levels.

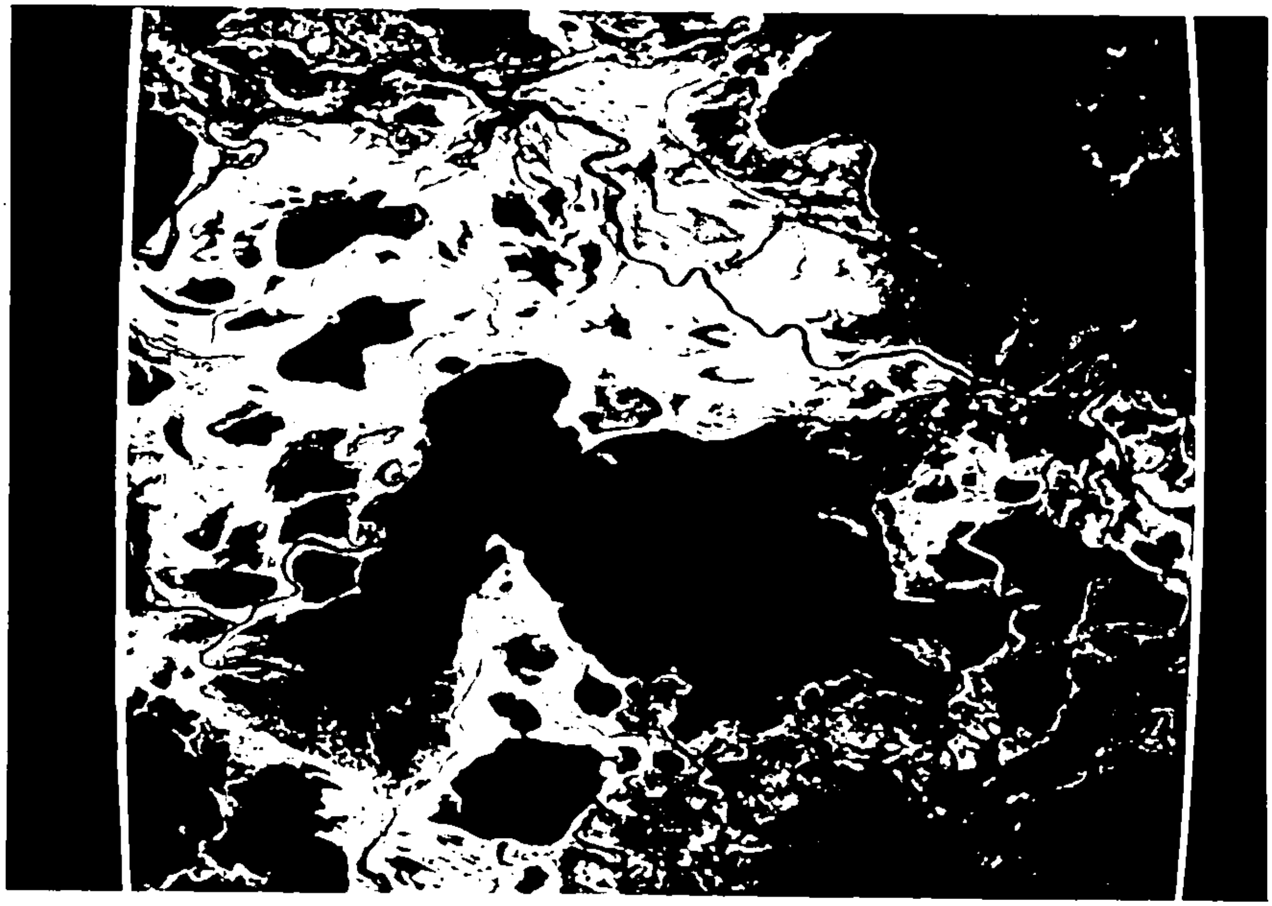


Figure 5.4 Color composite of Band 7 ratio of LANDSAT scenes E20557-17522 and E1399-18104. Areas dominated by water level changes are red (note Mamawi Lake shoreline). Areas dominated by vegetation changes are blue. Areas of relatively minor changes are displayed as browns, grays and whites.

In mapping the data at 1/2 and 1/8 areas, the same classification data are used and the information level thus remains the same. In the 1/8 area mapping, the original data are magnified two times to effect a nominal map scale of 1:125,000. To achieve this magnification each pixel is repeated four times (2 times horizontally, 2 times vertically). By doing this, unusually high pixel counts are observed. 'True' counts are obtained by dividing each number by four. Further, in calculating area percentages for 1/2 and 1/8 areas, only one-half screen is used to display the classification results for each year. Percentages are therefore based on a 512 x 256 pixel area rather than the normal 512 x 512 pixel area. Although not attempted for this study, the same approach to change detection used in section 5.2.3.2 can be used for either the 1/2 or 1/8 area analysis.

5.2.3.1 Change Statistics for Total Area: Visual Comparison

A simple visual comparison of Figures 4.1 and 4.12 reveals that significant changes occurred between 1973 and 1976. These changes have been summarized for the unfiltered classification and are presented in Table 5.2. As a result of gradually rising water levels in 1973, it is difficult to evaluate the exact nature of the changes. It can be seen, however, that differences appear to have occurred in the *Scolochloa*/*Scolochloa*-*Carex*, Wet *Carex* fen, fen-*Salix* and *Salix*-*Alnus*-*Populus* classes. As discussed earlier, changes in the latter two classes are somewhat misleading in that flooding in the habitats along the Lakeshore and Delta Plain makes it difficult to separate these habitat classes on a spectral basis. Using the post classification change detection technique, however, the exact nature of the change may be determined.

Table 5.2 Summary of Area Statistics for 1976 and 1973 Supervised Classifications

Habitat Class	Classification Statistics: No. of Pixels		Area in Km^2		Percent Area		Percent Area Changed
	1976	1973	1976	1973	1976	1973	1976-1973
Turbid Open Water	32,960	31,107	153.627	144.990	12.57	11.87	-0.70
Less Turbid Open Water	30,438	32,383	141.872	150.937	11.61	12.35	+0.74
Scolochloa/Scolochloa-Carex	18,367	7,029	85.609	32.762	7.01	2.68	-4.33
Wet *Carex* Fen	26,416	15,097	123.125	70.367	10.08	5.76	-4.32
Carex/Calamagrostis Fen	30,304	33,745	141.247	157.285	11.56	12.87	+1.31
Shrub Fen/Fen/*Salix-Alnus-Populus*	-	92,910	-	433.053	-	35.44	-
Shrub Fen	34,284	-	159.798	-	13.08	-	-
Salix-Alnus-Populus	40,997	-	191.087	-	15.64	-	-
Picea-Populus	5,528	6,348	25.766	29.588	2.11	2.42	+0.31
Unclassified	42,850	43,525	-	203.000	16.34	16.61	+0.27

5.2.3.2 Change Statistics for Total Area: Digital Comparison

Using the procedures outlined in Sections 3.3.3 and 3.3.5, a comparison of habitats for 1976 and 1973 was made for the entire Mamawi Lake Test Site. The results are presented in Tables 5.3 and 5.4. The main diagonal of the matrix (Table 5.3) represents areas of no change (overlap) in the classification. The values presented in Table 5.4 represent the portion of each habitat class that was unique to 1976 (i.e there was no overlap with pixels from 1973 in any habitat class).

Using this change detection technique, it is now possible to clearly identify the nature of the change as well as simply observing the fact that change has occurred. Caution in using these statistics is required because areas classified differently may represent one of the following:

a) true change,

b) misclassification on either or both scenes (Figures 4.1 and 4.12),

c) errors of registration, or

d) errors in classification training.

The inherent risks in attempting to detect change on a pixel by pixel basis are therefore evident. As discussed in Section 5.2, this danger is more pronounced where pixels are isolated and less where groups of pixels have changed. Using Table 5.3 it is now possible to separate the Shrub-fen/fen/*Salix-Alnus-Populus* habitat class of 1973, relative to 1976 habitat classes Shrub-fen and *Salix-Alnus-Populus*: 70.4% of the 1973 class overlaps the Shrub-fen class and 48.9% overlaps the *Salix-Alnus-Populus* class. The data presented in Tables 5.3 and 5.4 can be spatially represented in either a conflict character assignment map (Rubec, 1978) or

Table 5.3 Comparison of 1973 and 1976 Digital LANDSAT Classifications Indicating Areas and Percentages of Habitat Overlap. Overlaps are Expressed Relative to 1976 Habitats.

1976 Habitat Class	1973 Habitat Class: Turbid Open Water				Less Turbid Open Water				Scolochloa/Scolochloa-Carex				Wet Carex Fen				Carex/Calamagrostis Fen				Shrub-Fen/Fen/Salix-Alnus-Populus				Picea-Populus			
	No. Pixels	km²	% Area	% Overlap	No. Pixels	km²	% Area	% Overlap	No. Pixels	km²	% Area	% Overlap	No. Pixels	km²	% Area	% Overlap	No. Pixels	km²	% Area	% Overlap	No. Pixels	km²	% Area	% Overlap	No. Pixels	km²	% Area	% Overlap
Turbid Open Water	27596	130.6	19.5	77.9	4309	20.0	1.6	13.1	---	---	---	---	---	---	---	---	---	---	---	---		---	---	---	---	---	---	---
Less Turbid Open Water	2450	11.5	.9	8.1	19825	92.8	7.6	65.1	374	1.7	.1	1.2	912	4.3	.4	3.0	748	3.5	.3	2.5	3561	16.6	1.4	11.7	---	---	---	---
Scolochloa/ Scolochloa-Carex	---	---	---	---	2545	11.9	1.0	13.9	1796	8.4	.7	9.8	579	2.7	.2	3.2	1213	5.7	.5	6.6	9449	44.1	3.6	51.6	---	---	---	---
Wet Carex Fen	---	---	---	---	456	2.2	.2	1.0	711	3.3	.3	2.7	3904	18.6	1.5	15.1	8771	40.9	3.4	33.2	7390	34.5	2.8	28.0	---	---	---	---
Carex/Calamagrostis Fen	---	---	---	---	520	2.5	.2	1.1	723	3.4	.3	2.4	5539	25.8	2.1	18.1	9994	46.6	3.8	33.0	7270	33.9	2.8	24.0	---	---	---	---
Shrub Fen	---	---	---	--	325	1.5	.1	2.4	1210	5.6	.5	3.5	908	4.6	.4	2.9	3084	14.4	1.2	9.0	24151	112.6	9.2	70.4	---	---	---	---
Salix-Alnus-Populus	---	---	---	---	---	--	--	---	---	---	---	---	1052	6.0	.6	1.5	5770	26.9	2.2	14.1	20039	93.4	7.6	46.9	835	3.9	.3	2.0
Picea-Populus	---	---	---	---	476	2.2	.2	0.6	---	---	---	--	---	---	---	---	---	---	---	---	1711	8.0	.7	31.0	2050	11.1	1.0	51.6

