Land Use Change on the Assiniboine River: Resource Management Issues for Riparian Ecosystems in Southern Manitoba, Canada.

by

William Douglas Hamilton

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF ARTS

Department of Geography
Centre for Earth Observation Science
University of Manitoba
Winnipeg, Manitoba, Canada
R3T 2N2

UNIVERSITY
OF MANITOBA

0-612-53098-1

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree

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ABSTRACT

The reduction in the amount of arable land is one of the negative impacts produced by the continuous growth of our society. Of greater importance is that the natural environment is also impacted by the activities related to this continuous growth. Developers are able to acquire agricultural lands for new housing divisions, as well as build within ecologically sensitive areas (i.e. riparian ecosystems) due to lax regulations at all three levels of government (municipal, provincial and federal). By allowing construction within riparian ecosystems we are negatively impacting the ecology of these systems, the stability of river banks and the quality of water in streams. Furthermore, in removing arable land, society is effectively reducing the quantity of food a region is capable of producing. This activity is counterintuitive when considering the fact that society is faced with supporting an ever increasing population. This thesis will show that unregulated rural-residential development, west of The City of Winnipeg, has caused a significant reduction in the amount of riparian and agricultural lands. Construction within this riparian ecosystem has produced an increase in river-bank loading while reducing bank stability with the removal of trees. This is a tremendous abuse of a valuable natural resource.

ACKNOWLEDGEMENTS

This thesis is dedicated to my family. To my mother, Elizabeth, for her boundless generosity, as well as for her much needed encouragement. To my father, Robert*, who patiently tried to impress upon me the importance of thoroughness in my thinking and research. In addition, he taught me not to just focus on my chosen profession, but to read broadly. To my brothers, Dave and Rob, and sisters-in-law, Kathleen and Shelagh, who gave me guidance and encouragement. All of whom on a occasion, either singly or as a group, prodded me into continuing my research. Graduate research is truly a group effort, my many thanks to you all.

To my committee, thank you for your efforts in reading and returning this thesis in such an expedient manner; your comments were appreciated. I would like to extend a special thanks to Dr. Norm Kenkel who offered to read more chapters than his position as external examiner required of him.

I would also like to thank Richard Caners for his professional assistance at my study site, and for pointing me in the direction of some very useful botanical books.

I would also like to thank the Department of Geography, the Centre for Earth Observation Science and the Fresh Water Institute (Dept. of Fisheries and Oceans–Central & Arctic Division).

*Deceased November 09, 1994

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Introduction

By way of introduction this chapter discusses the topic of riparian ecosystems. Specifically, the difficulty in defining what constitutes a riparian ecosystem in the scientific literature. The need for protecting this ecosystem is briefly mentioned. In addition, this chapter contains: a description of the study site; the purpose and objective of this research; the procedures used during the course of developing this thesis; and the organization of this thesis.

1.0 INTRODUCTION

1.1 Defining & Protecting Riparian Habitat

In general terms, riparian ecosystems can be considered those assemblages of plants and animals which reside in close proximity to a stream. The quantity of scientific research relating specifically to prairie-riparian systems is limited at present (Kauffman and Krueger, 1984). This fact contributes to the importance of the research contained in this thesis. Developing a strict definition for what constitutes a riparian ecosystem is difficult due in part to the unique geographical location they occupy. In addition, their locale can make riparian ecosystems appear slightly paradoxical in that they are terrestrial (edaphic) but have as an integral part of their ecosystem an aquatic component (e.g. river or stream). Defining what constitutes a riparian ecosystem is argued at length in the literature review (Chapter 2.0). Briefly, there are several definitions provided in the literature and an ongoing debate regarding the status of the habitat as either a ecotone or ecosystem (Chapter 2.1, and Table 2-1). The lack of ecological significance afforded to riparian ecosystems points to a common problem, that of undervaluing their importance. These ecosystems hold rare (exclusive) and exotic (alien) species of flora and fauna as a result of the unique environmental conditions which are present within them (Décamps and Tabacchi, 1994). In addition to the environmental significance of this habitat, riparian ecosystems are all so important to the hydrologic system of the surrounding catchment. Given the current, limited spatial extent of this habitat, any anthropogenic activity within these narrow but highly diverse ecosystems is detrimental. Furthermore, most anthropogenic developments (i.e. logging, farming, urbanization) within these ecosystems produces varying degrees of habitat fragmentation. Because riparian ecosystems are "essential components of the structure and function of river ecosystems," (Décamps *et al.*, 1992, p. 1) they need to be protected and properly managed. The quality of the management policies drafted to govern the use of these ecosystems is currently related to catchment protection and all so their perceived aesthetic value. Catchment protection attempts to limit the impact of construction projects on stability of the river banks but does not afford any direct protection to riparian ecosystems. Existing government regulations do not protect the riparian ecosystems directly. As to aesthetics, this particular aspect of riparian ecosystems is essentially impossible to quantify, save for the economic value placed on these areas by the regional housing market. When looking at the expansion of a rural town, such as Saint François Xavier, or the nearby city of Winnipeg, the impact of these two housing markets on the local riparian ecosystems should not be understated. Locally, these ecosystems (along the Red and Assiniboine Rivers) have already been heavily impacted by agricultural activities and more recently by urban sprawl.

1.2 The Study Site

The study site is located in the Municipality of Cartier and south of the Saint François Xavier town site (Figure 1-1). More precisely, the study site ranges from Beaudry Provincial Park (West of The City of Winnipeg) to just South of Saint François Xavier, Manitoba, Canada (603800E 5528400N; 612600E 5523400N) (Figure 1-2). The study site is a deciduous riparian ecosystem surrounded by what

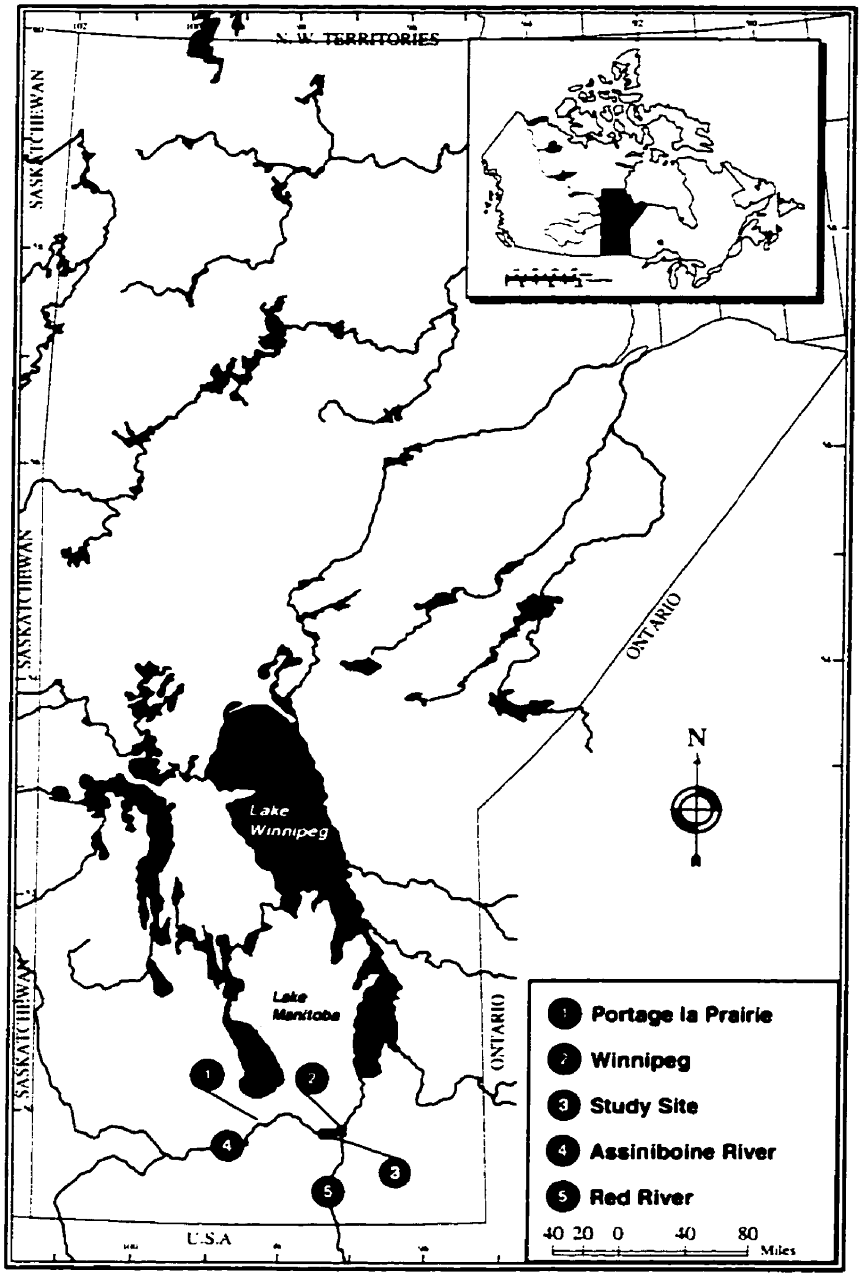


Figure 1-1 Map of Manitoba showing the location of the Study Site

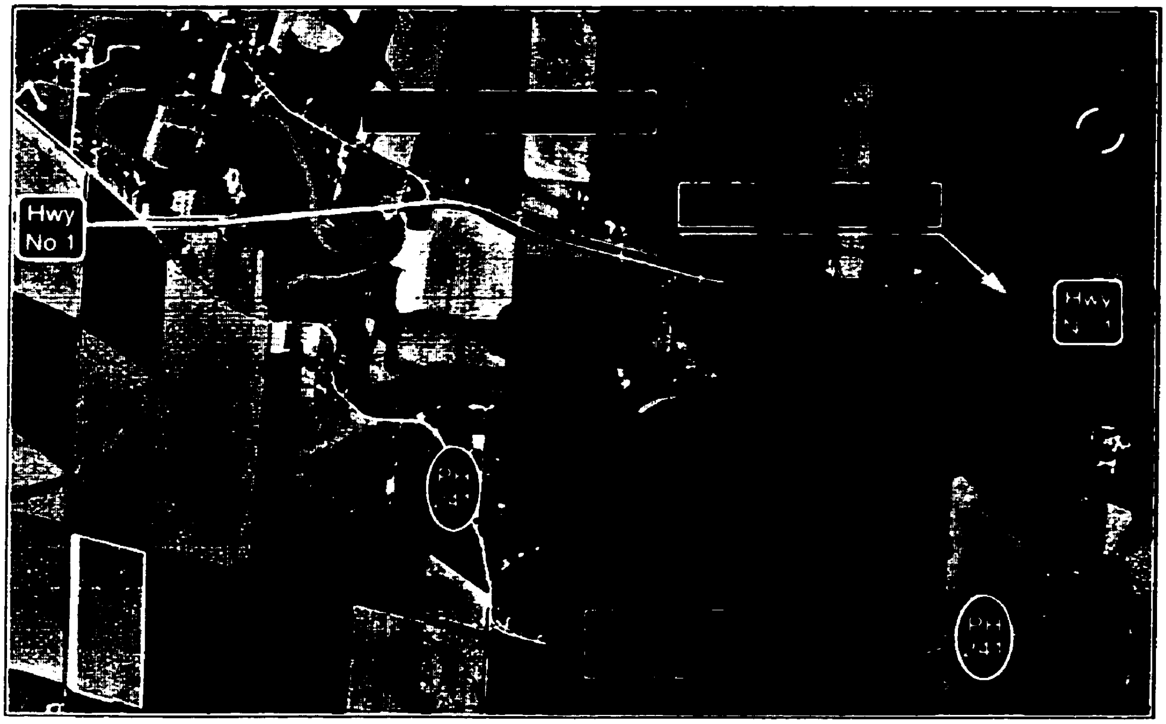


Figure 1-2 Large Scale aerial-photograph showing the areal extent of the study site

was once Prairie (Figure 1-3); most of this region having been converted to agricultural and rural land uses. The majority of the agricultural development occurred with the establishment of the Métis (ca.1824) and later the Hutterites (after World War I) (Corkey, 1996). The remaining riparian ecosystem contains: Eastern Cottonwood [*Populus deltoides* Bartr.], Bur Oak [*Quercus macrocarpa* Michx.] at the fringes, Green Ash [*Fraxnus pennsylvanica* var. *subintegerrima* (Vahi) Fern. (synonym var. *lanccolata* (Borkh.) Sarg.], Manitoba Maple [*Acer negundo* L.], White Elm [*Ulmus americana* L.], and Basswood [*Tilia americana* L.] which is reaching its north-western limit within the study site (Hosie, 1990) (please see Appendix 3).

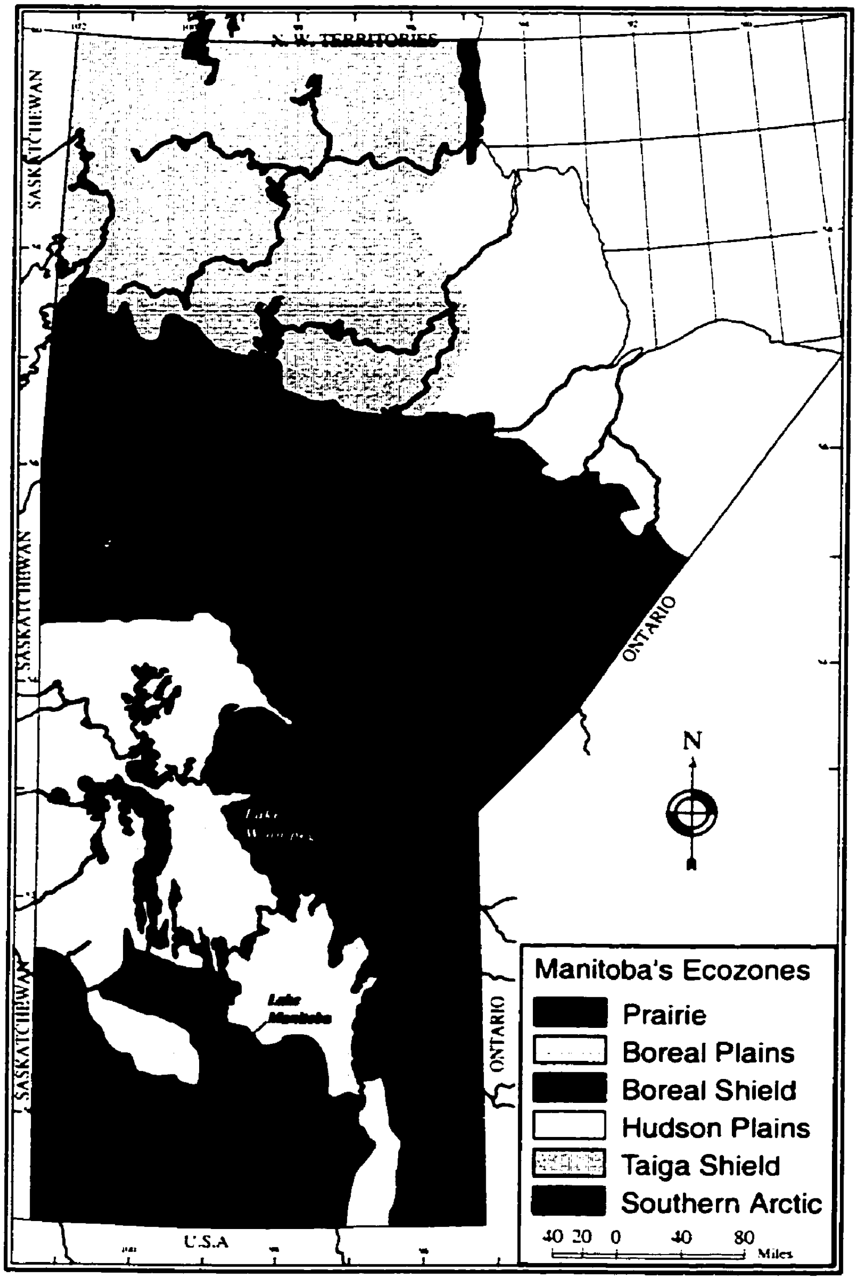


Figure 1-3 Ecozones of Manitoba (derived from Corkey, 1996)

The study site is located within a region of heavy sedimentation which is termed the Manitoba Lowlands (Corkey. 1996). The Manitoba Lowlands have very little relief, generally less than 8 meters at 1:250,000 (Corkey, 1996; Topographic Reference Map 62H/13/14). It is the combination of low relief, rich soil (Black Chernozem) and the availability of water which make this area one of the richest agricultural regions in Canada. The study site experienced heavy erosion by the most recent glacial action, approximately 10,000 years ago. This area was then inundated by Glacial Lake Agassiz, the result of melt waters from the receding glacial ice sheet. The Great Lakes in Manitoba (i.e., Lake Manitoba, Winnipeg, and Winnipegosis) are the largest remnants of Glacial Lake Agassiz (Figure 1-1). The confluence of the Assiniboine and the Red Rivers is located in an area of heavy fine-textured sediments (glaciolacustrine – i.e. deposited in Glacial Lake Agassiz). These sedimentary deposits are primarily comprised of fine sand, silt and clay, often layered in what appear to be annual alluvial deposits (Corkey, 1996).

1.3 Study Purpose & Objectives

The objectives of this thesis are: to demonstrate the importance of riparian ecosystems; to determine the rate over a 35 year period (1959-1994), extent, type and location of changes of the riparian ecosystem and to a lesser degree the changes in agricultural-lands within the study site; to identify the factors which may be responsible for these changes; and to identify regulatory deficiencies regarding the protection of riparian ecosystems.

1.4 Research Procedures

The research site was selected on the basis of the availability, quality, quantity (amount of repeat coverage), cost, and resolution of the data for this area. The minimum mapping unit (mmu) for this thesis is the tree canopy, which ranges from the meter to decimetre scale. As a result, **A**dvanced **V**ery **H**igh **R**esolution **R**adiometer (A.V.H.R.R., $1km^2$), **Land** Remote-**S**ensing **Sat**ellite (LANDSAT-6, $30m^2$) and *Système **P**robatoire d'**O**bservation de la **T**erre* (S.P.O.T., $10m^2$) data are precluded by cost and their insufficient resolutions. Other airborne sensor packages (e.g. CASI, and AVIRIS) are cost prohibitive and do not have the repeat coverage to allow a time series analysis. Aerial photography has proven to be a more suitable data source because of the availability of large-scale, repeat coverage high quality images. By comparing aerial photographs from 1959-1994, changes in the area of land use classes (Assiniboine River, Agricultural, Rural-residential, Riparian, Roads and Infrastructure) can be ascertained.

1.5 Organization

This thesis is organized into six chapters. Chapter two presents the background literature concerning the classification of riparian areas as ecosystems. In addition, chapter two discusses all aspects of the primary data source, aerial photography. Chapter three will discuss the specific methods used to process the data in this thesis. This includes data collection, input, rectification, classification, change detection and data analysis. The results are discussed in chapter four. The discussion of the results of this thesis are presented in chapter five and conclusions and possible further research in chapter six.

Literature Review

This chapter is comprised of two sections. The first section discusses at length the following topics: the difficulties in defining riparian ecosystems due to disparate opinions in the scientific literature; the productivity and diversity of this ecosystem; the management practices within Manitoba; the relevance of aesthetics in assessing the worth of riparian ecosystems; the issues of identifying this type of ecosystem; and the anthropogenic activities & impacts occurring within the research area. The second section deals with: the attributes of electromagnetic-radiation and the electromagnetic-spectrum, and how electromagnetic-radiation interacts with the Earth's atmosphere. It also discusses various aspects of the film stock used in this thesis; and the conversion of the film stock into a digital form.

2.0 LITERATURE REVIEW

At present, there is an absence of scientific research relating specifically to prairie riparian ecosystems (Kauffman and Krueger, 1984). Defining these ecosystems is complicated due to the unique geographical location that they occupy. Riparian ecosystems are located between terrestrial and aquatic ecosystems (Gregory *et al.*, 1991). However, there are aspects of riparian areas which make them distinct from the surrounding ecosystems. Specifically, these ecosystems exhibit a level of biodiversity and habitat-dynamics not found in any other terrestrial ecosystem (Naiman *et al.*, 1993). The importance of a riparian ecosystem to regional ecology is often marginalized, in part, because it may be perceived as having a small spatial extent and thus of a minor importance. However, these ecosystems have been shown to hold unique assemblages of species, both flora and fauna, because of the unique environmental conditions found within riparian ecosystems (Thomas *et al.*, 1979) (Section 2.1.1). Because of these unique features, measuring the rate of variation in the size of this type of habitat resulting from anthropogenic activities should be deemed as important to society. The size (spatial extent) of a riparian area is an important measure. Some bird species require a minimum amount of forest cover for nesting because they are easily disturbed (Croonquist and Brooks, 1993). Riparian ecosystems have been used historically for various forms of agriculture, from the cultivation of planted crops to the grazing of livestock (Section 2.1.6). Through the interpretation of aerial photographs, the rate of change in the areal extent of the riparian ecosystem along the Assiniboine River may be examined. Determining the rate and type of land use change has the potential to assist in the development of an effective management strategy for this region.

2.1 Riparian Ecosystems – Developing a Definition

The scientific literature provides several definitions of what constitutes a riparian area. Kauffman and Krueger (1984) define riparian ecosystems as an assemblage of species attracted directly or indirectly by stream induced factors (Table 2-1). What can be inferred from their definition is that the ecology (the assemblage of species) surrounding the streams is present because of the environmental factors created by the presence of the stream itself. Based on Kauffman and Krueger's definition, some species rely directly upon the habitat provided and induced by the stream. In addition, species present because of ecological associations they have with stream dependent species (e.g. predator-prey, symbiotic relationships) are considered to be indirectly influenced by the stream. Décamps (1993) envisages riparian corridors as continuous ribbons, containing rich assemblages of species. He makes a suggestion as to the size of this ecosystem, as being a continuous ribbon of varying width (tens to hundreds of metres) (Table 2-1). Naiman *et al.* (1993) also see riparian ecosystems as corridors. However, they delineate the spatial extent of the riparian ecosystem by defining the range of influence of the stream contained within, by including the floodplain and not just the stream channel (Table 2-1). As seen during the flood of 1997 in Manitoba, the spatial influence of the Assiniboine and Red Rivers is expansive, particularly the Red River (Figure 2-5). The description in Naiman *et al.* (1993) seems to concur with the definition proposed by Kauffman and Krueger's (1984). Specifically, their use of the words "influenced by" compliments Kauffman and Krueger's definition. In Naiman's definition, the presence of certain flora (plants) and fauna (animals) is directly or indirectly attributable to the presence of the stream. The impetus behind some researchers assertions that riparian areas are in fact ecosystems, is the level of productivity and species diversity found at these locales. An ecosystem is considered to be an ecological community in combination with the physical environment it occupies (O.E.D. 2nd Edition, Vol.V, p.61).

Riparian definitions in scientific literature.

Kauffman & Krueger (1984)	"...along streambanks, other lotic systems, and even ephemeral drainages, riparian ecosystems could be best defined as those assemblages of plant, animal and aquatic communities whose presence can be either directly or indirectly attributed to factors that are stream-induced or related." (p. 430)
Décamps (1993)	"These [continuous] ribbons often are wooded corridors with edges varying from tens to hundreds of metres wide and they have distinct ecological functions related to their location along the river continuum. Moreover, rich assemblages of species develop along riparian corridors." (p. 441)
Naiman, *et al.* (1993)	"The riparian corridor encompasses the stream channel and that portion of the terrestrial landscape from the high water mark towards the uplands where vegetation may be influenced by elevated water tables or flooding, and by the ability of soils to hold water." (p. 209)
Bretschko & Moser (1993)	"The land/stream ecotone is defined as the area where lotic [ecology of running waters] and edaphic [in reference to the soil] overlap at the time of observation." (p. 95)
Osbome & Kovacic (1993)	"Because riparian zones link the stream with its terrestrial catchment, they can modify, incorporate, dilute, or concentrate substances before they enter a lotic system. In small to mid-size streams forested riparian zones can moderate temperatures, reduce sediment inputs, provide important sources of organic matter, and stabilize stream banks" (p. 243)

Table 2-1 Table of Riparian Definitions.

Bretschko and Moser (1993) agree with the aforementioned definitions of Kauffman and Krueger (1984). and Naiman *et al.* (1993). In addition. Bretschko and Moser (1993) define where the stream ecosystem ends and the riparian ecosystem begins. by describing a land/stream ecotone (Table 2-1 and Figure 2-2). Their progressive approach of classifying riparian areas as separate ecosystems is not universally supported in the literature. Other authors never actually define their use of the word riparian and make the assumption that the reader knows what they mean (e.g. Jordan et al., 1992).

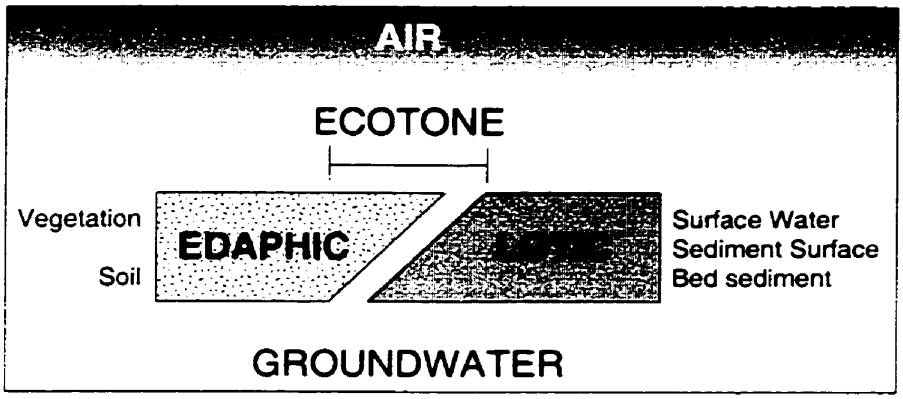


Figure 2-2 Schematic Presentation of the land/stream Ecotone (Bretschko and Moser, 1993)

Osborne and Kovacic (1993) conclude that riparian areas are not ecosystems, but rather they are zones which "link the stream with its terrestrial catchment" (Table 2-1). It is apparent that they believe that riparian areas do not qualify as distinct ecosystems but only as ecotones. However, they do clearly point out the beneficial environmental influence that "riparian zones" can produce. Specifically, these zones can reduce the amount of sediment input (e.g. from agricultural fields) and improve stream bank stability (Table 2-1). At this juncture, it should be made very clear the finite abilities of riparian ecosystem to filter ground-water and surface run-off are just that, finite abilities. Riparian ecosystems should not be viewed as a natural filter for the removal of agricultural, or industrial chemicals, from the above stated sources of water.

What can be gleaned from the above definitions, is that riparian areas should be considered distinct ecosystems which are in immediate proximity to a watercourse (stream/rivers). These areas are distinct from the surrounding ecological communities; in terms of both their diversity of species and level of productivity.

2.1.1 Riparian Ecosystem Productivity and Diversity

The level of diversity within riparian habitats is unique among the terrestrial environments. These habitats contain "rich assemblages" (Décamps, 1993) of biota making them distinct ecosystems because they are, "...the single most productive type of wildlife habitat, benefiting the greatest number of species" (Kauffman and Krueger, 1984, p.431). Riparian ecosystems are more fertile than the surrounding areas because of the unique set of conditions which exist in them. Streams are known to flood regularly in the spring and occasionally in the summer months during periods of excessive rainfall. Flooding can deposit nutrient rich sediments over the entire extent of a flood-basin, enhancing the fertility of the soil. In many regions annual flooding is an essential process for the support of this ecosystem. The Aswan High Dam in Egypt, on the Nile River Delta, retards the annual flood which covers the Delta. Unfortunately, this marvel of modern engineering has greatly reduced the total region of agricultural productivity (Fahim, 1983). This area would not support the agriculture it currently retains if not for the mitigating effects of fertilizers and irrigation.

The nutrient-rich sediment deposits resulting from the process of flooding help to support dense forests (Décamps *et al.* 1992), which in turn stabilize the soil during flooding, as well as providing stream bank stability during normal rates of flow (Richards, 1982; Mallik and Rasid, 1993). However, flooding events can also deposit agricultural and industrial pollutants transported from the upstream portion of the catchment. Deposition of agricultural pollutants could potentially be detrimental in regions where intensive agricultural is practiced, due to the increased use of agricultural chemicals (Section 2.1.2).

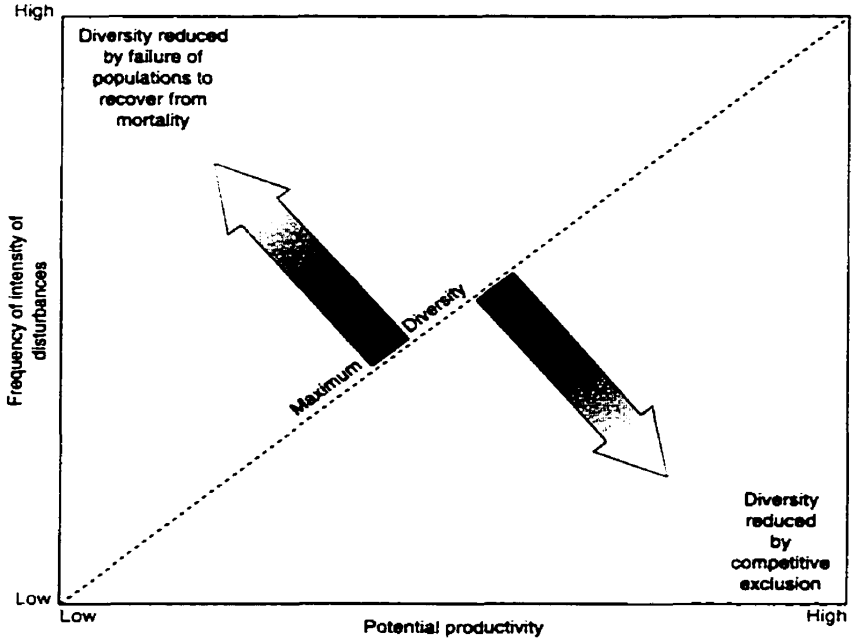


Figure 2-3 Huston's Dynamic Equilibrium Model (in Décamps et al., 1992)

Within areas which have had the riparian ecosystem largely removed, sediments as well as agricultural and industrial pollutants may be directly flushed into the stream. The intense disturbance caused by flooding and the frequency of such events, has been suggested as the main cause for the species richness found in riparian ecosystems (Décamps *et al.*, 1992) (Figure 2-3). This figure is designed to show how the principles of productivity and disturbance are linked according to Huston's model (Décamps *et al.*, 1992). It is obviously too simple in its present state to be considered a usable mathematical model. What the figure does not show is that with extreme disturbances (e.g., clear cutting, hydro electric dam flow regulation) comes a decrease in the diversity (Décamps *et al.*, 1992). For example, the removal of trees which line a river bank would have a detrimental impact on fish and insect populations (IFM Workshop, 1994). Trees which overhang the stream provide shelter for a variety of insect larvae and fish stocks, which in turn provide food for many bird species. The forest provides nesting materials, and the dense canopy provides protection against predators. The leaf litter, desposited annually, is a crucial source of soil nutrients, which in turn increases soil productivity (Décamps *et al.*, 1992).

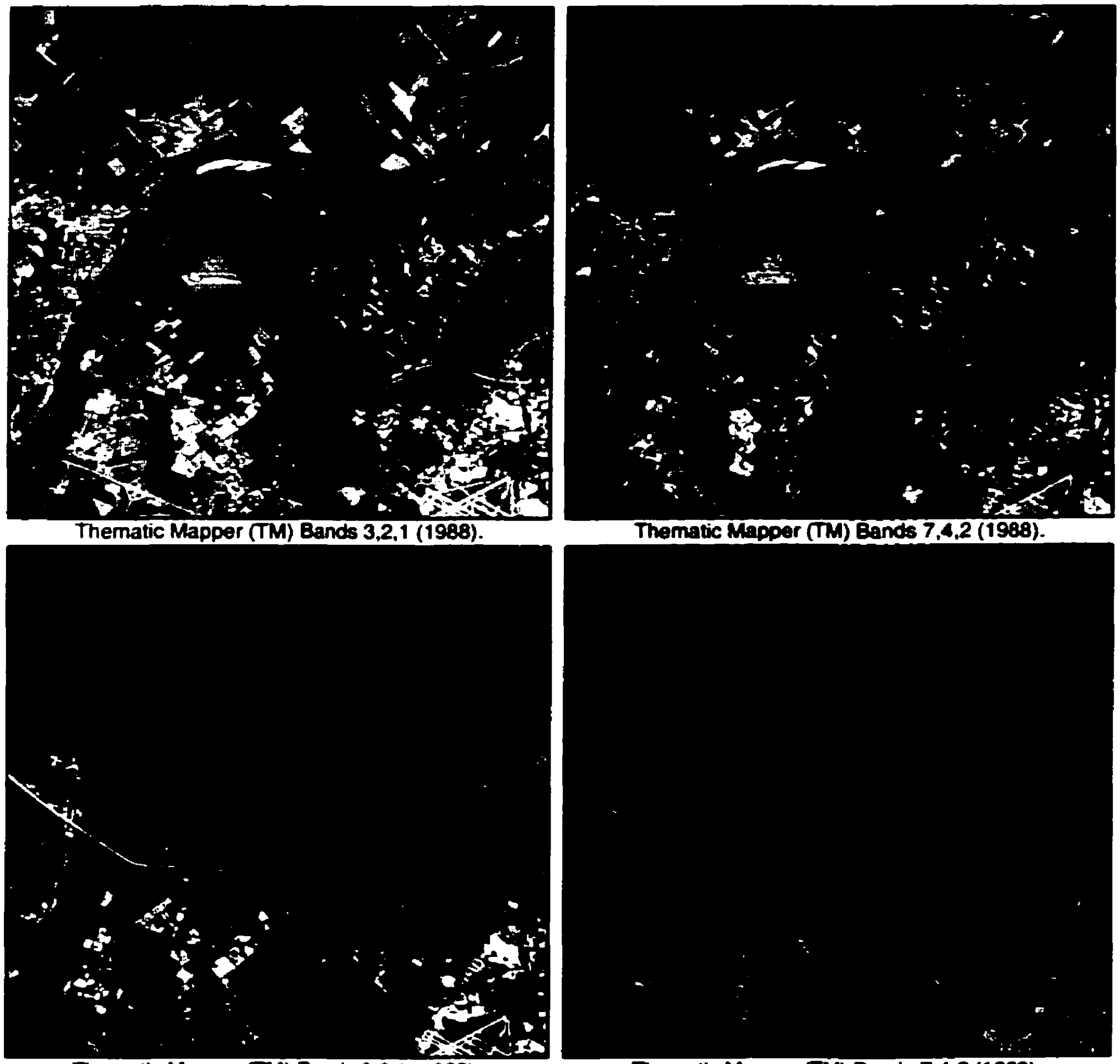
Kauffman and Krueger (1984) have suggested that some members of the biota present in riparian ecosystems should be considered specialists. Furthermore, they are specialists to such an extent that their ability to survive outside this ecosystem is severely hindered (Kauffman and Krueger, 1984). Thomas *et al.* (1979, in Kauffman and Krueger 1994), states that their riparian study site showed a greater level of productivity than the surrounding forested habitat. Their research showed how many bird species rely on this habitat for food and nesting sites.

What is apparent in the literature is that certain flora and fauna are only found within riparian ecosystems, and not in the surrounding habitat. Riparian ecosystems have developed over time to become some of the most unique ecological habitats in the world. This makes riparian ecosystems an inimitable and finite natural resource. Natural riparian habitats which are not affected by anthropogenic activities, are the "most diverse, dynamic, and complex biophysical habitats on the terrestrial portion of the Earth" (Naiman 1993, p. 209).

2.1.2 *Impacts of Anthropogenic Activities within Riparian Habitats*

Given the limited spatial extent of this habitat, anthropogenic activity within this narrow but highly productive ecosystem is detrimental. This habitat holds rare (exclusive) and exotic (alien) species of flora and fauna as a result of the unique environmental conditions within riparian habitats (Décamps and Tabacchi, 1994). Most anthropogenic developments (e.g. farming, urbanization) within these habitats result in some level of deforestation. Henke and Stone (1978) studied an area of the Sacramento river system (U.S.A.) prior to and after the removal of the riparian vegetation. They found that the number of birds was depleted by 95%, and bird species diversity by 32%. This occurred in areas of cultivated land which had been in close proximity to a riparian forest. The destruction of riparian habitat was not only detrimental to the immediate population but also to those in the surrounding habitats (Carothers, 1977). Understanding at what rate and how riparian ecosystems are impacted is important to those agencies responsible for managing such resources.

In addition to the environmental significance of this habitat, riparian areas are important to the hydrologic system of the surrounding catchment. The hydrological system of the reach of the Assiniboine River within the study site is comprised of: ground water, throughflow and overland flow; potholes; oxbows; riparian ecosystems; and the river itself. Natural prairie should be included in this list but all natural prairie has been extirpated from this catchment. Generations of intensive farming practices in this area, has resulted in a negative change to the naturally developed hydrologic system of the Assiniboine catchment. Specifically, the following practices have produced a detrimental impact on this catchment: draining and filling of pot-holes and oxbows; tillage and the grading of fields towards ditches, creeks and streams; channelization of streams; and the removal of riparian habitat. The net effect of these activities has been to decrease the ability of the Assiniboine catchment to storage water. As a result, water can now move more swiftly from field to stream. In turn, top-soil and agricultural chemicals may also be rapidly transported from fields and deposited in rivers. A dramatic example of what can potentially occur when the aforementioned activities are combined, is an anthropogenically exacerbated flood. One such flood occurred along the Mississippi River in 1993. What is visible within the LANDSAT-5 Thematic Mapper (TM) images of Figure 2-4 is the Mississippi River at Pre- and Post-flood stages. The LANDSAT images are centered on the Missouri River, near the St. Louis airport which is visible in the lower right-hand corner. Clearly, the region visible within the LANDSAT TM images sustained substantial financial losses as a result of flooding. Natural hazard events, such as anthropogenically exacerbated floods, are one source of evidence showing what can result from a lack of riparian habitat management policies; Removing a majority of the riparian habitat, replacing the previous diversity



Thematic Mapper (TM) Bands 3,2,1 (1988).
Thematic Mapper (TM) Bands 7,4,2 (1988).
Thematic Mapper (TM) Bands 3,2,1 (1993).
Thematic Mapper (TM) Bands 7,4,2 (1993).

Landsat Thematic Mapper (TM) images (30m x 30m) of the Mississippi River. The Landsat images are centered on the Missouri River, near the St. Louis airport (lower right-hand corner).

Figure 2-4 Mississippi Time Series, LANDSAT-5 TM (data source M.T.U., 1993) with mono-crop agriculture and regrading the land to improve drainage all contributed to intensifying flooding (Ross, 1997). All of the aforementioned anthropogenic factors (e.g. filling of potholes), with the exception of levee development, have occurred along the Red and Assiniboine Rivers. As a result of these activities, drainage would have normally taken days or weeks occurred in a matter of hours.

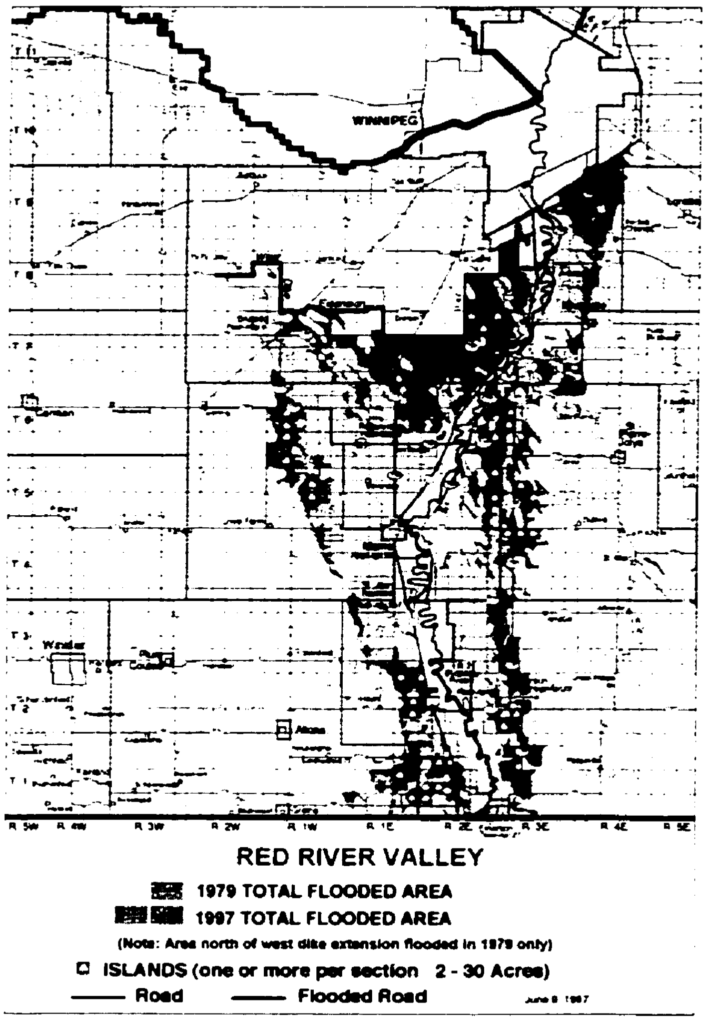


Figure 2-5 Red River Valley, Flooded Area Map for 1997 (Gov.'t of Manitoba, 1997)

producing a greater amount of flooding. When examining the two right-hand images in Figure 2-4, one could easily make the mistake of interpreting all of the "green" as riparian ecosystem. The only riparian ecosystem remaining in these images are the narrow discontinuous green strips running parallel to the river. With the riparian forest all but gone, the level of erosion in this area was much greater than had there been a buffer strip in place. This fact points to a need for a proper management strategy for riparian ecosystems. In should be noted that, major flooding events cannot be prevented regardless of how effectively the riparian ecosystem of a river catchment is being managed; floods occur naturally. For example, the Manitoba flood of 1997 (Figure 2-5) which was an extreme flooding event (Burn, 1999) could not have been prevented by proper riparian management. However, what effective riparian management can do is assist in reducing damage by retarding the flow-rate of the river (Li and Shen, 1973 in Kauffman and Krueger, 1984), stabilizing the river bank (Mallik and Rasid, 1993) and reduce silt loading (Wesche, 1993).

2.1.3 *Riparian Management Practices – A case for improvement in Manitoba*

When considering that riparian habitats are widely accepted as being "essential components of the structure and function of river ecosystems," they should be afforded some level of protection in legislation to facilitate proper management (Décamps *et al.*, 1992, p. 1). What is meant by the word "proper" is the sustainable management of these areas as wildlife preserves. When looking at a length of Assiniboine River bank, it is easy to see how the lack of a management plan can impact this habitat (Figure 2-6). There is clear evidence of deforestation in the two subsets shown in Figure 2-6. In subset [A] of Figure 2-6, a small residential

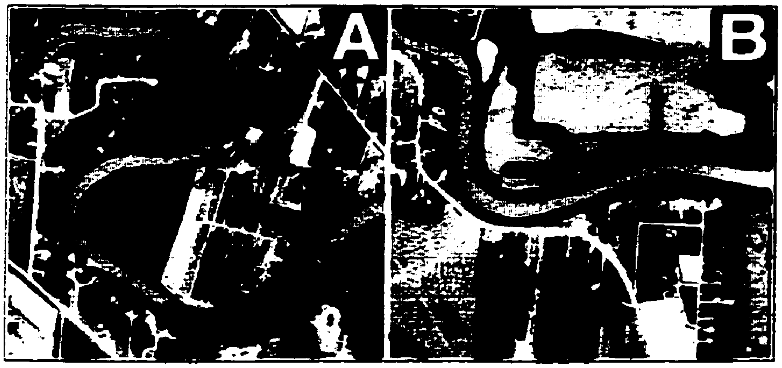


Figure 2-6 Riparian Habitat Deforestation on the Assiniboine River, Manitoba

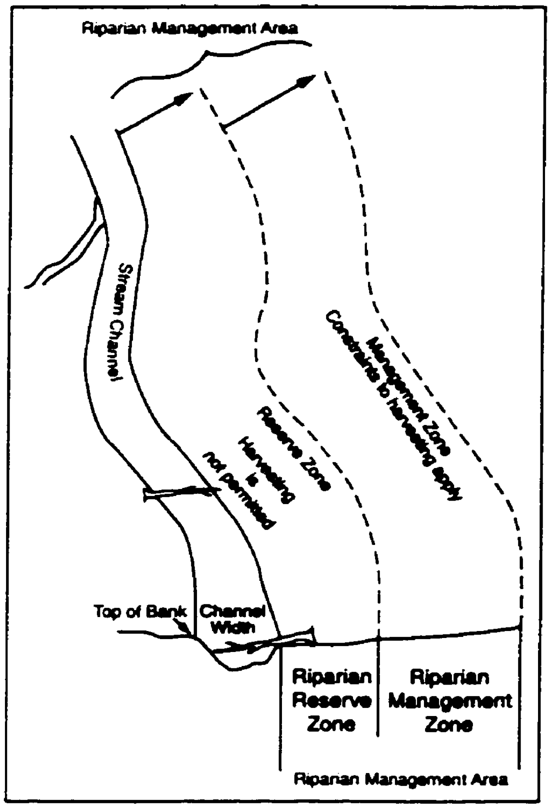


Figure 2-7 Riparian Management Area (Gov.'t of British Columbia, 1995)

development occupies a location on the inside of a meander, and has cut into a relatively large section of riparian habitat. Other examples of incursion into what should be a buffer strip are: trees being removed all the way to the river bank in both [A] and [B]; and in subset [B] a secondary road passing extremely close to the river. Another province which experiences a significant amount of activity in and around riparian ecosystems is British Columbia. If forestry companies in British Columbia continued their logging activities as close to a river as urban development is found along the Assiniboine River, those companies would incur significant fines (Gov.'t of British Columbia, 1999).

In Manitoba, farms and housing developments appear to be exempt from the local regulations which would normally govern logging activities. In comparison, British Columbia provincial forestry regulations specify that buffers strips must be left along all streams (Figure 2-7). The buffer strip depth varies based on the order of a stream. A river with the same order as the Assiniboine would have at least a 20m buffer strip along its entire length. At some farms in Manitoba, the riparian forests have been clear-cut to the river bank to provide access to the river. This activity is related to a common problem faced by land resource managers; that once landowners assume ownership implies that they, have certain privileges (Dwyer and Hodge, 1996). These can include the use of land for their particular needs. Specifically, ownership can imply the exclusion of others from using the same piece of property by the person holding title to that land. Other privileges include the right to protect the land from intruders and to be able to rent or sell parcels of their property. Dwyer and Hodge (1996) make an interesting point, that land ownership in many countries is not absolute. The government retains some specific rights: acquisition of land as deemed necessary (expropriation); development of the land requires government permission in the form of building permits and re-zoning assessments; and land-owners can not engage in activities which reduce the ability of other landowners from taking full benefit from their own properties (e.g., one landowner cannot stop a stream on their property from reaching their neighbours). In 1996, the Government of Manitoba published the "White Paper on the Sustainable Development Act." This white-paper does not directly list any management plan for riparian habitats in Manitoba. Another Provincial publication in 1993 which examined the use of silviculture in Manitoba in relation to logging activities, failed to mention riparian ecosystems (Gov.'t of Manitoba, 1993). A parliamentary document (Gov.'t of Canada, 1990) entitled "Environmental Degradation of the Assiniboine and Red Rivers" only looked at the lotic environment of these two river basins, and not the riparian environment surrounding the river. However, this document does correctly identify the City of Winnipeg as the single greatest point source of contaminants. Winnipeg still has older areas which have combined storm and grey-water sewer systems, resulting in raw sewage emptying into the Red and Assiniboine Rivers (primarily the Red River) (Gov.'t of Canada, 1990). This can occur during heavy rains when storm sewers are over loaded causing the direct discharge of sewer water into the Red River (Figure 2-8). Furthermore, no mention is made of the fact that Winnipeg lacks a tertiary sewage treatment facility. The report does make reference to the presence of pesticides and other agricultural chemicals in the water table (e.g., 2,4-D and 2,4-DP). What is absent from this report is any mention of the importance of riparian habitat in filtering out some portion of these chemicals from

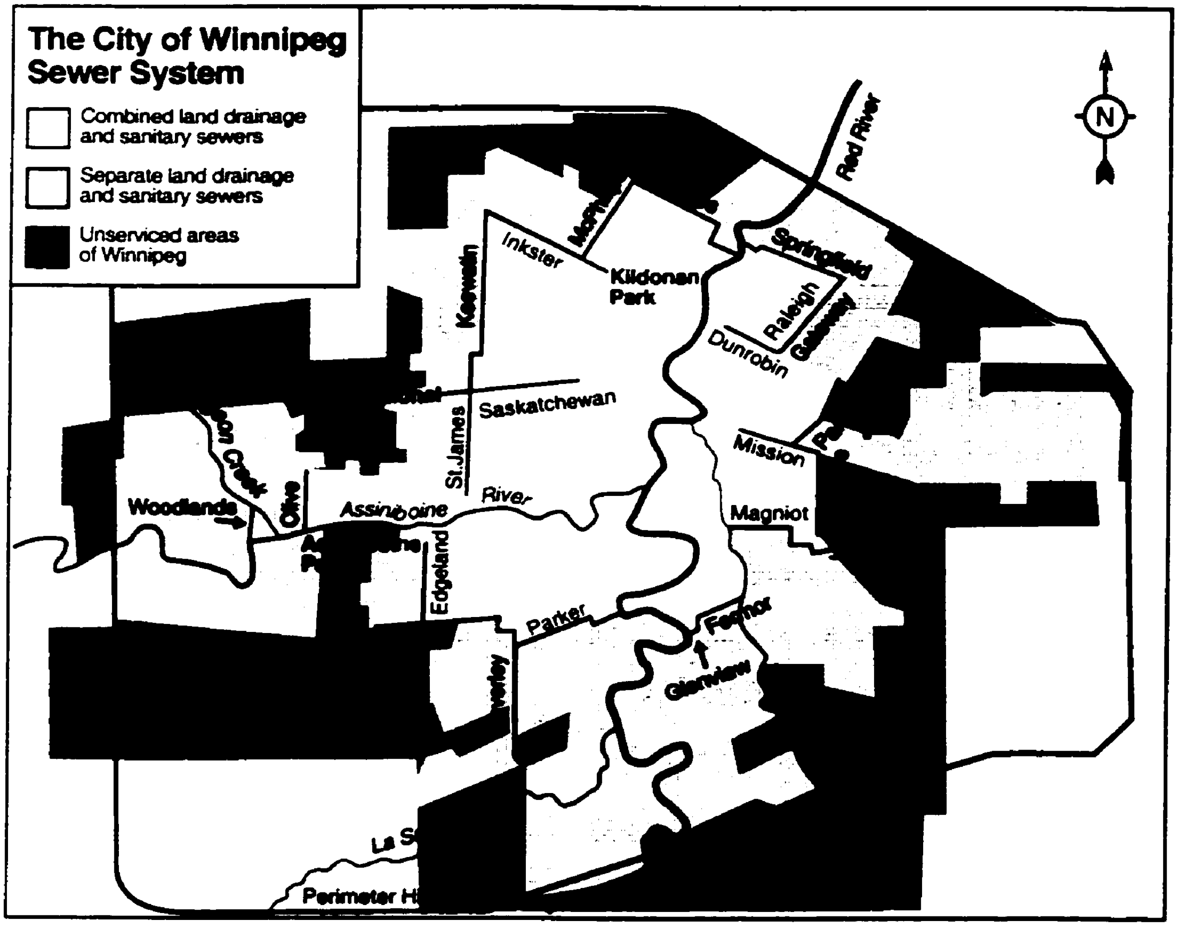


Figure 2-8 The City of Winnipeg Sewer System (Winnipeg Free Press, 27 April 1997)

surface runoff and throughflow before they enter a river system. As previously mentioned, some caution should be used when discussing abilities of riparian ecosystems to filter agricultural/industrial chemicals. While this habitat can aid in the reduction of some agricultural pollutants, the pollutions can in turn have detrimental effects on this habitat. For example, broad-leaf herbicides can damage the tree species comprising the riparian habitat.

2.1.4 *The Importance of Aesthetics as it Relates to Riparian Ecosystems*

As stated in previous sections, there are resource management reasons to protect riparian ecosystems. However, riparian ecosystems are deserving of protection because of their perceived aesthetic value. When examining Winnipeg's spatial development, the expansion of the city has followed the reaches of the Assiniboine & Red Rivers (Figure 2-12). This expansion cannot be entirely attributed to aesthetics, because access to the rivers was once highly desirable for transportation (Section 2.1.6). However, today river front property is the most costly real estate to acquire, not because of its access to water, but because of the desirable aesthetics associated with these locales.

2.1.5 *Issues of Identification*

Correctly identifying riparian habitats can be problematic owing to numerous professions applying their own methodologies to classifying riparian ecosystems. All habitats are identified by employing different criteria. These can include: ecological/botanical concepts of community, hierarchy, diversity, stability, fragmentation and ecosystem (Gov.'t of Canada, 1994); geographic constructs of scale and spatio-temporal relationships; and legal definitions. Those with the most relevance to this thesis are spatio-temporal relationships, scale, community and ecosystem. Areal extent (spatial) and geographic location are of significance to the geographer as are any temporal relationships. Plant species, and quantities and combinations of those species in an ecosystem, are important to ecologists. A composite of the principles of ecology and geography may prove to be more effective in correctly identifying riparian ecosystems.

2.1.5.1 Geographical Identification of Riparian Ecosystems

Geographically, a riparian habitat occupies a location in immediate proximity to a lotic environment. When considering scale, one can discern the large spatial differences in the riparian habitats from one region to another (e.g., the areal extent of the Amazon floodplain is considerably larger than that of the Assiniboine). The focus of this thesis is on prairie-riparian habitat in Manitoba. As mentioned previously, the most significant spatial aspect of any riparian habitat is its length but this aspect is usually overlooked causing an underestimation of the overall areal extent of the riparian habitat. The breadth of a riparian habitat appears insignificant in comparison to the length. Although a section of riparian habitat may only be twenty-five meters wide, it may continue for hundreds of kilometers following the course of a river, resulting in a much greater spatial extent than is immediately apparent. Bendix (1994) recognized the "linear nature" of this habitat type, and went so far as to distinguish between transverse and longitudinal environmental factors (Figure 2-9). Bendix theorizes that since riparian habitat has a linear spatial aspect, it should then follow that the ecological communities located in such a habitat would also express a linear nature. He further develops this theory to include longitudinal and transverse scales (Figure 2-9). Simply put, Bendix theorizes that plant and animal populations will change along the length of a river. This theory is held up by large river basins, such as the Mississippi and Amazon river basins. Furthermore, the composition of plant communities change the further away from the river bank an observer travels (Figure 2-9 [B]). This too is visible when looking at the plant communities along the Assiniboine River. For example, the types of plants species transition from the more flood tolerant species to the less tolerant. This may prove to be of importance during classification, because as the habitat changes so will its representation change in aerial photography.

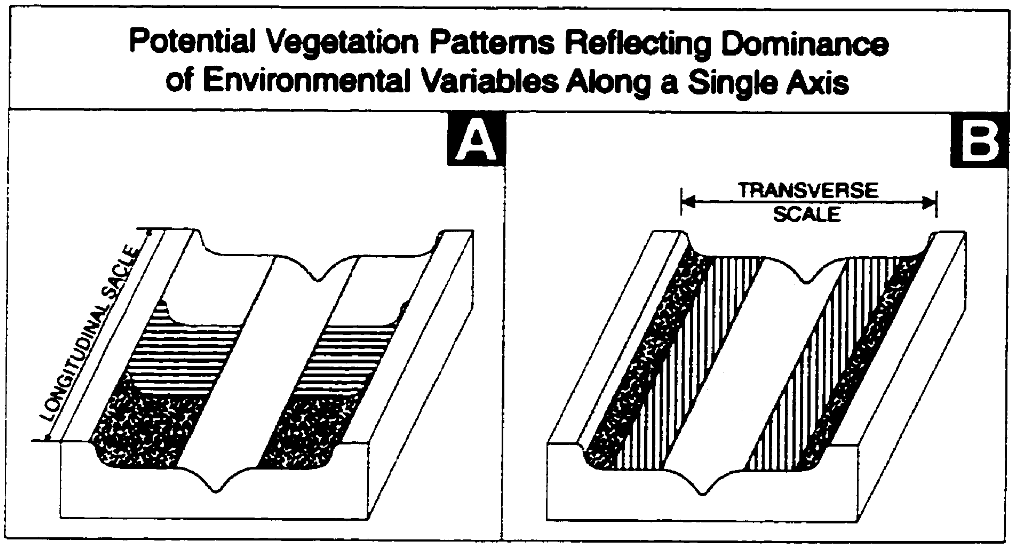


Figure 2-9 Longitudinal & Transverse Environmental Factors (derived from Bendix, 1994)

The most expedient method of identifying a riparian habitat is to establish its immediate proximity to a lotic environment. However, expedience is not accuracy; and the riparian habitat along the Assiniboine River has been significantly altered since the establishment of farms in the 19th century (Gov.'t of Canada, 1994) (Section 2.1.6). Access to river systems was crucial to the early settlers. Rivers were heavily used as transportation routes. The Assiniboine River was not an exception, as it has been used to move agricultural goods, trade goods and building materials (Kavanagh, 1966). Because of the extensive anthropogenic alterations to riparian habitat, identification is no longer as simple as merely establishing its immediate proximity to a river. Agricultural areas can extend up to, and in some cases include, the river bank itself. This results in a complete extirpation of the previously existing riparian habitat (Figure 2-10).

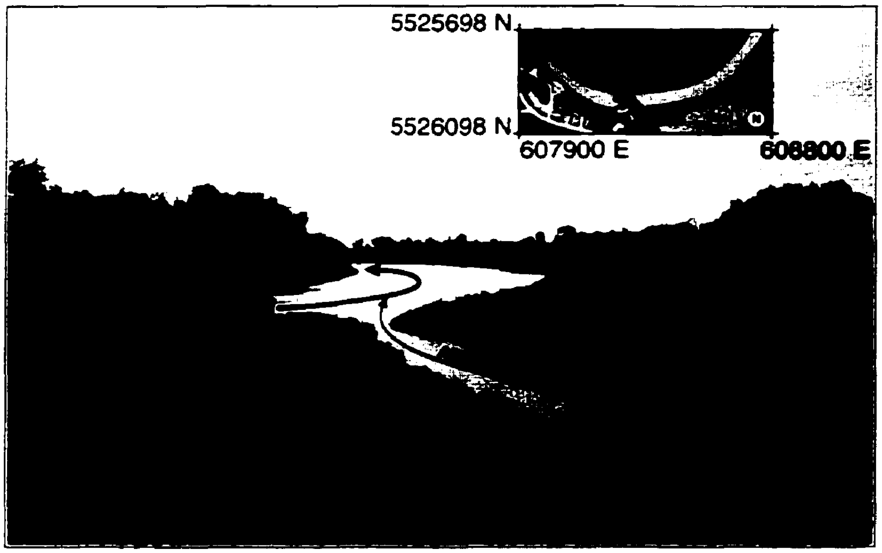


Figure 2-10 Farm within Study Site, south of the Trans-Canada Highway.

Agricultural areas that are situated next to a stream should not be considered riparian habitats merely because they occupy a location near a stream; nor should they be considered reasonable ecological surrogates for such habitat.

2.1.6 *Research Area–Anthropogenic Activities & Impacts*

The most noticeable land use shown in the aerial photography is agricultural; the landscape is a patchwork of various types of crops from cereals to tree farms. After agriculture, the most noticeable land use is urbanization; road systems and driveways are clearly visible. Riparian habitat is the next most noticeable land cover type. However, given the location and scale of the images used in this thesis (Table

3-5), the dominant land use which should be visible is riparian, not agriculture as it is presently.

The research site examined in this thesis has been extensively deforested as the land was brought into agricultural production. Among the earliest permanent inhabitants at this site where the Métis (ca.1824) who where followed by the Hutterites after World War I (Historical and Scientific Society of Manitoba, 1970). Over the intervening decades large reaches of riparian habitat have been removed right up to the Assiniboine River bank (Figure 2-11). Trees were harvested for use as construction materials and for fuel to heat homes. To a lesser degree trees where used as a fuel for the steam boats plying the Assiniboine. These were only in service for about 30 years due to the development of local roads and the Canadian National Railway; these vessels became outmoded (Historical and Scientific Society of Manitoba, 1970).

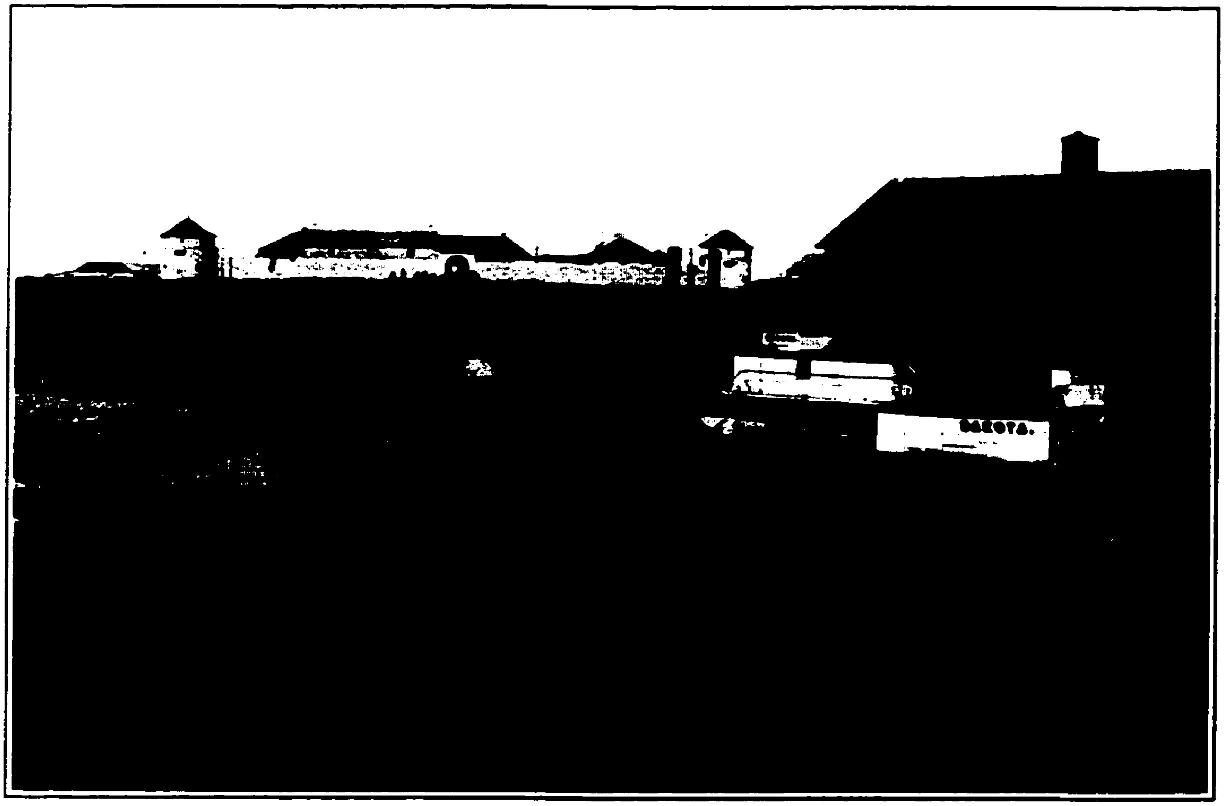


Figure 2-11 Hudson's Bay Company post of Upper Fort Garry, May 1873 (Artibise, 1977).

Originally, farms with river access were surveyed as four mile long lots. Water access was required to provide water for livestock and for transportation. The average frontage along the river was 250-yards (229 m.) (Corkey, 1996). In the early years of settlement, the farmland along the river was highly prized. Not only were these locations prized for the afforementioned reasons (water provided for livestock and transportation) but also for their close proximity to The City of Winnipeg. Farms needed to be near the largest point source of consumption. Currently, two miles (3.2 km.) away from the river the pattern of the landscape changes from the many narrow rows of long-lot farms, to the more dominant feature of the cultivated prairie landscape, large rectangular fields (Figure 2-12) (Corkey, 1996).

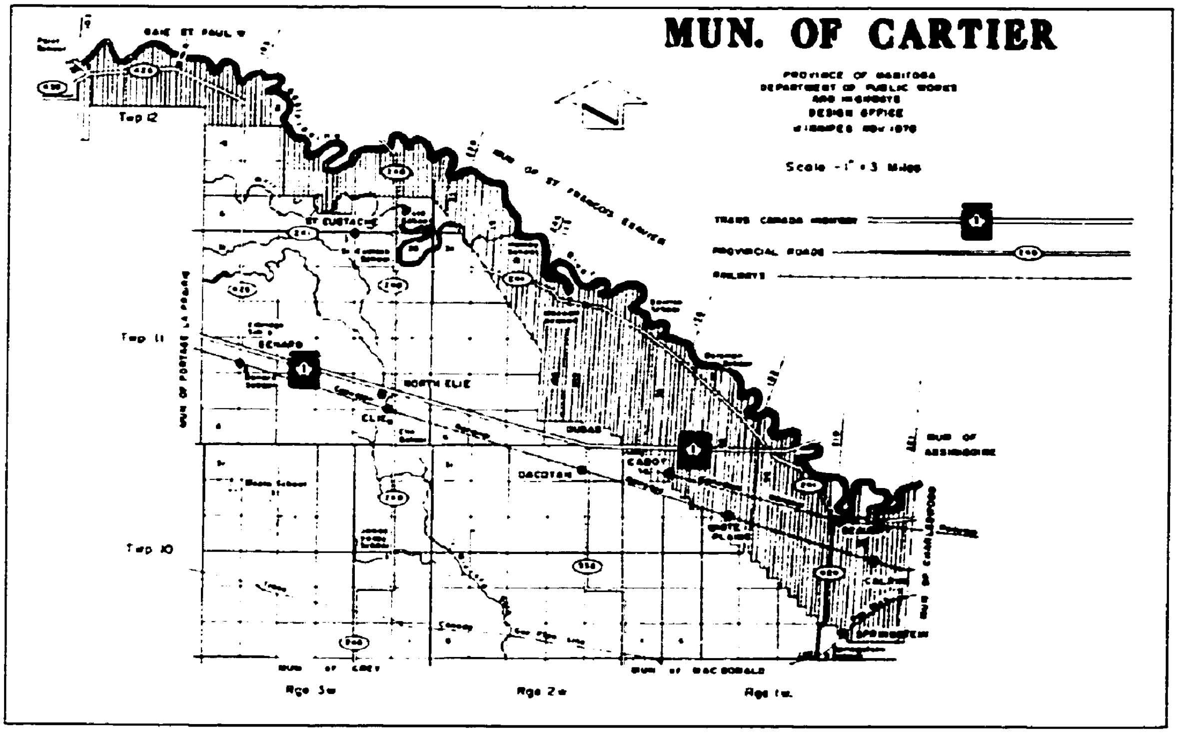


Figure 2-12 Municipality of Cartier ca.1970 (Gov.'t of Manitoba, 1970)

It is these larger "section" fields which give the western Canadian Prairies their distinctive patchwork appearance. However, as aesthetically pleasing as the cultivated prairies may appear to be to many people today, it has come at a great ecological cost. With the growth of The City of Winnipeg, there has been a steady sprawl outward from the city centre (Figure 2-13). Although Winnipeg has not yet consumed all the space allocated, residents seeking lower municipal taxes and greater seclusion have started building outside the city limits.

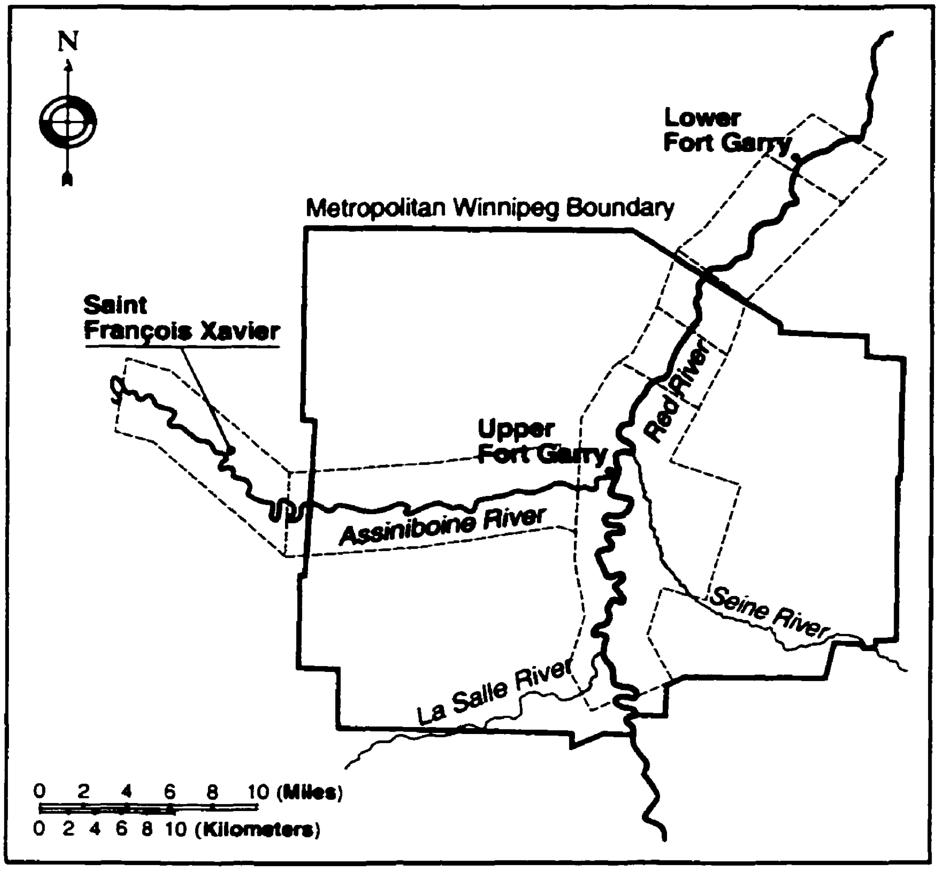


Figure 2-13 Red River Settlement ca.1836 (Artibise, 1977)

St.François Xavier is experiencing expansion as a result of the aforementioned "push factors". This expansion is in evidence in the aerial photography (Figure 2-6). There are similar rural-residential land use changes occurring on the south bank of the river, near Beaudry Provincial Park. However, in the case of the rural-residential expansion near St.Francois Xavier, riparian regrowth was removed to make room for a housing development. And with the rural-residential development near Beaudry Provincial Park, agricultural land was converted to an rural-residential land use. In both instances from an ecological standpoint, the land should not have been developed; rather, it should have undergone ecological restoration. This would have reestablished an important habitat as well as aided in river-bank stabilization and reduced the damage of caused during subsequent floods.

2.2 Remote Sensing

Remote sensing is the collection, via sensor equipment (photographic equipment, spectrophotometers), of reflected electromagnetic energy from an object(s), without coming into actual physical contact with the object(s) (Asrar, 1989). There are two principal types of sensors: the more common passive and the more recent active sensors.

Passive sensors collect reflected and refracted light from the Earth's surface (Figure 2-14). Active sensors send out a signal towards the Earth's surface, a portion of which is reflected back towards the sensor (Figure 2-15) (Colwell, 1983). Both passive and active sensor types are regularly used to collect reflected electromagnetic radiation usually from Earth surfaces. However, both geography and remote-sensing have been expanded to include celestial objects not just terrestrial analysis. The signals received by both sensor types are recorded digitally, usually as 8-bit images, although 16-bit images are now becoming more common. The exception is remote sensing equipment which still uses film of any type. In this instance a plastic surface coated with silver halide, or other photosensitive chemical compounds, is the recording medium (Colwell, 1983). These photographs can be placed into a digital format through the process of optical scanning; this thesis will be using digitally scanned aerial photographs.

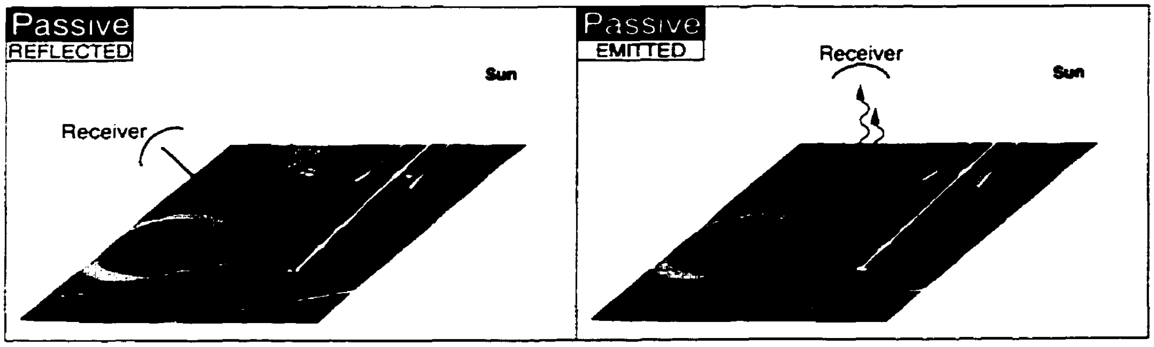


Figure 2-14 Passive Remote Sensors

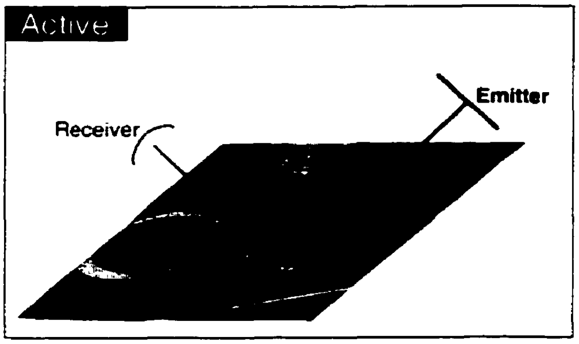


Figure 2-15 Active Remote Sensor

2.2.1 Electromagnetic-radiation

Virtually all the electromagnetic-radiation present in the Earth's atmosphere is generated directly or indirectly by the Sun. However, not all of the electromagnetic-radiation produced by the Sun can be transmitted through the Earth's atmosphere (Figure 2-17); some of the photons are deflected back into space, the remainder continues through the atmosphere. The source of electromagnetic-radiation is the fusion reactions on the surface of the Sun, which emits photons (Gillespie, 1986).

Furthermore, all matter above absolute zero (-273.15 °K) radiates energy at specific wavelengths. The rate at which an atom radiates is directly related to its temperature; as the temperature increases the emitted wavelength becomes a shorter and more energetic frequency (e.g., form 0.7 μm to 0.4 μm) (Sabins, 1987).

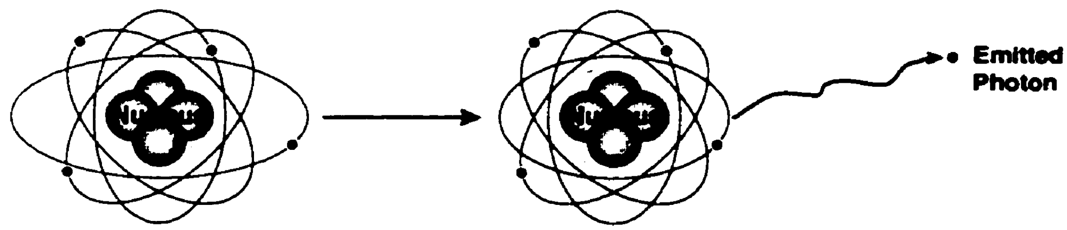


Figure 2-16 Photon emission

Photons are emitted when electrons in atoms return to a lower energy level from an excited state (Figure 2-16) (Gillespie, 1986). The frequency of the photon is dependent on the difference between the two energy levels (Gillespie, 1986). Fusion emissions of the Sun produce photons at numerous energetic states, covering the entire electromagnetic-spectrum (Campbell, 1996). Electromagnetic radiation has two main components, consisting of both an electric field and a magnetic field (Figure 2-17). Notice that the electric field has a magnitude which is perpendicular to the direction of transmission (Campbell, 1996). Moreover, electromagnetic-radiation has three measurable properties: wavelength (λ), amplitude (I), and frequency (ν). As seen in Figure 2-17[C], wavelength is the distance from one wave crest to the next. Amplitude is the height of the wave. Frequency is measured as the number of wave crest which pass a fixed point per second (Campbell, 1996). Wavelength is measured in units ranging from kilometers (*km*) and meters (*m*), down to millimeters (*mm*) and micrometers (μm). Hertz (*Hz*) is the measure used for frequency, and amplitude is measured in watts (*W*) per meter square (m^2) per micrometer written as $W/m^2/\mu m$.

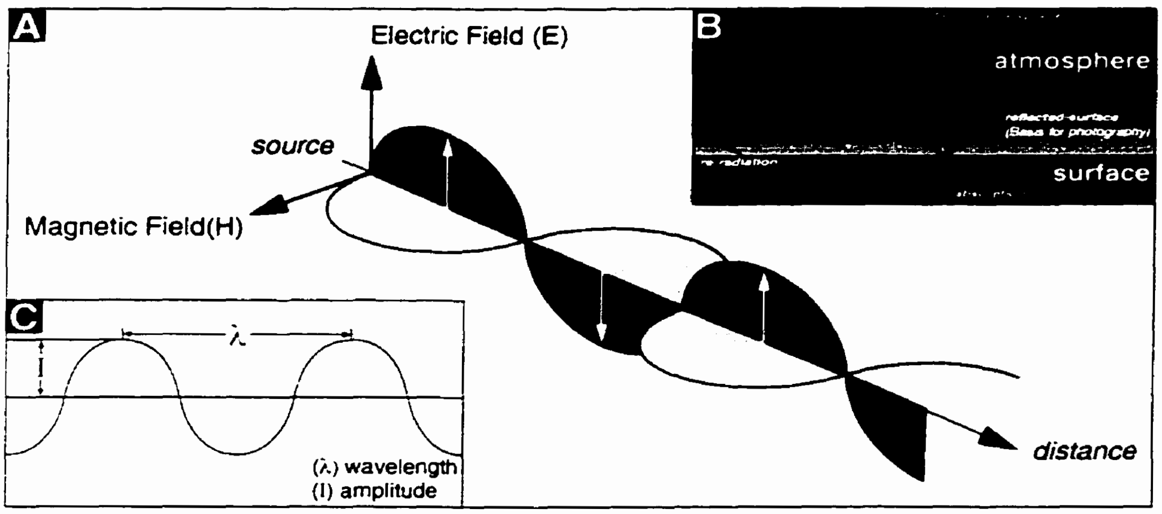


Figure 2-17 Properties of Electromagnetic-radiation

There is an additional property held in common by all frequencies of the electromagnetic spectrum, all electromagnetic-radiation travels at the speed of light (299,893 *km/s*) (Equation 2.1).

$$c = \lambda \bullet v \qquad \textit{Equation 2.1}$$

It is these energetic particles, reflected from earth surface materials, which are measured and then categorized based on the electromagnetic spectrum.

2.2.1.1 Electromagnetic-spectrum

The different wavelengths of electromagnetic radiation have been divided into ten groups which comprise the electromagnetic spectrum (Figure 2-18). Each group is differentiated by its wavelength. Humans are only capable of seeing a small proportion of the entire electromagnetic-spectrum, which has the anthropocentric name "visible light". The wavelengths recorded from visible light are used in this thesis. Visible light ranges from $0.38\mu m$ to $0.72\mu m$ (Figure 2-18), and consists of three primary colours (Blue, Green, and Red). When all three colours are reflected, the human eye registers the colour white; where all three are absorbed, black is the result.