Table 5.4 Class Statistics Represent the Portion of Each Habitat Class for which there was no Overlap with 1973 Habitat

HABITAT CLASS	CLASS STATISTICS			
	No. Pixels	Km^2	% Area	% Unique to 1976
Turbid Open Water	3511	16.4	1.3	9.9
Less Turbid Open Water	2560	11.9	1.0	8.4
Scolochloa/Scolochloa-Carex	2765	12.9	1.1	15.1
Wet *Carex* Fen	5085	23.7	1.9	19.3
Carex/Calamagrostis Fen	6250	29.1	2.4	20.6
Shrub-Fen	4026	18.8	1.5	11.7
Salix-Alnus-Populus	12893	60.1	4.9	31.5
Picea-Populus	491	2.3	.2	8.9

binary theme print maps. The latter method has been used during this study. To assist in the interpretation of the mapped data, colour overlays for each binary theme class overlap were prepared. When overlayed in combination, change detection can be easily carried out visually, (Figure 5.5).* In this diagram, Figure 5.5 (a) represents areas of Turbid Open Water common to both 1973 and 1976, Figure 5.5 (b) represents an increase in the area of Turbid Open Water in 1973 over 1976. This results from the higher water levels in 1973. Figure 5.5 (c) represents an overlap of Turbid Open Water, 1976 and Less Turbid Open Water 1973.

5.2.3.3 1/2 Area Change Detection

Using the same classification data, the Mamawi Lake Test Site was subdivided in two using a split screen (Figures 5.6 and 5.7) and new pixel counts were developed for each area (Tables 5.5 and 5.6). Using the split screen approach, visual comparison of the two dates is made easier. The effects of reduced water levels are readily apparent in Figure 5.7. On the bottom half of the figure, the extent of the blue pixels over the scene indicates the flooding of habitats along the Mamawi Lake shoreline and Delta Plain. With water levels reduced (1976, top half of Figure 5.6) the classes Wet *Carex* Fen (orange pixels), *Scolochloa*/*Scolochloa*-*Carex* (yellow pixels) and *Carex*/*Calamagrostis* (mauve pixels) are now spectrally distinct and readily separated from the Shrub Fen and *Salix*-*Alnus*-*Populus* habitats.

5.2.3.4 1/8 Area Change Detection

Using the same classification data, the test site was further subdivided into 8 areas (Figure 5.8). At this level of comparison, the mapping scale was changed to 1:125,000 making the maps more useful to

*see pocket insert

Figure 5.6 Top half of Mamawi Lake Test Site. Summary of classification statistics are presented in Table 5.5.

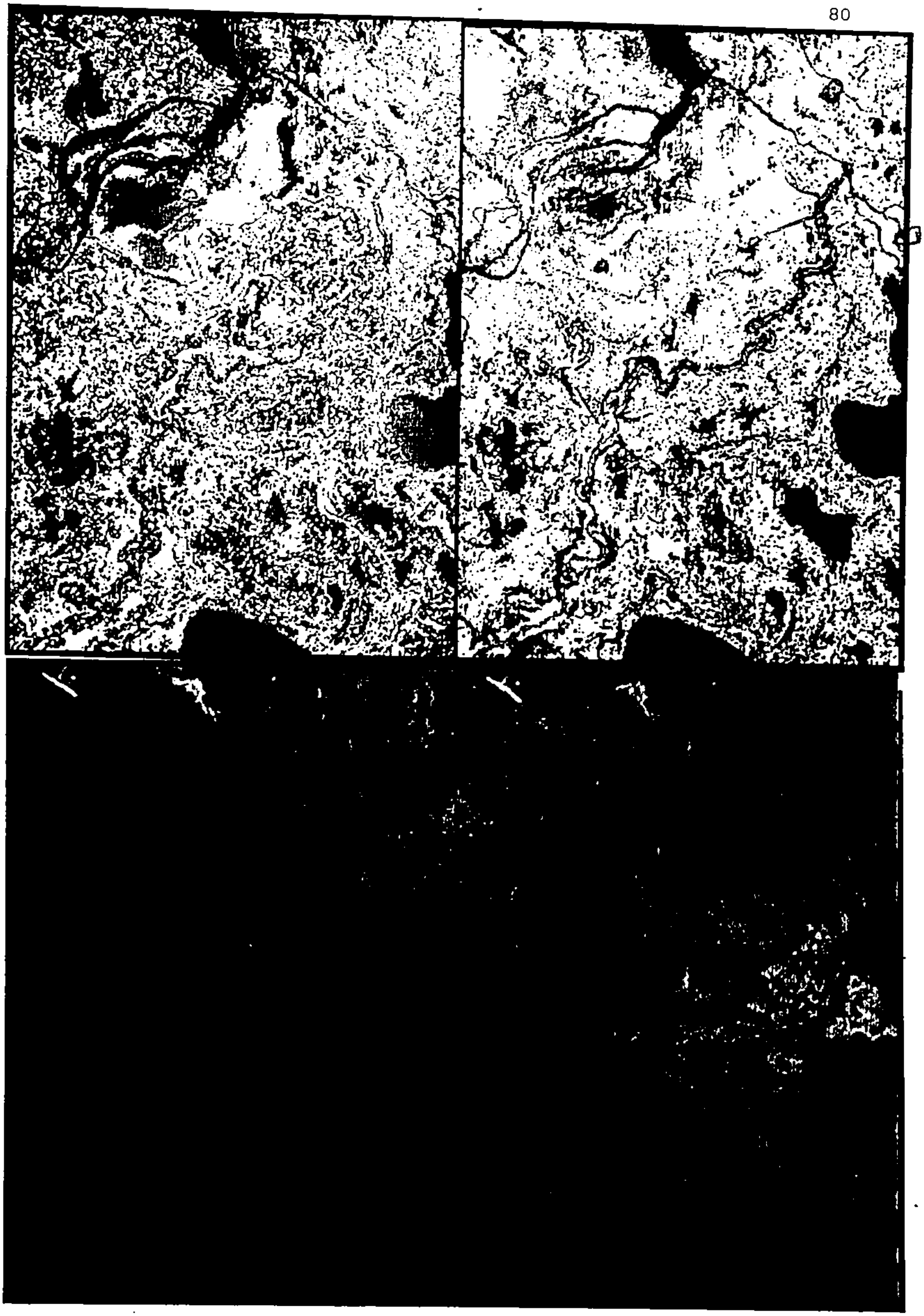


Table 5.5 Summary of Habitat Classification Statistics for Top Half of Mamawi Lake Test Site, 1973/1976

	Classification Statistics					
	1973			1976		
HABITAT TYPE	Pixels	Km^2	% Area	Pixles	Km^2	% Area
Turbid Open Water	6801	31.7	2.6	5968	27.8	2.3
Less Turbid Open Water	10365	48.3	4.0	14697	68.5	5.6
Scolochloa/*Scolochloa*-*Carex*	5216	24.3	2.0	14042	65.5	5.4
Wet *Carex* Fen	9357	43.6	3.6	12888	60.1	4.9
Carex/*Calamagrostis* Fen	20589	96.0	7.9	7727	36.0	3.0
Fen-*Salix*/Fen/*Salix*-*Alnus*-*Populus*	50559	235.7	19.3	---	---	---
Shrub-Fen	---	---	---	23312	108.7	8.9
Salix-*Alnus*-*Populus*	---	---	---	23684	110.4	9.0
Picea-*Populus*	2149	10.0	0.8	2770	12.9	1.1

Figure 5.7 Bottom half of Mamawi Lake Test Site. Summary of classification statistics are presented in Table 5.6.

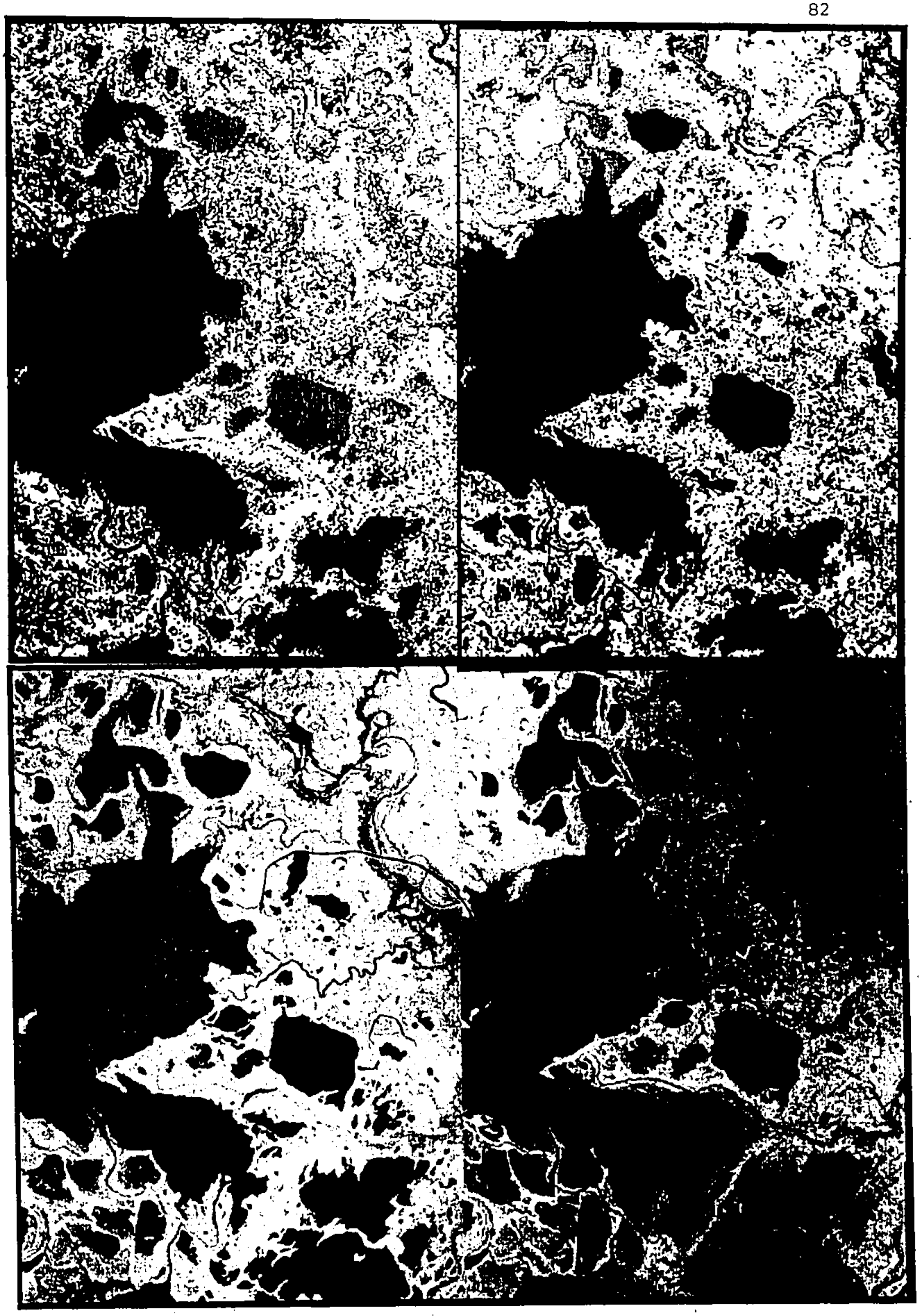


Table 5.6 Summary of Habitat Classification Statistics for Bottom Half of Mamawi Lake Test Site, 1973/1976

	Classification Statistics					
	1973			1976		
HABITAT TYPE	Pixels	Km^2	% Area	Pixels	Km^2	% Area
Turbid Open Water	23268	108.5	8.9	26761	124.7	10.2
Less Turbid Open Water	21460	100.0	8.2	15695	73.2	6.0
Scolochloa/*Scolochloa-Carex*	1896	8.8	0.7	4309	20.1	1.6
Wet *Carex* Fen	5762	26.8	2.2	13462	62.7	5.1
Fen-*Salix*/Fen/*Salix-Alnus-Populus*	39954	186.2	15.2	---	---	---
Shrub-Fen	---	---	---	11031	51.4	4.2
Salix-Alnus-Populus	---	---	---	18384	85.7	7.0
Picea-Populus	4090	19.1	1.6	2942	13.7	1.1

Figure 5.8 Schematic showing subdivision of the Mamawi Lake Test Site into 1/8 areas. At this level of analysis areas identified as particularly susceptible to change can be more effectively isolated and evaluated.

NW 1	NE 1
NW 2	NE 2
SW 1	SE 1
SW 2	SE 2

resource managers. At this scale of subdivision, areas identified as particularly susceptible to change can be more effectively isolated and analyzed. Results of the 8 subdivisions are presented in Figures 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, 5.15 and 5.16. In each scene, 1976 classification results are on the top half of the photograph, 1973 classification results are on the bottom.

Area: NW. 1 (Figure 5.9)

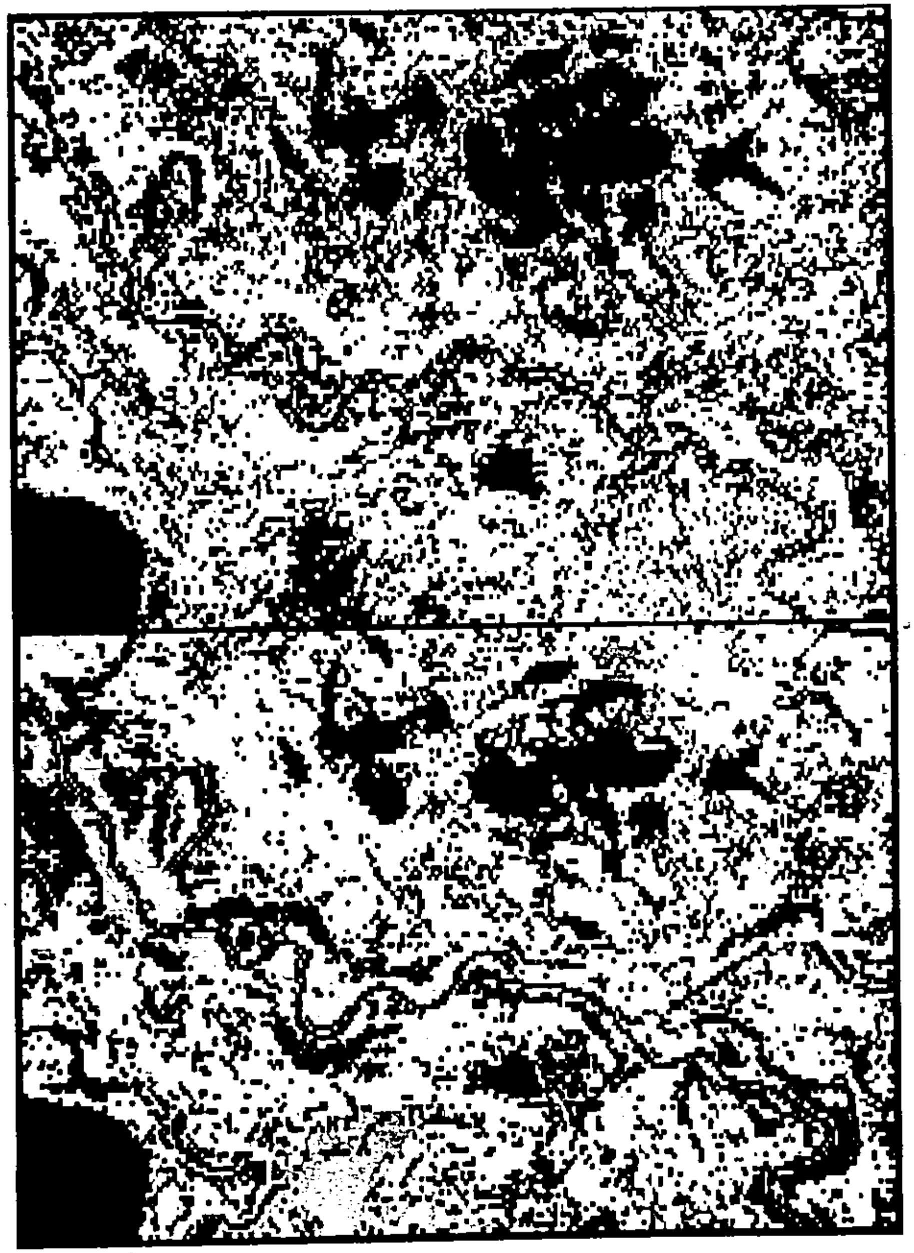
NW. 1 area is dominated by the relatively stable *Picea-Populus* habitat along the levée of the Chenal des Quatre Fourches and the *Salix-Alnus-Populus* habitat on the levée backslope. Effects of the high water levels from 1972-74 are evident by the increases in the *Scolochloa-Scolochloa-Carex* and Wet *Carex* fen habitats - habitats which favour higher water levels, and a reduction in the *Carex/Calamagrostis* habitat, one which favours lower water levels and drier conditions.

Area: NW. 2 (Figure 5.10)

This area is dominated by numerous perched basins which are particularly susceptible to flooding and changes in water levels. As a result of the higher water levels during the 1972-74 period, the area of both Turbid and Less Turbid Open Water has increased significantly in many of these perched basins. A significant increase in the *Scolochloa/Scolochloa-Carex* fen habitat, which is normally associated with continuously flooded areas, has also occurred.

Area: SW. 1 (Figure 5.11)

SW. 1 is dominated by fen habitats of the Mamawi Lake Lakeshore and Delta Plain physiographic unit. A large increase in the Wet *Carex* fen habitat is evident, as well as a smaller (yet still evident) increase in