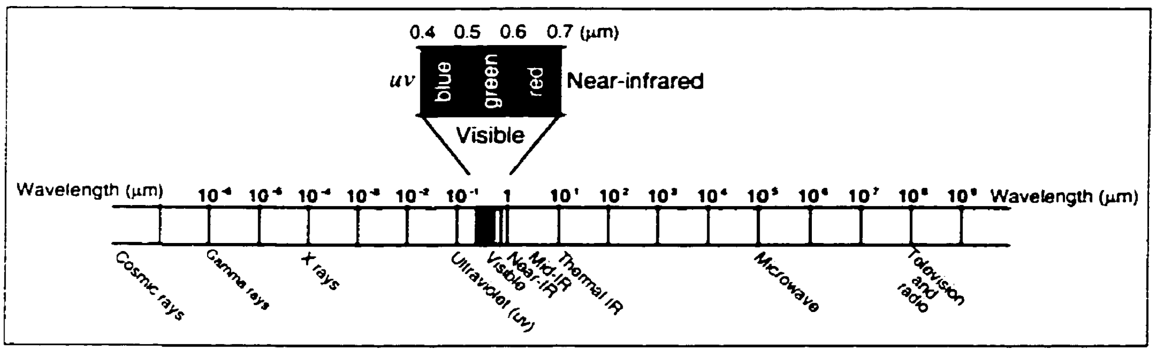


Figure 2-18 Electromagnetic-spectrum (Lillesand and Kiefer, 1994)

Black is not a colour, so much as it is the absence or complete absorption of light. As seen in Figure 2-19, the colour of an object is established by the wavelengths of electromagnetic-radiation reflected to the observer. The "visible" region of the spectrum is, by proportion, the smallest segment of the electromagnetic-spectrum when compared to other classifications. Even so, these wavelengths are present at recordable concentrations during the daytime and can be documented on photographic film. Traditionally, aerial photography used the visible spectrum of light, and later on infrared and colour films came into use.

Infrared (Reflected and Thermal) can be recorded at any time of the day or night with either special film or electronic equipment (Colwell, 1983). The current method for recording the electromagnetic-spectrum is through the use of specialized equipment which stores the results digitally through the use of charged-coupled-devices (CCDs).

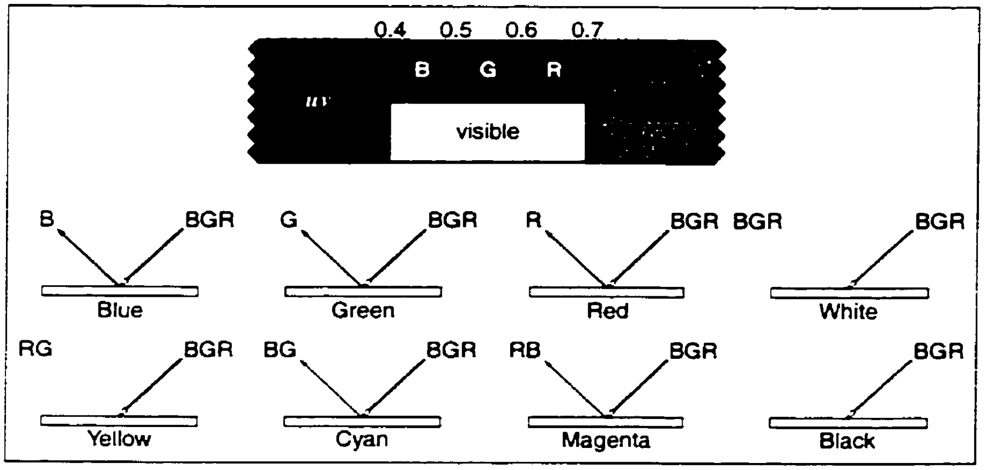


Figure 2-19 Visible light (Campbell, 1996)

The photographs used in this thesis are traditional visible-light black and white aerial photographs. Recordings of visible light are affected by the physical properties of the atmosphere (at the time of recording) and of the materials from which the light is being reflected. Clouds, smog and ice crystals are atmospheric variables which affect the quality of the photographs. Presently, smog is not a variable which is in effect within the study site. Examples of variation in the intensity of reflected light within the study site include the Assiniboine River and the surrounding tree canopy. When interacting with water most of the electromagnetic-radiation is absorbed which results in a poor signature and thus can be recorded as dark gray tones, approaching black. There is an exception which can be found in the Manitoba 1990 series (referred to as the MB-series). There is a seasonal variable present in the form of snow and ice covering the river, producing a strong electromagnetic-radiation return. This strong signal is recorded as white or near white in aerial photographs. The leaf canopy of the riparian habitat produces variability. Tree canopies can produce a strong "green" return in the visible portion of the electromagnetic-spectrum. This appears as varying shades of medium to dark greys in black and white photography. Notice that the canopy appears highly textured due to changes in the orientation of leaf surfaces, which produces differential electromagnetic-radiation returns. The fallow agricultural fields occupy the same gray levels as tree canopies. However, this feature is distinguishable due to the relative uniformity in the electromagnetic-radiation returns recorded in the imagery.

2.2.1.2 Interaction of Electromagnetic-radiation in the Atmosphere

Not all frequencies of electromagnetic-radiation are capable of penetrating the Earth's atmosphere. A large portion of the electromagnetic-radiation is reflected by the atmosphere, clouds and suspended particulates in the atmosphere (Figure 2-20). Frequencies which can penetrate the atmosphere are termed "atmospheric windows" and are the segments of the electromagnetic-spectrum in which the researchers are interested. These wavelengths were given this descriptive name, because they are the least distorted by the various constituents of the atmosphere; that is, these particular wavelengths provide a window through the atmosphere from which to view the Earth's surface (Figure 2-21).

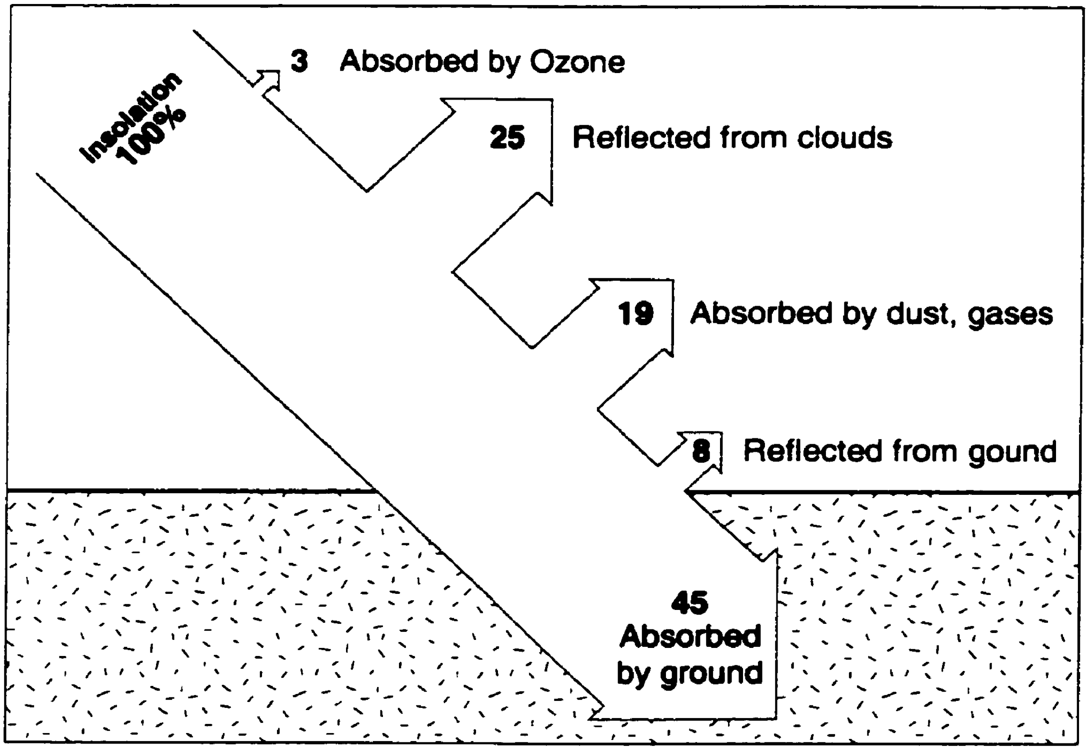


Figure 2-20 Insolation: Incoming solar radiation. (Campbell, J. 1996)

A diagrammatic representation of the interactions of shorter wavelengths which are able to pass through the atmosphere is shown in Figure 2-20. The principle employed in the diagram is that there are 100 units of incoming solar radiation (insolation): three units are directly reflected by the Ozone (O_3) layer; 25 units are reflected from clouds; 19 units are absorbed by dust and gases; and six units are reflected from earth surface materials (albedo); the remainder is absorbed by the Earth's surface (Campbell, 1996; Colwell, 1983).

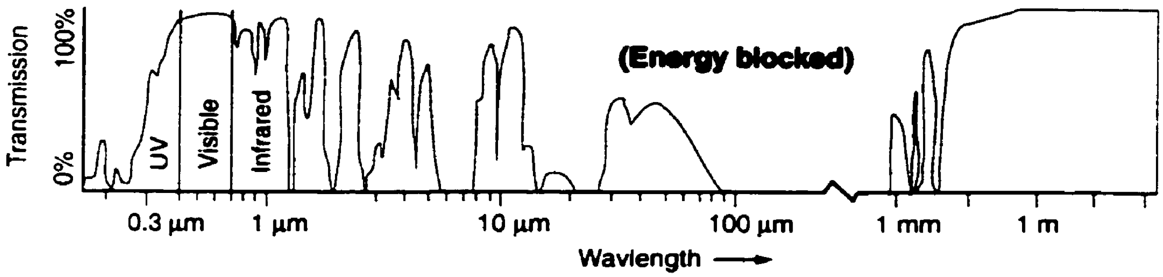


Figure 2-21 Atmospheric Windows (Lillesand and Kiefer, 1994)

Some of the radiation lost through absorption is returned as emitted radiation in the form of infrared radiation. As mentioned previously, not all the electromagnetic-radiation is capable of passing through the ozone-layer or the atmosphere. This significantly reduces the types of electromagnetic-radiation available for passive sensors to collect. As eluded to in Figure 2-20, the radiation that does penetrate the atmosphere is still affected by other variables. The regions of the electromagnetic-spectrum which pass through the atmosphere are known as atmospheric windows (Colwell, 1983). Through absorption and reflection, the atmosphere prevents gamma-ray, X-ray, and most of the ultraviolet (*uv*) radiation from penetrating deeply into the atmosphere (Sabins, 1987). Of the electromagnetic-radiation which does penetrate the atmosphere, there are additional impedances: aerosols (airborne particles); gases ($CO_2(g)$, $O_3(g)$, $H_2O(g)$); water vapour and ice crystals (clouds) suspended within the Earth's atmosphere (Colwell, 1983). The absorption of electromagnetic-radiation by the chemical constituents of the atmosphere reduces the amount of electromagnetic-radiation available for remote sensing equipment to detect (Asrar, 1989).

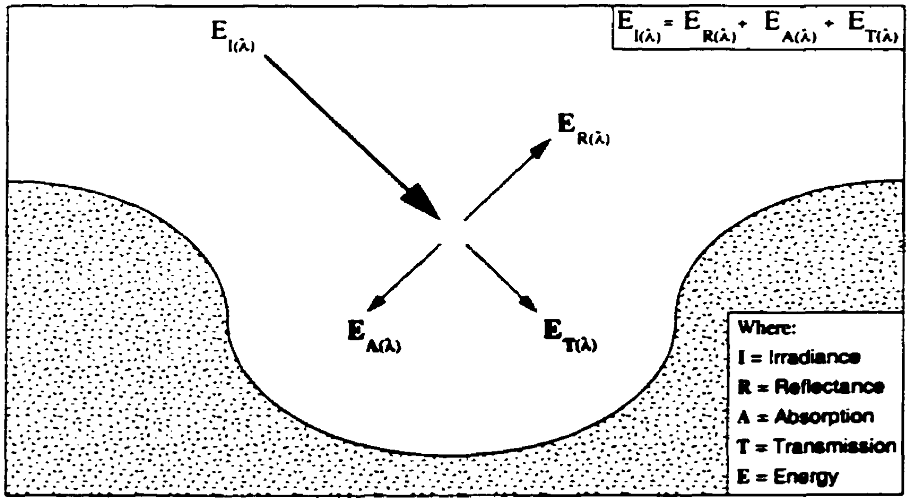


Figure 2-22 Energy Balance Equation, as seen in Lillesand and Kiefer (1994)

The result is either the absence or a reduction in the spectral signature of objects on the Earth's surface. In order to account for the variables affecting the insolation incident on the Earth's surface a general purpose equation was developed (Figure 2-22). Contained in that diagram are the primary components of the electromagnetic-radiation interaction: scattering, reflection (Section 2.2.1.3) and absorption (Section 2.2.1.4). Scattering within the atmosphere is the result of differential density of the constituent materials of the atmosphere (Asrar, 1989; Sabins, 1987). The outcome of scattering on remotely sensed images is a reduction in spatial resolution, owing to alteration of the intensity of the reflected radiation by atmospheric particulates. This effect is evident in the hazy MB-series of aerial photographs, particularly when comparing them to the clear N-series images (Figure 2-23); both photographs captured at the same altitude (1:12,000). The cause of the haziness in MB-series is the result of ice crystals in the atmosphere (photograph was taken in November). The precise term

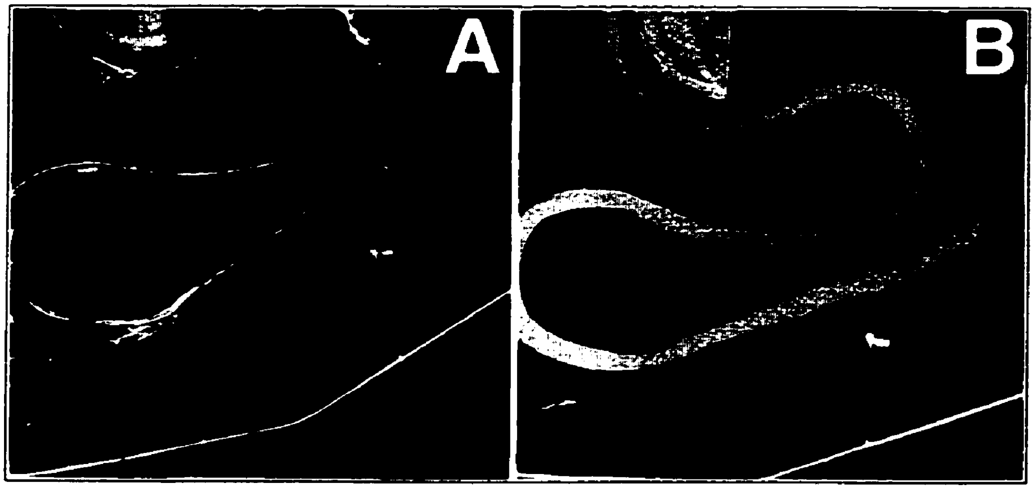


Figure 2-23 Photographic comparison; (a)MB Series, (b) N Series

for what Asrar (1989) and Sabins (1987) are describing is Rayleigh scattering. Scattering of this type was shown to occur when atmospheric molecules have diameters smaller than that of the wavelength of insolation.[1] Earth's blue sky is produced by this type of scattering. Mie scattering is produced by larger atmospheric particles, and includes: dust, pollen, smoke (from any source of combustion) and water droplets (Campbell, 1996). This type of scattering is present when atmospheric particles have diameters that are approximately the same size as a wavelength in the electromagnetic-spectrum; it can influence the entire visible spectrum (Lillesand and Kiefer, 1994). Because of the different types of particles affecting insolation, Rayleigh scattering occurs up to 10 km (Campbell, 1996) while Mie scattering is prevalent from 0-5 km (Colwell, 1983).

1. Rayleigh scattering was named after Lord J.W.S. Rayleigh who was the first to discover this electromagnetic-radiation interaction with atmospheric molecules.

2.2.1.3 Reflectance Values

Objects, natural or manufactured, are comprised of more than one substance. As a result, the electromagnetic-radiation reflected from a single object can be unique to the material comprising the object. The spectral reflectance from an object can be thought of as a spectral signature (Barrett and Curtis, 1992), which is comprised of varying reflectance values. By plotting the spectral signatures (frequency histogram) of the objects, the researcher can see where the signatures overlap (Barrett and Curtis, 1992).

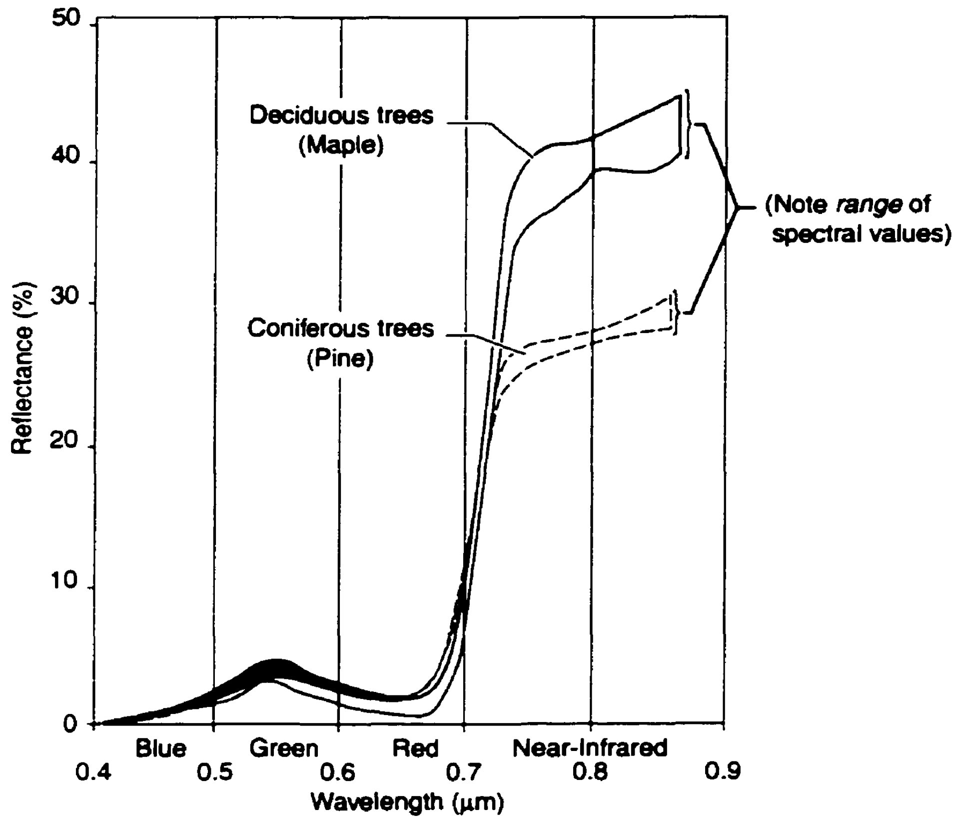


Figure 2-24 Comparison of Spectral Values (Lillesand and Kiefer, 1994)

Graphing is a simple but very powerful tool, as it enables the researcher to establish whether or not an object's spectral values are distinguishable from those of other objects within the same image (Figure 2-24). Another method which achieves the same effect as plotting is density slicing. This can be performed in an image analysis software program. Many programs allow the user to select the range of gray-values the image is to be sliced by. Density slicing causes areas of the image, within the selected range, to become monochromatic in a highly contrasting colour to make the slice visible (Figure 2-28). This technique enables the researcher to see what regions within image share the same spectral values. When performing this technique on the images to be used in this thesis, it becomes apparent that the images have too many spectrally similar areas to facilitate classification (Figure 2-28).

2.2.1.4 Interaction of Electromagnetic-radiation at the Earth's Surface

The wavelengths known as atmospheric windows can pass relatively unaffected through the atmosphere. However, these wavelengths are still subject to further attenuation by absorption, scattering, reflection and/or refraction at the Earth's surface (Colwell, 1983) (Figure 2-20 & Figure 2-25). When electromagnetic-radiation reaches the Earth's surface it can come into contact with numerous materials each with varying densities and textures which can further change its intensity and electromagnetic-spectrum value. Plants absorb portions of the electromagnetic-spectrum for use in photosynthesis and emit waste heat in different wavelengths (Colwell, 1983). As a result, they tend to reflect the green wavelength of the electromagnetic-spectrum but emit in the thermal infrared due to the processes of photosynthesis (Colwell, 1983). Water can reflect, scatter, refract or absorb electromagnetic-radiation depending upon the angle of incidence and the texture of the surface (calm sea vs. storm conditions) (Asrar, 1989). The numerous types of soils can also have one or more of these properties. As mentioned previously the electromagnetic-spectrum value of electromagnetic-radiation can change as it passes through the atmosphere and materials on the Earth's surface (Colwell, 1983). The heating of the atmosphere and various components of the Earth surface are proof of the interaction of electromagnetic-radiation (Gillespie, 1986). As a particle of electromagnetic-radiation collides with an object, as opposed to passing straight through as gamma-rays usually do, some energy is transferred to the object from the particle incident upon it. This energy transfer changes the wavelength of the particle and thus the electromagnetic value (Gillespie, 1986). The energy transferred is usually absorbed, used up in resultant chemical reactions and thermal increases the initial transfer caused, to be re-emitted at a later time (Gillespie, 1986). Reflectance values can be affected by the angle at which the electromagnetic-radiation is incident upon a surface (Asrar, 1989). The greater the angle of incident the less chance for reflection and scattering to occur.

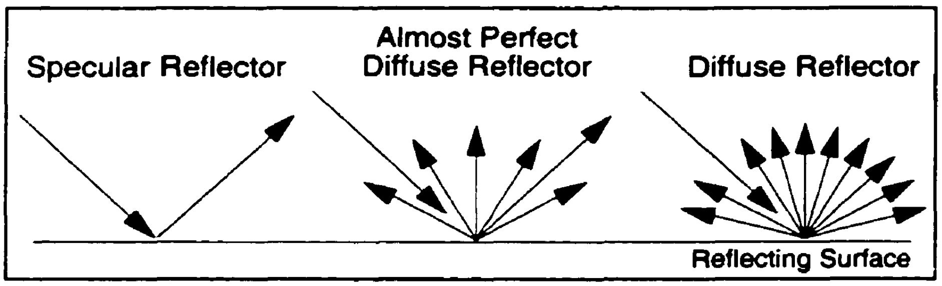


Figure 2-25 Surface Interaction of Electromagnetic-radiation, Specular Reflection

There are three basic types of reflectors: perfect or specular (theoretical black body); almost perfect diffuse; and diffuse reflector (theoretical maximum). Natural surfaces will fall between the two extremes of a perfect reflector and perfect diffuse reflector. Leaves are a good example of a natural surface which falls between the extremes mentioned above. They are almost diffuse perfect reflectors, absorbing all but the green portion of the visible spectrum. The most prominent example of the effect of changing incident angles is the forest canopy comprising areas of riparian habitat. Leaves are continually changing position with respect to the position of the Sun and as the result of wind action. In addition, tree canopies are not completely uniform; the density changes with the seasons and the health of the plants. The net effect of these factors are manifested in remotely sensed imagery as highly textured and patchy regions (Figure 2-26).

Figure 2-26 Subset of A25233-140

2.2.2 *Interpretation of Aerial Photography*

Many people mistakenly assume that an aerial photograph is the same as a standard ground based photograph. Interpretation of aerial photography, or any remotely sensed image, is distinguished from ground based images by three main differences according to Lillesand and Keifer (1994). The most obvious difference is one of perspective. Areal photographs are collected from an overhead vantage point, a perspective most people are not familiar with. Another difference, although not a factor in this thesis, is the collection of remotely sensed data from sections of the electro-magnetic-spectrum other than the visible portion. The third difference is related to the first, remotely sensed data tends to be collected from overhead, that is from some altitude. This is an important distinction, because not only are most people unable to conceptualize the world from above, but they also have difficulty with changes in scale. Altitude comes into play during the interpretation, or recognition of terrestrial objects at different scales (e.g., a tree at ground level differs greatly from a overhead image taken at a 1:12,000 scale). Because of the three stated differences between the interpretation of the remotely sensed images and ground based images, techniques have been developed to aid in the correct interpretation of earth surface features. These techniques take advantage of specific characteristics of the collected data and human cognitive skills. These specific characteristics include: shape, size, pattern, tone (or hue), shadows, site, association and texture (Colwell, 1983; Lillesand and Keifer, 1994). Humans rely considerably on vision to learn about their environment, e.g. identifying objects by their shape. The ability to identify something by its shape can be expanded upon by cognitive skills to include the identification of similar shapes. This ability to classify similar objects is used by photogrammetrists when they utilize shape to assist in classification. It is the basic form of an object which can assist in its correct identification. An example is differentiating agricultural fields from the surrounding riparian habitat. Agricultural land use appears very distinctive in aerial photography; this cultivated prairie landscape (as opposed to natural prairie)

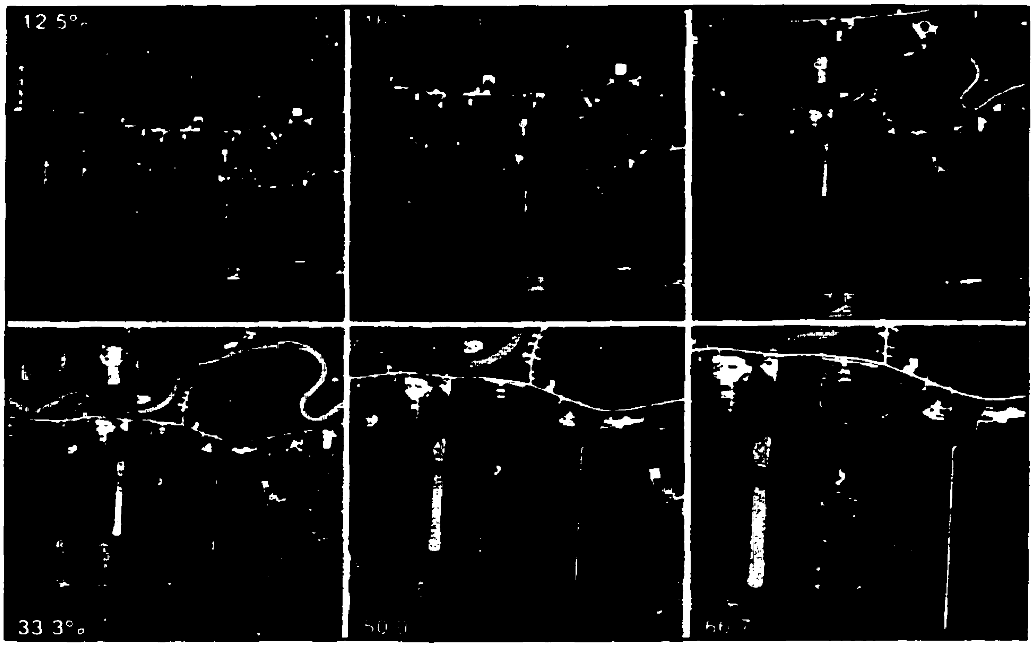


Figure 2-27 Aerial Photographs–Effect of Scale Change

can look like a quilt when viewed from overhead (Figure 2-27). The shape of the agricultural plots is very distinctive, but it is not always possible to identify something entirely by shape. The size of an object can play an important role in identification. To use the prairie example again, if we didn't know that the areal photograph was a 1:12,000 image we might mistaken think it was a personal garden. If we were totally unfamiliar at looking at a scenes like Figure 2-27, we might incorrectly identify the grids of agricultural activity as the grid system commonly used to layout roadways in urban centres.

Measurements can be taken from a photograph to determine the actual size of an object relative to its surroundings. In the 66.7% panel of Figure 2-27, each picture element (pixel) is approximately 6 m^2. Therefore, the secondary highway shown in this panel is about 24 meters wide. Knowing the scale and resolution of the imagery, as well as the shape of a roadway, enabled the correct identification of a highway. Furthermore, it prevented an incorrect classification of the highway as a rural road or smaller right-of-way. Although the overall shape of agricultural fields tends to be rectangular; the general appearance or pattern of cultivated land can be described as 'quilted'. Although shape is important to identification, texture can be a source of valuable information. Tree canopies have a distinctive appearance (Figure 2-26). To the trained eye, one can discern the heavily treed areas from the surrounding agricultural land use. It is this pattern, created by the variance in individual pixels, which facilitates the classification of trees. Another property of photography is tone. Generally, tone is the manifestation of reflective properties, which is produced by the particular physical properties of the object being studied. The factors which influence the reflectance include: the intensity of the insolation; the incidence angle of the insolation on the object; and the angle the image was collected (i.e., oblique) (Lillesand and Keifer, 1994; Colwell, 1983). These factors influence the texture of an image, because texture is tone variance and the tone of an object is affected by the variables previously stated. Tonal property alone would not allow for an accurate classification. For example, the tones in the treed areas are clearly visible in other parts of the image (Figure 2-28). By performing a density slice on the image in Figure 2-26, the tones held in common are clearly seen in red.

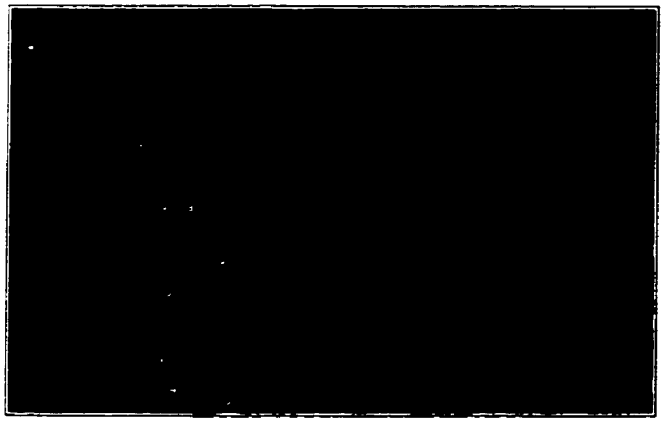


Figure 2-28 Subset of A25233-140 (Density Slice)

Density slicing is a technique whereby an image can be segmented based on the pixel values (digital numbers, DN; referred to as image tone). It is the tonal variance in an area which creates patterns and textures. The pattern of agricultural land use is clearly visible, as is the variance in the tree canopy caused by leaf orientation (Figure 2-26). Another feature of the photography is the presence of shadows, which can be used to calculate the height of objects. To get the necessary shadow length, oblique images have to be collected. Images which are taken straight down when the sun angle is high, do not have the necessary shadow length (Colwell, 1983). Shadows can have detrimental effects on the quality of an image by obscuring features. Shadows can also produce classification artifacts by being incorrectly grouped into their own class or that of another. One of the most important aspects of remotely sensed imagery which must be known, is the site or the geographical location from which the picture was taken (Campbell, 1996). Knowing where geographically a picture was taken will automatically assist in classification by reducing the number of classification possibilities. A regional knowledge is valuable, as is a working knowledge of how earth surface features are created. Earth surface features are not usually formed by a single factor (e.g., seismic), but by a combination of factors. These factors can be either morphological or ecological in origin. For example, if there was a rotational-slump visible in a photograph one could postulate that the bank may contain poorly drained cohesive soil. Because rotational-slumping usually only occurs in certain soil types, a geomorphologist could begin to narrow down the possible soil types. It is a combination of all the above discussed variables which facilitate classification, not just one specific attribute.

2.2.2.1 Black and White Aerial-Photographic Film

Black and white aerial film is a combination of a plastic substrate sprayed with a photosensitive emulsion (Sabins, 1987) (Figure 2-29). The silver halide is a light sensitive chemical which can record reflected electromagnetic-radiation (Colwell, 1983).

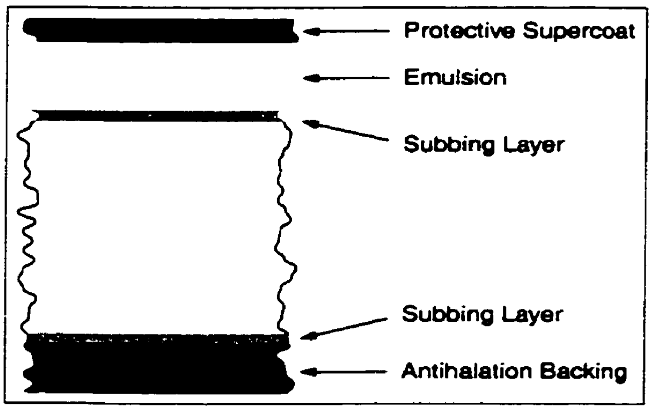


Figure 2-29 Cross section through Black & White film (Cambell, 1996)

Taking a photograph initiates a photochemical reaction between the photosensitive emulsion and the photons comprising the electromagnetic-radiation incident upon the film (Sabins, 1987). This photochemical reaction changes the silver nitrate into elemental silver atoms (Colwell 1983; Cambell, 1996). More than one photon must impact with a silver halide molecule in less than one second for the reaction to produce stable silver atoms (Sabins, 1987). Once the film has been exposed it must be developed in a developing solution, then "fixed" to stop the reaction of the developing solution (Colwell, 1983). A "negative" is the product of the developing process (bright areas appear dark and dark appear bright) which is inverted when printed onto photographic paper to resulting in a recognizable photograph (Sabins, 1987). It is this "contact" print which has been digitally scanned for use in this thesis.

2.2.2.2 Digital Conversion

Traditional photographs can be converted into digital representations through digitizing or scanning. This section will only focus on the process of scanning. A flatbed scanner works by using a light source (usually a fluorescent light tube, Figure 2-30) and a series of charged-coupled-devices (CCDs). CCDs detect the reflected light from the surface of the photograph being scanned and perform the same function as silver halide but through electronic means (Asrar, 1989). The photograph is place upon a transparent glass surface through which the light can pass relatively unimpeded. As the CCDs detect photons, signals are produced in relation to the wavelength and intensity of the photons (Asrar 1989). These signals are the digital representations of the values assigned to the wavelengths of the detected photon by the computer. The signals can be stored magnetically or optically by various computer hardware devices. These signals can then be manipulated mathematically, within the image analysis programme, to orientate the image to the surface of the Earth. The "corrected" image can then be placed into a geographic information system (GIS) for classification and statistical analysis.

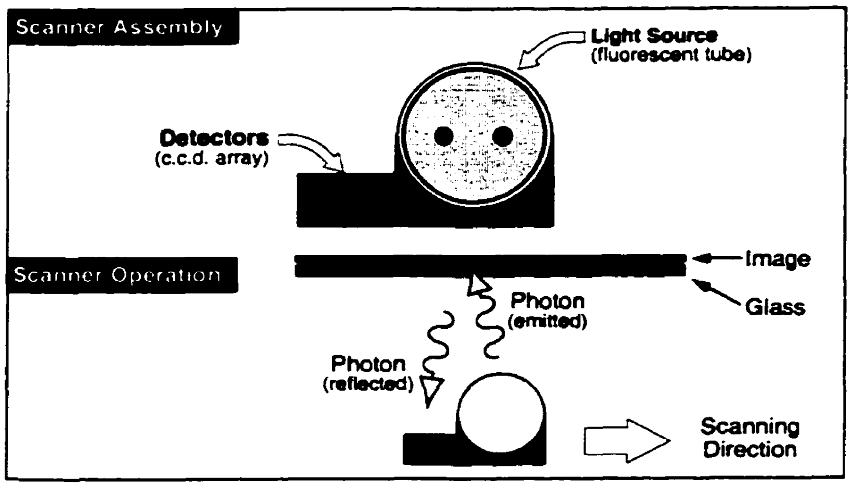


Figure 2-30 Principle Components of a Flatbed Scanner

Keep in mind that density-slicing has already shown that automated-classification of single-band imagery is not possible. The current methods rely on electromagnetic-spectrum derived segmentation and this does not take into account spatial variability (texture).

2.3 Summary

Riparian ecosystems contain a diverse ecological community, a community which must be protected. This ecosystem provides many important functions: it has a stabilizing effect on river banks; it provides a buffer between the lotic system and agricultural chemicals; it is home to many species of birds and fish; and it increases the duration of water run-off (both overland and through-flow). Developing a management strategy for this ecosystem type is of great importance. Riparian ecosystems continue to be removed at an alarming rate. Understanding what land use types are replacing riparian ecosystems can aid in interpreting the factors influencing the development of a particular region.

Methods

This chapters discusses at length the procedures used in this thesis: for data collection; data input; geometric rectification; the selection of ground control points (GCPs) and reciprocal control points (RCPs); resampling methods; and calculation image scale. In addition, the manual classification used in this thesis is defined and described, as is the change detection analysis and sources of error.

3.0 METHODS

3.1 Data Collection

The data collected for this thesis is in the form of aerial-photographs which were obtained from the Land Surveys Branch (LSB) of the Manitoba Remote Sensing Centre and Linnet Inc. (both located in Winnipeg, Manitoba, Canada) (Table 3-1).

Data Source	Land Surveys Branch of the Manitoba Remote Sensing Centre					
Month Collected	June			August		
Year Collected	1959			1989		
Scale	1:8,800			1:16,800		
Catalogue Number	A16547	A16548	A16576	A21142	A21178	
Frame Numbers	100-104	77-79,107-109	159-163	13-15	26, 27, 44, 45	
Referred to in thesis	A165-Series			A211-Series		
Data Source	Land Surveys Branch of the Manitoba Remote Sensing Centre					Linnet Inc
Month Collected	October	September			November	March
Year Collected	1975	1979			1990	1984
Scale	1:12,000	1:15,840			1:12,000	1:80,000
Catalogue Number	N75122	A25232	A25233	A25234	MB90059	6005520
Frame Numbers	62-67, 80, 87	54	140	55	22-25, 31-35	6005520, 6105520
Referred to in thesis	N-Series	A252-Series			MB-Series	6005520

Table 3-1 Remotely Sensed Data Sources

There is no computer-based catalogue for any of the aerial-photograph coverage of Manitoba held by the LSB. Presently, aerial-photographs are catalogued on paper by role number, flight line and then frame. The method used for indexing the catalogue consists of varying scales of microfiched sheets from the Federal Land Use Map Series; upon which flight lines of the aircraft are then drawn.The role of film and the exposure number are listed on the microfiche. This greatly complicates finding the repeat coverage necessary for a time-series analysis.

3.2 Site Selection

The study site was chosen for its proximity to a high order stream (Assiniboine River) and a major urban centre (City of Winnipeg). In addition, the availability of remotely sensed data with repeat coverage was of importance for the time differentiated cross-tabulations. The quality of the remotely sensed data was important for discerning earth surface features, and land use types. Cost was a factor as well, aerial photography is a very economical remotely sensed data source. Particularly when compared with the cost associated with multi-spectral data types (e.g. LANDSAT, S.P.O.T.). The 35 year range (1959-1994) of the data was depended on the above criteria. Images earlier the 1959 did not provide complete coverage of the study site; in some cases the quality of earlier images was poor. The last complete aerial-photographic coverage of this area was collected by Linnet in 1994. It was thought that should the surrounding land uses have a potential influence on the changes occurring within the riparian ecosystem, it would be important to have images with a large areal extent. This factor was also considered in site selection as the aerial photographs did not just show the riparian ecosystem but the surrounding land uses as well.

3.3 Data Input

The aerial photographs used in this thesis were scanned into a computer system at 300 DPI (dots per inch), with the exception of Series 6005520 which was purchased as pre-processed imagery. Based on the requirements of the minimum mapping unit (MMU) the photographs were ultimately resampled down to 150 DPI in a remote-sensing software package. The MMU for this thesis was qualitatively defined as being able to discern tree canopies, which was possible at 150 DPI for all of the photographs.

The initial scan setting of 300 DPI was chosen because that was the true optical resolution of the scanner being used. Having the scanner set at its optical resolution would preclude the scanner and its controlling software from interpolating the photograph being scanned. Most scanning software is not intended for scientific use and thus lacks the rigorous controls required by researchers. However, a remote-sensing software package does contain the rigorous controls and as a result was better suited to resampling the images. Furthermore, working with images scanned at 300 DPI, would result in photo-mosaics greater than 200 megabytes (MB). Images of that size would make analysis extremely difficult and would require a great deal of computer time to process any analysis. Resampling down to 150 DPI produced an image that met the requirements of the MMU and was easier to analyze within a computer system. The resampling performed in the 300 DPI images was a bilinear type; that is, the resampling takes into account the surrounding four pixel values to produce one pixel in the output image. The resampled images were saved in RPD format (Raw Pixel Data) to reduce the possibility of file read/write errors, particularly during the transfer from one computer system to another. After the photographs were scanned they were geo-rectified to the UTM coordinate system.

3.4 Geometric Rectification

The method of applying a map-projection to remotely-sensed imagery is termed geometric-rectification and is considered part of image-preprocessing. Most often images are oriented to the Earth's surface using the Universal Transverse Mercator(UTM) projection. This produces an image upon which areal and distance calculations can be performed quickly. The UTM projection uses metres as the unit of

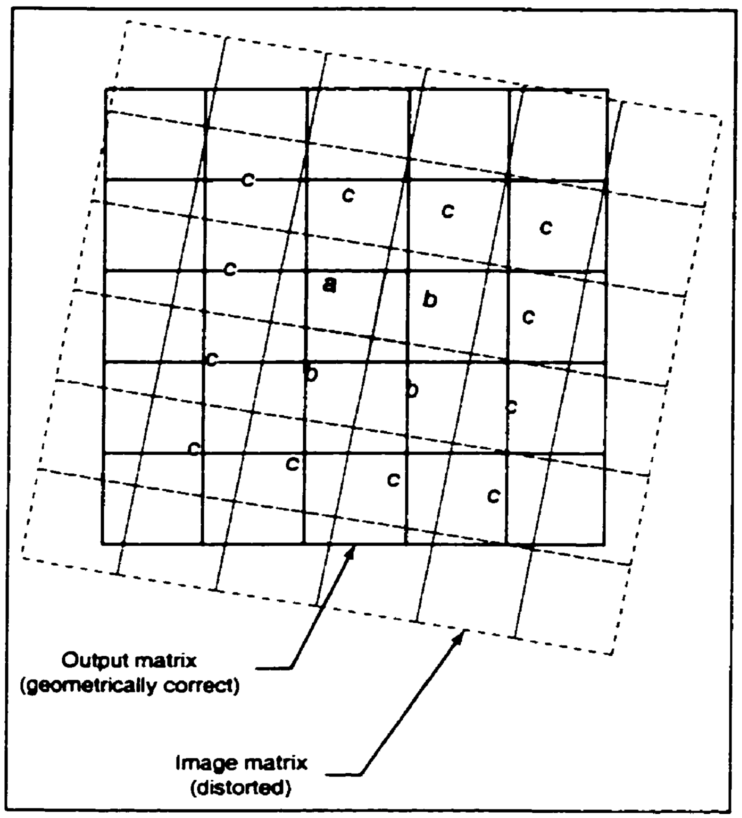


Figure 3-2 Geometric Rectification (Lillesand and Kiefer, 1994)

measure and is considered an equidistance-projection. A projection is applied via a series of calculations performed in a computer system by using known locations to stretch or "rubber-sheet" an image on to the desired projection (Figure 3-2). Locational information can include benchmarks, survey information (including GPS data), and other map products. The greater the number of evenly space known locations, the more accurate the resultant geometric-rectification.

3.4.1 Selecting Ground Control Points (GCPs)

As mentioned above (section 3.4) known locations of objects within the image are used to orient the image to the Earth's surface. These known locations are referred to as Ground Control Points or GCPs; they should be as evenly spaced across the image as possible. The most common GCPs are road intersections and railway crossings. These "hard-points" provide an easily identifiable location both within the image and on the ground, which is particularly useful when collecting Globe Position System (GPS) information. Furthermore, if the source of the locational information is either another rectified image, or some other map product (e.g. topographic map sheet), using readily identifiable points simplifies the rectification process. In turn, this reduces the possibility of incorrect GCP selection as a possible source of error. Should an incorrect GCP be selected, it would reduce the overall accuracy of the rectification. The term "hard-point" is not only in reference to the ease associated with locating the aforementioned common GCPs, but all so implies that said locations will be the least likely to change over time. For example, a road intersection would be adequate as a hard-point, whereas a sand-bar within a river would not.

3.4.1.1 About the use of Reciprocal Control Points (RCPs)

This type of GCP is used when rectifying one remotely sensing image to another. A RCP is merely a point with a known location, which does not change between the georectified image and the non-georectified image (i.e. a reciprocal point).

3.4.2 Resampling

Resampling can be used when the images which need to be compared are not of the same resolution. In addition, if the images undergoing analysis contain more information (i.e. too high a resolution) than is needed, resampling may be used. This process involves decreasing the scale of the image (e.g. $10m^2$ to $30m^2$). Through the use of fractal mathematics the opposite is now possible as well (Lam and De Cola, 1993). However, the results are completely synthetic, being derived from the information available, and thus it is a technique that should be avoided. Images are

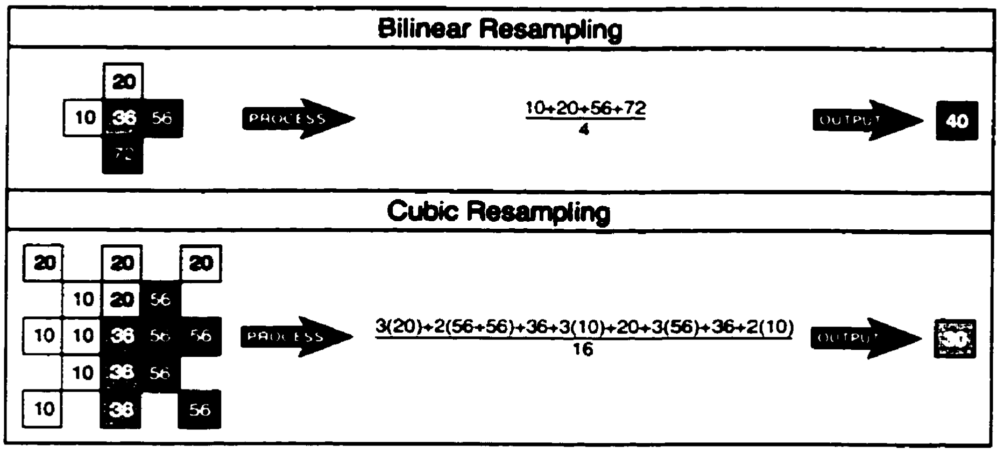


Figure 3-3 Bilinear & Cubic Resampling

commonly resampled using either nearest-neighbour, bilinear or cubic calculations. Nearest-neighbour resampling operates by taking the pixel value at the nearest integral pixel coordinates (i.e. x=120,y=36 not x=120.55,y=36.67) to the calculated coordinates. The resulting image will have a coarse appearance, specifically, linear features will appear blocky. Bilinear resampling involves a weighted average of the nearest surrounding four pixels to produce one output pixel. Cubic resampling uses the weighted average of sixteen of the surrounding pixels values to calculate one output pixel. Both the bilinear and cubic resampling techniques produce images which appear smoother due to the averaging calculations for each output pixel. Resampling is not always required but some image preprocessing is usually required to remove artifacts (i.e. band-striping in satellite data).

3.4.3 Determining Image Scale

In an aerial-photograph series, the first frame will usually contain the information shown in Figure 3-4. In this figure the flying altitude is listed as 6775' ASL. This altitude can be used to check the accuracy of the other photographs. By measuring the bridge in georectified versions of MB90059-34 (3 mm.) and in A25234-55 (2 mm.) the following calculations can be made, see Table 3-5. Where, the scales of the photographs was provided from the original contact prints; "Bridge Width-P" is the length of the bridge as measured from the contact prints; "Bridge Width-G" is the length of the bridge as calculated using the stated scale of the contact prints. These calculations must be performed in rectified images. Any calculation based on measurements from a non-georectified photograph would be inaccurate due to distortions caused by the altitude the picture was taken, camera lens imperfections,

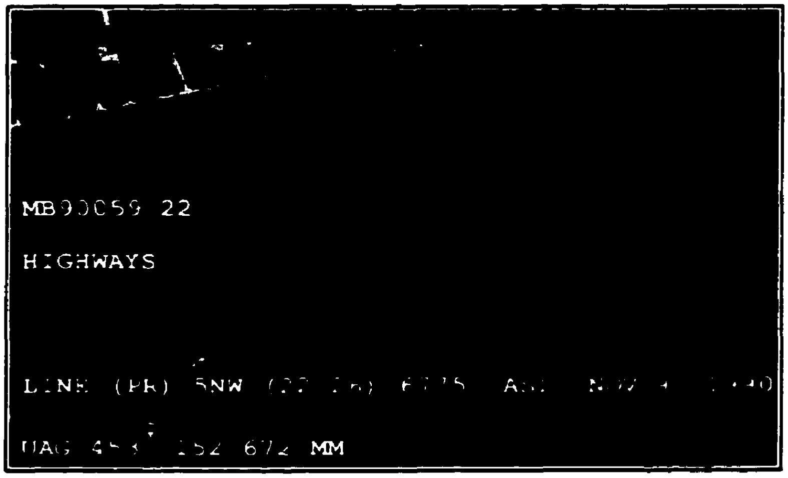


Figure 3-4 Aerial Photograph Informational Overlays

relief in the Earth's surface and atmosphere effects. Because the photographs are taken at altitude, the image is the least distorted in the center (nadir), but becomes increasingly distorted toward the edges. To adjust for the aforementioned distortions, images are rectified to the Earth's surface using map projections.

Aerial-Photo No.	A25234-55	MB90059-34
Scale of Photo's	1:15,840	1:6,775
Bridge Width-P (photo)	2 mm	3 mm
Bridge Width-G (ground)	31,680 mm	20,325 mm
Ratio of Width-P	15,840 mm : 6,775 mm =2.338	
Ratio of Width-G	31,680 mm : 20,325 mm =1.559	
Actual Scale of MB90059	6,775 • 1.559=10,562 1:10,562	

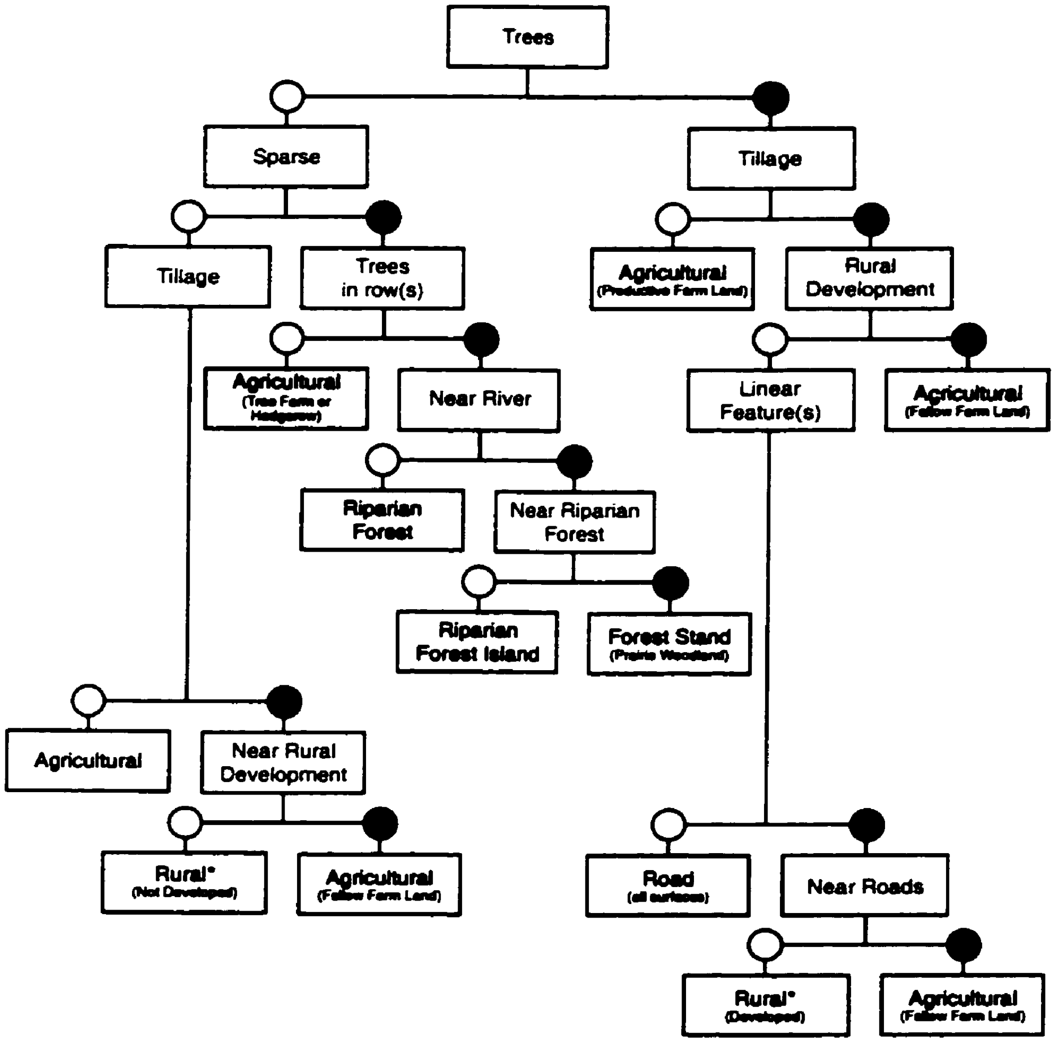
Table 3-5 Aerial Photograph Scale Calculation

Given the relatively small areal extent of the images used in this thesis, a Universal Transverse Mercator (UTM) projection was applied (section 3.4).

3.5 Manual Classification Decision Tree

Manual classification is the method used in this thesis to classify and interpret aerial photographs. The reason for selecting this method is due to the absence of an effectual automated classification scheme for single-band remotely sensed imagery. Current methods require multi-spectral data sets. The space-based multi-spectral sensors lack the necessary resolution for the study being undertaken. Airborne multi-spectral sensors proved too costly, thus leaving the only viable data source, aerial photographs. Repeat coverage for the study site was single-band, visible spectrum, aerial photography. Because manual classification is qualitative, a systematic manual classification method was required (Figure 3-6). The classification scheme used by the Province of Manitoba was assessed, and found not to be entirely applicable to the type of analysis being performed in this thesis (Figure A2–1). The classifications used in the Federal Canada Land Inventory were also examined. The Canada Land Inventory was concerned with providing an inventory of suitability. This classification scheme was not appropriate for land use change, as they were assessing the suitability of a region for use by a particular type of productivity (e.g. forestry, mining, various forms of agriculture). Further to what was stated above, a manual classification scheme was needed in order to make the classification as repeatable as possible, given that this method is qualitative in design. This decision tree was constructed for the specific geographic location of the study site discussed in this thesis. It should not be applied to another region without modification. Descriptions of each of the land use types has been included, to aid in the correct identification of the land use types used in this thesis (section 3.6). The only notable exception is the infrastructure land use description. This land use type requires ground verification as it can easily be misclassified as Rural-residential land use. Infrastructure land uses include property used for recreational, water-distribution, and waste-management facilities.

Manual Classification Decision Tree



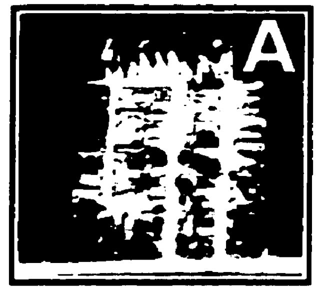
YES NO

*May require ground verification to determine if the land is being used to locate infrastruture facilities.

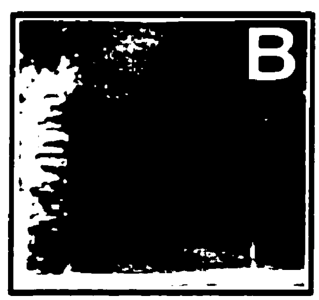
Figure 3-6 Manual Classification Decision Tree

3.6 Manual Classification Decision Tree – Supplemental Descriptive Information

3.6.1 Rural-residential Land Use

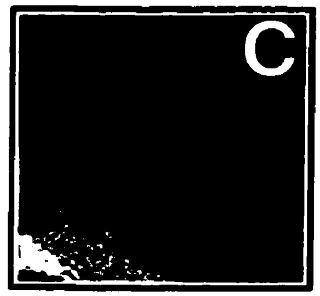


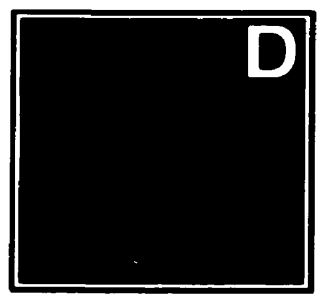
Developed... This land use type is identified as cleared land and can be initially identified by either a complete absence, or an extremely sparse coverage of trees (image A). The land shouldn't show any agricultural activities (the one exception being domestic gardens), specifically furrows or tillage; this should include tree farms. In aerial photography, this classification appears to have a consistently smooth texture, can be either dark or light in overall tone (season and road surface-type dependent), and contains a road network (not necessarily a grid system). The smooth texture is the result of the removal of trees and the planting of short urban grasses (as opposed to longer wild prairie grasses). In the picture to the right a road system is clearly visible. The features in this aerial photograph have been identified as the trailer park located just west of the Highway No.1 bridge spanning the Assiniboine within the research area. Notice the short segments of road surface running on either side of the main roadways, these are the roofs of the trailers.



Not Developed... This land use type is identified as cleared land, and can be initially identified by either a complete absence of, or, extremely sparse coverage of trees. The land shouldn't show any agricultural activities (the one exception being domestic gardens), specifically furrows or tillage; this should include tree farms (image B). In aerial photography this classification appears to have a consistently smooth texture, can be either dark or light in overall tone (season dependent), and may contain a road network (not necessarily a grid system). The smooth texture is the result of the removal of trees and, in some instances, the planting of short urban grasses (as opposed to longer wild prairie grasses). The aerial photograph to the right is located immediately east of the image above. Notice the large rectangular area of clear land, and the consistence of the image tone and texture. This is an area which has been recently taken out of production. There is a ridge running up the middle of the image, this is actually a drainage ditch for the field. According to Topographic Reference Map 62H/13 (fourth edition), this area is identified as a municipal park. A visual inspection shows this area to be an undeveloped green-space, no park structures or constructed pathways.

3.6.2 Riparian Land Use



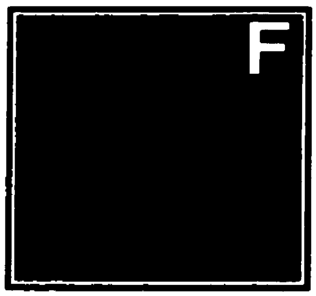


Riparian Forest... This land use type has a complete forest canopy obscuring most, or all of the ground beneath (image C). To avoid the misclassification of tree farms as riparian habitat, the trees should not appear to be in straight parallel rows. Having stated this, keep in mind that riparian habitat expands and contracts in synchronization with the river meander movement; this too can result in trees growing in rows. The difference, however, is that the rows will appear to follow the meanders, and should not be oriented in perfectly straight rows. Furthermore, the tree stand in question should be in the immediate vicinity of a river. In aerial photography this land use type appears to have a rough texture and can be either dark or light in overall tone depending on the tree species, as well as the season. If the riparian habitat is primarily deciduous, then the texture will differ from one season to the next. The aerial photography to the right of this paragraph is of a riparian habitat. It is a relatively large forest stand in immediate proximity to the Assiniboine River, and is primarily comprised of deciduous trees. The image below this one is of the same area in the winter season (image D). Note the "fuzzy" quality of the image, this is created by the reflection of sunlight off of the denuded deciduous tree canopy. The Assiniboine River appears to have narrowed at the bottom of this image; in actuality it is ice on river which gives it this appearance. In both images, it is possible to see the trees closest to the river grow in a row following the course of the meander.

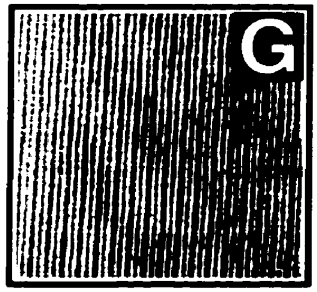
Riparian Forest Island... This land use type has a complete forest canopy obscuring most, or all of the ground beneath (image E). Like the previous classification, to avoid the misclassification of tree farms as riparian habitat, the trees should not appear to be in straight parallel rows. Furthermore, the tree stand in question should be in the close proximity to a riparian forest, river, or both. Similar to the "riparian forest" above, in aerial photography (image to the right) this classification appears to have a rough texture, and can be either dark or light in overall tone depending on the tree type (deciduous or coniferous). The Assiniboine River is visible at the top-right of this image. The riparian island has be separated from the remaining riparian forest by a Rural-residential land use incursion to the north (the top in all of these images is north)

3.6.3 *Agriculture Land Use*

*Agricultural (productive)...*This land use type in aerial photography appears to have a consistently smooth homogeneous texture, can be either dark or light in overall tone (season and crop dependent), and tends to have a large continuous coverage (image F). The picture to the right is of a mature crop, the furrows are almost entirely obscured by the foliage of the crop. An area where there is a gap in the foliage shows the straight lines of the furrows at the bottom right of the image.

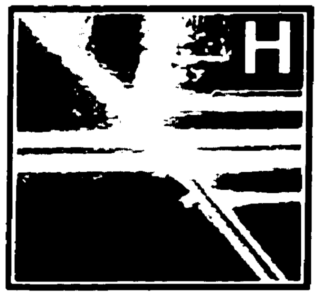


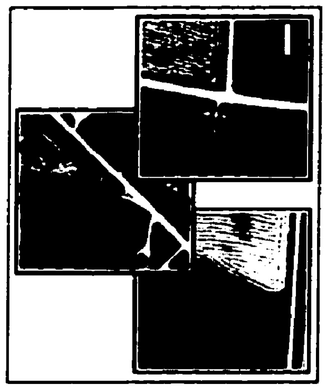
*Agricultural (fallow)...*This land use type in aerial photography appears to have a consistently smooth texture, can be either dark or light in overall tone (season and crop dependent), and tends to have a large continuous areal extent. The picture to the right (image G) is of a fallow field, the furrows are clearly visible as there is no obscuring foliage. It should be noted that it is easy to incorrectly identify fallow and productive fields early in the growing season, and after harvest. Because there is no crop showing early in growing season, and both fallow and productive fields tend to be tilled, they will be indistinguishable in aerial photography at this time in the growing season. The same problem of identification exists after harvest. As a result, any study looking at the percentage of fallow to productive agriculture land use should be done in mid-summer; when the crops on productive land are clearly visible.



3.6.4 *Road System Land Use*

Road Land Use...This land use type can be easily identified as long continuous lines across the Earth's surface (image H) and which commonly has very high reflectance due to the road surface material. Concrete has a very high reflectance and as a result appears white in black & white aerial photography. Black-top or asphalt generally appears to be a mid tone gray; new black top will be intensely black in the photography. Gravel roads can effectively scatter sunlight incident upon the road surface, and generally appears white in Manitoba. The prevalent use of crushed limestone as a surfacing material in this province can account for the high scattering visible in image (I). Other common road surfaces include red-stone (sedimentary based), pea-stone (igneous based), and earth (clay based). Respectively, these roads surfaces appear as a lighter shade of gray, very light shade of gray approaching white, and dark gray approaching black. Below the initial example of road land use, there are three smaller representative images of gravel, gravel/mud meeting concrete and mud meeting concrete (displayed in that order; image I). The final distinction can only be made via ground verification.

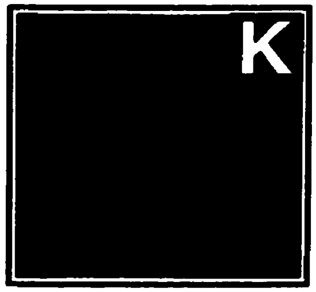




3.6.5 Water Land Use

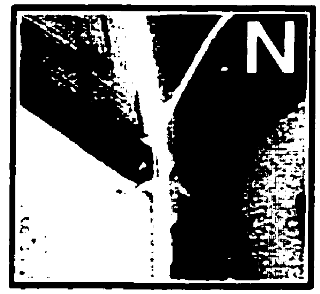
River...This earth surface feature is rather obvious, particularly when trying to identify a high order stream like the Assiniboine river. The river is a dominant feature in aerial photography, and it appears as a long meandering ribbon and the surface tone is homogeneous (image J). In large scale aerial photography it is easy to incorrectly classify the shadows cast by large river side trees as part of the riparian habitat. Shadows case by trees in this image are evident along the southern riparian strip.

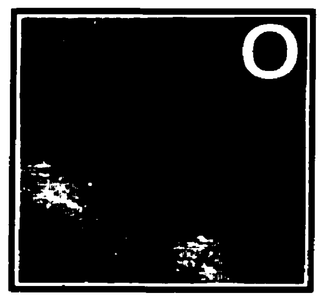
Pot-hole...This earth surface feature is not as obvious as a high order stream. In the image to the right (image K) a pot-hole can be see in the center. They range from a dark gray to black in colour. Usually they can be identified by either a surrounding of tall grass and reeds, or by perimeter tillage scares. As farmers try to increase their arable land, they drain pot-holes and back-fill them. Prior to back-filling the very fertile sediments are removed, to be re-applied later. They can be mistakenly identified as a riparian island. However, notice that there are no shadows cast by any trees which should be present if this feature was a riparian island. The homogeneous tone of the pot-hole is more indicative of water, and dissimilar to the texture prevalent in a riparian habitat.



Oxbow Lake...This earth surface feature is rather obvious due to the distinctive oxbow shape (image L). Oxbow lakes occur when the river cuts through a meander and has filled in the ends with sediment, thus isolating the remaining water from the river and produces the distinctive shape. The images (L) and (M) are examples of two oxbow lakes in the research area of this thesis. Image (L) is reminiscent of a untouched oxbow, while image (M) shows the results of a farmer's efforts to drain an oxbow.

Intermittent Streams...Two examples of intermittent streams can be seen in the images to the right of this paragraph (images M and N). Image (N) has a channelized stream running from left to right, terminating in the Assiniboine River. The lower image has a "Y" shaped intermittent stream (image O). Both of these examples can be easily mistaken as having trees running their length. However, the streams have been lined with grass to capture topsoil from the adjacent fields, and to reduce the rate of down-cutting. The dark-green of the grass appears a dark-gray in these examples. In addition, in the dark band in the center of the channel is water (image N), or high soil moisture (image O). Because the grass is allowed to grow to long lengths, the texture may appear similar to the canopy of a riparian habitat. However, with practice and ground verification these land use features can be detected. These streams carry runoff from agricultural fields directly to the Assiniboine River.





3.6.6 Colours assigned to Land Use Classes

The CYMK colour blends assigned to the eight different land use classes are listed in Figure 3-7. These colours where chosen based upon some common cartographic colour assignments (e.g. blue for water, green for vegetation, *et cetera*). In addition, the contrast between similar colours was taken into consideration and designed to aid in correctly identifying land use classes.

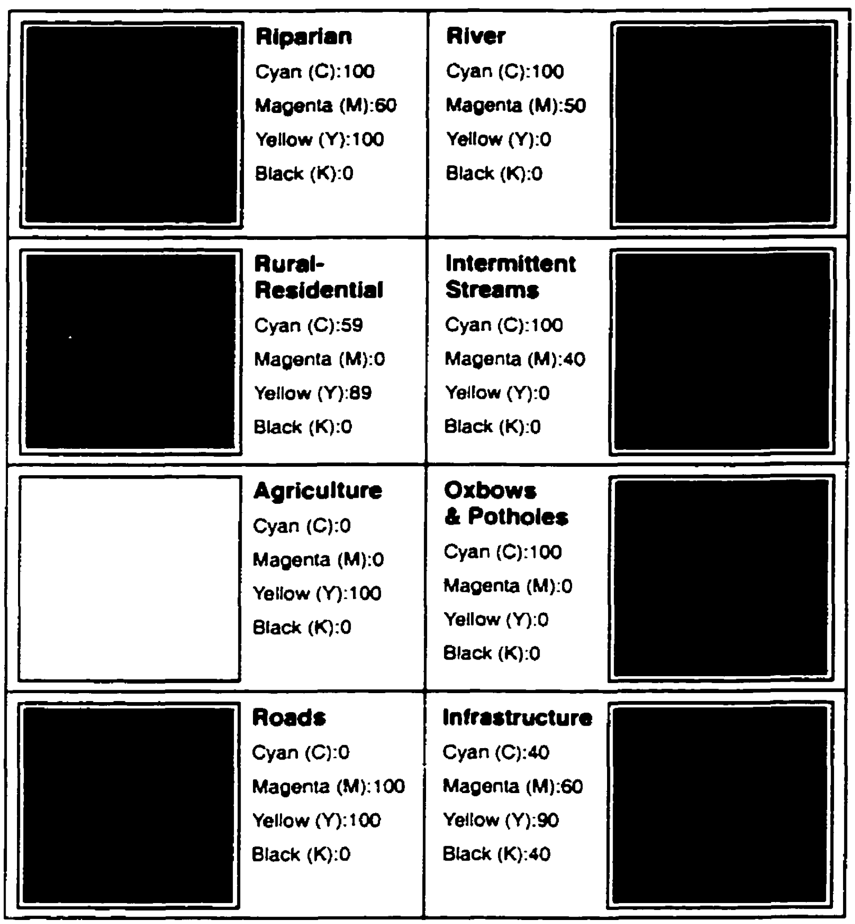


Figure 3-7 Classification Colour Scheme

3.7 Change-Detection

This type of spatial-analysis is used to show the change between time-differentiated map products. The minimum number of map products required for this analysis is two. However, if the intended use of the output from a change-detection analysis is to support a conjecture that there is a trend within a region, then a trend or time-series analysis should be performed. Trend analyses requires many more time differentiated map products. While trend calculations are performed and discussed, the intended application here is to show overall land use change. There are different methods of comparing map products temporally. These include Pairwise comparison and Cross-tabulation. Pairwise comparison is most useful in detecting change in unclassified remotely-sensed imagery, particularly if the intent is to show change in the spectral properties of a material over time (e.g. leaves, concrete, soil). Cross-tabulation is better suited to comparing classified imagery. This method can show which land use classes have changed, how they have changed (e.g. Agriculture to Rural-residential housing), quantify the changes (e.g. meters^2) and show when they occurred (e.g. between 1975 and 1994).

3.7.1 Pairwise Comparison

A pairwise comparison type of change-detection (CD), specifically an image differencing, is a quantitative analysis. This method is appropriate for determining where change has occurred in unclassified images. A pairwise comparison is a mathematically simple comparison of two geometrically corrected images (Figure 3-8). The output from this type of analysis must be assessed carefully, because pairwise comparison cannot delineate between naturally occurring changes versus anthropogenic changes. The analyst has to distinguish between these principal types of variations (Eastman, 1991).The image which is produced by this operation will be comprised of differenced pixels (Eastman, 1991).

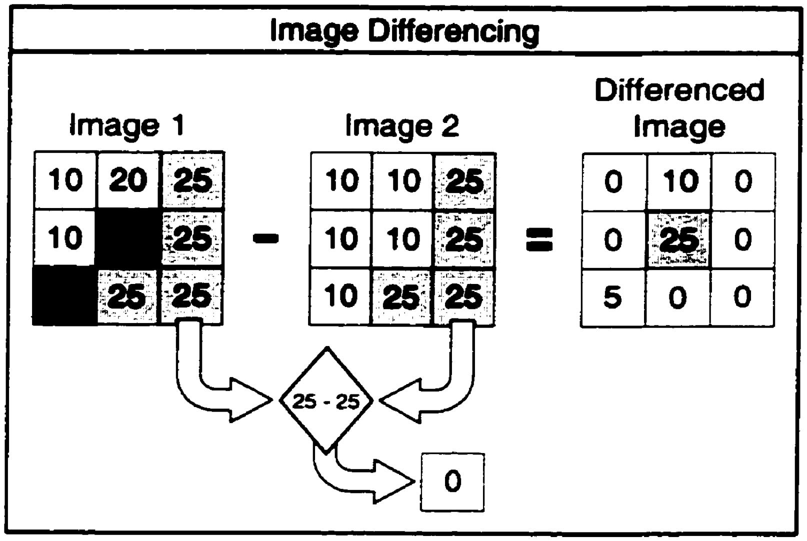


Figure 3-8 Image Differencing

This image will show change between the two images by the difference in pixel values. In relation to TSA and trend analysis, which is not the intent here, the ability of trend calculations to accurately predict types of change will increase with every additional image (i.e. larger sample size).

3.7.2 Cross-tabulation

Straight cross-tabulation using the total number of pixels in each land use class can show which land use types have changed and by how much. By virtue of the fact that the pixels (in this thesis) have a known area, this method can also determine the amount of change (e.g. Km^2) in each class as well (Figure 3-9). When performing a cross-tabulation on classified images each pixel in every class has the weight of 1. The spectral values (0-255 gray-scale) of the original remotely-sensed images having been substituted for land-use designations during the classification process. The total number of pixels contained in each class, for each image, are listed in the totals columns (Figure 3-9).

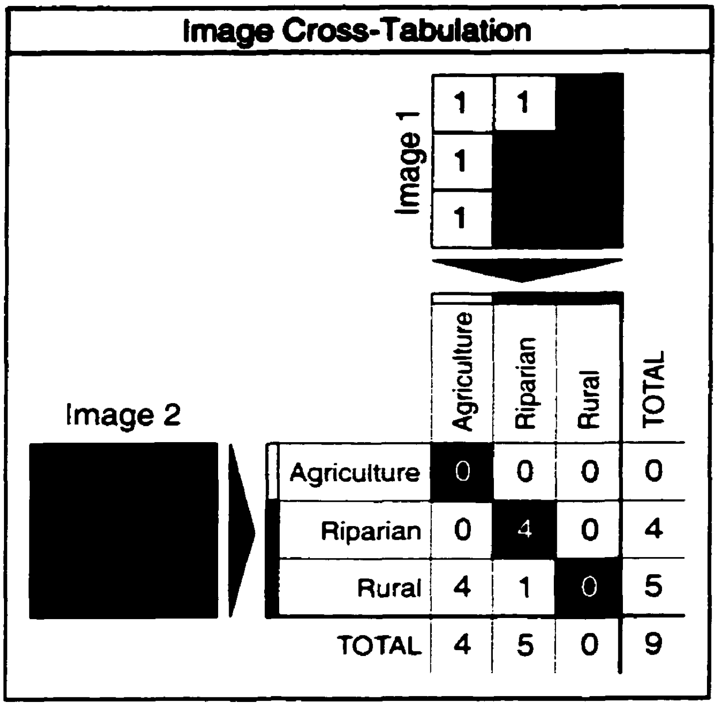


Figure 3-9 Cross-tabulation

Pixels which have not changed between the images are listed diagonally (excluding the value in the totals). This method quickly and easily shows what land uses have experienced any change. For example (Figure 3-9), four units of agriculture land use and one unit of riparian land use have been changed to Rural-residential. Furthermore, this method can promptly show which land uses have undergone the greatest amount of change. It should be noted that cross-tabulation is an aspatial technique, as it does not account for the effect of changes in the surrounding area on a pixel. By design this analysis only assesses what has changed, by what quantity and where (if the output is presented as a map product). The table produced from this type of comparison has values in pixel counts. These pixel counts have to be converted into a unit of measure, which is calculation using the equation below (Equation 3.1).

$$\frac{((2\text{m}\cdot 2\text{m})\times a)}{1000000} = \frac{((2\cdot 2\text{m}^2)\times a)}{1000000} = \frac{(4\text{m}^2\times a)}{1000000} = b$$

Where:

Number of Pixels (variable) = a
Meters (unit of measure) = m^2
Kilometres-Squared (variable with a unit of measure of Km^2) = b

Equation 3.1 Conversion from Pixel Counts to Kilometre-Squared (Km^2)

All of the pixels in the classified images have a surface area of 2 meters by 2 meters, or 4 meters-squared ($4m^2$). Multiplying the surface area of the pixels by the number of pixels found in any of the cross-tabulation cells, will give a product in meters-squared; dividing by 1 000 000 will convert the product to kilometres-squared (Km^2).

3.8 Sources of Error

The sources of error identified in this thesis include: equipment defects; data entry errors; and misclassification. Equipment defects can include camera lens artifacts, defects in the film stock, and scanner artifacts. Camera lens artifacts are not a concern because this equipment is very well maintained and camera lenses are manufactured to extremely high tolerances; as a result this error source is minimized. Problems with the film stock can occur, but usually appear as obvious defects. These can include random image contrast and brightness, overall poor image quality (i.e. fuzzy images). Defective film usually does not develop properly; or results in a portion of the images being of such poor quality, as to be considered useless. Some abnormalities in aerial photography can be created during the development process. Improper film development can produce artifacts such as streaking, excessively dark (under exposed) or washed-out (over exposed) images. The streaking which can be produced from the development process usually takes the form of parallel lines. This type of streaking usually covers the surface of the image uniformly. Development problems can occur but are not common today. In part, this is due to the level of automation in the processing of film, which produces well balanced images. Other errors could result from the mishandling of the film during the loading and unloading of the camera. If dust is not removed from an aerial-photograph prior to scanning, this may produce minuscule defects in the scanned image. The scanning surface should also be checked carefully for finger-prints, dust and scratches.

Data entry errors can result during: the scanning process; transferring files between computers and software packages; entering data into spread sheets. If the resolution of the scanner is set beyond what the aerial photography is capable of resolving, given the altitude it was obtained, this can result in an inaccurate computer image. This would be a rare error, as scanners with the resolving power beyond that of photography are costly and thus few have access to this type of equipment. Transferring files between computers systems and improper use of computer software can produce errors in the data. These errors are usually the result of selecting a destructive file compression algorithm prior to transmitting the file via a network. Transferring files between programmes requires selecting a file type which is supported by both software packages. Some file types (e.g. GIF, JPEG) use destructive compression while saving a file and should not be used. The use of non-destructive file types such as PICT, TIFF, and Raw (ASCII or binary) are required. Entering data manually can produce miscalculations resulting from human error. Data which has been entered manually, must be rechecked to reduce the possibility of errors being propagated; particularly into subsequent analyses. Misclassification can be considered a data entry error when accomplished manually. Misclassification can happen easily and must be limited by producing classification guidelines. These guidelines also allow manual classifications to be repeated by other researchers.

3.8.1 Error Estimation Matrix

Estimating the error associated with a qualitative analysis such as a manual classification is difficult. However, a method used for estimating error is to calculate a error estimation matrix. The error matrix calculated in this thesis was produced by

Error Estimation Matrix – resulting frc

1st Classification [columns] *against* 2nd Clas

	Assiniboine River	Intermittent Stream	Oxbow & Pothole	Riparian	Rural-res
Assiniboine River	[illegible]	0	0	640	0
Intermittent Stream	0	[illegible]	0	154	0
Oxbow & Pothole	0	0	[illegible]	0	0
Riparian	0	0	254	[illegible]	0
Rural-residential	0	0	0	576	[illegible]
Agriculture	0	612	0	0	84
All Road Surfaces	0	0	0	0	0
Infrastructure	0	0	0	0	0
TOTAL	47953	11445	8492	296177	721

User Counts No.1 (UC1)

	Pixel Counts
Assiniboine River	47953
Intermittent Stream	11445
Oxbow & Pothole	8492
Riparian	296177
Rural-residential	72142
Agriculture	496705
All Road Surfaces	49107
Infrastructure	19980

User Counts No.2 (UC2)

	Pixel Counts
Assiniboine River	48593
Intermittent Stream	10987
Oxbow & Pothole	8238
Riparian	295061
Rural-residential	71875
Agriculture	498160
All Road Surfaces	49306
Infrastructure	19781

Figure 3-10 Error Estimation M

ulting from classifying training area
st 2nd Classification [rows] as Pixel Counts

ı	Rural-residential	Agriculture	All Road Surfaces	Infrastructure	TOTAL
	0	0	0	0	48593
	0	0	0	0	10987
	0	0	0	0	8238
	0	0	0	0	295061
		0	0	0	71875
	843		0	0	498160
	0	0		199	49306
	0	0	0		19781
7	72142	496705	49107	19980	1002001

C2)

its

User's Estimated Accuracy

	UC1-UC2 Pixel Cnt.	Error (Pixels)	Error (Km²)
Assiniboine River	47953-48593	±640	±0.00256
Intermittent Stream	11445-10987	±458	±0.00183
Oxbow & Pothole	8492-8238	±254	±0.00102
Riparian	296177-295061	±1116	±0.00464
Rural-residential	72142-71875	±267	±0.00107
Agriculture	496705-498160	±1455	±0.00582
All Road Surfaces	49107-49306	±199	±0.00080
Infrastructure	19980-19781	±199	±0.00080

-10 Error Estimation Matrix

manually classifying a subset of the 1994 image twice but on different dates (Figure 3-10). The sample was chosen because it contains all the land use classes defined in this thesis. A cross-tabulation was performed to show two features: the number of pixels which were classified differently; and in which land use class these differences occurred. The total number of pixels in each land use class, produced during the different classification dates, are shown below the cross-tabulation table (Figure 3-10; User Counts No.1 and User Counts No.2). These total pixel counts are then subtracted to show the amount of difference (Figure 3-10; User's Estimated Accuracy). The pixel counts have also been converted to square-kilometres.

Results

The results presented in this chapter are derived from the analyses described in the previous chapter. Additional statistical calculations are performed on the results and presented in the later sections of this chapter.