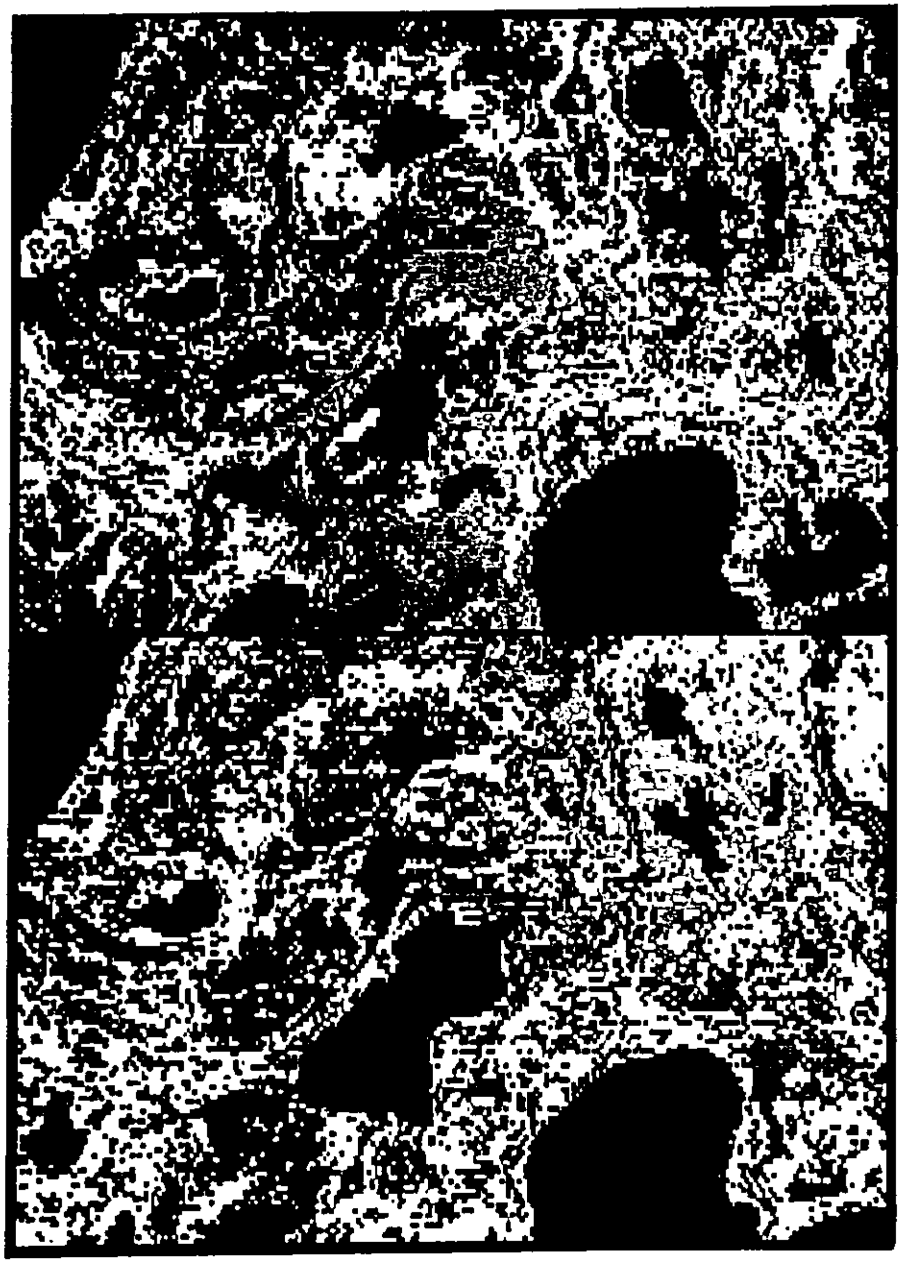


LANDSAT THEMATIC MAP

AREA NO. 1

Habitat Type	1976 Theme Colour	1976 Pixels	1976 Km^2	1976 % Area	1973 Theme Colour	1973 Pixels	1973 Km^2	1973 % Area
Turbid Open Water	Green	2980	3.5	1.1	Green	3518	4.1	1.3
Less Turbid Open Water	Purple	15514	18.1	5.9	Purple	13618	15.9	5.2
Scolochloa/ *Scolochloa-Carex*	Yellow	6244	7.3	2.4	Orange	976	1.1	.4
Wet *Carex* Fen	Orange	10808	12.6	4.1	Mauve	5238	6.1	2.0
Carex/*Calamagrostis* Fen	Mauve	6360	7.4	2.4	Pink	24428	28.5	9.3
Fen-*Salix*/Fen/ *Salix-Alnus-Populus*	---	---	---	---	Blue	47050	54.8	18.0
Shrub-Fen	Pink	19880	23.2	7.6	---	---	---	---
Salix-Alnus-Populus	Blue	39666	46.2	15.1	---	---	---	---
Picea/*Populus*	Brindle	5042	5.9	1.9	Brindle	5666	6.6	2.2

Figure 5.9



LANDSAT THEMATIC MAP

AREA NW. 2

Habitat Type	1976 Theme Colour	1976 Pixels	1976 Km^2	1976 % Area	1973 Theme Colour	1973 Pixels	1973 Km^2	1973 % Area
Turbid Open Water	Green	7156	8.3	2.7	Green	9144	10.7	3.5
Less Turbid Open Water	Purple	22298	26.0	8.5	Purple	15336	17.9	5.9
Scolochloa/ *Scolochloa*-*Carex*	Yellow	11028	12.9	4.2	Orange	1654	1.9	0.6
Wet *Carex* Fen	Orange	24098	28.1	9.2	Mauve	26056	30.4	9.9
Carex/*Calamagrostis* Fen	Mauve	19228	22.4	7.3	Pink	28580	33.3	11.0
Fen-*Salix*/Fen/ *Salix*-*Alnus*-*Populus*	---	---	---	---	Blue	21626	25.2	8.3
Shrub-Fen	Pink	10652	12.4	4.1	---	---	---	---
Salix-*Alnus*-*Populus*	Blue	20066	23.4	7.7	---	---	---	---
Picea/*Populus*	Brindle	1044	1.2	0.4	Brindle	228	0.3	0.1

Figure 5.10

LANDSAT THEMATIC MAP

Area SW. 1

Habitat Type	1976				1973			
	Theme Colour	Pixels	Km^2	% Area	Theme Colour	Pixels	Km^2	% Area
Turbid Open Water	Green	52880	61.6	20.2	Green	47968	55.9	18.3
Less Turbid Open Water	Purple	7778	9.1	3.0	Purple	16030	18.7	6.1
Scolochloa/ *Scolochloa-Carex*	Yellow	5046	5.9	2.0	Orange	2104	2.5	0.8
Wet *Carex* Fen	Orange	16058	18.7	6.1	Mauve	4450	5.2	1.7
Carex/*Calamagrostis* Fen	Mauve	28136	32.8	10.7	Pink	18556	21.6	7.1
Fen-*Salix*/Fen/ *Salix-Alnus-Populus*	---	---	---	---	Blue	20102	23.4	7.7
Shrub-Fen	Pink	5398	6.3	2.1	---	---	---	---
Salix-Alnus-Populus	Blue	3066	3.6	1.2	---	---	---	---
Picea/*Populus*	Brindle	92	0.1	0.04	Brindle	104	0.1	.04

Figure 5.11

the *Scolochloa/Scolochloa-Carex* fen habitat. The large number of black or unclassified pixels represents areas of 'immature fen - sparsely vegetated mudflats'. This habitat generally results following drawdown in the basins and is quickly (1-2 years) colonized by Senecio on the mud-flats or *Carex* on decaying reed mats.

Area: SW. 2 (Figure 5.12)

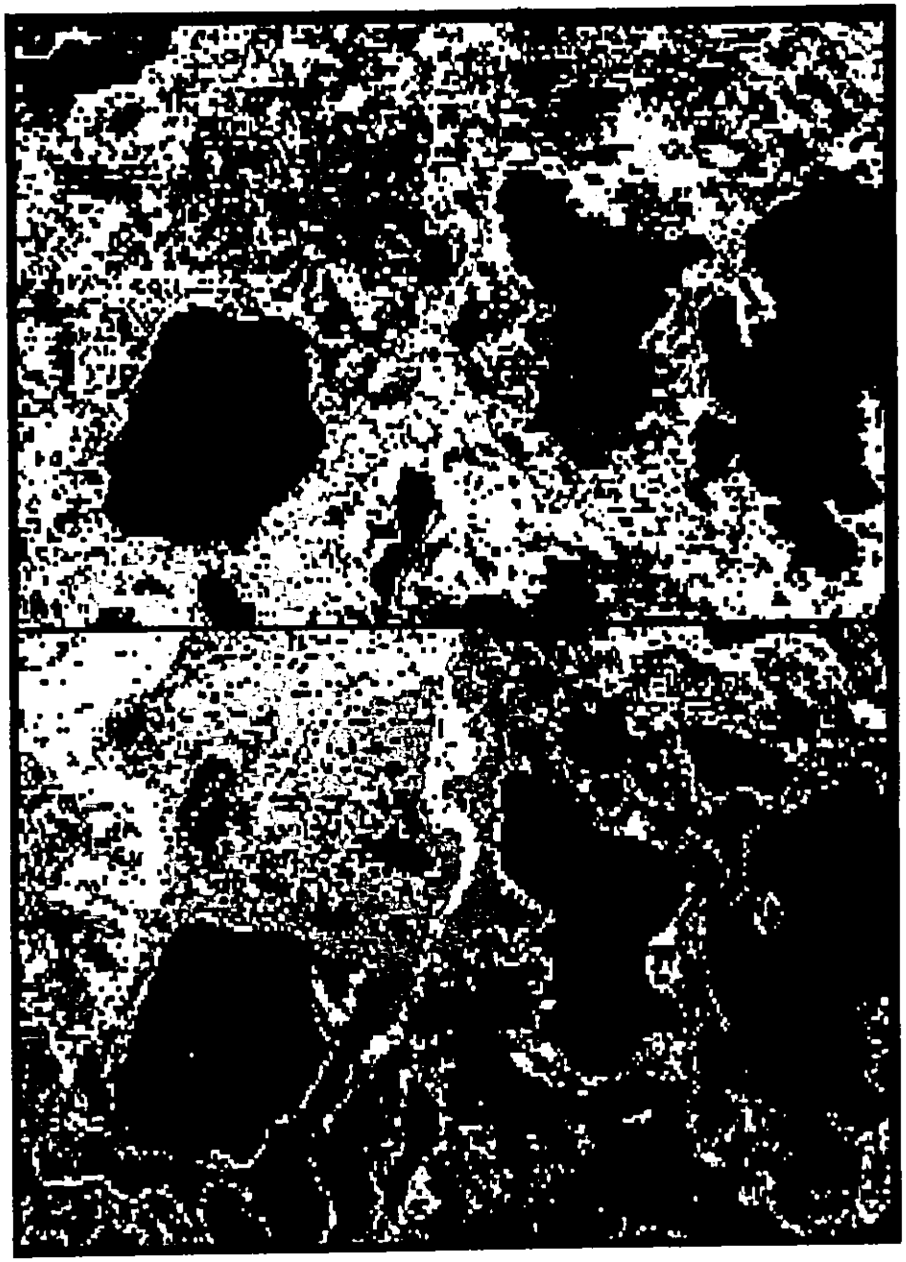
This area, also part of the Lakeshore and Delta Plain complex, is dominated by a number of large lake basins. Differences in turbidity in the open water habitats between 1973 and 1976 are easily observed. The large number of blue pixels around the basin perimeters in 1973 is evidence to the high waters in the basins. These areas have, with lower water levels in 1976 been subsequently colonized by the *Carex/Calamagrostis* habitat type.

Area: NE. 1 (Figure 5.13)

The NE. 1 area is dominated by Lake Athabasca and the major outflow channels of the Rivière des Rochers. The impact of high water levels in Lake Athabasca (1973) are readily appreciated by the dominance of blue pixels in the 1973 classified scene. With lower water levels in 1976 many of these flooded areas have experienced a substantial growth in *Scolochloa/ Scolochloa-Carex*. This habitat also delineated very effectively the large basin located immediately west of Lake Athabasca. (Compare this Figure to Figure 3.4). The airport runway, near Ft. Chipewayn located near the top right hand corner of Figure 5.13 remains unclassified but easily identifiable.

Area NE. 2 (Figure 5.14)

This area, also directly linked hydrologically to Lake Athabasca,

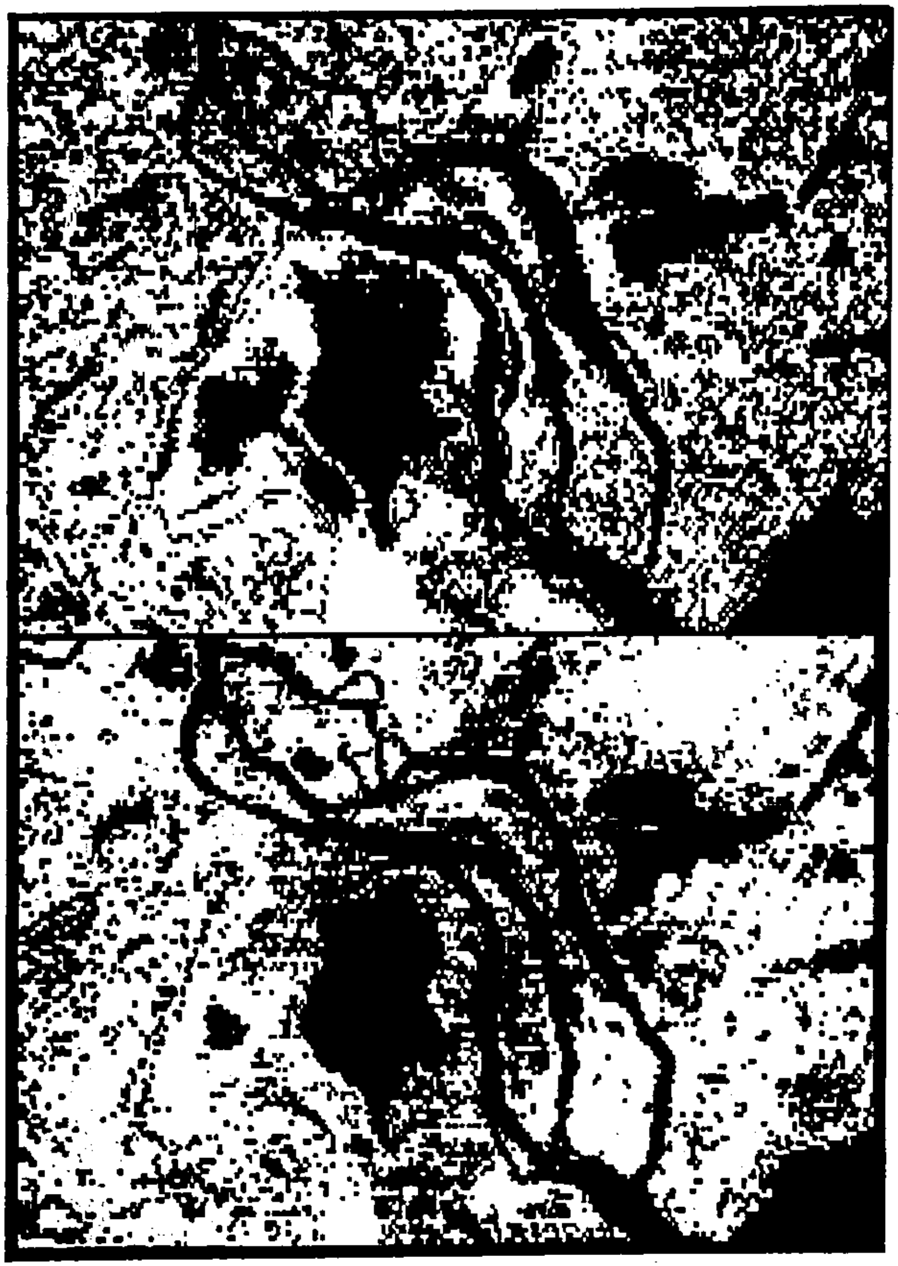


LANDSAT THEMATIC MAP

Area SW. 2

Habitat Type	1976 Theme Colour	1976 Pixels	1976 Km^2	1976 % Area	1973 Theme Colour	1973 Pixels	1973 Km^2	1973 % Area
Turbid Open Water	Green	8396	9.8	3.2	Green	2540	3.0	1.0
Less Turbid Open Water	Purple	32928	38.4	12.6	Purple	32940	38.4	12.6
Scolochloa/ *Scolochloa-Carex*	Yellow	3932	4.6	1.5	Orange	1578	1.8	0.6
Wet *Carex* Fen	Orange	11412	13.3	4.4	Mauve	16794	19.6	6.4
Carex/*Calamagrostis* Fen	Mauve	37596	43.8	14.3	Pink	20332	23.7	7.8
Fen-*Salix*/Fen *Salix-Alnus-Populus*	---	---	---	---	Blue	28184	32.8	10.8
Shrub-Fen	Pink	6374	7.4	2.4	---	---	---	---
Salix-Alnus-Populus	Blue	16478	19.2	6.3	---	---	---	---
Picea/*Populus*	Brindle	1130	1.3	0.4	Brindle	980	1.1	0.4

Figure 5.12

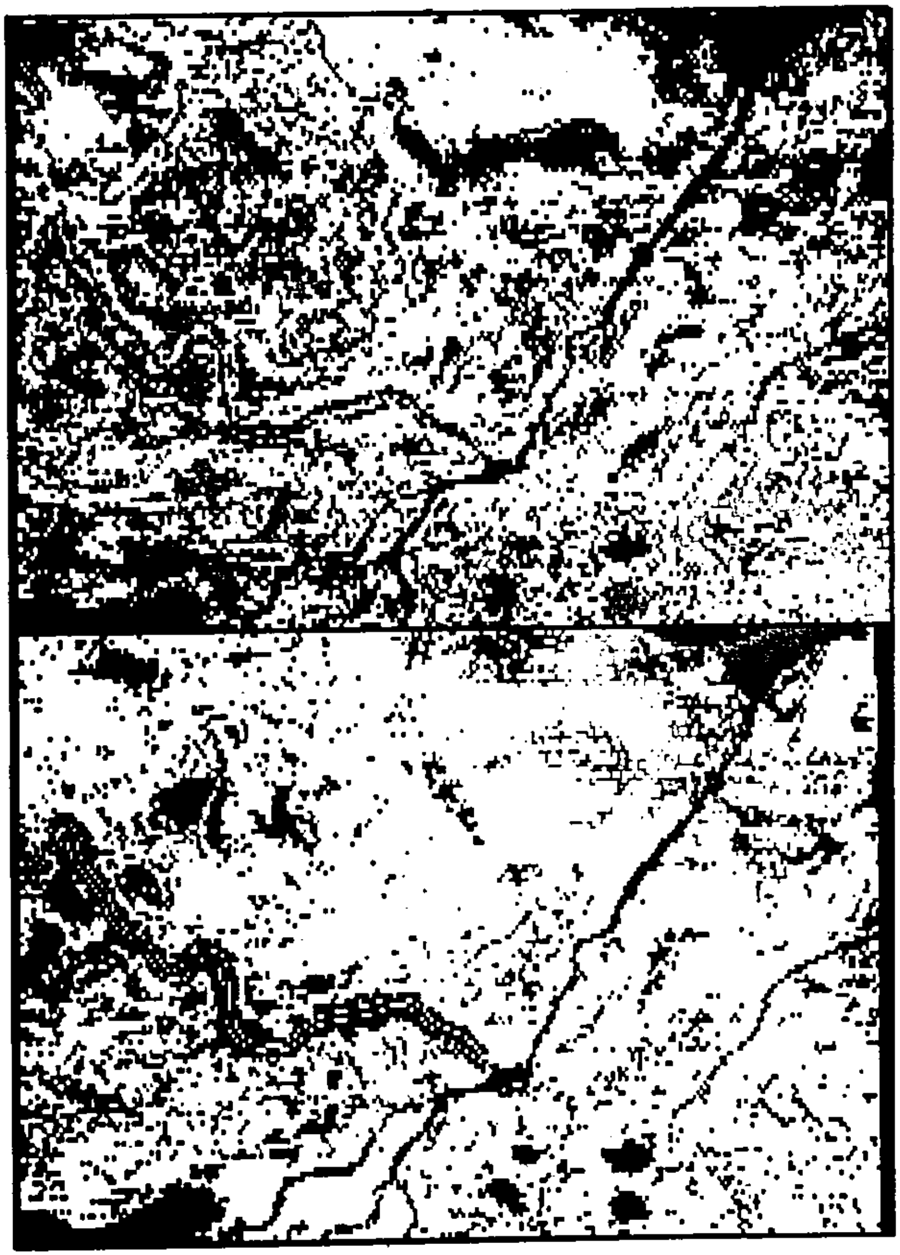


LANDSAT THEMATIC MAP

Area NE. 1

Habitat Type	1976 Theme Colour	1976 Pixels	1976 Km^2	1976 % Area	1973 Theme Colour	1973 Pixels	1973 Km^2	1973 % Area
Turbid Open Water	Green	11930	13.9	4.6	Green	13914	16.2	5.3
Less Turbid Open Water	Purple	15652	18.2	6.0	Purple	6904	8.1	2.6
Scolochloa/ *Scolochloa*-*Carex*	Yellow	22902	26.7	8.7	Orange	11750	13.7	4.5
Wet *Carex* Fen	Orange	3232	3.8	1.2	Mauve	1076	1.3	0.4
Carex/*Calamagrostis* Fen	Mauve	648	0.8	0.3	Pink	9002	10.5	3.4
Fen-*Salix*/Fen/ *Salix*-*Alnus*-*Populus*	---	---	---	---	Blue	63852	74.4	24.4
Shrub-Fen	Pink	25982	30.3	9.9	---	---	---	---
Salix-*Alnus*-*Populus*	Blue	14174	16.5	5.4	---	---	---	---
Picea/*Populus*	Brindle	2098	2.5	0.8	Brindle	1300	1.5	0.5

Figure 5.13



LANDSAT THEMATIC MAP

NE. 2

Habitat Type	1976 Theme Colour	1976 Pixels	1976 Km^2	1976 % Area	1973 Theme Colour	1973 Pixels	1973 Km^2	1973 % Area
Turbid Open Water	Green	2664	3.1	1.0	Green	1516	1.8	0.6
Less Turbid Open Water	Purple	5140	6.0	2.0	Purple	5842	6.8	2.2
Scolochloa/ *Scolochloa-Carex*	Yellow	15668	18.3	6.0	Orange	5984	7.0	2.3
Wet *Carex* Fen	Orange	13410	15.6	5.1	Mauve	4220	4.9	1.6
Carex/Calamagrostis Fen	Mauve	4644	5.4	1.8	Pink	20174	23.5	7.7
Fen-*Salix*/Fen *Salix-Alnus-Populus*	---	---	---	---	Blue	71108	82.9	27.1
Shrub-Fen	Pink	36564	42.6	14.0	---	---	---	---
Salix-Alnus-Populus	Blue	20490	23.9	7.8	---	---	---	---
Picea/Populus	Brindle	2948	3.4	1.1	Brindle	1552	1.8	0.6