4.0 RESULTS

The type of temporal analysis applied to the classified aerial photographs used in this thesis is cross-tabulation (Section 3.7.2). This method does not apply any weighting to either image being used in the analysis, which allows for examining the subsequent change in a relative sense. That is, a one percent increase is a land use which comprises 90% of the land use in an area (90% vs 91%), may not be as significant as the same change occurring in a land use which was only one percent prior to the increase (1% vs 2%). A one percent increase in a land use to a total of two percent would be a two-fold increase in that land use. Furthermore, this method allows the examination of changes based on the intervals between images (e.g. 1969 – 1959 = 10 year interval). The following sections deal with the summary statistics of the images and the results of the image-differencing performed between them.

4.1 Summary Statistics

The study site comprises 47.42Km^2 along the Assiniboine River west of The City of Winnipeg, in the Municipality of Cartier. In 1959 there were two significant land uses: agriculture and a riparian ecosystem. The study site contains five tributaries of the Assiniboine River; of which only one (south of the Assiniboine) remains mostly intact, the remaining four having been channelized prior to 1959. At this time agriculture utilized 36.31Km^2 or 76.57% of this area, while the riparian ecosystem covered 7.84Km^2 or 16.53% (Figure 4-1). The Roads, Infrastructure and Rural-residential landuses collectively utilized only 1.38Km^2 (2.95%) in 1959.

These combined land uses reached 1.55Km^2 (3.24%) an increase of 0.17Km^2 (0.29%). During the same period Agriculture saw an increase from 1959 to 1969 of 0.63Km^2 (1.33%) and Riparian decreased 0.8Km^2 (1.68%).

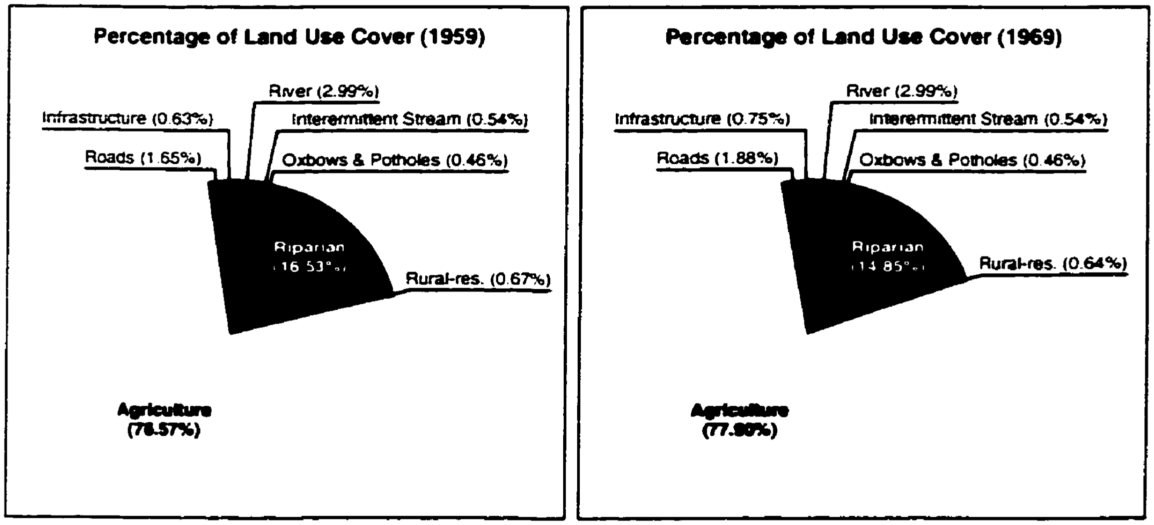


Figure 4-1 Percent Coverage by Land Use for 1959 & 1969

Between 1969 and 1975 the land use of this area started to change (Figure 4-2). Agriculture decreased to 36.18Km^2 (76.24%) and the combined land uses of Roads, Infrastructure and Rural-residential expanded to 2.3Km^2 (4.96%). There was also an increase in the Riparian ecosystem of 0.02Km2 (0.05%), or an increase of 20,000m^2. This increase occurred in an area immediately west of the Trans-Canada Highway No.1 bridge, crossing the Assiniboine River. This bridge was under construction to add an additional parallel span related to the 'twinning' of this section of highway. The area of construction was heavily impacted by machinery

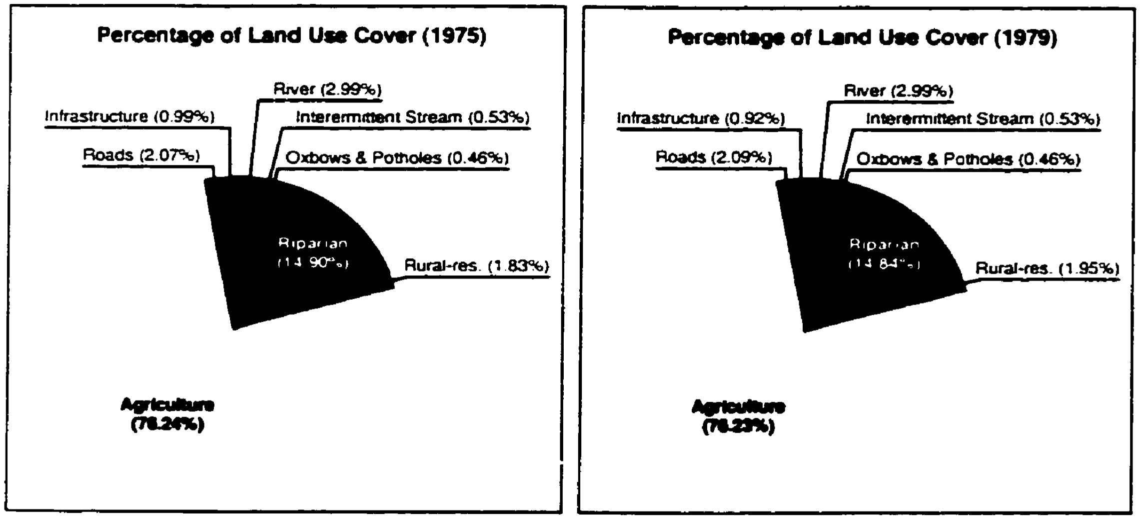


Figure 4-2 Percent Coverage by Land Use for 1975 & 1979

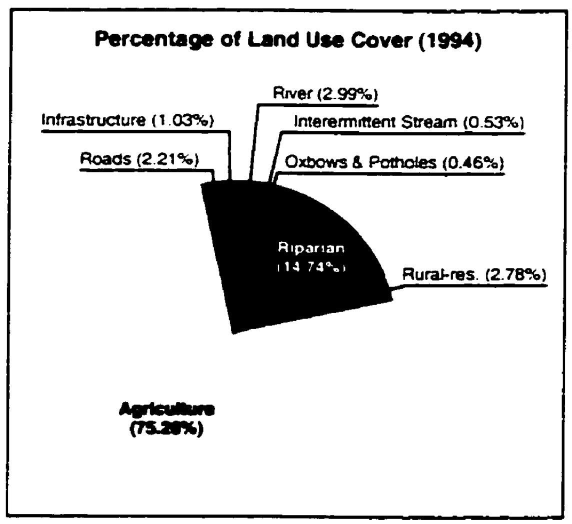


Figure 4-3 Percent Coverage by Land Use for 1994

during the assembly of the bridge span. The 1975 photograph shows that this area had been replanted with trees and thus classified as riparian, which explains the apparent rapid (6 years) re-establishment of the riparian ecosystem. By 1979, Riparian had decreased to slightly less than it had been in 1969 at 14.84%. While during the same period of time (1969-1975) Roads, Infrastructure and Rural-residential land uses all experienced significant increases. The increases were 0.091Km^2 (90,788m^2), 0.114Km^2 (114,156m^2) and 0.545Km^2 (545,428m^2) respectively. In 1979 there were was no significant change in land use coverage in comparison to those in 1975. By 1994 agriculture had been reduced to 75.26% of the total land use within the study site (Figure 4-3), the Riparian ecosystem was also reduced to 14.74%. Rural-residential land use had undergone a significant increase to 2.78%, Roads and Infrastructure saw smaller increases to 2.21% and 1.03% respectively.

In Figure 4-4, the change in six land uses is expressed in units of Kilometres-squared (y-axis) over the calendar year (x-axis) when the photograph was collected. The x-axis points are distributed proportionately to the difference between calendar years. has been These summary charts show changes through time in Agriculture, Riparian, Rural-residential, Roads and Infrastructure land uses. The change in the "Oxbows & Potholes" land use does not appear to be significant. However, there are noticeable decreases in the Agriculture and Riparian land uses, and matching increases in Roads, Infrastructure and Rural-residential land uses. In particular there appears to be a statistically significant relationship between the Agriculture and Rural-residential land uses.

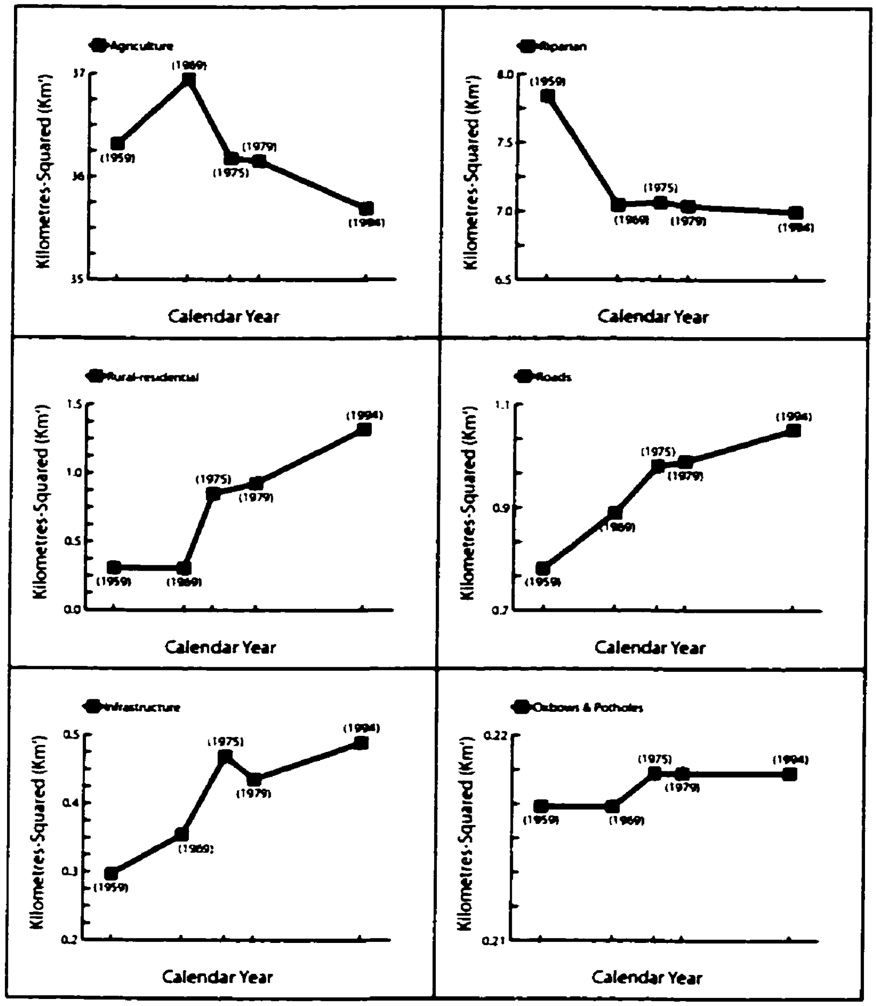


Figure 4-4 Changes in land use (Kilometres-squared) expressed over time

4.2 Cross-tabulation Results

A set of four cross-tabulations was performed by comparing two classified images at a time. These analyses produced the data contained in Figure 4-5, Figure 4-6, Figure 4-7 and Figure 4-8.

4.2.1 *Change from 1959-1969*

There was an increase of 0.63Km^2 (631,364m^2) in Agricultural land use during this time period. This is the only increase in Agriculture during the 35 year coverage of the time series used in this thesis (1959-1994). Riparian land use was the most effected by this increase, comprising 99.29% of land converted to Agriculture. While the Rural-residential land use remained largely unchanged during this period, both Infrastructure and Roads both increased, 0.05Km^2 and 0.12Km^2 respectively.

4.2.2 *Change from 1969-1975*

There were numerous incremental changes during this time. Riparian underwent a small increase of 0.021Km^2 (21,000m^2). While Agriculture saw a significant decrease of 0.77Km^2, the majority of this change was from a 0.55Km^2 increase in Rural-residential land use. The combined increases in Roads and Infrastructure make up the remainder of the decrease in Agriculture at 0.2Km^2.

4.2.3 *Change from 1975-1979*

During this these four years were few changes. Roads and Infrastructure did not experience an significant change. Riparian underwent some loss to Rural-residential land use (0.02Km^2). Agriculture also lost area to Rural-residential expansion, but not significant amounts (0.06Km^2). Rural-residential land use experienced the greatest change of any land use during this period (0.08km^2). Infrastructure and Road land uses are unchanged.

4.2.4 Change from 1979-1994

The most significant change to occur during this period is a 0.38km^2 lost in Agriculture to Rural-residential expansion. To a lesser degree, Riparian land use also decreased in area because of a Rural-residential increase (0.025Km^2). Roads and Infrastructure both experienced some increases of 0.06Km^2 and 0.05Km^2, respectively.

Cross-tabulation of **1959** [columns] *against*

	Assiniboine River	Intermittent Stream	Oxbow & Pothole	Riparian	Rural-residen
Assiniboine River	[illegible]	0	0	0	0
Intermittent Stream	0	[illegible]	0	0	0
Oxbow & Pothole	0	0	[illegible]	0	0
Riparian	0	0	0	[illegible]	0
Rural-residential	0	0	0	**4**	[illegible]
Agriculture	0	0	0	**189754**	0
All Road Surfaces	**2**	0	0	**4794**	**551**
Infrastructure	0	0	0	**4608**	0
TOTAL	353975	63790	54134	1959821	76746

Cross-tabulation of **1959** [columns] *against* **1969** [

	Assiniboine River	Intermittent Stream	Oxbow & Pothole	Riparian	Rural-residen
Assiniboine River	[illegible]	0	0	0	0
Intermittent Stream	0	[illegible]	0	0	0
Oxbow & Pothole	0	0	[illegible]	0	0
Riparian	0	0	0	[illegible]	0
Rural-residential	0	0	0	**0.000016**	[illegible]
Agriculture	0	0	0	**0.759016**	0
All Road Surfaces	**0.000008**	0	0	**0.019176**	**0.00220**
Infrastructure	0	0	0	**0.018432**	0
TOTAL	1.415900	0.255160	0.216536	7.839284	0.30698

Figure 4-5 Cross-tabulation Table 1959 aga

s] *against* **1969** [rows] as **Pixel Counts**

Rural-residential	Agriculture	All Road Surfaces	Infrastructure	TOTAL
0	0	0	0	353973
0	0	0	0	63790
0	0	0	0	54134
0	0	**259**	0	1760920
	0	0	0	76199
0	[illegible]	**1350**	0	9236089
551	**23538**	[illegible]	0	222419
0	**9725**	**144**	[illegible]	88661
76746	9078248	195287	74184	11856185

st **1969** [rows] as **Kilometres-squared** (Km²)

Rural-residential	Agriculture	All Road Surfaces	Infrastructure	TOTAL
0	0	0	0	1.415892
0	0	0	0	0.255160
0	0	0	0	0.216536
0	0	**0.001036**	0	7.043680
	0	0	0	0.304796
0	[illegible]	**0.005400**	0	36.944356
0.002204	**0.094152**	[illegible]	0	0.889676
0	**0.038900**	**0.000576**	[illegible]	0.354644
0.306984	36.312992	0.781148	0.296736	47.424740

bulation Table 1959 against 1969

Cross-tabulation of **1969** [columns] *again*

	Assiniboine River	Intermittent Stream	Oxbow & Pothole	Riparian	Rural-res
Assiniboine River	[illegible]	0	0	**2**	0
Intermittent Stream	0	[illegible]	0	0	0
Oxbow & Pothole	0	0	[illegible]	**62**	**43**
Riparian	0	**150**	**362**	[illegible]	**277**
Rural-residential	0	0	**20**	**34798**	[illegible]
Agriculture	0	**750**	0	**37573**	**221**
All Road Surfaces	0	**460**	0	**8791**	**108**
Infrastructure	0	0	0	**3574**	0
TOTAL	353973	63790	54134	1760920	761[illegible]

Cross-tabulation of **1969** [columns] *against* **1975**

	Assiniboine River	Intermittent Stream	Oxbow & Pothole	Riparian	Rural-resic
Assiniboine River	[illegible]	0	0	**0.000008**	0
Intermittent Stream	0	[illegible]	0	0	0
Oxbow & Pothole	0	0	[illegible]	**0.000248**	**0.0001**
Riparian	0	**0.000600**	**0.001448**	[illegible]	**0.0110**
Rural-residential	0	0	**0.000080**	**0.139756**	[illegible]
Agriculture	0	**0.003000**	0	**0.150292**	**0.0088**
All Road Surfaces	0	**0.001840**	0	**0.035164**	**0.0043**
Infrastructure	0	0	0	**0.014296**	0
TOTAL	1.415892	0.255160	0.216536	7.043680	0.3047

Figure 4-6 Cross-tabulation Table 1969 a

ns] *against* **1975** [rows] as **Pixel Counts**

ian	Rural-residential	Agriculture	All Road Surfaces	Infrastructure	TOTAL
	0	0	**2**	0	353977
	0	**9**	**319**	0	62758
!	**43**	**681**	0	0	54538
[illegible]	**2770**	**81573**	**4919**	**360**	1766254
98		**100481**	**7131**	**41**	212556
73	**2217**	[illegible]	**45558**	**657**	9043786
1	**1084**	**70653**	[illegible]	**39**	245116
4	0	**25661**	**401**	[illegible]	117200
)20	76199	9236089	222419	88661	11856185

inst **1975** [rows] as **Kilometres-squared** (Km²)

an	Rural-residential	Agriculture	All Road Surfaces	Infrastructure	TOTAL
)08	0	0	**0.000008**	0	1.415908
	0	**0.000036**	**0.001276**	0	0.251032
:48	**0.000172**	**0.002724**	0	0	0.218152
	0.011080		**0.019676**	**0.001440**	7.065016
56		**0.421180**	**0.028524**	**0.000164**	0.850224
92	**0.008868**	**35.808840**	**0.182232**	**0.002628**	36.175144
64	**0.004336**	**0.282640**	[illegible]	**0.000156**	0.980464
96	0	**0.102644**	**0.001604**	[illegible]	0.468800
80	0.304796	36.944356	0.889676	0.354644	47.424740

-tabulation Table 1969 against 1975

Cross-tabulation of **1975** [columns] *again*

	Assiniboine River	Intermittent Stream	Oxbow & Pothole	Riparian	Rural-resi
Assiniboine River	[illegible]	0	0	0	0
Intermittent Stream	0	[illegible]	0	0	0
Oxbow & Pothole	0	0	[illegible]	0	0
Riparian	0	0	0	[illegible]	**20**
Rural-residential	0	0	0	**5814**	[illegible]
Agriculture	0	0	0	**52**	0
All Road Surfaces	**6**	0	0	**1731**	**215**
Infrastructure	0	0	0	**958**	0
TOTAL	353977	62758	54538	1766254	2125

Cross-tabulation of **1975** [columns] *against* **1979**

	Assiniboine River	Intermittent Stream	Oxbow & Pothole	Riparian	Rural-resic
Assiniboine River	[illegible]	0	0	0	0
Intermittent Stream	0	[illegible]	0	0	0
Oxbow & Pothole	0	0	[illegible]	0	0
Riparian	0	0	0	[illegible]	**0.0000**
Rural-residential	0	0	0	**0.023256**	[illegible]
Agriculture	0	0	0	**0.000208**	0
All Road Surfaces	**0.000024**	0	0	**0.006924**	**0.0086**
Infrastructure	0	0	0	**0.003832**	0
TOTAL	1.415908	0.251032	0.218152	7.065016	0.8502

Figure 4-7 Cross-tabulation Table 1975 a

...nns] *against* **1979** [rows] as **Pixel Counts**

...iparian	Rural-residential	Agriculture	All Road Surfaces	Infrastructure	TOTAL
0	0	0	0	0	353971
0	0	0	0	0	62758
0	0	0	0	0	54538
[illegible]	**20**	**110**	**1018**	**453**	1759300
...5814	[illegible]	**13933**	**1508**	0	231632
...52	0	[illegible]	**2945**	**13164**	9037870
...1731	**2159**	**3736**	[illegible]	0	247277
...958	0	**4298**	0	[illegible]	108839
...66254	212556	9043786	245116	117200	11856185

...ainst **1979** [rows] as **Kilometres-squared** (Km²)

...parian	Rural-residential	Agriculture	All Road Surfaces	Infrastructure	TOTAL
0	0	0	0	0	1.415884
0	0	0	0	0	0.251032
0	0	0	0	0	0.218152
	0.000080	**0.000440**	**0.004072**	**0.001812**	7.037200
...23256	[illegible]	**0.055732**	**0.006032**	0	0.926528
...00208	0	[illegible]	**0.011780**	**0.052656**	36.151480
...06924	**0.008636**	**0.014944**	[illegible]	0	0.989108
...03832	0	**0.017192**	0	[illegible]	0.435356
...55016	0.850224	36.175144	0.980464	0.468800	47.424740

...Cross-tabulation Table 1975 against 1979

Cross-tabulation of **1979** [columns] *agair*

	Assiniboine River	Intermittent Stream	Oxbow & Pothole	Riparian	Rural-re
Assiniboine River	[illegible]	0	0	0	[illegible]
Intermittent Stream	0	[illegible]	0	0	[illegible]
Oxbow & Pothole	0	0	[illegible]	0	[illegible]
Riparian	0	0	0	[illegible]	[illegible]
Rural-residential	0	0	0	**6362**	[illegible]
Agriculture	0	0	0	0	**4**
All Road Surfaces	0	0	0	**6098**	**17**
Infrastructure	0	0	0	**453**	[illegible]
TOTAL	353971	62758	54538	17599300	231

Cross-tabulation of **1979** [columns] *against* **199**

	Assiniboine River	Intermittent Stream	Oxbow & Pothole	Riparian	Rural-re
Assiniboine River	[illegible]	0	0	0	0
Intermittent Stream	0	[illegible]	0	0	0
Oxbow & Pothole	0	0	[illegible]	0	0
Riparian	0	0	0	[illegible]	0
Rural-residential	0	0	0	**0.025448**	[illegible]
Agriculture	0	0	0	0	**0.00**
All Road Surfaces	0	0	0	**0.024392**	**0.00**
Infrastructure	0	0	0	**0.001812**	0
TOTAL	1.415884	0.251032	0.218152	7.037200	0.92

Figure 4-8 Cross-tabulation Table 197

mns] *against* **1994** [rows] as **Pixel Counts**

iparian	Rural-residential	Agriculture	All Road Surfaces	Infrastructure	TOTAL
0	0	0	0	0	353971
0	0	0	0	0	62758
0	0	0	0	0	54538
	0	**1251**	**155**	**264**	1748057
6362		**91989**	**1984**	0	329743
0	**430**		**424**	0	8922392
5098	**1794**	**9928**		0	262534
453	0	**13164**	0		122192
599300	231632	9037870	247277	108839	11856185

gainst **1994** [rows] as **Kilometres-squared** (Km^2)

parian	Rural-residential	Agriculture	All Road Surfaces	Infrastructure	TOTAL
0	0	0	0	0	1.415884
0	0	0	0	0	0.251032
0	0	0	0	0	0.218152
	0	**0.005004**	**0.000620**	**0.001056**	6.992228
25448		**0.367956**	**0.007936**	0	1.318972
0	**0.001720**		**0.001696**	0	35.689568
24392	**0.007176**	**0.039712**		0	1.050136
01812	0	**0.052656**	0		0.488768
37200	0.926528	36.151480	0.989108	0.435356	47.424740

Cross-tabulation Table 1979 against 1994

4.3 Probabilities of Land Use Change with Study Site

Below are the calculated land use changes and the corresponding probabilities for the given periods of time (Figure 4-9).

1959-1969 Δ (Km²)

1969

		Riparian	Agriculture	Combined Rural
	Riparian	[illegible]	0.759016	0.037624
1959	Agriculture	0	[illegible]	0.133052
	Combined Rural	0	0	[illegible]

1959-1969 Probability of Δ

1969

		Riparian	Agriculture	Combined Rural
	Riparian	[illegible]	0.096822	0.004799
1959	Agriculture	0	[illegible]	0.003664
	Combined Rural	0	0	[illegible]

1969-1979 Δ (Km²)

1979

		Riparian	Agriculture	Combined Rural
	Riparian	[illegible]	0.140424	0.227692
1969	Agriculture	0.326932	[illegible]	0.800552
	Combined Rural	0.032906	0.193944	[illegible]

1969-1979 Probability of Δ

1979

		Riparian	Agriculture	Combined Rural
	Riparian	[illegible]	0.019937	0.032327
1969	Agriculture	0.00885	[illegible]	0.021671
	Combined Rural	0.021709	0.12794	[illegible]

1979-1994 Δ (Km²)

1994

		Riparian	Agriculture	Combined Rural
	Riparian	[illegible]	0	0.025448
1979	Agriculture	0.005004	[illegible]	0.460324
	Combined Rural	0.001676	0.003416	[illegible]

1979-1994 Probability of Δ

1994

		Riparian	Agriculture	Combined Rural
	Riparian	[illegible]	0	0.003630
1979	Agriculture	0.000138	[illegible]	0.012733
	Combined Rural	0.000718	0.001462	[illegible]

Figure 4-9 Land Use Change (Km²) and Probabilities of Change

The land use "Combined Rural" is the combination of the Infrastructure, Roads, and Rural-residential land uses. The data (Figure 4-4) supports the conjecture that Infrastructure and roads change in relation to the Rural-residential land use as defined for this thesis (Section 3.6.1). In addition, this combination of related land uses simplifies the results of the probability calculations of Figure 4-9. What can be seen in the probabilities calculated in Figure 4-9 is that between 1959-1969 given that Riparian land use does change, then there was a probability of 0.097 of Riparian land use being converted to Agricultural. This would indicate that there is a trend, during this ten year period, toward increased Agricultural growth and a reduction in Riparian land use. There are also much lower conditional probabilities for Riparian and Agriculture land uses being converted to the Combined-Rural land use. The likelihood that there will be no change in the Combined-Rural land is extremely high.

Between 1969-79 there is a significant alteration in the land-use change probabilities from those of 1959-1969. The probability of Riparian changing to Combined-Rural is 0.032, while the opposite change has a probability of 0.0217. However, land use with the greatest conditional probability of changing, is that of Agriculture to Combined-Rural at 0.129. There are also significant conditional probabilities relating the change of Riparian to Agriculture (0.02), Riparian to Combined-Rural (0.032) and Agriculture to Combined-Rural (0.022). At first the aforementioned probabilities would seem to be counterintuitive. That is, the higher probability of Rural-residential lands converting to Riparian would not seem to support the conjecture that Riparian lands are decreasing from Rural-residential developments.

However, what is being calculated is the probability of the land uses changing given that a certain condition is present. The condition is that any change in Rural-residential land uses occurs at all. If this condition is met (that change occurs), what is the probability that the change will manifest itself in either the Riparian or Agricultural land uses. Therefore, these are conditional probabilities with no weighting applied.

It is obvious from the data presented in Figure 4-9, that from 1969-1979 more land was converted from Riparian to that of the Combined-Rural land use (as opposed to the opposite) by a factor of 6.9 to 1. Specifically, 0.229 Km^2 of Riparian land use was converted to Combined-Rural but only 0.033 Km^2 of Combined-Rural was converted to Riparian. While the conditional probability of Riparian changing to Combined-Rural was lower than the opposite event, when the change did occur in Riparian it was of greater magnitude. What is also evident from the probabilities in Figure 4-9, is that the during the period in question (1969-1979) trends in land use within this area were undergoing some form of change. By way of example the probabilities of Riparian to Agriculture, Riparian to Combined-Rural, Agriculture to Combined-Rural and Combined-Rural to Riparian are all very similar; 0.019, 0.032, 0.022, 0.022 respectively. Contrast this variability to the consistency found in the previous ten year span; it becomes evident that land use trends are in flux during the 1969-1979 time frame.

From 1979 to 1994, a fifteen year period, there appears to be some degree of stabilization in the probabilities. Two probabilities appear to indicate some trend, those of Riparian to Combined-Rural and Agriculture to Combined-Rural; 0.004 and 0.013

respectively. The other land use probabilities are several orders of magnitude lower in comparison with the aforementioned land uses changes.

Discussion

This chapter is an in-depth discussion of the results from the change detection analysis, including the significance of the results on how these riparian ecosystems could potentially be managed in a context of sustainable development.

5.0 DISCUSSION

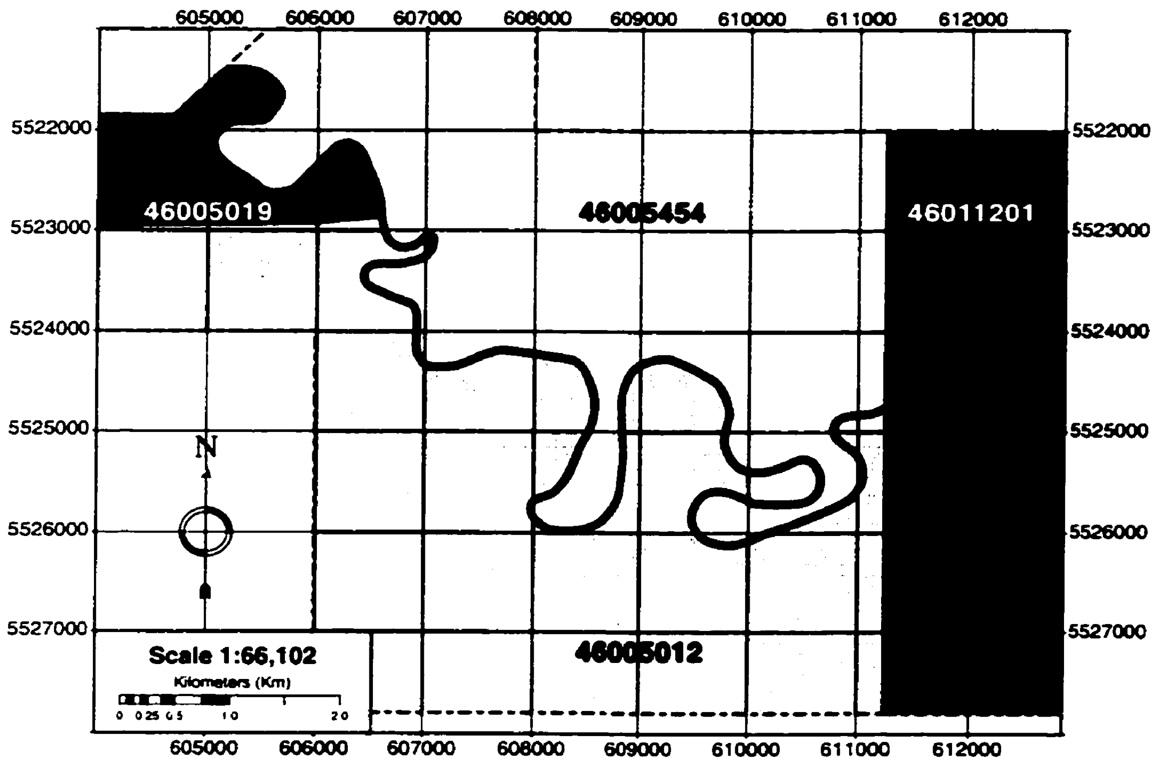
5.1 Riparian Ecosystems – Local Disturbances

As previously mentioned (Section 2.1.1) riparian ecosystems are highly productive and contain a great number of species (Kauffman and Krueger, 1984). These two attributes are what make this ecosystem type important to the natural environment. The perceived aesthetic beauty of riparian ecosystems establishes their value socio-economically (Section 2.1.4). Unfortunately, it is this perceived aesthetic value which has resulted in houses being constructed within this ecosystem. While these ecosystems experience intermittent disturbances which are beneficial (e.g. flooding, fires), they are negatively impacted by permanent disturbances (Section 2.1.1). Specifically, the removal of trees, construction of houses, and the resulting noise of human habitation can all have negative impacts upon this ecosystem (Taccogna and Munro, 1995). Agricultural activities within this habitat are also detrimental, because it involves the complete removal of this ecosystem to some degree.

5.2 Land Use Changes within the Research Area

The result of the cross-tabulation shows a marked transformation in land use during the period of 1959 to 1994. There has been a significant change to a more Rural-residential land use, and a move away from agriculture after 1969 (Figure 4-4). Data were not collected to determine the cause of this Rural-residential expansion, as it would be outside the scope of this thesis. However, it can be postulated that probable reasons include reduced property taxes and larger & less expensive properties than those found within The City of Winnipeg. Additional impetuses for people to seek property outside Winnipeg may be the perception that these areas are less likely to suffer from criminal activities, and are more aesthetically desirable. The property sizes at Ground Verification Site No.3 are greater than a standard city lot; and heavily treed which many people consider a highly desirable aesthetic attribute (Figure A3–6; [e]-4). Taxes are less than those of Winnipeg, as there are fewer but similar services to those found in the city (e.g. sewage, and hydro but no public transportation). The lots found at Ground Verification Site No.6 range in size, from standard city lots to double the standard size (Figure A3–15). These could all be considered push factors as discussed in Section 2.1.6. The remotely sensed data collected supports the conjecture that the move towards Rural-residential land use is a trend for this area. The results of the analysis performed in Section 4.2 also show an increase in the Rural-residential landuse for the same period expressed in the census data. In addition, the data collected during the 1996 Census from the enumeration areas within the study site all show increased housing starts until the 1991-1996 time period (Figure 5-1); a period of time when Canada was experiencing an economic recession. The 1996 Census also contains data regarding the age of the respondents. In Figure 5-2, three population pyramids are shown with three basic population calculations: Total Dependency Ratio; Age Dependency Ratio; and Youth Dependency Ratio. The Total Dependency Ratio is the sum of the ages 65-85^{+} + ages 0-14 divided by population between the ages of 15-64. The Age Dependency Ratio is calculated by dividing the ages 65-85+ by the same denominator as above; The Youth Dependency is calculated by dividing those between 0-

14 years of age by the



	Enumeration Areas				
Time Periods	**46005012**	**45005019**	**46005454**	**46011201**	**46012201**
Period of construction, before 1946	30	0	15	25	75
Period of construction, 1946-1960	25	0	15	25	25
Period of construction, 1961-1970	15	20	50	25	50
Period of construction, 1971-1980	25	25	55	45	90
Period of construction, 1981-1990	65	45	70	20	65
Period of construction, 1991-1996	0	0	10	10	45

Data Source. Statistics Canada—1996 Canada Census

Figure 5-1 Census Data & Enumeration Areas (Statics Canada, 1996)

aforementioned denominator (Nam, 1984). What can be seen in Figure 5-2 is that population distribution within these three enumeration areas are distinctly bimodal. There are two spikes in the population data which is present in both genders. The spikes are at the ages of 34-49 and 5-14, based on this data and the Age

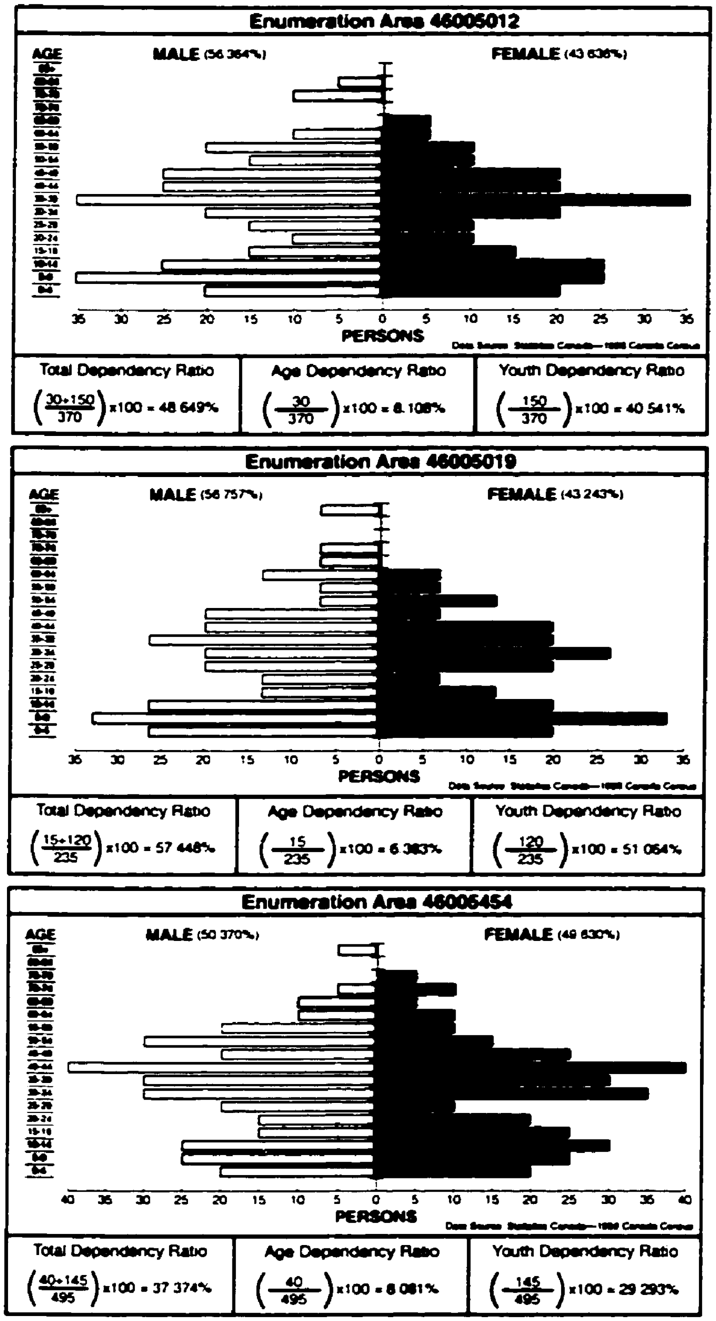


Figure 5-2 Population Pyramids at the Enumeration Area Scale

Dependency Ratios, one can infer that there are young families in residence within these enumeration areas. These enumeration areas coincide with zones within the study site which have experienced an increase in Rural-residential land use. Construction within the enumeration area 46005454 tapers off from 1991-1996. However, if Statistics Canada were to apply the same census questionnaire in this area presently, they would find that construction numbers would have increased by at least twenty homes between 1997-2000. Ground-truthing at a site within this enumeration area showed the new housing development of "Sunny Harbour Estates" being constructed (Figure A3–12). The amount of agricultural land sold to developers during the period 1959-1994 is significant. The amount of property which has been added to the Rural-residential land use class over this 35 year period was 1.01 Km^2 (1,014,176 m^2). Of 1.01 Km2 added to the Rural-residential land use class, 0.83 Km^2 (825,612 m^2) comprising 81.4% of the total increase had previously been classified as agriculture. The riparian areas in the research area experienced a 0.19 Km^2 (187,912 m^2) reduction caused by a subsequent increase in the Rural-residential land-use. These incursions into riparian habitats are the product of insufficient urban planning and poor environmental regulations. Fully 18.5% of the Rural-residential land-use increase would have fallen within a regulated area, had this expansion occurred within the limits of The City of Winnipeg (Figure 5-4). That equates to 187,644 m^2 (of which 123,324 m^2 was within the riparian land-use class) of Rural-residential development which would have had to been assessed under Municipal Waterways development by-laws (Section 5.3.1; City of

Winnipeg, 1992). As in Section 4.3, probability matrices were calculated for the

1959-1969 Δ in Buffer (Km²)

1959 \ 1969	Riparian	Agriculture	Combined Rural
Riparian	3.40498	0.111772	0.008596
Agriculture	0	0.784108	0.006104
Combined Rural	0.001036	0.00068	0.18658

1959-1969 Probability of Δ in Buffer

1959 \ 1969	Riparian	Agriculture	Combined Rural
Riparian	0.965856	0.031705	0.002438
Agriculture	0	0.9922[illegible]	0.007725
Combined Rural	0.005502	0.003611	0.99088[illegible]

1969-1979 Δ in Buffer (Km²)

1969 \ 1979	Riparian	Agriculture	Combined Rural
Riparian	3.241544	0.062328	0.102144
Agriculture	0.109544	0.71024	0.076776
Combined Rural	0.012576	0.006064	0.173992

1969-1979 Probability of Δ in Buffer

1969 \ 1979	Riparian	Agriculture	Combined Rural
Riparian	0.951711	0.018299	0.029989
Agriculture	0.122183	0.792183	0.085634
Combined Rural	0.065285	0.031480	0.903235

1979-1994 Δ in Buffer (Km²)

1979 \ 1994	Riparian	Agriculture	Combined Rural
Riparian	3.3515	0	0.012584
Agriculture	0.00046	0.721756	0.056444
Combined Rural	0.000692	0.001908	0.35734

1979-1994 Probability of Δ in Buffer

1979 \ 1994	Riparian	Agriculture	Combined Rural
Riparian	0.996259	0	0.003741
Agriculture	0.000591	0.926921	0.072489
Combined Rural	0.001923	0.005301	0.992777

Figure 5-3 Land Use Change (Km²) and Probabilities of Change within 106m Buffer

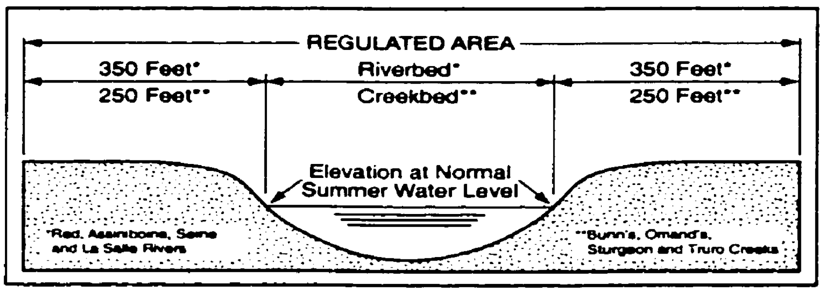
land-use classes of Riparian, Agriculture and Combined-Rural (Figure 5-3); but for land uses that would have been within the 106 metre buffer used in the City of Winnipeg. The Combined-Rural land-use classification is the same as previously defined in Section 4.3. As with the probabilities calculated for the entire image, the most prominent trend is towards Riparian being converted to Agriculture between 1959 and 1969. Again, as with the probabilities calculated for the entire image, there is considerably more variability between 1969 and 1979. However, there are some similarities, the most significant trends are: Agriculture to Riparian, Riparian to Combined-Rural and Agriculture to Combined-Rural. There appears to be a trend within the buffer, as opposed to outside it, towards some Agriculture being converted to Riparian. However, the probabilities associated with this type of change is lower than that calculated for opposite action (i.e. Riparian being converted to Agriculture; Figure 5-3). The probabilities for the period of time from 1979 to 1994 within the buffer appear similar to those outside it. There is a strong trend towards Agriculture being changed to a Combined-Rural land use. The next most significant probability is that Riparian will be converted to a Combined-Rural land use. In Summary, within the 106 metre buffer the trends in land use appeared to have two stable periods from 1959-1969 and again from 1979-1994, with an intervening period of transition from 1969 to 1979. Should the present trends continue, more riparian lands could be lost to unregulated Rural-residential expansion.