Figure 5.14

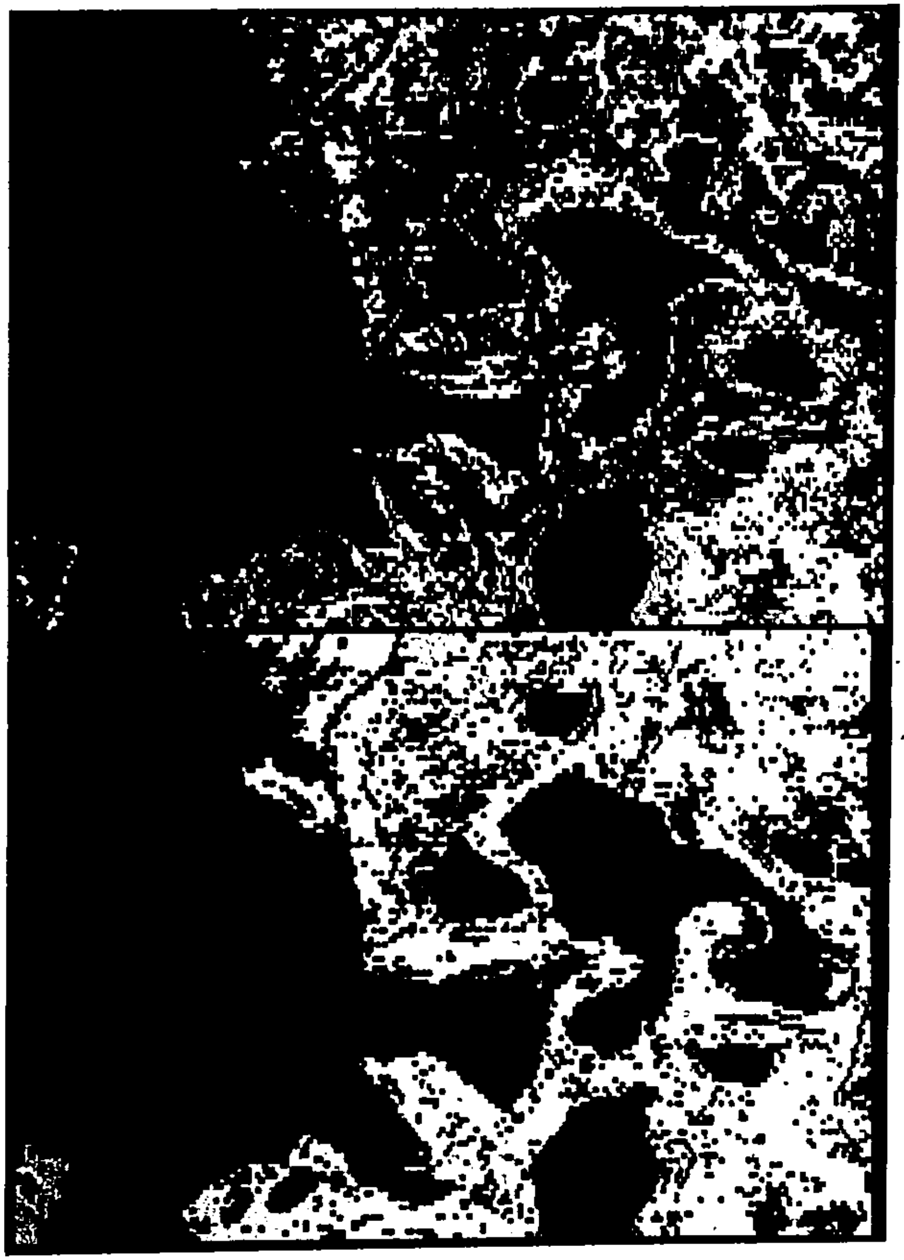
illustrates the impact of the high water levels in 1973 with the large number of blue pixels. The Shrub-fen habitat dominates the area in 1976 following water level reductions.

Area: SE. 1 (Figure 5.15)

The SE. 1 area is similar to NW. 3 and is dominated by fen habitats along the Mamawi Lakes shoreline. The area was entirely inundated during the 1972-74 period. With lower water levels in 1976, however, the *Scolochloa/Scolochloa-Carex* habitat can be observed fringing the major lakes basins (yellow pixels) with *Carex* fen (orange pixels) and *Carex/Calamagrostis* fen habitats dominating the slightly drier sites.

Area: SE. 2 (Figure 5.16)

This area is dominated by the relatively stable *Picea-Populus* *Salix-Alnus-Populus* and Shrub-fen habitats along the Embarras River. Backswamps and small perched basins flooded in 1973, have been replaced in 1976 by 'Immature fen/sparsely vegetated mudflats' and by the Shrub-fen habitat. This latter habitat experienced little change as a result of flooding. The major problem in identifying the class results from the inability to spectrally discriminate this class when flooded (See Section 4.3).

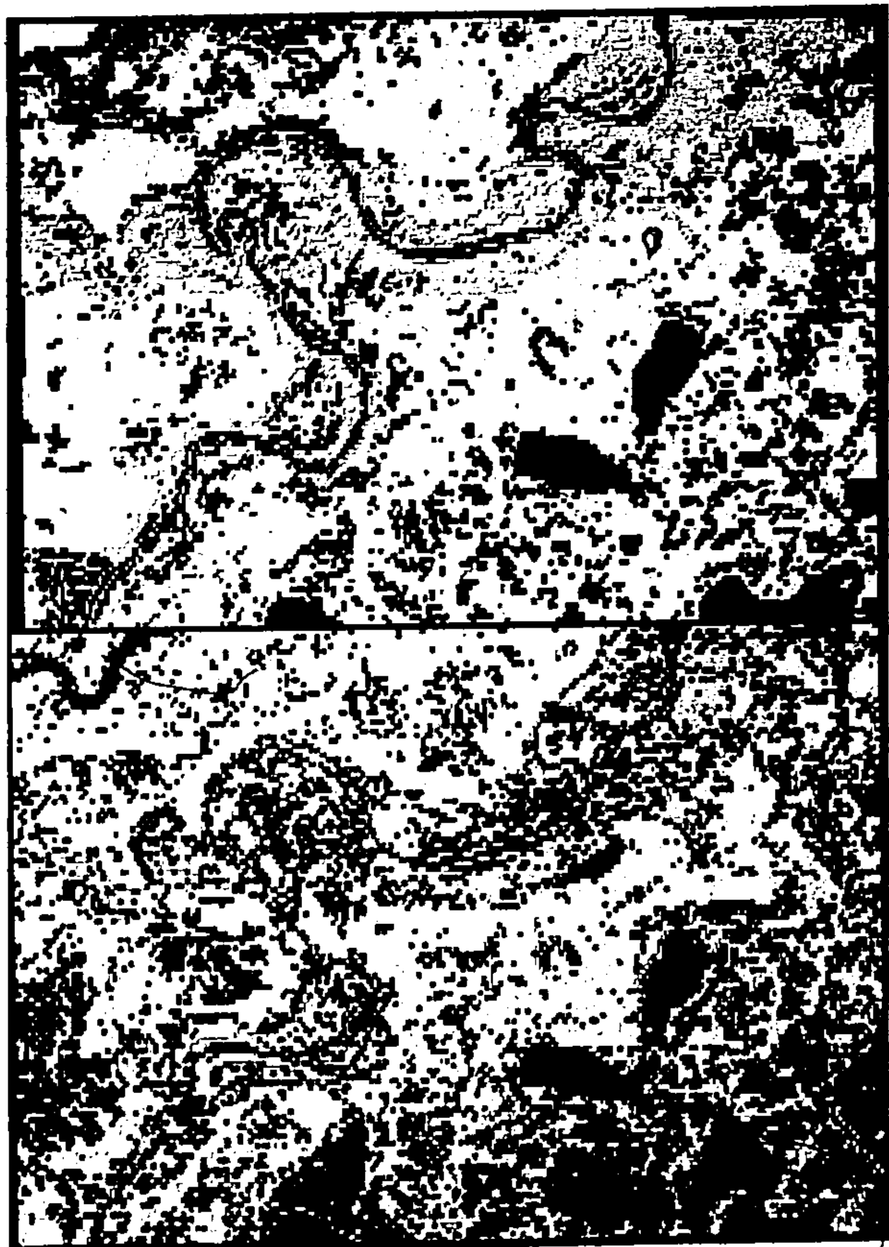


LANDSAT THEMATIC MAP

Area SE. 1

Habitat Type	1976 Theme Colour	1976 Pixels	1976 Km^2	1976 % Area	1973 Theme Colour	1973 Pixels	1973 Km^2	1973 % Area
Turbid Open Water	Green	43818	51.1	16.7	Green	41776	48.7	16.0
Less Turbid Open Water	Purple	16332	19.0	6.2	Purple	24996	29.1	9.5
Scolochloa/ *Scolochloa-Carex*	Yellow	4010	4.7	1.5	Orange	1534	1.8	0.6
Wet *Carex* Fen	Orange	16485	19.2	6.3	Mauve	536	0.6	0.2
Carex/*Calamagrostis* Fen	Mauve	17042	19.9	6.5	Pink	7774	9.1	3.0
Fen-*Salix*/Fen/ *Salix-Alnus* *Populus*	---	---	---	---	Blue	36438	42.5	14.0
Shrub-Fen	Pink	10044	11.7	3.8	---	---	---	---
Salix-Alnus-*Populus*	Blue	10720	12.5	4.1	---	---	---	---
Picea/*Populus*	Brindle	584	0.7	0.2	Brindle	494	0.6	0.2

Figure 5.15



LANDSAT THEMATIC MAP

Area SE. 2

Habitat Type	1976 Theme Colour	1976 Pixels	1976 Km^2	1976 % Area	1973 Theme Colour	1973 Pixels	1973 Km^2	1973 % Area
Turbid Open Water	Green	1994	2.3	0.8	Green	662	0.8	0.3
Less Turbid Open Water	Purple	5500	6.4	2.1	Purple	10244	11.9	3.9
Scolochloa/ *Scolochloa*-*Carex*	Yellow	4210	4.9	1.6	Orange	1588	1.9	0.6
Wet *Carex* Fen	Orange	9632	11.2	3.7	Mauve	448	0.5	0.2
Carex/*Calamagrostis* Fen	Mauve	7734	9.0	3.0	Pink	3008	3.5	1.2
Fen-*Salix*/Fen/ *Salix*-*Alnus*-*Populus*	---	---	---	---	Blue	76456	89.1	29.2
Shrub-Fen	Pink	22120	25.8	8.4	---	---	---	---
Salix-*Alnus*-*Populus*	Blue	43646	50.9	16.7	---	---	---	---
Picea/*Populus*	Brindle	10024	11.7	3.8	Brindle	15812	18.4	6.0

Figure 5.16

CHAPTER 6

DISCUSSION and CONCLUSIONS

6.1 Effectiveness of the Classifications

The classification system developed during this study is necessarily broad in the categories that have been identified. This is because of the large area of the delta and the complexity of the habitats that are encountered.

The level of classification incorporates most of the habitats identified at the generalized mapping scale (1:37,000) of Dabbs (1971) and a few of the habitats (particularly the various fen types) identified at the more detailed level of mapping (1:10,000) by Cordes and Pearce (1977). In general, major habitats in the delta have been effectively mapped, particularly those which cover large areas. As a result, they are well suited for mapping with LANDSAT. Less effectively mapped and identified are the smaller habitats which occur in areas less than 1 hectare in size or in narrow dynamic zones at the land/water interface. These habitats can remain unclassified or can be misclassified, as they are often located in 'boundary' situations. Furthermore, it was not possible to directly classify and relate habitat types in terms of their physiographic positions. Habitat/physiographic site relationships could, however, be indirectly identified by interpreting the classified images and developing the topographic/habitat relationships (Figure 5.1).

Improvements in classification should be possible because of the multi-variate approach to data analysis on the Image 100, especially if a more detailed species-oriented classification is desired. Taking advantage of the different spectral responses among the various vegetation species during the growing season, two different dates from the same season could be analysed. By replotting the two data sets in four dimensional space (i.e. the reflectance at wavelengths 1 and 2 from date 1 as dimensions 1 and 2 and the reflectance at the same wavelengths from date 2 as dimensions 3 and 4) greater accuracy might be possible (Swain and Davis, 1978). Using this approach, the possibility of separating *Carex* and *Calamagrostis* might be improved, as would the possibility of separating *Senecio* from other immature fen species. Improved separation of the *Picea-Populis* class might be possible using this technique, although this habitat separation is less important, as fluctuating water levels do not substantially affect it.

6.2 Ground data

It is necessary to emphasize the importance of ground data in the classification process. In this study, the work by Cordes and Pearce (1977) provided excellent ground data and hence the confidence placed in the classification results for the 1976 scene is high. The lack of ground data for 1973 and dependence on aerial photographs from 1971 (Table 1.1) for providing training data reduce the confidence placed in this classification. In spite of this, it is felt that the 1973 classified scene is sufficiently good to place confidence in the results of the change detection studies. It would be valuable in the future, however, to establish a number of ground reference sites for each habitat with the following type of data collected at each site: species composition, canopy density, vigor, height, depth to water table and background exposure. These reference sites could then be used as training data for supervised classification. The collection of such data could be undertaken by technical staff over a relatively short time period. Furthermore, it is possible that using the results from the 1/8 area change detection studies, training and monitoring sites could be more effectively located.

6.3 Change Detection

The adoption of a quantitative or non-quantitative approach to change detection depends largely on the objectives of the monitoring program being established. The less quantitative methods, ratioing and visual interpretation of classified LANDSAT scenes, appear to be effective methods for the rapid identification of change, and over relatively large areas. Although not essential, the results obtained using these methods become most useful when available to an analyst with some *a priori* knowledge of the resources and processes of the area being monitored. An understanding of successional trends, and topographic relationships of habitats in the Delta, for example, enabled an evaluation of the vegetation-hydrologic patterns identified in Figure 5.1 for their susceptibility to short or long term environmental changes. Such *a priori* knowledge is perhaps less important for ratioing as some measure of the magnitude of change forms the basis for the approach, however, the significance of the magnitudes are more readily appreciated with some knowledge of the area.

These first level approaches are useful, in that once areas of significant change have been broadly identified, more detailed classification and post classification change detection studies can be effectively located.

The post classification change detection technique provides the user with a relatively sophisticated method of identifying both the change, and the nature of the change. By abstracting portions of the results of Figures 4.1, 4.11 and Table 5.3, the importance of using the change detection data with some discretion, however, can be demonstrated. In Table 6.1 a comparison of the area percentages for each habitat classified in 1973 and 1976 is presented in conjunction with the percent overlap obtained for each habitat class using the post classification technique. In the *Picea-Populus* habitat, little change would be expected to occur between 1973 and 1976, as this habitat remains relatively unaffected by fluctuating water levels. The classified 2.4 and 2.1 percent for 1973 and 1976 respectively bear out this expectation.

When overlayed, however, only 52% of the pixels actually correspond, and results suggest that 48% of the class experienced change! Such a massive shift is clearly impossible in this habitat. From an examination of Table 5.3, it can be seen that 31.0% of the pixels overlap with the Shrub-fen/Fen/*Salix-Alnus-Populus* habitat class. This suggests a problem of spectral confusion. In comparing the spectral values (Band 7) for these classes in Table 5.1 the confusion is clearly evident. The low spectral value (Band 7) of 37.20 for this class in 1973 (as opposed to 49.26 for 1976) suggests that in training on the *Picea-Populus* class in 1976, more *Populus* was encountered than in 1973. Classification accuracy, and hence improvements in change detection accuracy, would probably be improved with more consistent training from year to year.

Table 6.1 Percentage of the Total Mamawi Lake Test Site Occupied by Each Habitat in 1976 and 1973, and the Overlap Between the Two Years

Habitat Class	% Area 1976	% Area 1973	% Overlap* (1976/1973)
Turbid Open Water	12.6	11.9	77.9
Less Turbid Open Water	11.6	12.4	65.1
Scolochloa/Scolochloa-Carex	7.0	2.7	9.8
Wet *Carex* Fen	10.1	5.8	15.1
Carex/Calamagrostis Fen	11.6	12.9	33.0
Shrub Fen/Fen/*Salix-Alnus-Populus*	-	35.4	-
Shrub Fen	13.1	-	-
Salix-Alnus-Populus	15.6	-	-
Picea/Populus	2.1	2.4	51.6

* The percent overlap between the two years is expressed relative to the 1976 class. It indicates the proportion of pixels that did not change between the two years.

That this fact holds true for all habitat classes is evidenced by similar problems for the other habitat classes (Table 5.3). Of course differences in spectral responses from one year to another may also be attributed in part to those other factors mentioned in Section 5.2.1. In the classes where direct comparability is possible, it is not as easy to determine the significance one should place in the change statistics. As suggested in Table 6.1, the changes from one habitat to another produced by varying water levels between 1973 and 1976 appear realistic, although the significance of actual magnitudes may be questioned for those reasons discussed previously. Several more years of monitoring are needed, preferably with years where only minor shifts are known to have occurred, before a more definitive statement on the significance of the change statistics can be made. At this point it can be said that the expected direction in shifts from one habitat type to another, under declining water levels, can be detected. The confidence placed on the absolute values are in some doubt, however, until further evaluation is carried out.

6.4 Future Role for LANDSAT

Using the results of the study, it is now possible to evaluate the role that LANDSAT might play in a future long-term monitoring program in the delta.

Under the new modified hydrologic regime, summer amplitudes are not as great as experienced under the natural regime (Cordes and Pearce, 1977). In addition, continuously high water levels are being maintained during the growing season and into the fall and winter months (Cordes and Pearce, 1978). Two continuing problems affecting the habitats have therefore been identified; namely, long periods of flooding during the growing season in the topographically lower areas connected to the Clair-Mamawi lakes basin and the lack of recharge in the perched basins.

On the basis of the results of this study, it would appear that the integration of LANDSAT into an operational monitoring program would be feasible. The study has demonstrated that:

(a) major habitat types in the Mamawi Lake basin can be effectively mapped under presently occurring water levels, although more detailed ground sampling in selected areas would be necessary if detailed species composition of some habitats was required; and

(b) falling water levels, even in the relatively small perched basins, can be effectively identified and monitored.

The 1/8 mapping areas are particularly suited to this purpose. It would therefore be possible to identify those basins experiencing significant change. As discussed in Chapter 5, due to the problems associated with the spatial resolution of LANDSAT and the very narrow widths of the rapidly changing communities at the land/water interface in these smaller basins, more detailed ground sampling, in conjunction with large scale 70 mm colour infrared photography would be required to identify changes in species composition.

On the basis of the results to date for the Mamawi Lake Test Site, those areas which might best serve as monitoring areas would include: NW. 1 (Figure 5.9), NW. 2 (Figure 5.10), SW. 1 (Figure 5.11), and SE. 1 (Figure 5.15). These areas contain both the perched basin landscapes and the lakeshore and other topographically lower areas influenced directly by water levels in the Claire-Mamawi basins. Meeting the requirements for ground reference sites, as discussed above, should also be incorporated into a monitoring program.

CHAPTER 7

SUMMARY and RECOMMENDATIONS

7.1 Summary

The Peace-Athabasca Delta is a 4,000 Km^2 wetland complex located on the west end of Lake Athabasca in northeastern Alberta. Construction of the W.A.C. Bennett Dam on the upper Peace River in northern British Columbia in 1968 modified the downstream flow regime. This in turn seriously affected the traditional ecological role of the internationally important region of the Peace-Athabasca Delta. Subsequent studies recommended remedial measures designed to restore 'natural' conditions. In spite of these measures, however, the need for a long term monitoring program was established.

Through the use of LANDSAT digital data and automated image classification techniques, habitats in the Mamawi Lake area of the Peace-Athabasca Delta were classified and mapped, a number of change detection techniques were evaluated and the potential of LANDSAT digital data in a long-term monitoring program was assessed.

The General Electric Image 100 Multispectral Image Analysis System was used to conduct a supervised classification for a 1,200 Km^2 test site centered on Mamawi Lake at the east end of the delta complex. To provide optimum opportunity for detecting change and for testing the classification of habitat types in the Delta under differing conditions, two images,one with normal water levels (August 1, 1976) and one with above normal water levels (August 26, 1973), were selected for analysis. A total of eight habitats were identified for the 1976 date and seven for the 1973 date.

Classification accuracy of the 1976 habitats was considered excellent when compared with available ground reference data. Although ground reference data for 1973 were not available, classification results are considered good. Spatial filtering of the classified scenes was found to improve the visual quality of the images, although only marginal improvements in classification accuracy resulted.

The classified scenes were found to be useful in delineating major topographic subdivisions within the Delta. These subdivisions can be used to identify areas most susceptible to change. Using an image registration technique, the 1973 and 1976 scenes were overlayed and two change detection analyses were carried out. These were ratioing and post classification change detection. Ratioing was found to be a relatively simple and fast method for determining the areal extent of flooding (1973 vs. 1976) and areas of major vegetation change. The major disadvantages to this technique are its lack of quantitative capabilities and the inability of the analyst to determine the nature of change. Post classification change detection was carried out for the entire study area, 1/2 areas and 1/8 areas. The technique was found to be useful in identifying the nature of change, although further research is required before an evaluation of the absolute values generated in the analyses can be fully assessed.

The 1/2 area and 1/8 area change detections were found to be useful because of the complexity of the delta. Change is more pronounced in some areas than others. By varying the scale of analyses, the user is able to examine areas more susceptible to change in greater detail.