5.3 Government Regulations Applicable to Riparian Areas

The jurisdictions of all three levels of government (Municipal, Provincial, and Federal) overlap in the area of waterway management. The City of Winnipeg has regulations in place to protect against activities which may further degrade the banks of rivers and streams within city limits. Beyond the boundaries of the municipalities the responsibility of protecting stream banks on non-navigable waterways falls to the provincial government. The Federal Department of Fisheries & Oceans is ultimately responsible for ensuring that water quality and fish stocks are not diminished by human activities on navigable waterways and areas considered fish habitat; specifically, those human activities which may occur in close proximity to water. It is bewildering, given the aforementioned government concerns and responsibilities, that management plans have not been developed by these agencies to protect the one ecosystem which could mitigate their concerns most appreciably, the riparian ecosystem.

5.3.1 Municipal Level

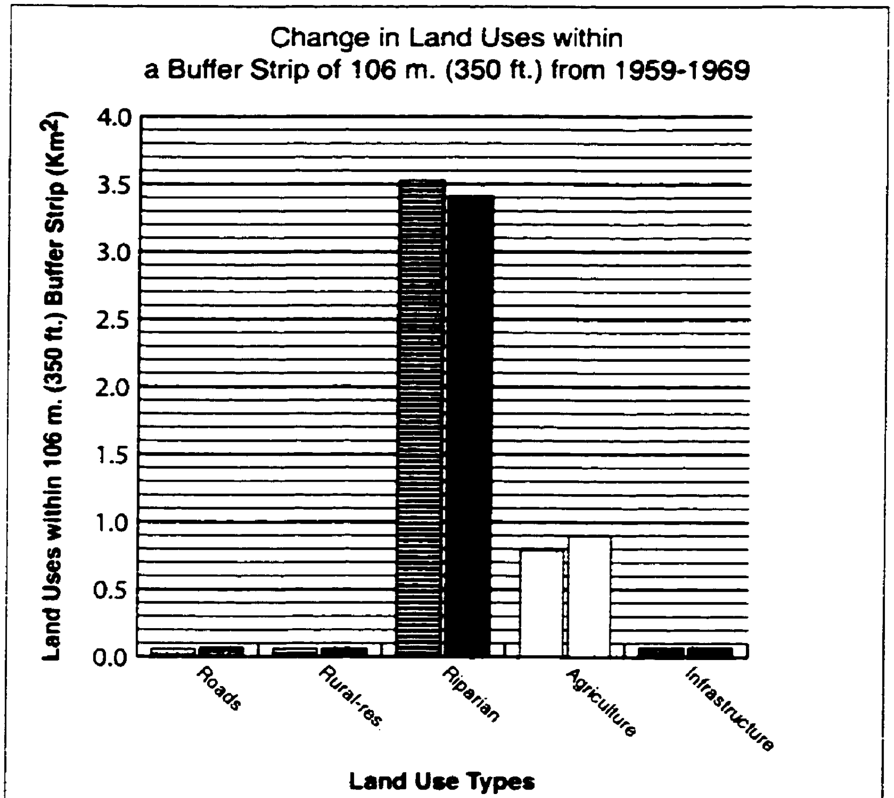
The City of Winnipeg has regulated construction along streams within the city limits for the past 45 years (City of Winnipeg, 1996). A Waterway Permit is required before construction can begin within 106 metres (350 ft.) (Figure 5-4) of the



"Construction Regulations along City Waterways." Winnipeg: City of Winnipeg, Land and Development Services. February, 1996.

Figure 5-4 City of Winnipeg Regulated River Front Area (City of Winnipeg, 1996)

Assiniboine or Red Rivers (City of Winnipeg, 1996). A 106 m. buffer-strip image was applied to the classified images; to extract the present land uses which would fall within the City of Winnipeg's regulated area had the study site been within the city limits; the resulting extracted land uses are presented in Figure 5-5, Figure 5-6.

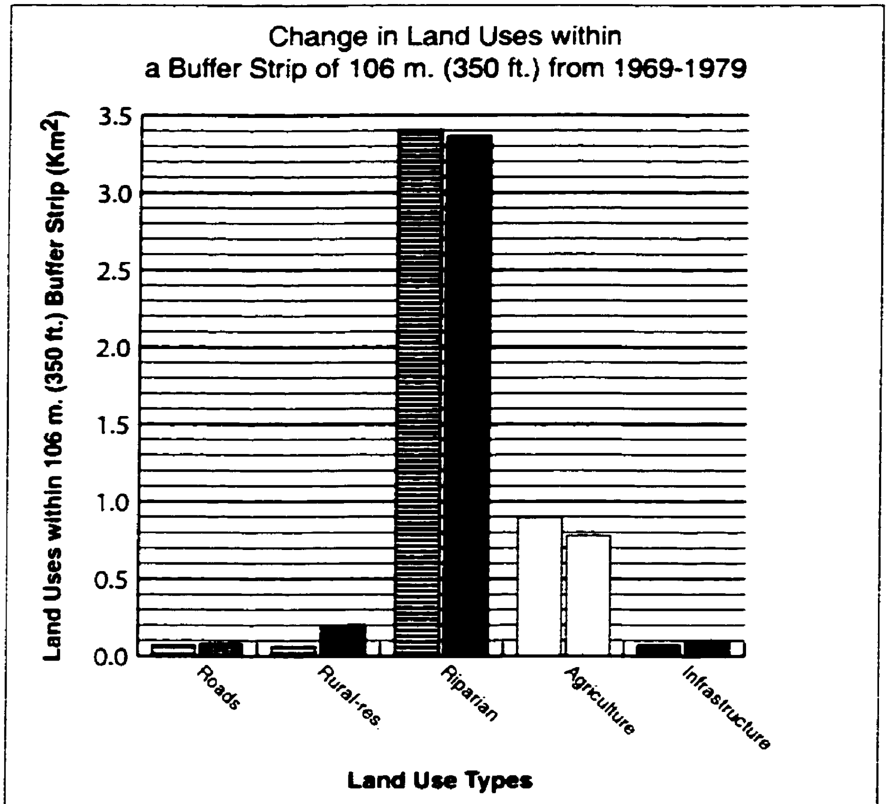


1959	Land Use Classes (pixels)	Land Use Classes (Km²)
All Road Surfaces	14705	0 05882
Rural-residential	15547	0 062188
Riparian	881337	3 525348
Agriculture	197553	0 790212
Infrastructure	16843	0 067372
TOTAL	1125985	4 503940

1969	Land Use Classes (pixels)	Land Use Classes (Km²)
All Road Surfaces	17317	0 069268
Rural-residential	15530	0 06212
Riparian	851504	3 406016
Agriculture	224140	0 89656
Infrastructure	17494	0 069976
TOTAL	1125985	4.503940

Figure 5-5 Changes in Land Use Within a 106 metre (350 ft.) Buffer Strip (1959-1969)

and Figure 5-7. It is clear from these charts that the foremost land use is riparian. followed by the agriculture and Rural-residential land uses. However. the amount of riparian and agricultural land uses have decreased. while Rural-residential land use has increased. The City of Winnipeg does regulate construction activities within

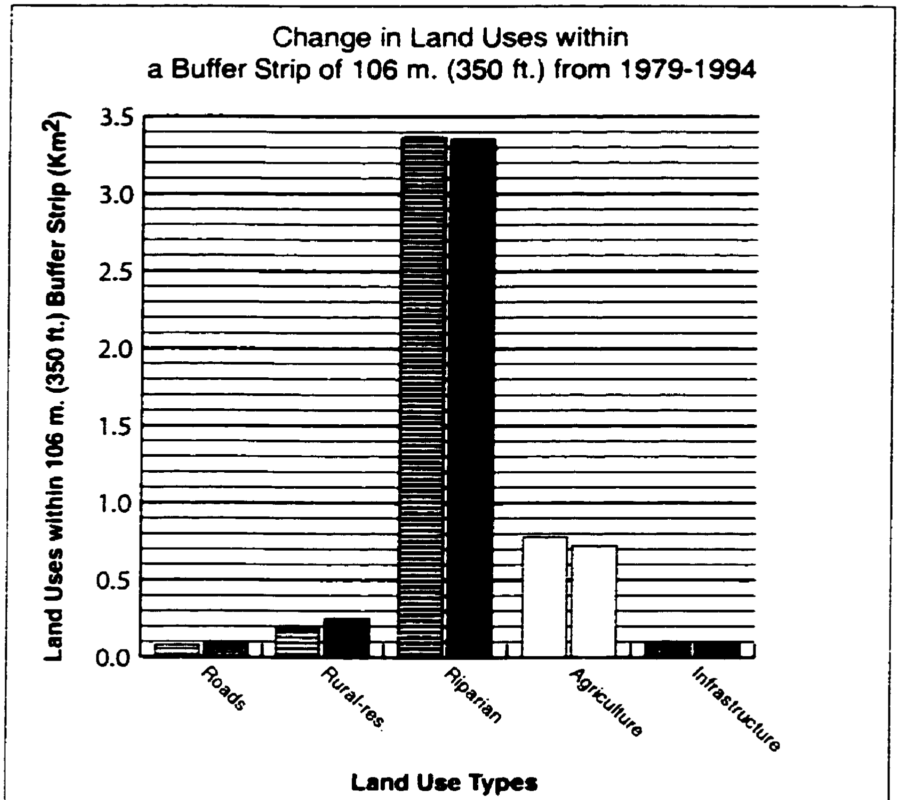


1969	Land Use Classes (pixels)	Land Use Classes (Km²)
All Road Surfaces	17317	0 069268
Rural-residential	15530	0 06212
Riparian	851504	3 406016
Agriculture	224140	0 89656
Infrastructure	17494	0 069976
TOTAL	1125985	4 503940

1979	Land Use Classes (pixels)	Land Use Classes (Km²)
All Road Surfaces	20048	0 080192
Rural-residential	47280	0 18912
Riparian	841021	3 364084
Agriculture	194665	0 77866
Infrastructure	23083	0 092332
TOTAL	1126097	4 504388

Figure 5-6 Changes in Land Use Within a 106 metre (350 ft.) Buffer Strip (1969-1979)

106 m. of the Assiniboine and Red Rivers; no such regulations exist beyond the city limits. Furthermore, the City of Winnipeg does not necessarily restrict activities within the regulated 106 metre area. The primary concern of the City is to minimize any impact on the river bank, because the rivers are an integral part of the City's



1979	Land Use Classes (pixels)	Land Use Classes (Km²)
All Road Surfaces	20048	0 080192
Rural-residential	47280	0 18912
Riparian	841021	3 364084
Agriculture	194665	0 77866
Infrastructure	23083	0 092332
TOTAL	1131097	4 524388

1994	Land Use Classes (pixels)	Land Use Classes (Km²)
All Road Surfaces	21622	0 086488
Rural-residential	62458	0 249832
Riparian	838163	3 352652
Agriculture	180439	0 721756
Infrastructure	22910	0 09164
TOTAL	1126097	4 502368

Figure 5-7 Changes in Land Use Within a 106 metre (350 ft.) Buffer Strip (1979-1994)

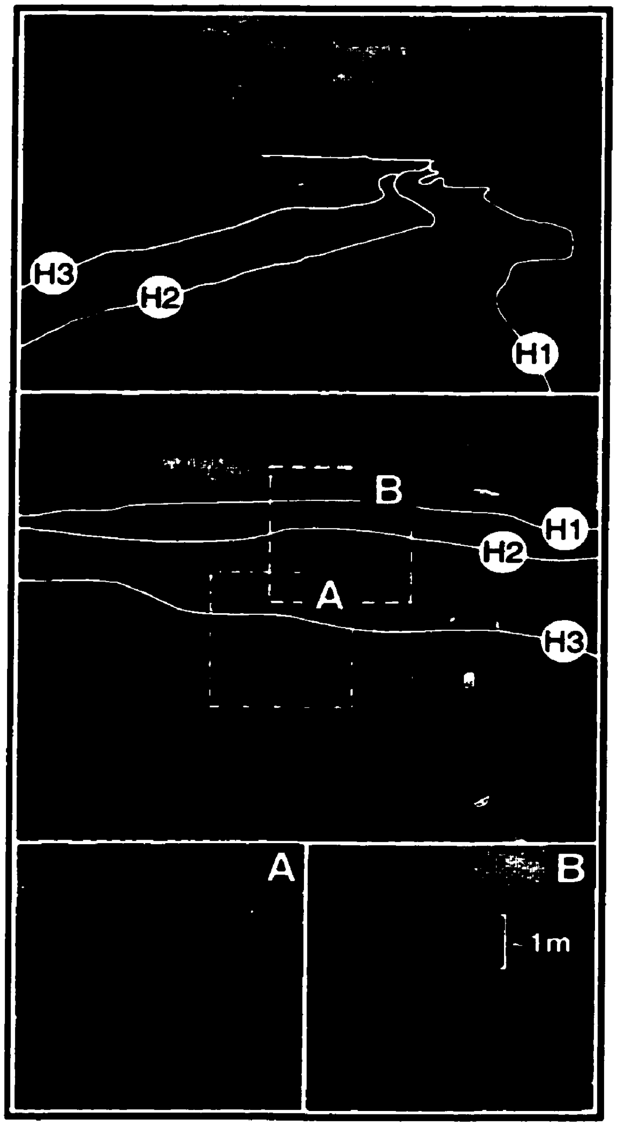


Figure 5-8 Slumping, North-West of the intersection of St.Mary's Rd. and the Perimeter Hwy.

flood management system (Winnipeg Municipal By-Law No. 5888/92:3.2(a)-(d); Figure A2–2)). Therefore, any proposed project that can be shown to have little, or no potential impact upon the stability of the stream bank, will most likely be

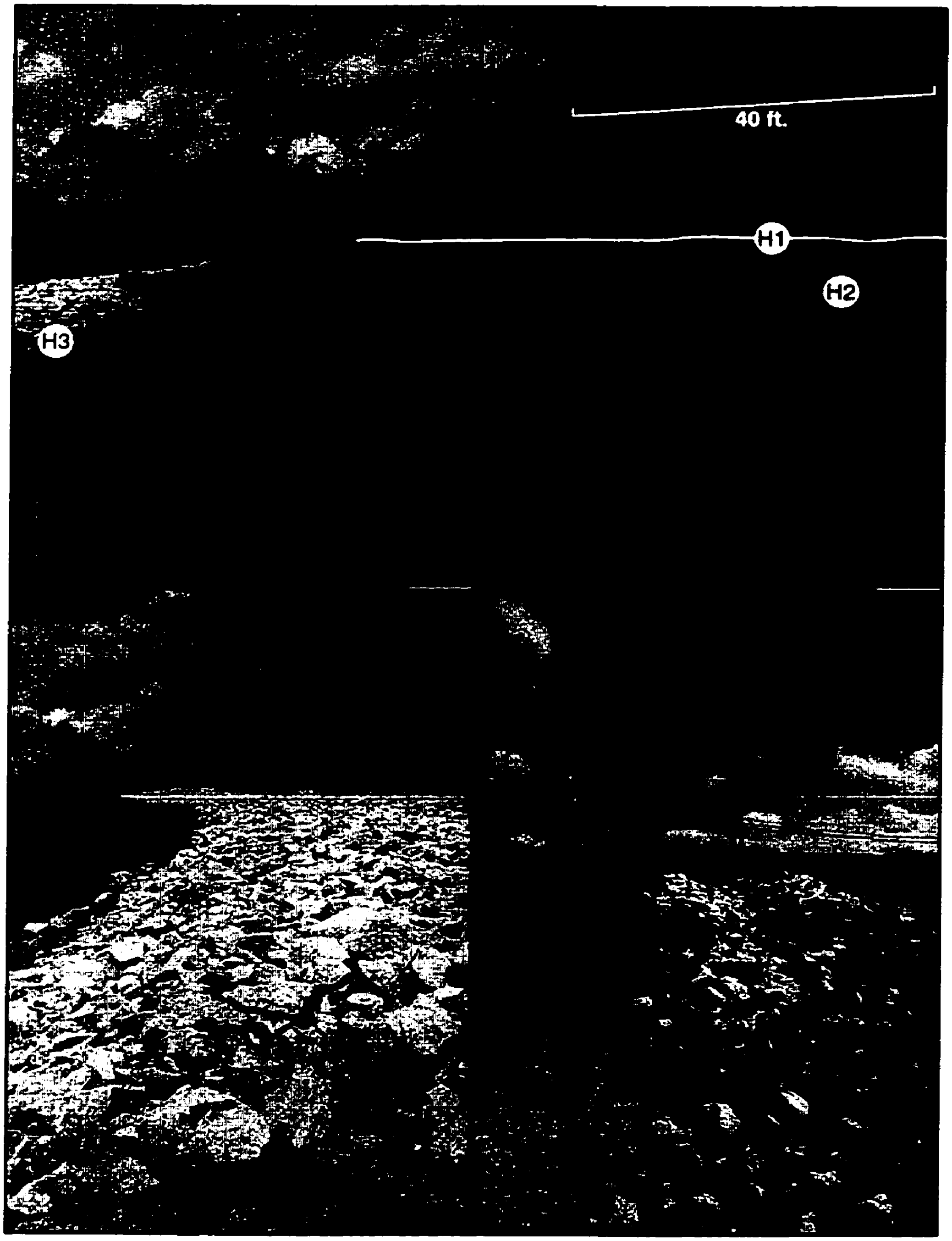


Figure 5-9 River Bank Engineering (ca. 2000).

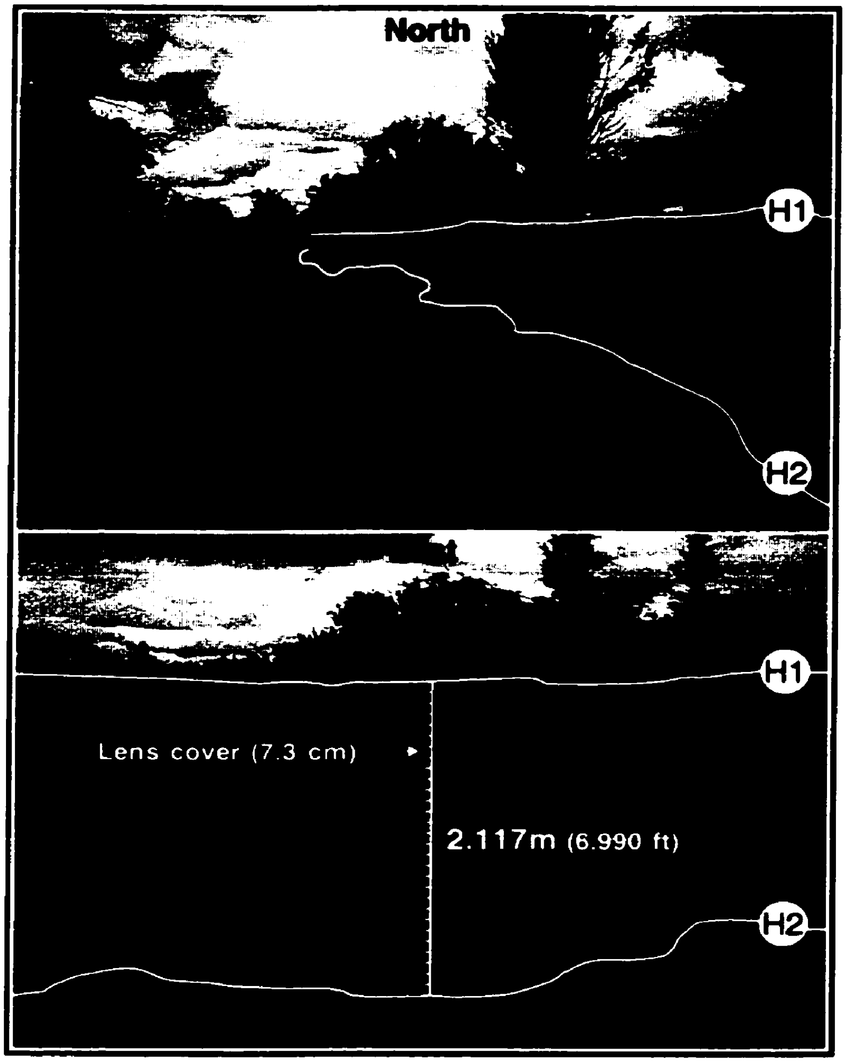


Figure 5-10 Slumping, St.Vital Municipal Park, Winnipeg, Manitoba.

approved (barring a city zoning variance which may be required). When examining Figure 5-8 and Figure 5-10 it becomes apparent that the present bank-stabilization programme in Winnipeg appears to be ineffectual. This ineffectualness may be due, in part, to a lack of funding, or inadequate regulations; regardless of the reason the results are the same, a degrading river bank. Figure 5-8 shows the shallow mass-wasting which is occurring along the Red River (North-West of the intersection of St.Mary's Rd. and the Perimeter Hwy). This shallow mass-wasting is on the outside of a meander. While this is the natural location for erosion to occur on a river, the type (shallow mass-wasting) and rate of erosion are not. This slope was not under any loading from buildings. However, there is recent construction to north of the location, where an entire housing division has been built. What may have contributed to the degradation of the bank shown in Figure 5-8 was not any single event, but rather a combination of effects: high water levels and flow-rates during the 1997 Manitoba flood; artificially generated seismic activities from nearby construction (e.g. pile-driving, and the movement of heavy equipment); the traffic vibration from the nearby road (St.Mary's Road) and highway (Perimeter Highway); and the absence of any large trees with substantive roots systems.While there are root systems retaining some of the soil at this site, the roots are too shallow, too small and not present in any significant density (Figure 5-8 [A]). The City recently re-engineered this river bank during the summer of 2000 (Figure 5-9). In that figure, the area highlighted in red shows the extent of the Red River during increased flows. Additional insets show the extent of the rip-rap along the shoreline and coming down from a culvert. The Red River is powerful and it is questionable as to whether the size of rip-rap used (from 0.5 to 1.0 foot) is large enough. In the upper-right corner of Figure 5-9, there is an inset showing a 40 foot tree (diameter ranging from 0.5 to 3 feet) which had be deposited some 60 feet up the river bank. It should be noted, that regardless of the new engineering this bank is continuing to experience shallow mass-wasting. In Figure 5-10 the sizable shallow mass-wasting event (2.117 metres) which occurred in St.Vital Municipal Park (ca.1998) is clearly visible. Like the bank is Figure 5-8 there was no direct loading from buildings. Unlike the locale in Figure 5-8, St.Vital Park does not experience the same level of vehicle traffic nor is there any nearby heavy construction. Within St.Vital Park, what appears to have occurred was that due to a dearth of large trees (specifically the cohesion provided by their root systems) and significant stream under-cutting this particularly high river bank destabilized. The sod visible in Figure 5-8 [A] is comprised of weed species and long grasses; while the sod visible in Figure 5-10 is cultivated grass with very shallow roots. The poor condition of the river bank at these two sites can be attributed to some degree to the City of Winnipeg's building by-laws. Winnipeg does have a general long-term urban plan concerning river front development. The location of any proposed construction will be assessed to see if it conflicts with the overall urban development plan (e.g. proposed park space). However, the City currently has no environmental protection regulations for the riparian ecosystems. The majority of the environmental protection efforts have been from local non-government organizations. Of particular note, the "Save Our Seine" group has done a great deal of work to clean-up the Seine River within the City of Winnipeg.

5.3.2 *Provincial Level*

The Province also lacks environmental regulations dealing specifically with riparian ecosystems. As with the City of Winnipeg, the Provincial regulations are in place to protect catchments (e.g. water quality, flood management). These regulations can, by default, provide some measure of protection to the regions riparian ecosystems but only indirectly. However, riparian areas are not even directly protected within Provincial Parks. Figure 5-11 clearly shows the current boundaries of Beaudry Provincial Heritage Park (ca. 1999). While the fields north of Provincial Highway 241 (PH241) and south of the river are mostly fallow, they are full of noxious weeds particularly Canada-thistle [*Cirsium arvense* (L.) Scop.] and Dandelion [*Taraxacum* sp. Zinn]. However, the fields south of PH241 appear to be under some cultivation, which are well within the boundaries of Beaudry Provincial Heritage Park. Portions of this park should have been replanted to aid in the re-establishment of the riparian ecosystem.

Furthermore, current provincial regulations do not appear to have any authority over the development of municipal centres, enabling municipalities to build within ecologically sensitive riparian ecosystems. For example, the Rural-residential developments being constructed within the riparian ecosystem located in the site study. The Province of Manitoba, like the City of Winnipeg, does not appear to be intentionally neglecting local riparian ecosystems. Instead, there appears to be a lack of understanding regarding the importance of riparian ecosystems. This has resulted in regulations which do not afford any direct protection to the local riparian ecosystems.

5.3.3 Federal Level

The Federal Government currently manages all waterways, including the channel/lake/ocean beds (the only notable exception being those who had property rights prior to the current Act). However, the Federal Government does not have direct control over the land surrounding waterways with one main exception.

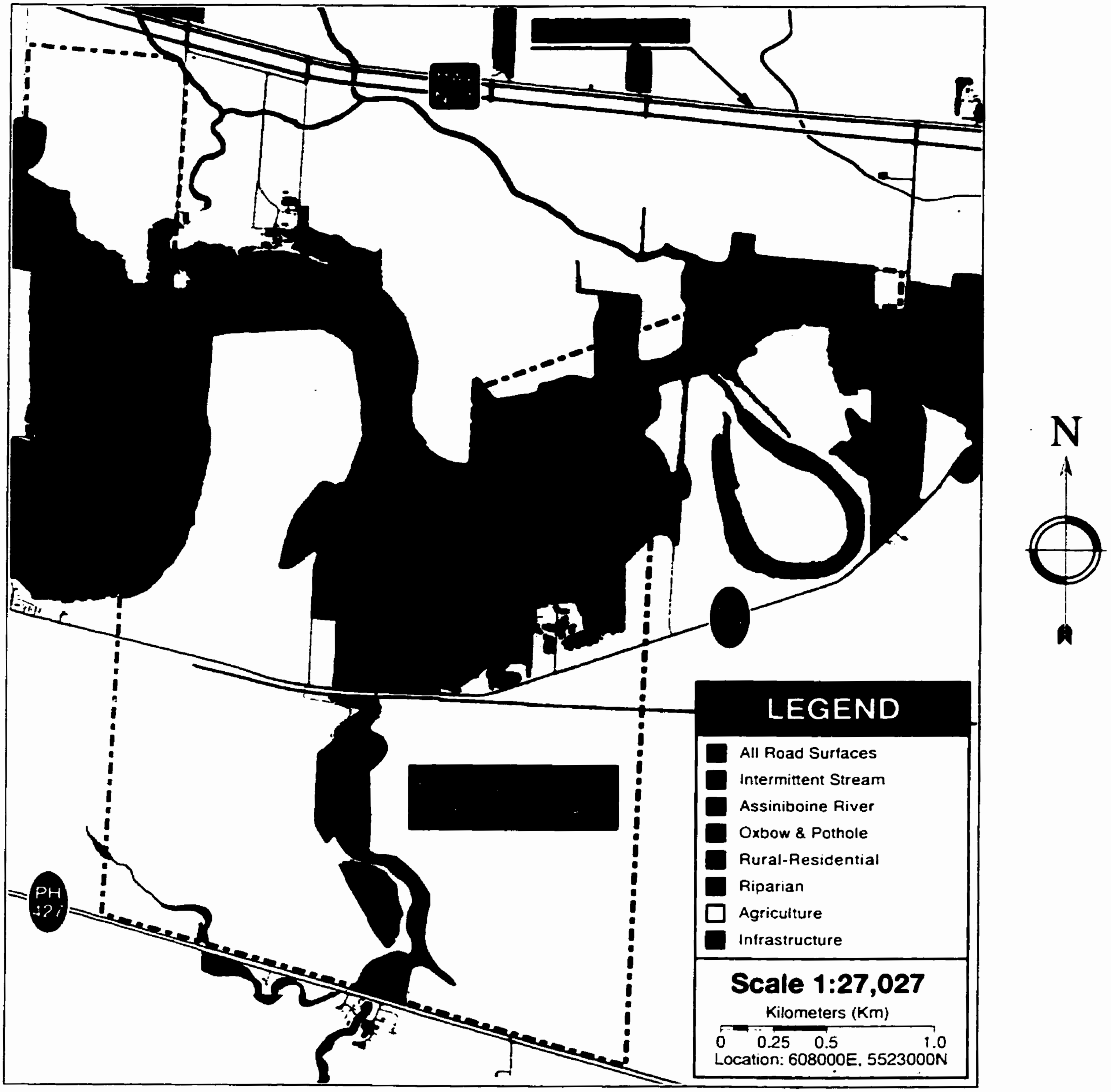
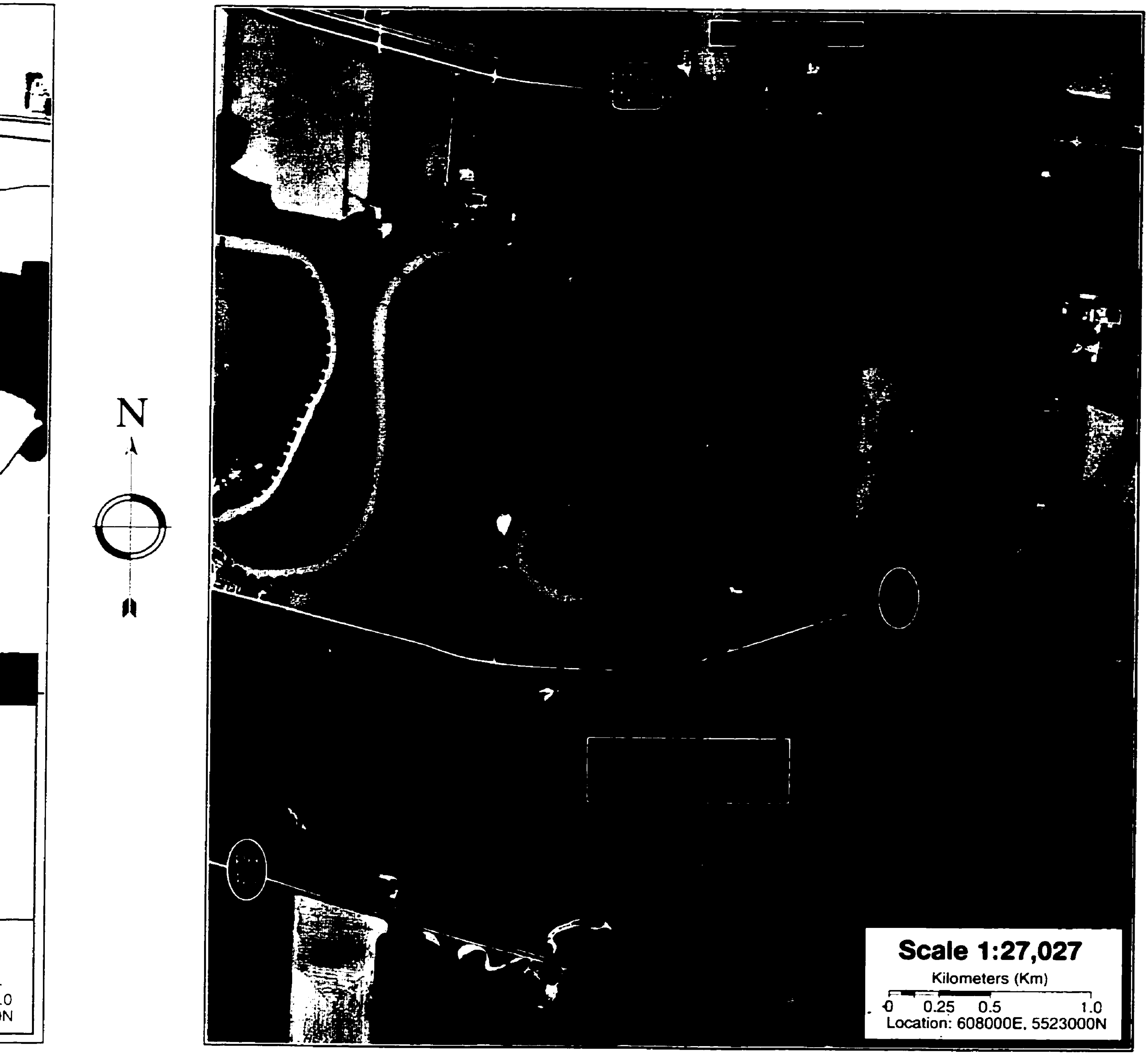


Figure 5-11 Boundary of Beaudry Provincia



undary of Beaudry Provincial Heritage Park

The current policy of the Federal Department of Fisheries & Oceans (DFO) is "no net loss" (Gov.'t of Canada, 1995). That is, if a development required the removal of fish habitat, the amount of habitat removed must be recreated in another locale; this is referred to as compensation (Gov.'t of Canada, 1995). Under the Fisheries Act fish habitat cannot be damaged (Figure A2–3). The Act may be suspended for specific projects after they have been reviewed by the Minister of Fisheries (Gov.'t of Canada, 1991), and compensation would be a condition of the suspension. However, like the provincial and municipal regulations, the federal regulations can only provide indirect protection to riparian ecosystems. Federal regulations address water quality and fish habitat concerns; not the condition of the environment immediately surrounding a water-body or stream (unless that environment is negatively impacting a water-body). Where a housing developer may trigger a review under Fisheries Act, is the placement of septic fields. However, new developments within the research area have been connected to the municipal sewage system. Under the Fisheries Act may a review may be warranted if a developer wanted to take water from, or put substances into a water-body. Again, the developments within the research area have been tied into existing Municipal systems. In addition, the new developments never built upon or altered the river bank (i.e. fish habitat), thus never prompting a review by DFO. This is a regulatory deficiency considering that the environment immediately surrounding a stream is part of the catchment basin, and it has the greatest influence over the quality of the water in a stream.

Conclusions & Recommendations

This chapter draws conclusions based upon the findings from the research performed in Chapters 4.0 & 5.0 and the literature review in Chapter 2.0. It also makes recommendations based upon the aforementioned research.

6.0 CONCLUSIONS & RECOMMENDATIONS

While there is existing research dealing with the topics of riparian ecosystems (e.g. productivity), agricultural and rural-residential development; none deals specifically with quantifying the impact of Rural-residential expansion on Agriculture and Riparian land uses. Nor does existing research point out the current regulatory deficiencies, which hinders government agencies from effectively managing riparian ecosystems in the Province of Manitoba.

It can be concluded from the data, that within the study site the Rural-residential land use has been increasing since 1979. The two land uses which sustained losses due to the Rural-residential increases are Agriculture and Riparian. This change in land use trend occurred over a ten year period 1969-1979. Prior to 1969 the likelihood calculations indicated an increase in Agriculture. However, based upon likelihood calculations using the images from 1979 and 1994, it would appear that Rural-residential increases will continue so long as the conditions giving rise to this trend remain in effect. The 1996 Federal Census indicates that young families are the predominant residents at this location; and that the housing being constructed within the study site has largely been single-family dwellings. In addition, 18.5% (187,644 m^2) of the Rural-residential development occurred within 106 metres (350 feet) of the Assiniboine River; and of this development 65.7% of the land had been Riparian (123,324 m^2).

The regulations from all three levels of government regarding catchment protection are ineffectual, because they do not directly provide protection to riparian ecosystems. They are primarily concerned with water quality, health of fisheries & fish habitat, and flood mitigation. What the regulations are not concerned with is the direct protection of riparian ecosystems. This deficiency is due in part to the absence of any standardized method of characterizing riparian ecosystems. Physical evidence of this deficiency in protection is visible in the classified aerial-photographs used in this thesis. There are areas where the riparian ecosystem has been completely removed and replaced with either agriculture or Rural-residential developments. Completely removing a section of riparian ecosystem produces increased bank erosion and destabilization, as well as fragmentation of the ecosystem. The cause of this denudation of large sections of river bank is primarily due to poorly constructed regulations, resulting in regulator loop-holes. What further compounds the difficulties in protecting this ecosystem is the number of agencies involved at all levels of government. Riparian ecosystems could fall under the purview of either, the Department of Fisheries & Oceans, or the Department of Environment. In addition, what was the provincial Department of Manitoba Environment, re-titled Manitoba Conservation, could also have some level of jurisdiction. To complicate matters further, the local municipalities have some authority within their respective municipal boundaries. Besides the above reasons, there are political reasons for provincial and municipal governments to be included in the development of management policies relating to riparian ecosystems. However, there are additional problems related to economics. Greatly reduced government budgets have precluded the hiring of enough personnel to enforce the current regulations at any level (i.e., municipal, provincial and federal). Riparian ecosystems are important to the local environment and should be afforded an effective level of protection against anthropogenic activities by legislation from all three levels of government. While a complete ban on construction within riparian ecosystems is impossible and impractical, strong regulations protecting the long-term health of this ecosystem, not short-term financial gains of any municipality or individuals, should be developed immediately. The first step toward developing such regulations would require the formalization of communications between the different levels of governments and their respective agencies regarding environmental matters. After this has been completed, the other "stake-holders" must become involved (developers, home owners, et cetera). The time frame for this is short, as urban centres continue to expand with the continually growing population, there will be increasing pressure on this ecosystem (Ruhl, 1999). The pressures originate from developers wanting to build more housing, and from the desire of a growing human population for more park space. A management strategy must be in place to protect this ecosystem from further damage, such as the damage identified by this thesis. Additional research needs to be done, to determine the cause of the current trend for people to move out into the capital region surrounding Winnipeg (e.g. Saint Francois Xavier, Headingly, Oak Bluff, Birds Hill, Stonewall, Stoney Mountain, and La Salle). Research into municipal taxation, property values and building costs could disclose the cause of this outward migration. Once the causes are known, new regulations could be drafted to redress the current deficiencies and thus afford some level of effectual protection, to Manitoba's riparian ecosystems, against further degradation. Riparian ecosystems must be protected; not only because they contain unique assemblages of species but because they are an integral part of the watershed.