7.2 Recommendations

As a result of this study, it would appear that the apparent sensitivity of LANDSAT data to changes in moisture and to the various wetland habitats suggests that the use of LANDSAT digital data for the mapping, classification and monitoring of wetland types in the Peace-Athabasca Delta will be useful. The following recommendations are made so that any role which is chosen for LANDSAT in a long-term monitoring program can be made most effective:

1. That a number of ground reference sites for each habitat be established with the following type of data to be collected at each site:

   (a) species composition

   (b) canopy density

   (c) vigor

   (d) height

   (e) depth of water table

   (f) background exposure

2. That on the basis of the results to date, the following areas would best serve as monitoring areas:

   (a) NW. 1

   (b) NW. 2

   (c) NW. 3

   (d) SE. 2

3. That more effective discrimination among the various fen species be attempted, particularly between the *Carex* and *Calamagrostis*. This

should be possible by taking better advantage of the different spectral responses among the various species during the growing season.

4. That further work be carried out on the change detection statistics to further refine their accuracy, thereby improving their reliability in future change detection studies.

GLOSSARY

Algorithm	A series of well defined steps used in carrying out a specific process; e.g., the classification algorithm.
Alphanumeric	Using or composed of a character set which is made up of both letters and digits, e.g., a computer line printer and its output products.
Binary Theme Print	The representation of each pixel in the image plane by a matrix of dots on a printer/plotter. The presence of the selected theme at any given pixel/line position causes the dot matrix to be printed.
Electron Beam Image Recorder	A machine which, from digital imagery, generates a high quality photographic image.
Image-100	An interactive multispectral image analysis system which operates on the general principle that all objects possess unique spectral characteristics or signatures. The Image-100 uses this signature uniqueness to identify similar features in an image by simultaneously analysing signatures in multiple frequency bands. Pseudo-colors, or themes, are assigned to these features and then displayed on a color CRT, either individually or in combination.
Pixel	A term derived from "picture element". A data element having both spatial and spectral aspects. The spatial variable defines the apparent size of resolution cell (i.e., the area on the ground represented by the data values), and the spectral variable defines the intensity of the spectral response for that cell in a particular channel.
Registration	The process of geometrically aligning two or more sets of image data such that resolution cells for a single ground area can be digitally or visually superimposed.
Supervised Classification	A computer-implemented process through which each measurement vector is assigned to a class according to a specified decision rule, where the possible classes have been defined based on representative training samples of known identify.

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THE AUTHOR HAS SUBMITTED PLASTIC MAPS WITH HIS THESIS.

PLASTIC SHEETS OFTEN DO NOT FILM CLEARLY.

TO PRODUCE THE BEST IMAGE, THE MAPS HAVE FIRST
BEEN FILMED SEPARATELY, THEN TOGETHER.

COMMON TURBID OPEN WATER OF BOTH 1978 AND 1976

SCALE 1:125,000

IMAGE-100 SCALED DIGITAL

Poor Copy

INCREASE OF TURBID OPEN WATER IN 1978 OVER 1976

THEME TRACK : 6 FROM PIXEL : 0.000 TO PIXEL :511.000
PIXELS/MILLIMETRE : 2.119 LINES/MILLIMETRE : 1.582
SCALE 1:125,000

IMAGE-100 SCALED BINARY THEME-SUMMARY

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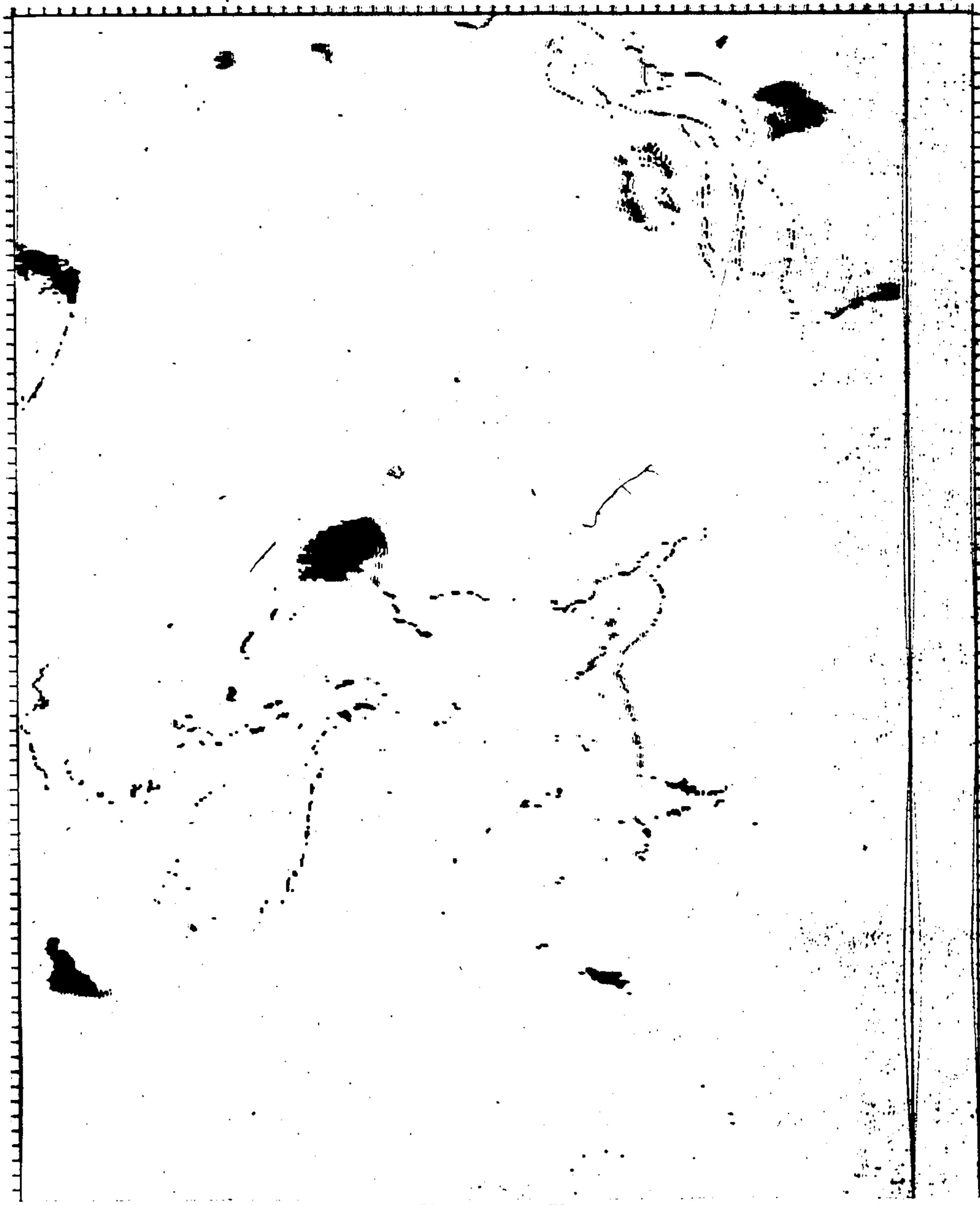

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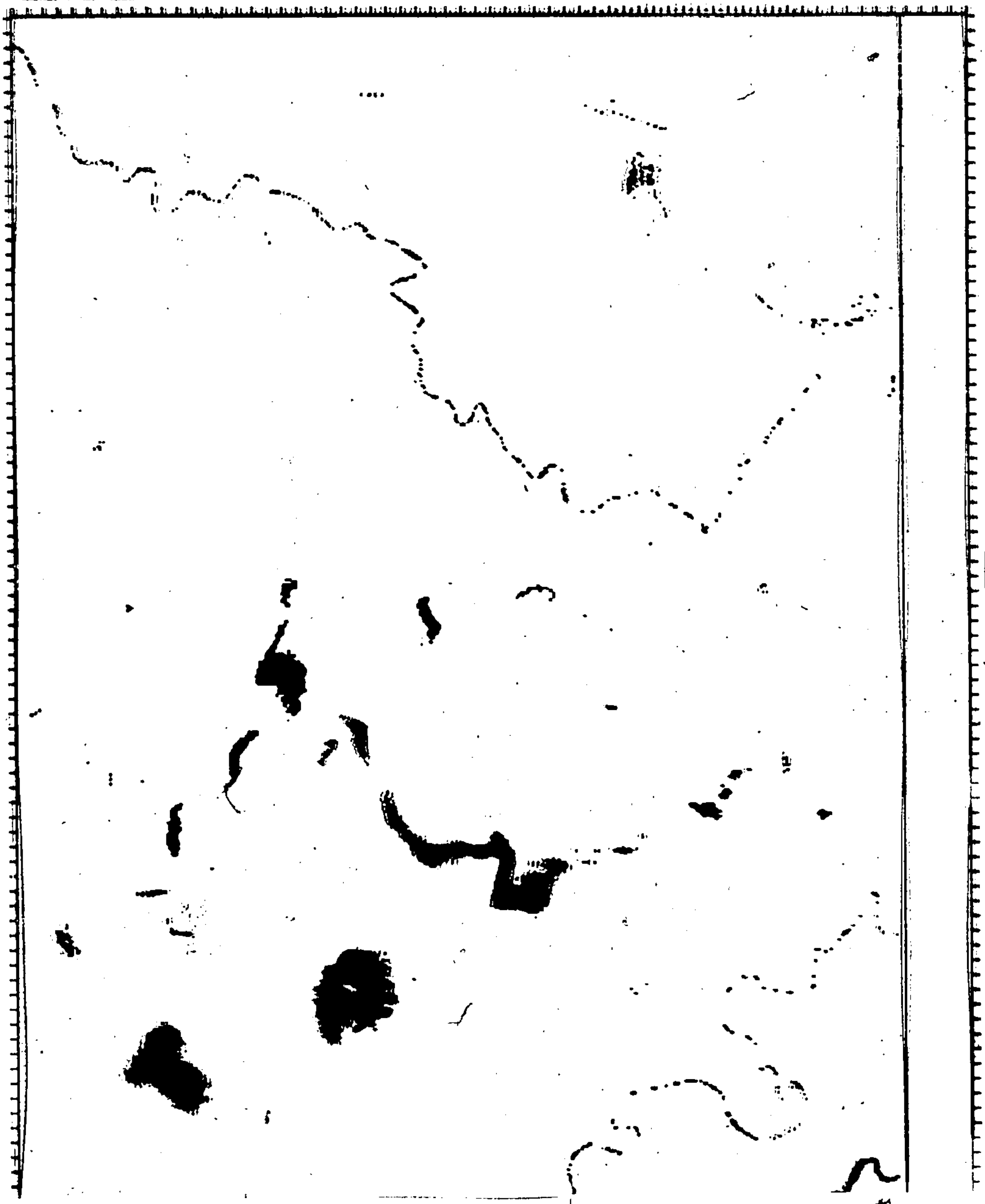
COMMON AREA OF OPEN TURBID 76 AND LESS TURBID OPEN WATER 75

IMAGE-100 SCALED; BINARY THEME-OUTPUT

SECTION 1



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