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Appendix-1: Abbreviations & Terms

While the following terms are defined in the body of this thesis, Appendix-1 is intend to assist the reader by providing a single area devoted to defining the technical and professional terms used in this thesis.

8–bit Imagery–This denotes the number of colours present in an image. 8-bit is an image comprised of pixels each defined by 8 bits of data. This type of imagery has a pallet of 256 colours available.

16–bit Imagery–This denotes the number of colours present in an image. 16-bit is an image comprised of pixels each defined by 16 bits of data. This type of imagery has a pallet of 32,768 colours available. Not all of the 16 bits are used as colours by the computer, some bits are used for graphic effects such as opacity.

Albedo–"The proportion of the solar light incident upon an element of the surface of a planet, which is again diffusely reflected from it. Hence in extended use, applied to the proportion of light reflected from various surfaces." (O.E.D. 2nd Edition, Vol. I, p. 296)

Anthropogenic–is any activity initiated by a human-being producing an effect, be it either detrimental or beneficial.

Atmospheric Windows–are those regions of the electromagnetic spectrum (EMS) which have detectable levels after passing through the Earth's atmosphere. (Colwell, 1983)

Avifauna–"Collective term for the various kinds of birds found in any district or country; the 'Fauna' so far as concerns birds." (O.E.D. 2nd Edition, Vol. I, p. 821)

Biota–"A collective term for the animal and plant life of a region." (O.E.D. 2nd Edition, Vol. II, p. 210)

Charged Coupled Device (CCD)–The CCD's essentially perform the same function as silver halide but through electronic means. CCD's detect the reflected light from the surface begin scanned be it the Earth or a photograph. The as the CCD's detect photons signals are produced in relation to the wavelength and intensity of the photons. These signals are the digital representation of the values assigned to the wavelengths of the detected photon by the computer program.

Database (dB)–A database is a method of storing data digitally in a computer system. Specifically it is a file or groups of files containing information on one or more objects of interest organized in such a manner as to facilitate rapid retrieval.

Datum–"The quantities, characters, or symbols on which opertions are performed by computers and other automatic equipment, and which may be stored or transmitted in the form of electrical signals..." (O.E.D. 2nd Edition, Vol. IV, p. 264) Cartographically it is essentially the same thing, a reference point, in this instance a cartographic reference point.

Dots Per Inch (dpi)–The resolution of scanning equipment is measured in dpi. The higher the dpi the greater the accuracy in the resultant image in relation to the original (ex. 600 dpi is more accurate than 300 dpi).

Ecology–"The science of the economy of animals and plants, that branch of biology which deals with the relations of living organisms to their surrounding, their habitats and modes of life, etc." (O.E.D. 2nd Edition, Vol. V, p. 58)

Ecotone–"Transitional belts between well-marked communities are called ecotones or 'tension belts'." (O.E.D. 2nd Edition, Vol. V, p. 61)

Ecosystem–"The unit of ecology is the ecosystem, which includes the plants and animals occurring together plus that part of their environment over which they have an influence." (O.E.D. 2nd Edition, Vol. V, p. 61)

Edaphic–"Pertaining to, produced or influenced by, the soil." (O.E.D. 2nd Edition, Vol. V, p. 65)

Electromagnetic Radiation–All electromagnetic radiation (EMR) travels at the "speed of light" (3 x 108 m s-1) either from the source of emission or through reflection and reradiation. EMR is comprised of photons which are quantums of light.(Gillespie, 1986)

Electromagnetic Spectrum–Photons can be travelling at an infinite number of different frequencies. These frequencies are what comprised the Electromagnetic Spectrum.

File Transfer Protocol (ftp)–This is a protocol established to allow the transfer of files between different locations and computer platforms. Transfers of this type can be accomplished in one of three ways: keeping the original file type (creator) intact, binary and ASCII.

Geographic Information System (GIS)–GIS's are information systems designed to manipulate dB's where spatial relationship between data points are important.

Ground Verification–Is the visual verification of objects which appear in remotely-sensed imagery. Usually done to confirm the accuracy of the classification method used to assign land uses within a scene.

Habitat–"...the natural place of growth or occurrence of a species." (O.E.D. 2nd Edition, Vol. VI, p. 995)

Hard-Point–These are locations on the Earth's surface used to rectified remotely sensed image to a map projection. They are chosen due to ease with which they can be located both within the image to be rectified, as well as on the Earth's surface. Furthermore, these locations are the least likely to change with the passage of time. (e.g. road intersections, and railway crossings).

Insolation"The action of placing in the sun; expose to the sun's rays; sometimes..." (O.E.D. 2nd Edition, Vol. VII, p. 1031) The modem use of insolation is a reference to **incoming solar radiation** (in-sol-ation).

Large Scale–In the professions of geography and cartography a large scale is not a close-up view of an area. Rather, it a spatial representation which literally has a large "scale." (i.e. 1:500,000 or 1:1,000,000). (all so see small scale)

Lotic Environment–"Of fresh-water organisms or habitats, situated in rapidly moving water." (O.E.D. 2nd Edition, Vol. IX, p. 42)

Map product–This term is a general one, relating to any cartographic materials produced from a mapping project. These products can include, but are not restricted to: thematic maps; topographic sheets and digital elevation models.

Minimum Mapping Unit (MMU)–The MMU is the smallest feature in the map product which must be identifiable (e.g. a domestic dwelling).

Projection–Where a projection is the planar transformation of a geodetic speroid. (Eastman, 1993)

Pull Factor–is a principle of human geography, relating to human migration. This term is descriptive of those positive or attractive qualities of riparian ecosystems which result in species concentrating this these areas.

Raster Data–This data type is comprised of cells, within each of these cells is a value. In GIS applications the cells values range from 0-255 for a total of 256 possible values. The cells are positioned into roles and columns which form a matrix, and when displayed this matrix may form an image. Where the gray shades (Digital Numbers, DN's) would be representative of values within the data set. In relation to satellite data, the more pixels which comprise/describe a feature the better the image can depict the feature. The trade off is that as the amount of pixels increases so does file size.

Raw Pixel Data (RPD)–Saving data as a RPD places the data in binary format. It is important to note that with this file type you have to know the numbers of rows and columns of pixels in the image because there is no descriptive information stored in the actual data file (i.e. no header).

Rayleigh Scattering–originally discovered by Lord J.W.S. Rayleigh (1824-1919), this type of scattering occurs when "atmospheric particles have diameters that are small relative to the wavelength of the radiation" (Campbell, 1996). Radiation is in reference to electromagnetic radiation or EMR.

Remote Sensing (RS)–Remote Sensing is the collection, via sensor equipment, of reflected electromagnetic energy from an object, and/or objects, without coming into actual physical contact with the object. (Ghassem Asrar, 1989)

Right of way–"The legal right, established by usage of a person or persons to pass and repass through grounds or property belonging to another." (O.E.D. 2nd Edition, Vol. XIII, p. 936) A right of way can all so be used a road and/or railway.

Riparian–"of, pertaining to, or situated in the bank of a river; riverine." (O.E.D. 2nd Edition, Vol. XIII, p. 971)

Scene–Is used in reference to a remotely-sensed image. A scene is the entire image captured by a remote-sensing device.

Small Scale–This is a spatial representation which has a small "scale." (i.e. 1:25,000 or 1:50,000). (all so see large scale)

Tagged Image File Format (TIFF)–A raster graphic image format, similar to PICT or PIC. However, this format is capable of describing 24-bit data, unlike the 8-bit PICT format.

Time Series Analysis (TSA)– is a technique which shows the difference between to temporally distinguished data-sets of the same spatial location.

Universal Transverse Mercator (UTM)–This is a cartographic projection which divides the globe into 60, 6° sections latitudinally and A to Z sections longitudinally, and is measured in meters.

Vignette–"To make with a gradually shaded background or border." (Funk&Wagnalls Canadian College Dictionary, 1986) Single aerial photographs can have a radial-graduated darkening toward the edges, and is an artifact of the lens and the incidence angle of the recorded visible light.

Appendix-2: Classification Schemes & Government Regulations

Appendix-2 contains the classification scheme currently used by the Province of Manitoba for land cover mapping in southern Manitoba. This is an internal and unpublished document obtained from the Manitoba Remote Sensing Centre. In addition, pertinent City of Winnipeg by-laws, and sections of the federal Fisheries Act are all so contained in this appendix for reference purposes.

CLASSIFICATION SCHEME: land cover mapping of southern manitoba.

1. **AGRICULTURAL CROPLAND** — Consists of all lands dedicated to the production of annual cereal, oil seed and other speciality crops. These lands would normally be cultivated on an annual basis. This class will be broken into three crop residue classes: 0% – 33%, 34% – 66%, and 67% – 100%.

2. **FORAGE CROPS** — Consists of perennial forage such as alfalfa and clover or blends of these with tame species of grass. Fall seeded crops such as winter wheat or fall rye are included here.

3. **GRASSLAND / RANGELAND** — Consists of mixed native and/or tame prairie grasses and herbs. May also include scattered stands of associated shrubs such as willow, chokecherry, saskatoon and pincherry. Many of these areas are also used for the cutting of hay while others are gazed. both upland and lowland meadows fall into this class. There is normally less than 10% shrub of tree cover.

4. **OPEN DECIDUOUS** — Consists of lands characterized by rough topography, shallow soil or poor drainage which supports a growth of shrubs such as willow, alder, saskatoon and/or stunted trees such as trembling aspen, balsam poplar and birch. An area could contain up to 50% scattered tree or shrub cover.

5. **DECIDUOUS FOREST** — Forest in which 75% to 100% of the canopy is deciduous. Dominant species are trembling aspen, balsam poplar and white birch. May include small patches of grassland, marsh or fens less than two hectares in size.

6. **CONIFEROUS FOREST** — Forest is which 75% to 100% of the canopy is coniferous. Jackpine and spruce are combined under this class. May include patches of treed bogs, marsh or fens less than two hectares in size.

7. **MIXEDWOOD FOREST** — A forest type in which 25% to 75% of the canopy is coniferous. May include patches of treed bogs, marsh or fens less than two hectares in size.

8. **TREED ROCK** — Areas of exposed bedrock with less than 50% tree cover. the dominant species is jackpine and occasional areas of shrub.

9. **BOGS** — Pear covered or peat-filled depressions with a high water table. The bogs are covered with a carpet of sphagnum spp. and ericaceous shrubs and may be treeless or treed with black spruce and/or tamarack.

10. **MARSH & FENS** — Grassy, wet areas with standing or slowly moving water. Vegetation consists of grass and sedge sods, and common hydrophytic vegetation such as cattail and rushes. Areas are frequently interspersed with channels or pools of open water.

11. **BARE ROCK, GRAVEL & SAND** — Exposed areas of bedrock with little or no vegetation, or exposed areas such as sand dunes and beaches. Also included area all gravel quarry/pit operations, mine tailings, burrow pits, and rock quarries.

12. **BURNT AREAS** — Burned forested areas with sporadic regeneration and can include pockets of unburnt tree stands.

13. **FOREST CUTOVERS** — Areas where commercial timber has been completely or partially removed by logging operations. Includes areas which have been replants.

14. **OPEN WATER** — Consists of all open water – lakes, rivers, streams, ponds and lagoons.

15. **CULTURAL FEATURES** — Built-up areas such as cities and towns, peat farms, golf courses, cemeteries, shopping centres, large recreation sites, auto wreck-yards, airports, cottage areas, race trackers, dumps, tren nurseries.

16. **ROADS & TRAILS** — All highways, secondary roads, trails and cut survey lines or right of ways such as railway lines and transmission lines.

INTERNAL & UNPUBLISHED DOCUMENT OF THE PROVINCE OF MANITOBA: MANITOBA REMOTE SENSING CENTRE

Figure A2–1 Classification scheme for land cover mapping of southern Manitoba

THE CITY OF WINNIPEG BY-LAW NO. 5888/92

A By-Law of the City of Winnipeg designating waterways and adjacent land as regulated areas, providing for the issuance, renewal and cancellation of permits and enforcement of orders, prescribing the information to be submitted by an applicant in support of an application for permit, prescribing a tariff of fees and designating employees of the City to supervise and enforce this By-Law.

3.3 A permit shall not be issued for work to be done in a regulated area unless the applicant demonstrates to the reasonable satisfaction of the designated employee that the proposed work will not, or will have a tendency to:

(a) restrict or impede surface or subsurface water flow;

(b) endanger the stability of any land, including the bed of a waterways;

(c) cause land to slip into a waterway; or

(d) adversely alter the channel of a waterway.

FILE NO. E-5.1, GL-5.6 & E-1

Figure A2–2 The City of Winnipeg By-Law No. 5888/92

Canadian federal **Fisheries Act** on the destruction of fish and fish habitat:

Section 32: No person shall destroy fish by any means other than fishing except as authorized by the Minister or under regulations made by the Governor in Council under this Act.

Section 34(1): For the purpose of sections 35 to 43, "fish habitat" means spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes.

Section 35(1): No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat.

Section 35(2): No person contravenes subsection (1) by causing the alteration, disruption or destruction of fish habitat by any means or under any conditions authorized by the Minister or under regulations made by the Governor in Council under this Act.

Section 78: Except as otherwise provided in this Act, every person who contravences this Act or the reuglations is guilty of

(a) an offence punishable on summary conviction and liable, for a first offence, to a fine not exceeding one hundred thousand dollars and, for any subsequent offence, to a fine not exceeding one hundred thousand dollars or to imprisonment for a term not exceeding one year, or to both; or

(b) an indictable offence and liable, for a first offence, to a fine not exceeding five hundred thousand dollars and, for any subsequent offence, to a fine not exceeding five hundred thousand dollars or to imprisonment for a term not exceeding two years, or to both.

Figure A2–3 Select sections of the federal Fisheries Act

Appendix-3: Ground Verification with Images

Appendix-3 contains the results of the ground verification, as well as the ground based photographs collected to verify the accuracy of the classification scheme developed in this thesis. The ground verification figures include: the location and direction that the ground photographs were gathered; as well as ground verification information (i.e. features of interest); in conjunction with the ground based photographs for the verification site being examined.

A3-0 GROUND TRUTHING

It is important when utilizing classified remotely-sensed imagery to verify the results of the method used in the classification, as all methods can produce mis-classifications. Invariably some portion of a scene is misinterpreted by either the automated or manual method selected by the analyst. The following sections describe eight ground verification sites. These sites where chosen because some attribute in the aerial-photography of these locales was not discernable. Once the classification of the images was further refined using the information gathered from the ground verification sites, these images where analysed via cross-tabulation. As mentioned in Section 3.7.2, cross tabulation can show which land use types have changed and by how much.

A3-1 Research Area: Vascular Plant Species Present–Ground Verification

Ground verification is an important component of classification. Ground-verification is a method of visual confirmation of the accuracy of any method used for the classification of remotely-sensed imagery. The accuracy of automated classification methods is derived from statistical tests for standard deviation. However, statistical accuracy does not necessarily transfer into real-world accuracy. Automated methods require multi-channel remotely-sensed data, and do not assess every physical attribute of an object within the scene. Many classification schemes utilize probabilistic methods of determining the likelihood of a pixel, or group of pixels, representing some known object or land use type. Specifically, a land use type may be determined via such probabilistic statistical methods as: maximum likelihood; principal component analysis and *k*-means. Ground-verification is all so of importance to the accuracy of a manual classification. A remote-sensing professional may have a specialized knowledge of the area being classified. Having such knowledge is valuable, but should not be used with such confidence as to appear to negate the need for ground-verification.

A3-1.1 Ground Verification Site #1

The primary land use at this location is agricultural. There are some homes located in area (Figure A3–3 [a_i]), as well as a small memorial [a_i]-2. Some wooded areas can all so be seen in photograph [a] of Figure A3–3. The grassy areas visible in Figure A3–3 are populated by a mixture of grasses and weed species such as Canada-thistle [*Cirsium arvense* (L.) Scop.] and Dandelion [*Taraxacum* sp. Zinn]. These grassy sidings are managed by the surrounding farms, and thus classified as agricultural.

A3-1.2 Ground Verification Site #2

In ground verification site #2 (Figure A3–4) a small pasture used for the grazing of horses was located (Figure A3–4 [c]). Within this verification site there is an oxbow lake; both ends have been closed off by the river. Unlike the river, the water in the oxbow is clear and unmuddied (Figure A3–4 [c]-1—[c]-3). The oxbow has been bisected by the Trans-Canada Highway (Hwy. No.1) running east-west. There was no odour of stagnation, this may be an indication that at some level water is still being exchanged with the river. Numerous tree species have been located within this verification site. These species include: Eastern Cottonwood [*Populus deltoides* Bartr.], Bur Oak [*Quercus macrocarpa* Michx.], Green Ash [*Fraxnus pennsylvanica* var. *subintegerrima* (Vahi) Fern. (synonym var. *lanccolata* (Borkh.) Sarg.], Manitoba Maple [*Acer negundo* L.], White Elm [*Ulmus americana* L.], and Basswood [*Tilia americana* L.]. There are very large specimens of the Eastern Cottonwood and Basswood. Although not measured directly, there were specimens which were of considerable size, approximately 9-12 meters (30 to 40 feet). The Green Ash, Manitoba Maple, and White Elm appeared to make-up the understory in this area. In the north-west quadrant of this verification site is a camp-ground which is no longer in use. The understory in the area has been completely cleared to make room for camp-sites. At this location the Cottonwood have achieved considerable height 12 to 15 meters (40-50 feet) (Figure A3–9 [g_i]). There was an unusual shape located at Figure A3–5 [g], which was found to be the wading pool of the closed camp-ground (Figure A3–9 [g]). A camp-ground which is still in operation can be found in the south-east quadrant of this verification site [e]-2 (Figure A3–4). However, this area has had most of the tree cover removed. Only the perimeter of this camp-ground has trees of any appreciable size (9-12 meters).

A3-1.3 Ground Verification Site #3

Verification Site #3 has two areas of interest: an urban development in the north-central section; and the previously mentioned defunct camp-ground, now located in the south-east of this site (Figure A3–5). The urban development in the north is an area where the homes have been inserted into the surrounding riparian ecosystem (Figure A3–6 [e]-4). Specifically, as few trees as possible have been removed at the front of these lots. Each home does have a clearing to the rear, most likely a back-yard. Most of these homes are situated in such a manner as to give the owner the impression of being in the wilderness, as the neighbouring homes are not visible. Trees species found in this area include: Cottonwood, Basswood, White Elm, Green Ash, and Bur Oak. An extremely large Cottonwood specimen was found in this area (Figure A3–6 [e]-2). It should be noted, that another house was constructed in this development after the aerial photo was taken. This new house occupies a lot at the end the road in image [e] (Figure A3–6). Another development as begun south of this location and is denoted as [f] in Figure A3–5. Ground photographs of this development shows more tree removal than that found in the development to the north (Figure A3–8). However, two houses (Figure A3–8 [f_i] and [f_i]-2) have been built within the riparian forest in a similar manner to the house in Figure A3–6 [e]-4.

To find Bur Oak in such close proximity to a river as that found in Figure A3–9 is unusual. This species does not tolerate prolonged inundation of its roots (Hosie, 1990). Furthermore, its bark can experience rotting if submerged for extended periods of time. The specimens found in Figure A3–9 [h] were clearly planted by hand because they are growing in distinct rows. Some nearby specimens of Bur Oak have established themselves near to the Cottonwood west of the oxbow. The likely source of the seeds is the Bur Oak seen in Figure A3–9 [h].

While it is true that not all streams experience seasonal flow-rates which exceed bank-full, the streams within the catchment of the Red River Valley can regularly over-top their banks during the period of seasonal run-off (March to May). This is of relevance because, as mentioned previously, Bur Oak do not tolerate prolonged flooding of their root systems (Hosie, 1990). Due to the environmental conditions Bur Oak find conducive for growth, their presence could be an indication that this area does not experience flooding; or flooding of the duration which would negatively affect this species.

Of further interest is that this region is covered by heavy sedimentation from Glacial Lake Agassiz (Corkey, 1996). This type of sediment does not drain quickly. If this area were flooded seasonally, the soil would most likely not drain quickly enough for Bur Oak. This information further supports the conjecture that this area does not experience flooding on a seasonal basis. In Figure A3–6 [e]-3, Bur Oak is again seen growing in an location which would become submerged if this area did experience flooding regularly.

A3-1.4 Ground Verification Site #4

Verification Site #4 is located west and south of Hwy No.1 and is a small clump of trees (Figure A3–10). The composition of this small area was not discernable from the aerial photography. Ground verification shows it to be a site of closely grown Bur Oak overstory, with a heavy undergrowth (Figure A3–10 [j],[j]-2). This sites appears indicative of a prairie woodlot, albeit a very small example.

A3-1.5 Ground Verification Site #5

Verification Site #5 (Figure A3–11) comprises five locations of interest. At the very top of this site is the camp ground located just east of the bridge and south of Hwy No.1 (Figure A3–4 [e]-2). This site was examined to determine its use, which was found to be recreational and thus a part of the infrastructure land use category used in this thesis. South of this camp ground and east of the river is a very thin line of Bur

Oak along the bank of the river (Figure A3–12 [L_i]). Finding Bur Oak in such close proximity to the river would support the earlier contention regarding this species proximity to the river at Site #3. Further south from the Bur Oak is an urban development "Sunny Harbour Estates", which is much more recent than the developments found at Site #3. Parcels of land have been surveyed and staked-out (Figure A3–12 [m], [m]-2), some lots are listed as sold (Figure A3–12 [m]-6, [m]-7).

Near the bottom (south) of this verification site are two other areas of interest [o] & [p] (Figure A3–11). It was difficult to ascertain from the aerial-photography whether these two sites had trees, or if the texture was due to slumping of the river bank. However, trees were found to be the source of the texture at both locations (Figure A3–14). Eastern Cottonwood was the predominant species comprising the overstory at both locations, Manitoba-Maple was present but found in fewer numbers.

A3-1.6 Ground Verification Site #6

Verification Site #6 is located south of the river (Figure A3–15). There are two points of interest at this location: an area north of a farm; and an urban development. The first point of interest, is the outlet of a channelized stream located on agricultural land north-west of a farm. The river bank is almost entirely unprotected against erosion, with the exception of grasses (Figure A3–16 [q], [q]-2). This stream has been channelized. The straightened channel has been lined with grass to slow the flowrate of any run-off (Figure A3–16 [q]-2). This in turn reduces the rate of down-cutting by the stream, and the amount of top-soil carried off the adjacent fields. The grasses can all so aid in the capture of topsoil which has been flushed off the fields allowing the farmer to collect it, and reapply it to the fields. all so of note is the section of the river-bank which comprises the northern property boundary of this farm, it is completely denuded of trees (Figure A3–16 [q]). Within Figure A3–16 [q] and [q]-3, it is possible to see that the opposite bank (inside of the meander) is completely treed. There are all so trees protecting the river-bank north of the confluence of the channelized stream and the Assiniboine River.

The second point of interest is the urban development being constructed in the north-western portion of this verification site (Figure A3–15 [q_i]—[q_i]-4). This area has undergone land use change from an agricultural to an urban land use. The land having already been cleared previously, in combination with its close proximity to the river, make this property attractive to prospective builders. This area is now the site of a new urban development called "Beaudry Park Estates" (Figure A3–15, Figure A3–17 [q_i]—[q_i]4), offering new home builders treed and cleared lots.

A3-1.7 Ground Verification Site #7

Verification Site #7 is Beaudry Provincial Park (Figure A3–18). Within the park Basswood, Green Ash, some Bur Oak as well as some Manitoba-Maple were found. Most of the overstory was comprised of Basswood. Green Ash all so appeared very common in this area (Figure A3–21 [s_i],[s_i]-2). Several muskrat tracks were all so seen along the river bank within the park (Figure A3–20 [f]-3 *inset*). In the area of the parking lot for the park, there is access to the river. The trees and shrubbery have been completely removed, and replaced by a lawn; there is some bank erosion and slumping as a result (Figure A3–19 [s]). A path has been put in place which runs from the access road of the park down to the river in the area of Figure A3–19 [s]-4. There is no structure at this location which could be deemed a boat launch but the path does provide direct access to the river for small craft like canoes, kayaks and perhaps Personal Water Craft (PWC).

While inside Beaudry Provincial Park, it was observed that there was a very audible difference in the number and variety of bird calls within the park, as opposed to the well treed area undergoing development in Site #3. This observation all so holds true when Site #7 is compared to the development within Site #5. Based on these auditory observations, it appears that the locations of Rural-residential development have fewer birds, song-birds in particular.

A3-1.8 Ground Verification Site #8

Verification Site #8 is located south of the Assiniboine River along Provincial Highway No.241 and west of Beaudry Provincial Park. It is the site of an oxbow lake (Figure A3–22). The dominant land use within this site is agricultural. This land use has impacted the oxbow lake, as the lake has been almost completely drained. Located on the north most tip of the lake is a ditch which is allowing the lake to drain into the Assiniboine River. Even with the drainage ditch in place, the majority of the oxbow still retains too much moisture to allow farming. As a result, the farm gains a minimal amount of arable land, while aquatic species can no longer benefit from what was once a wetland.

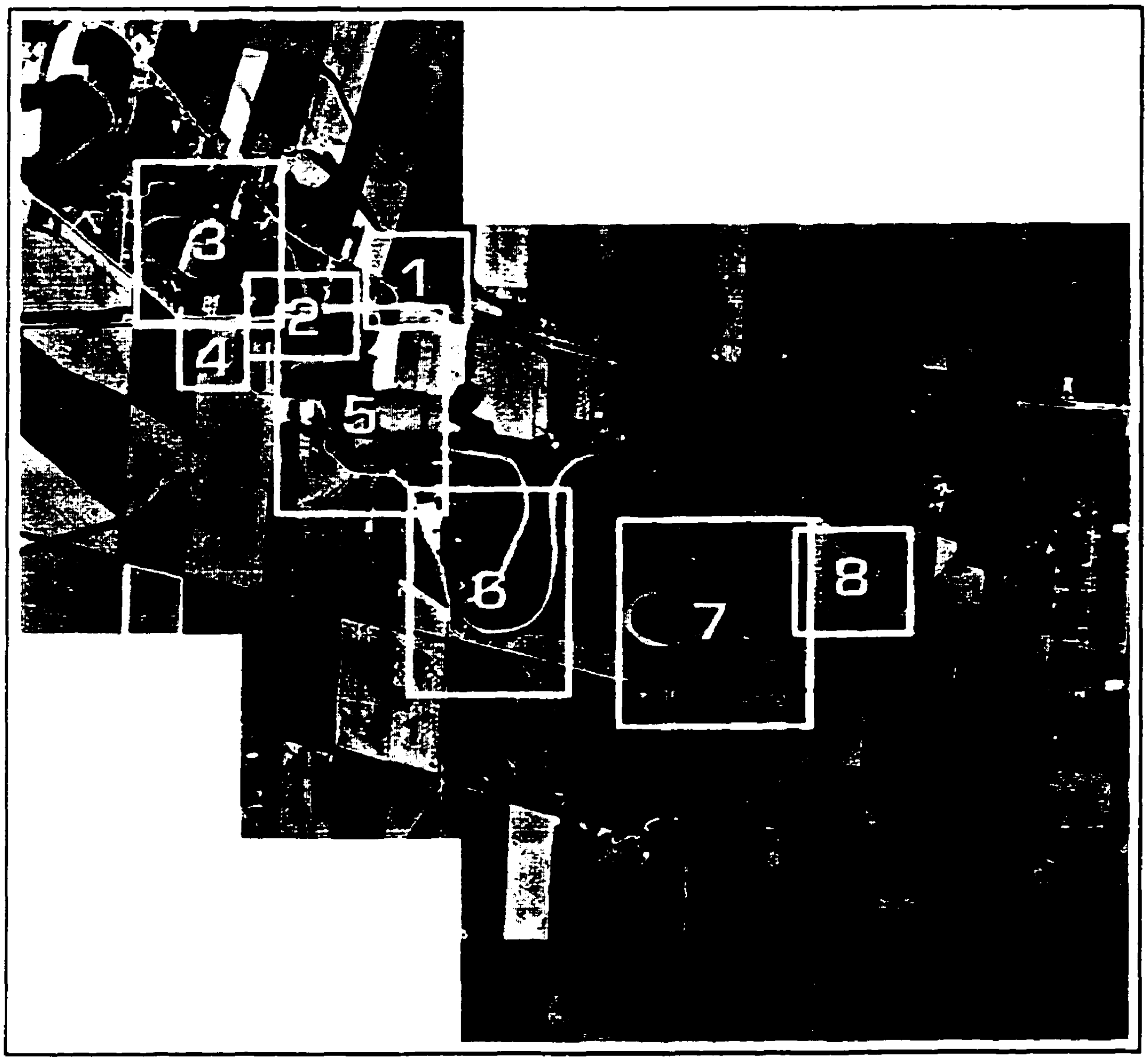

Figure A3–2 Location of Ground Verification Sites (ca. 1998)

All the aerial photographs used in this appendix are from the 6005520 series (ca. 1994), the most recent for this area. The use of the aerial photographs is merely intended to show the location and direction that the ground verification photographs were gathered.

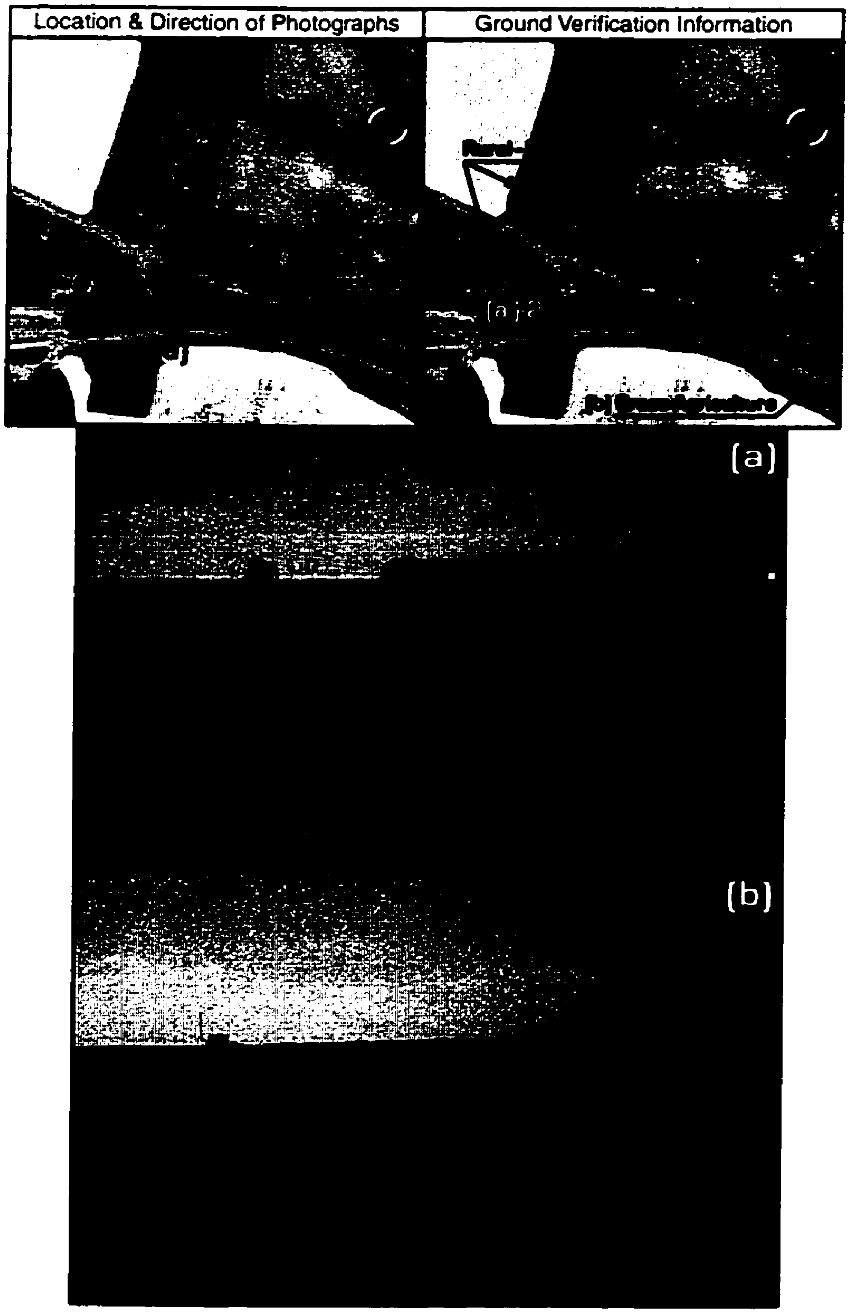

Figure A3–3 Ground Verification Site No.1

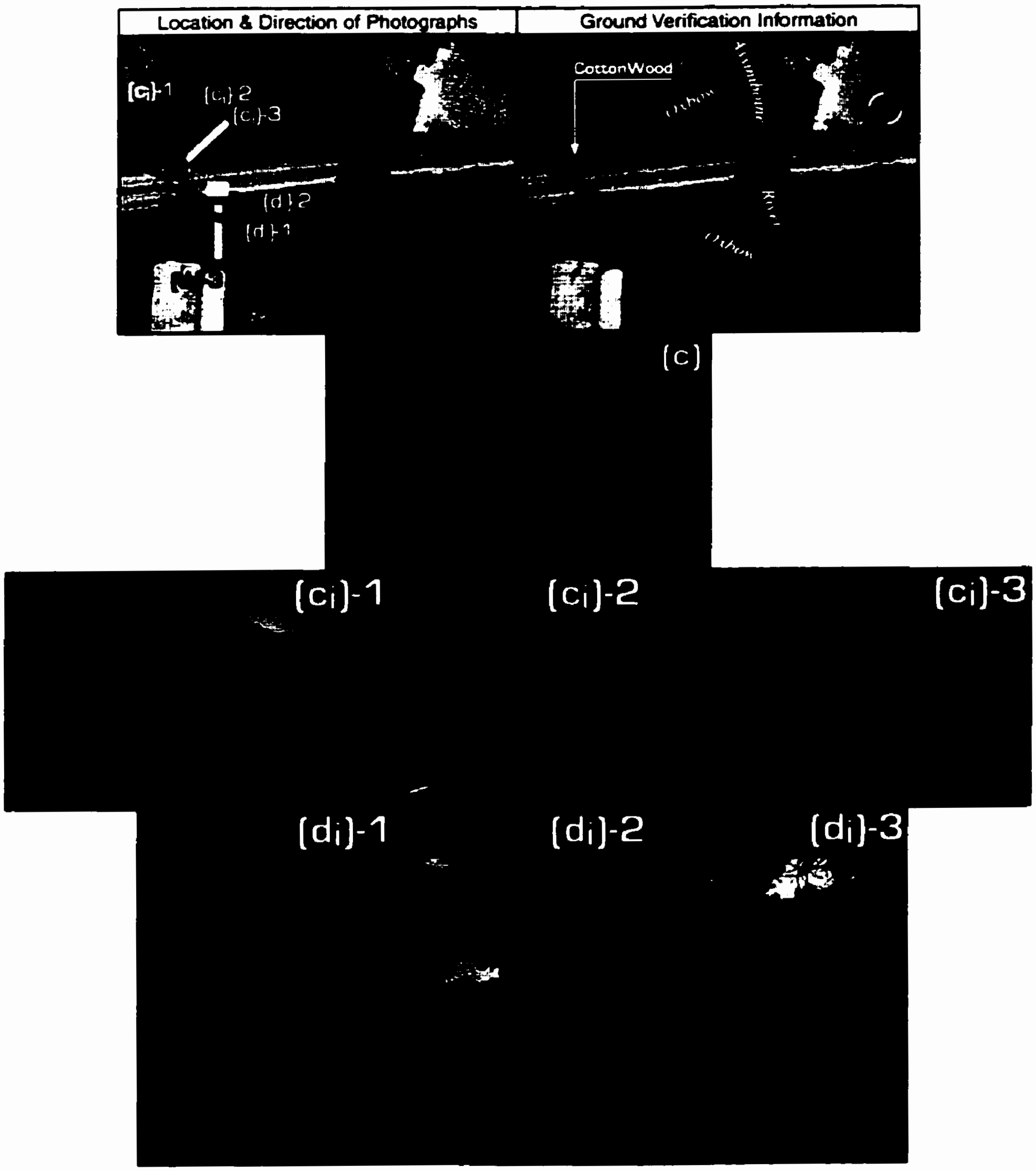

Figure A3–4 Ground Verification Site No.2

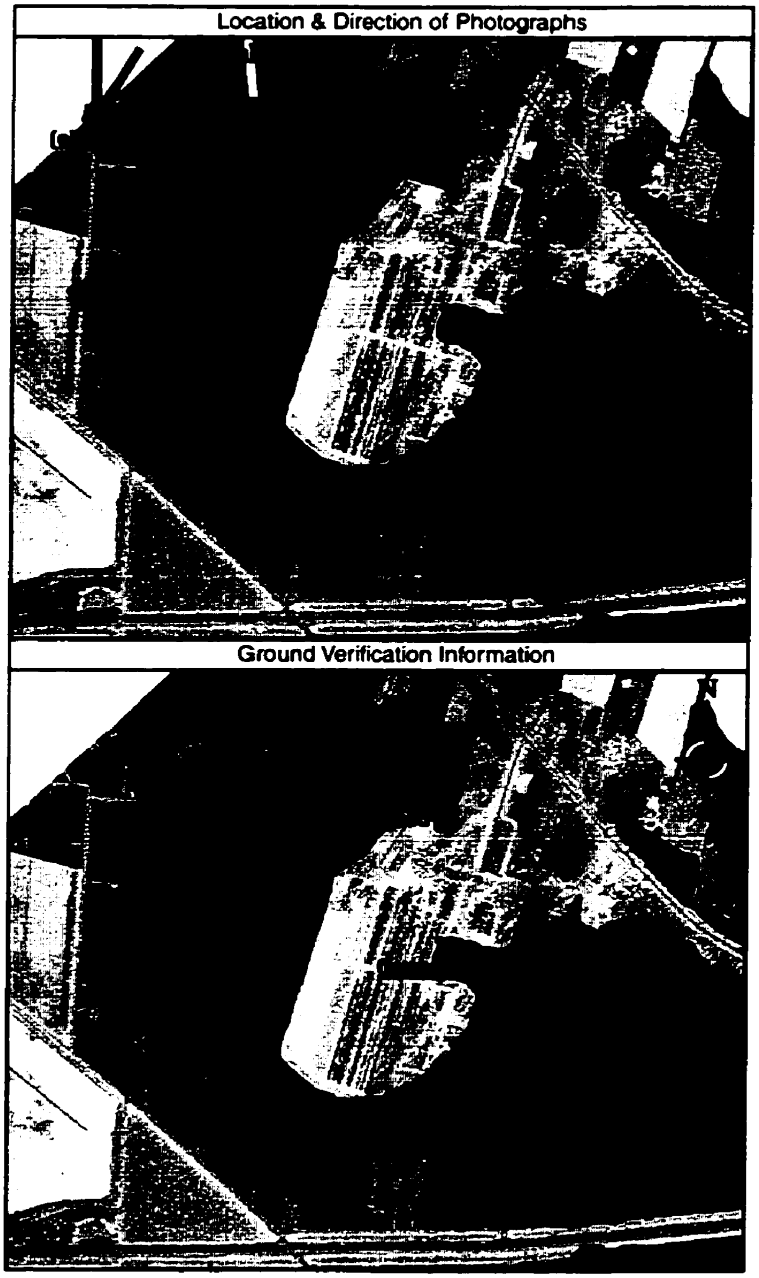

Figure A3–5 Ground Verification Site No.3 - Information

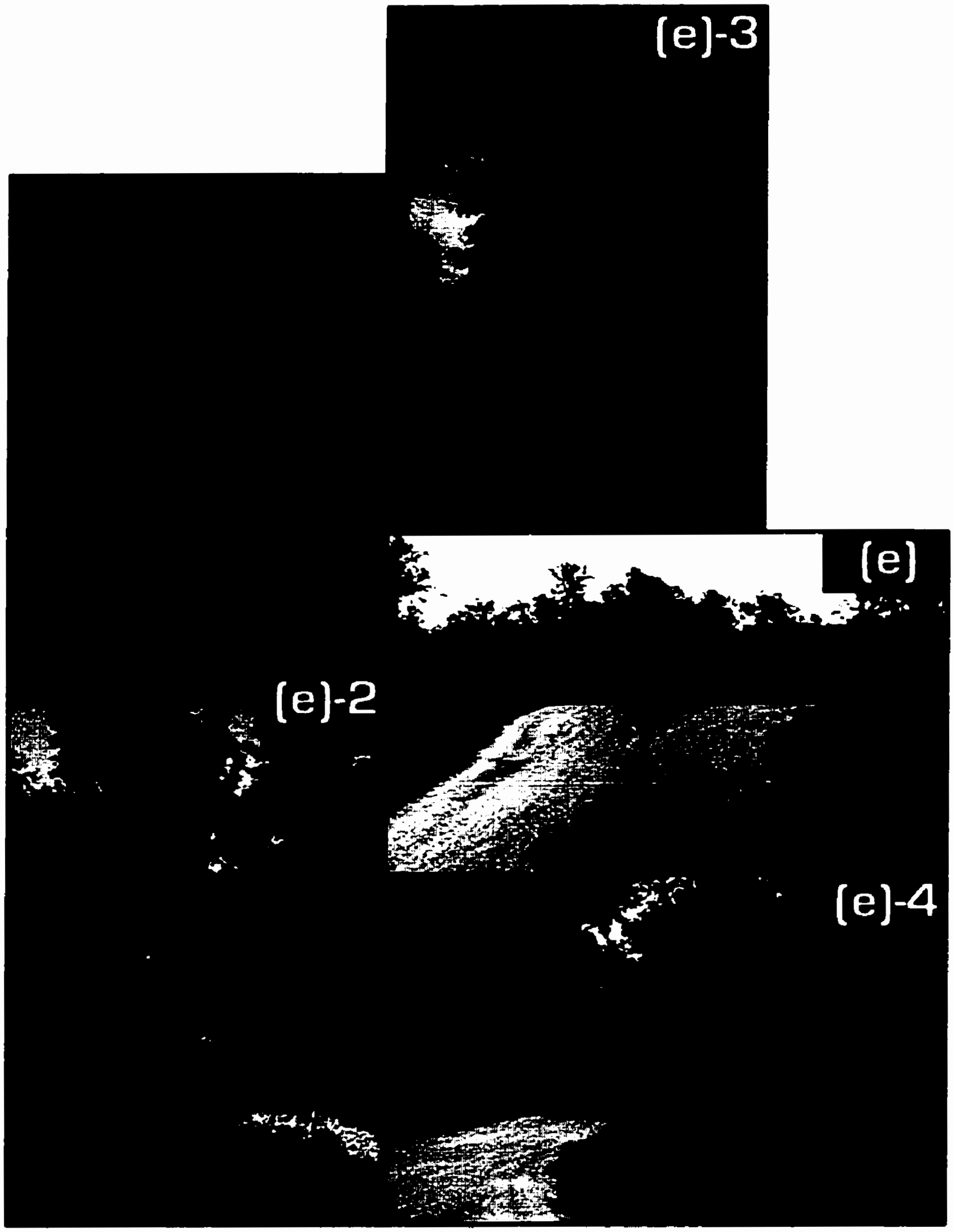

Figure A3–6 Ground Verification Site No.3 - Photographs [e]—[e]-4

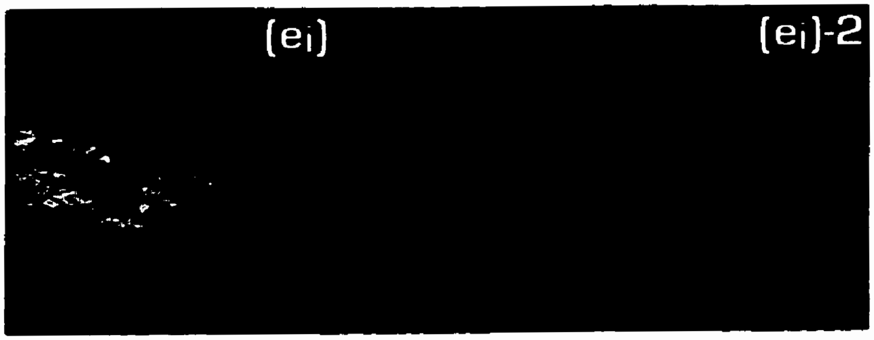

Figure A3–7 Ground Verification Site No.3 - Photographs [e_i] & [e_i]-2

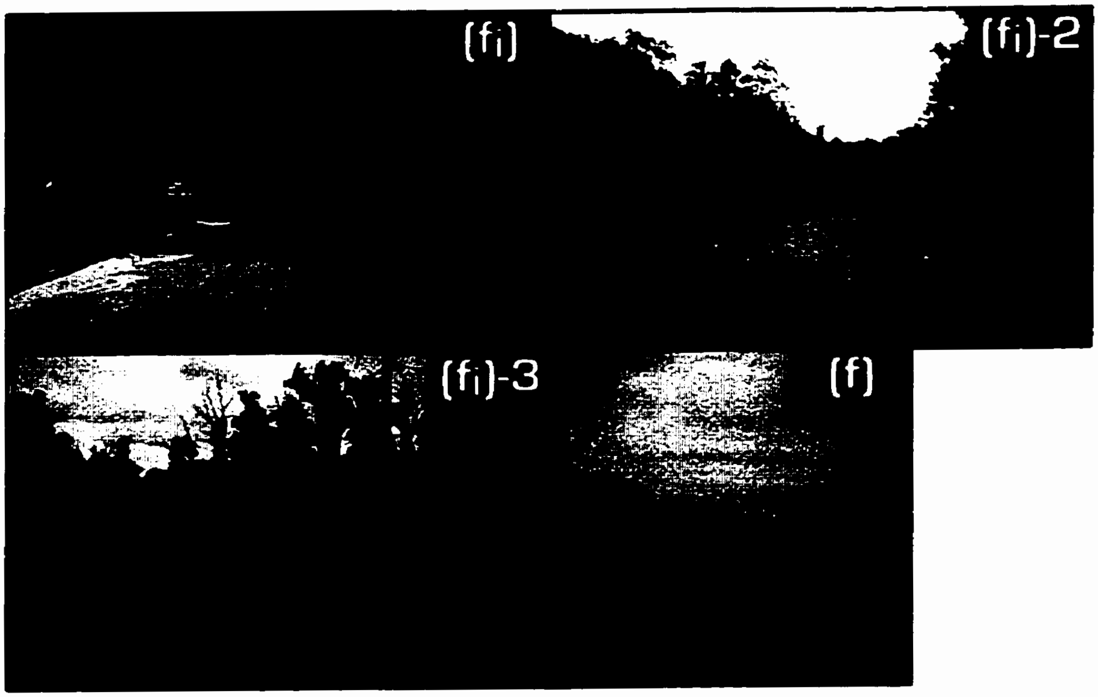

Figure A3–8 Ground Verification Site No.3 - Photographs [f], [f_i]—[f_i]-3

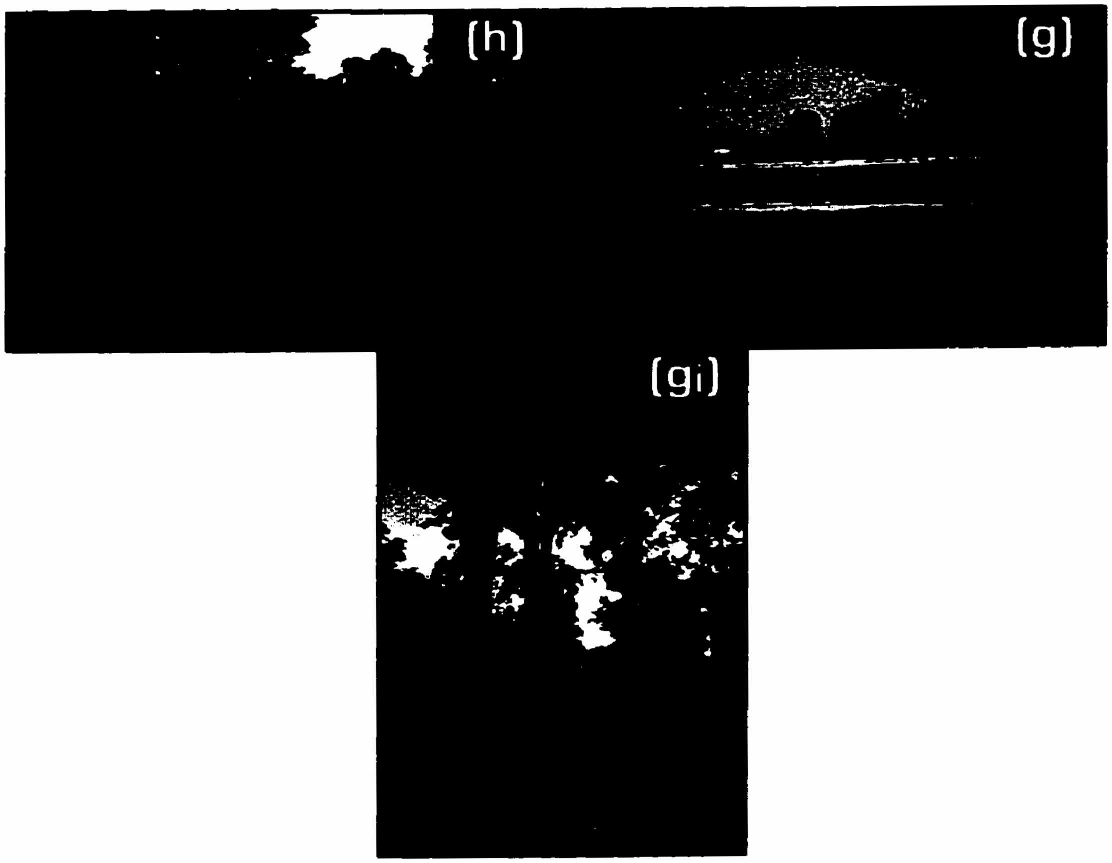

Figure A3–9 Ground Verification Site No.3 - Photographs [g], [g_i], [h]

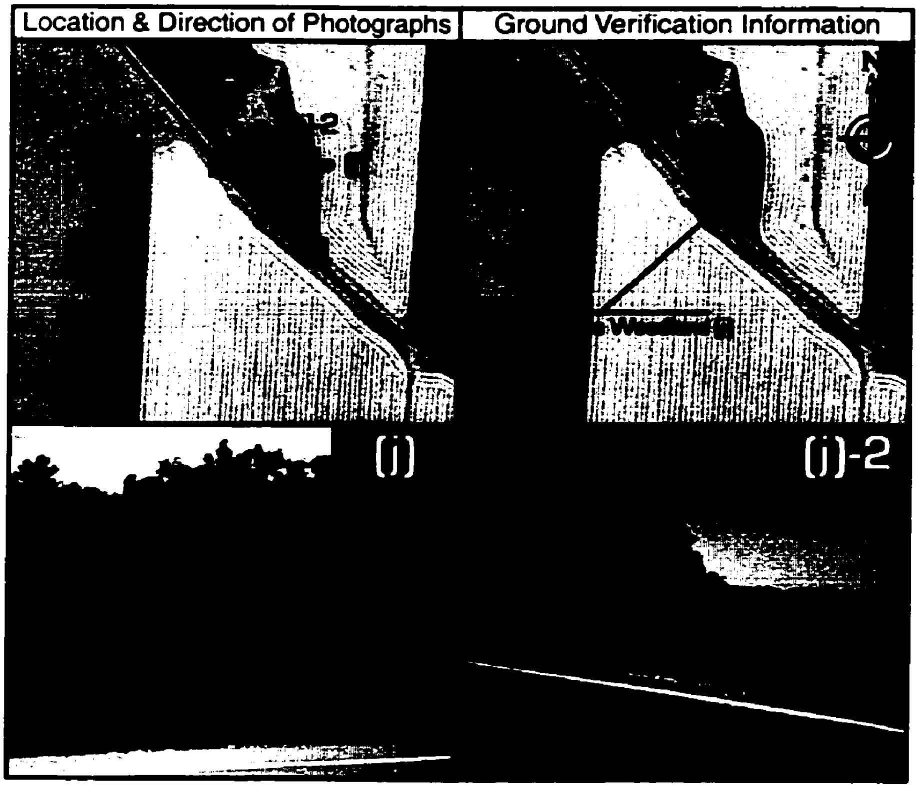

Figure A3–10 Ground Verification Site No.4

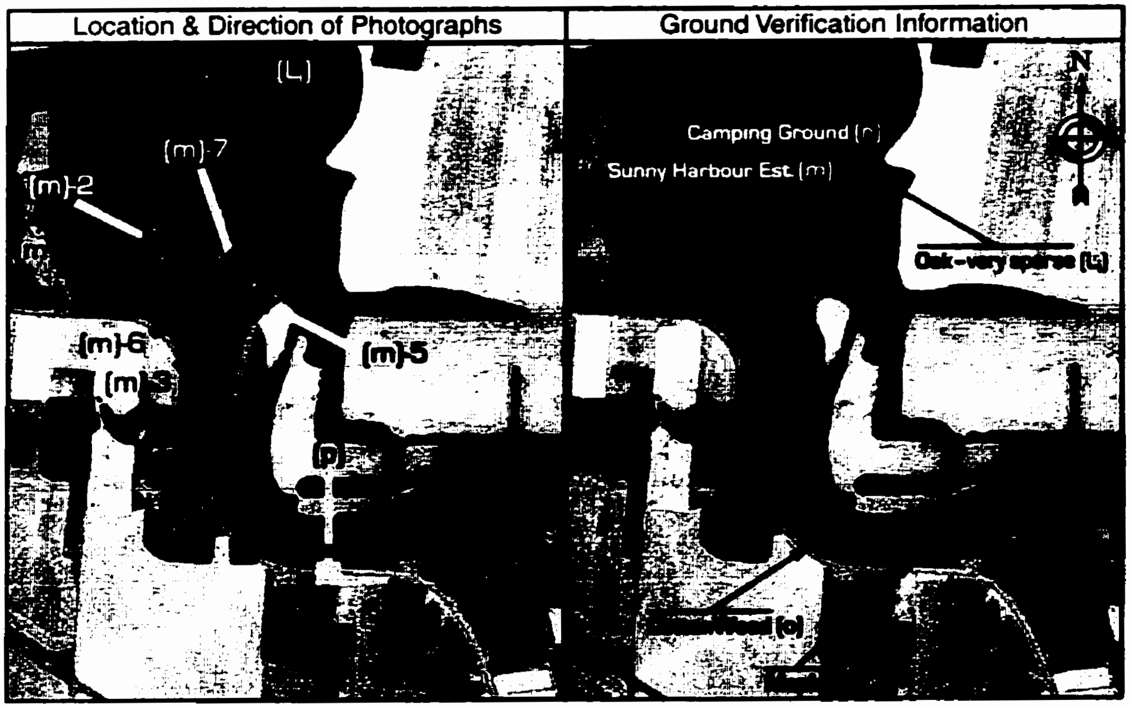

Figure A3–11 Ground Verification Site No.5 - Information

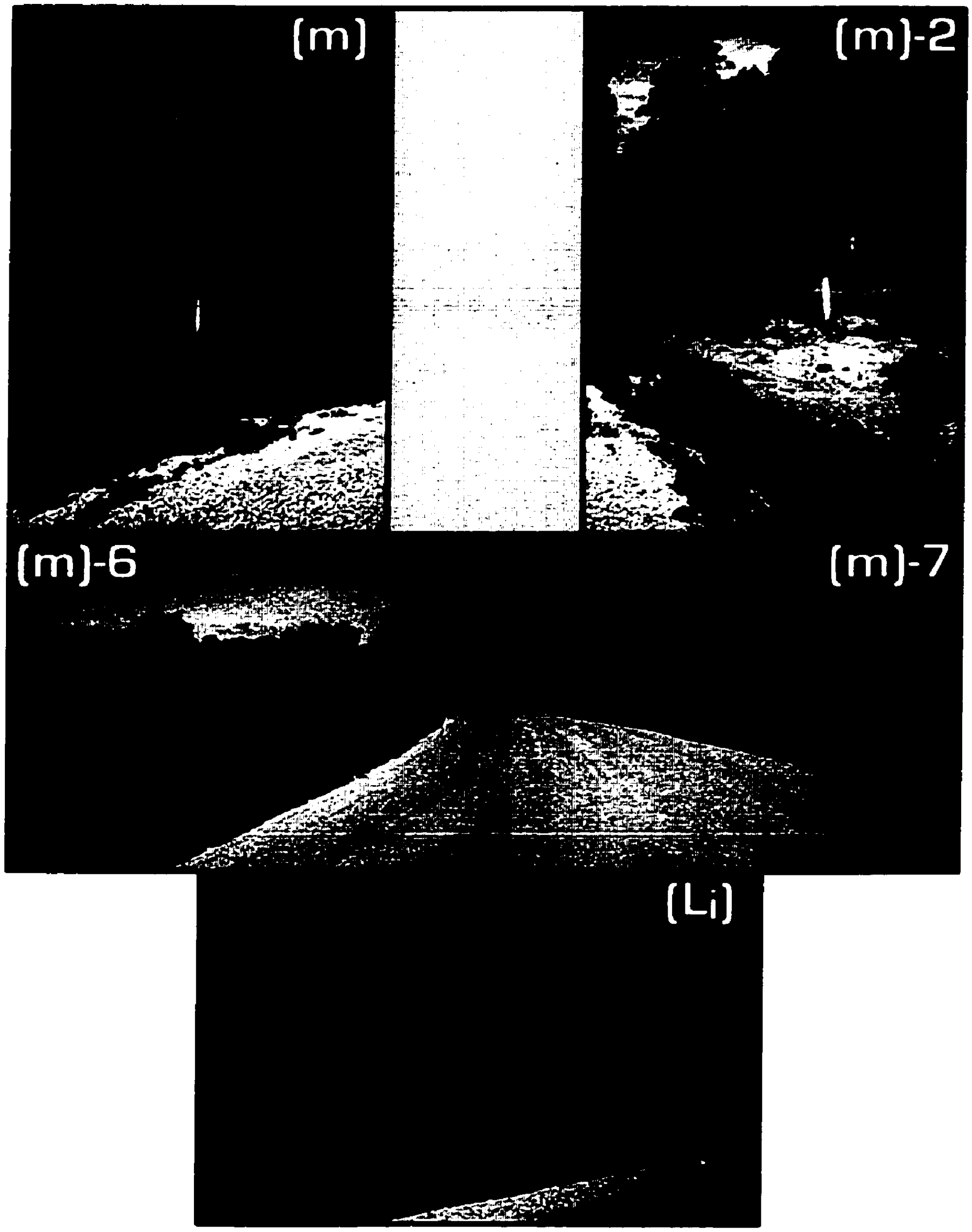

Figure A3–12 Ground Verification Site No.5 - Photographs [m], [m]-2, [m]-6, [m]-7 & [L_i]

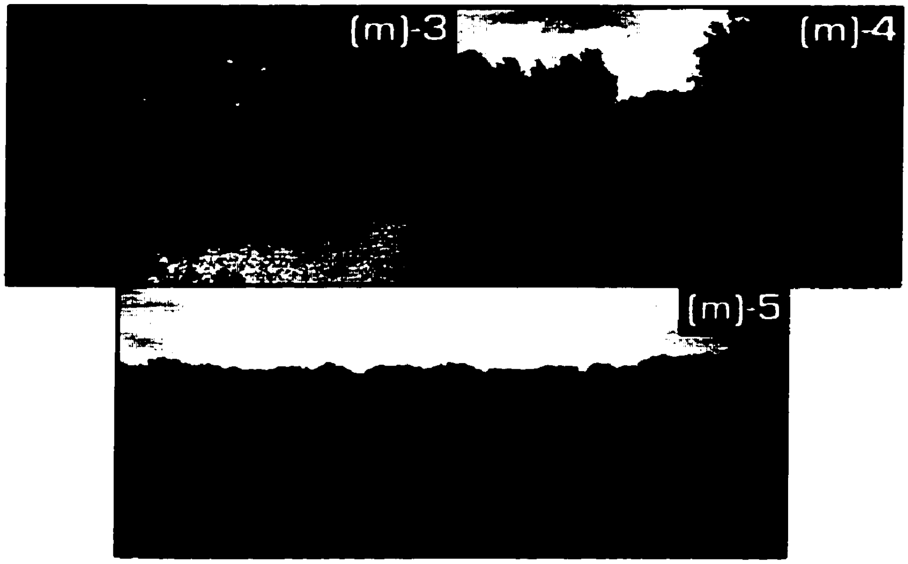

Figure A3–13 Ground Verification Site No.5 - Photographs [m]-3—[m]-5

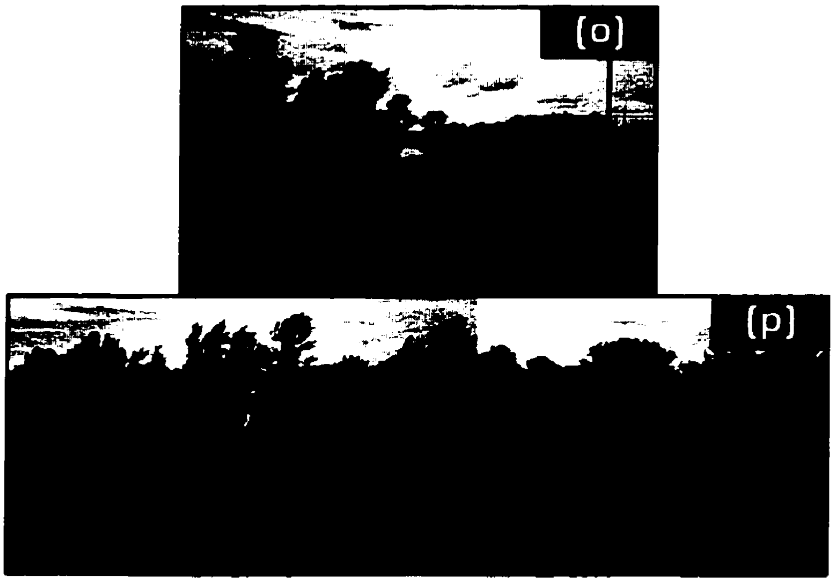

Figure A3–14 Ground Verification Site No.5 - Photographs [o], [p]

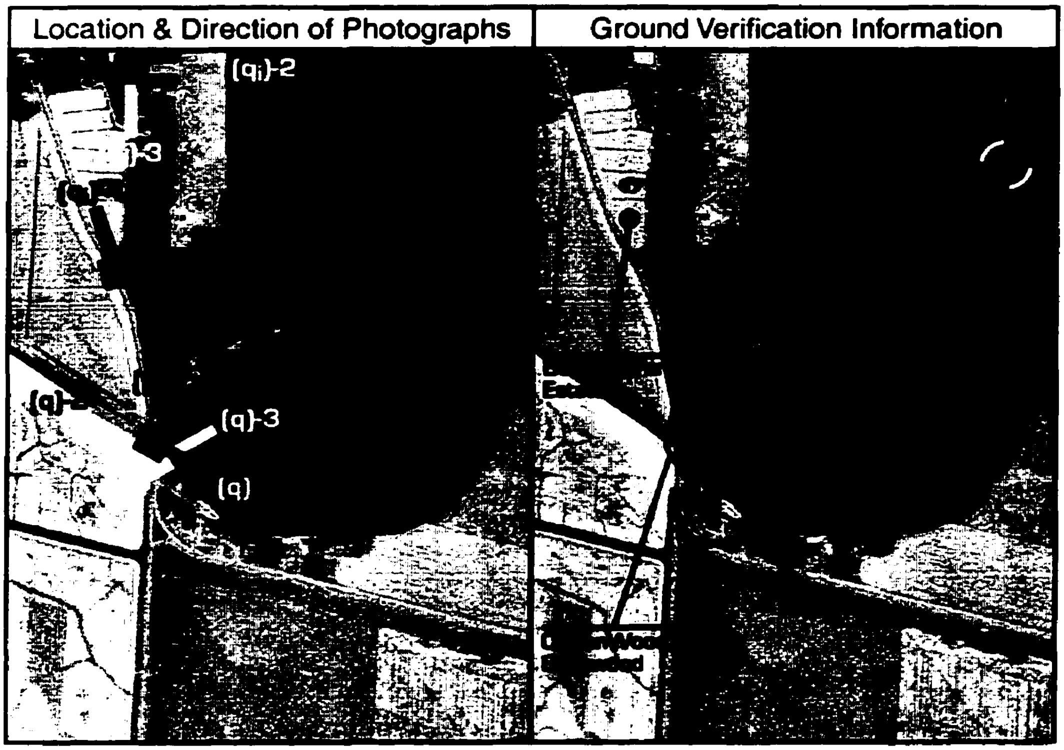

Figure A3–15 Ground Verification Site No.6 - Information

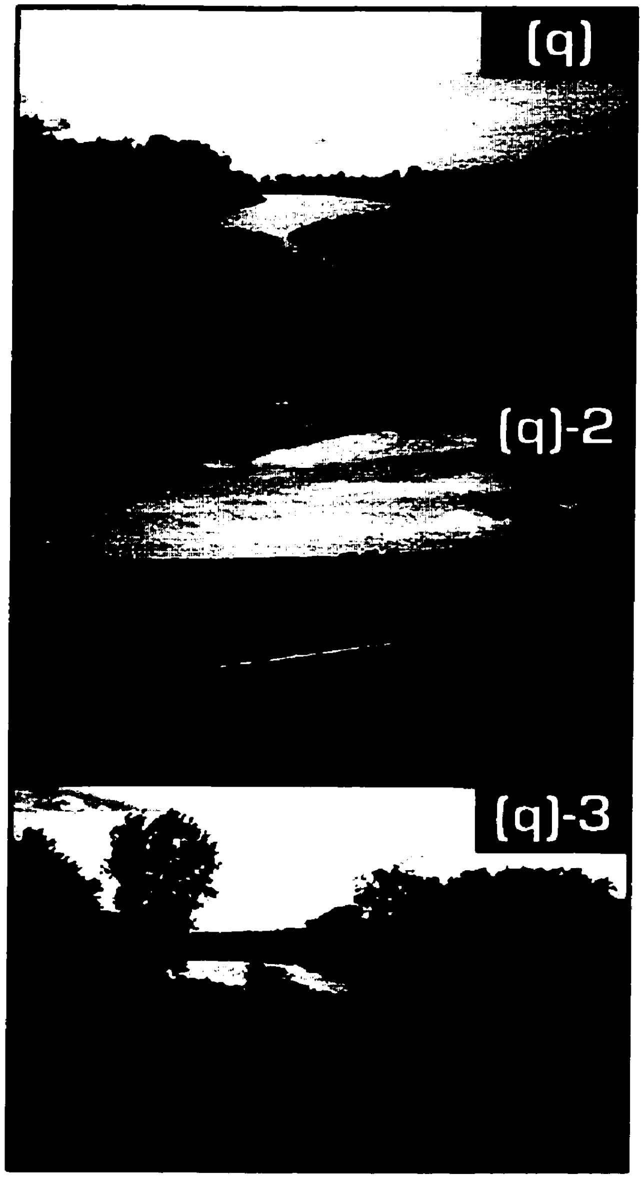

Figure A3–16 Ground Verification Site No.6 - Photographs [q]—[q]-3

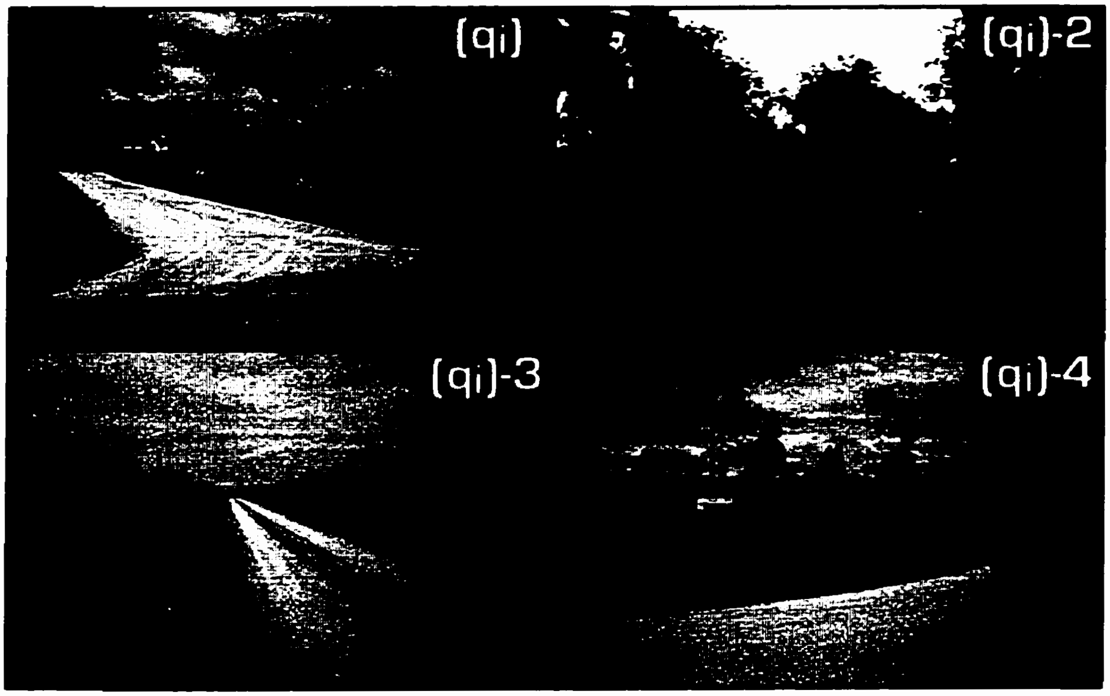

Figure A3–17 Ground Verification Site No.6 - Photographs [q_i]—[q_i]-4

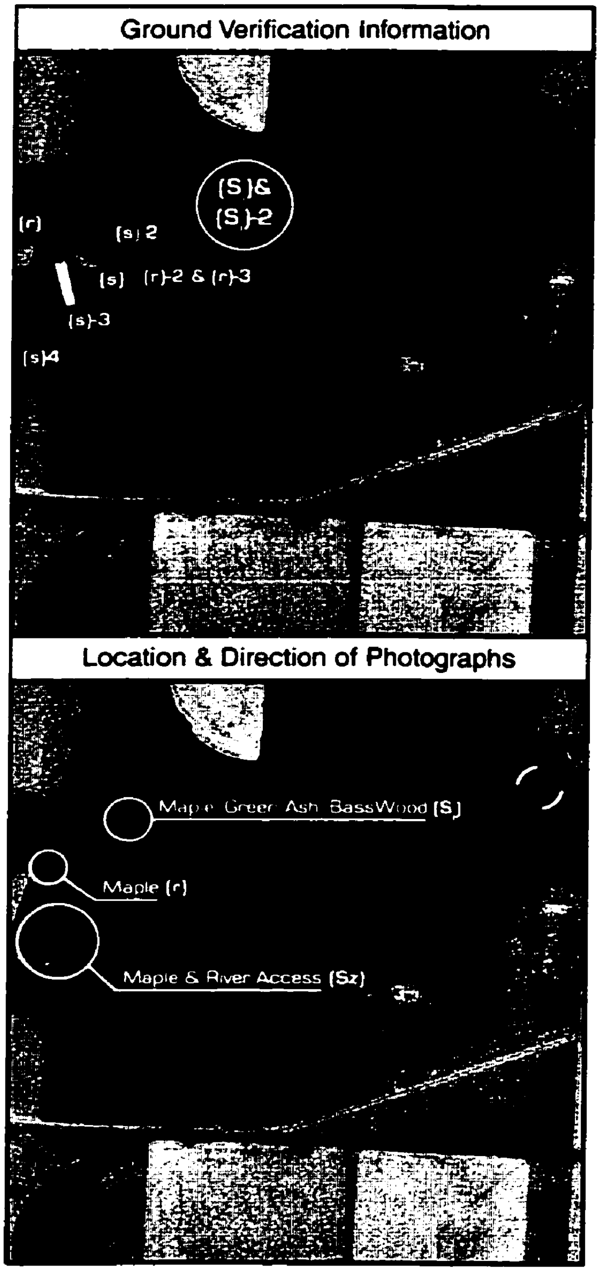

Figure A3–18 Ground Verification Site No.7 - Information

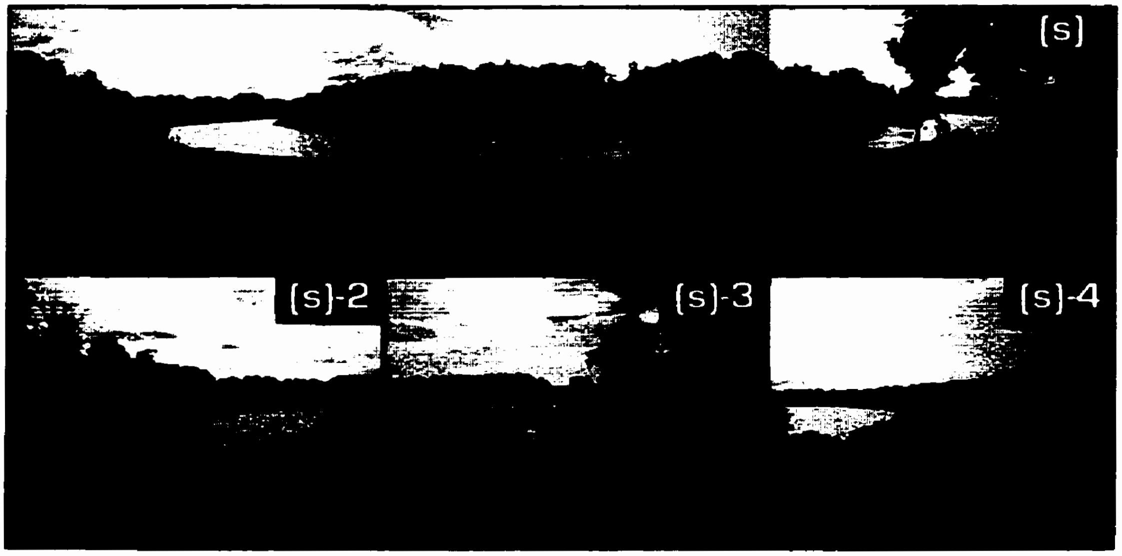

Figure A3–19 Ground Verification Site No.7 - Photographs [s]—[s]-4

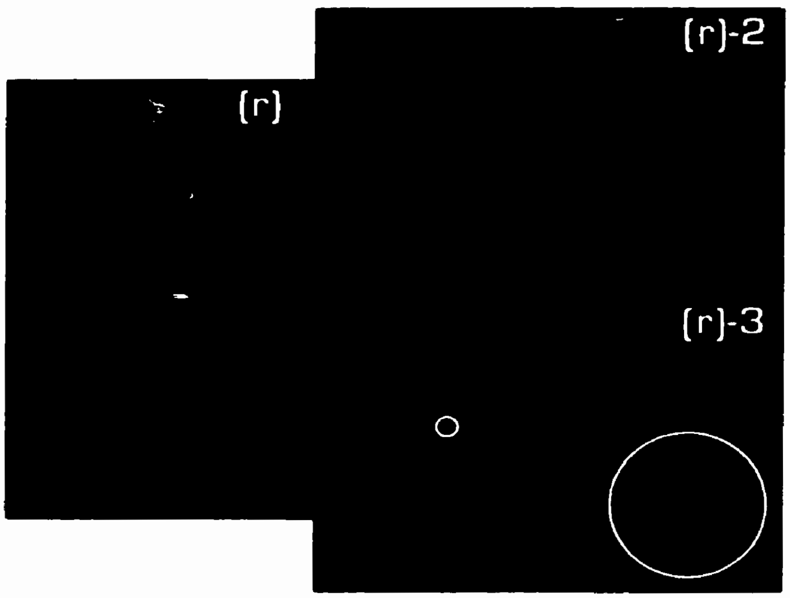

Figure A3–20 Ground Verification Site No.7 - Photographs [r], [r]-2

Figure A3–21 Ground Verification Site No.7 - Photographs [s_i], [s_i]-2

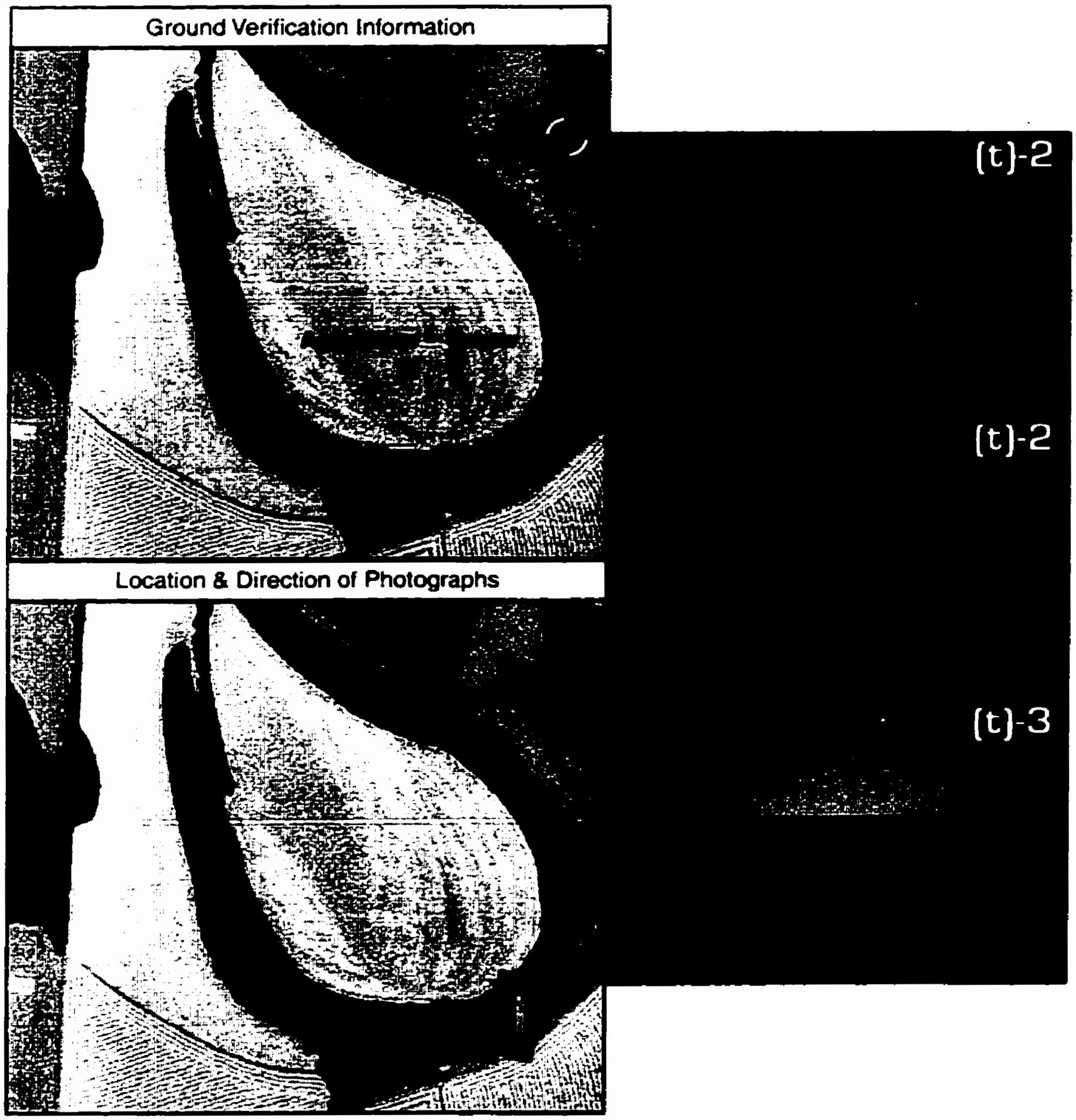

Figure A3–22 Ground Verification Site No.8