A LAND CLASSIFICATION TO INTEGRATE REMOTELY SENSED DATA WITH A PROVINCIAL GEOGRAPHIC INFORMATION SYSTEM

by

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A Practicum Submitted in Partial
Fulfillment of the Requirements for the Degree,
Master of Natural Resources Management

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ABSTRACT

The Cadastral Mapping Committee of Manitoba is developing a Multipurpose Land Information Network based on a geodetic reference framework, base maps, cadastral overlays, linkage mechanisms and specific land attributes. Of particular concern is the contribution that remote sensing can provide to this proposed provincial geographic information system. A standardized, integrated approach to land classification was considered. The Manitoba Land Classification System developed in this study was based on land cover classes that can be identified on imagery obtained by satellite and aircraft sensors. This interdisciplinary method may increase the utility of stored resource information for a variety of users and reduce the redundancy of single discipline resource data. User needs such as land cover types to be identified in resource inventories, map updates, map accuracy, scale of mapped data, and format of required data were assessed for resource managers and planners that use Manitoba land related information. These needs were then compared to existing classification systems to develop a common land classification system that enabled remotely sensed data to be integrated with a provincial geographic information system.

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At the completion of my practicum I had the opportunity to relax and reflect on the research process. I also had the time to evaluate and appreciate the assistance provided to me by the many people involved. It is those people to whom I would like to express my gratitude.

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Second, I would like to thank the other two committee members, Drs. Merlin Shoesmith and Andy Lockery. Both provided constructive criticism with regard to the application of the classification system and to the structure of the practicum.

Third, thanks go to the Manitoba Department of Natural Resources which funded this study, and to the people who see the results as a tool to plan future remote sensing and geographic information systems.

Fourth, the Natural Resources Institute staff, Dr. Walter Henson, and Mssrs. Thomas Henley and Rick Baydack, were instrumental in the practicum process of proposal writing, research design and final review. Chris Hofer prevented my frustration from reaching fatal levels by designing the Tables in chapter 4.

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INTRODUCTION

1.1 BACKGROUND

The natural resource managers' information requirements have been changing over the past decade and their questions have become more complex. Solutions require an integration of a diverse array of data types such as soils, topography, hydrology, land use, land cover, transportation routes, political boundaries, land ownership and census units into a well-organized information system.

All resource managers should be aware of the sources of information available which may aid them in decision-making. The Geographic Information System (GIS) will most likely be the one adopted by resource managers of the future (Myers,1982, Thome,1982, and Starr and Anderson,1982). In his outlook for the future Estes (1982) states,

> . . . computer based information systems are improving our capability for assembling, storing, and analyzing data in a framework designed to facilitate the resource management decision . . . The challenge of all of us today is to effectively combine these new concepts concerning relevant data with interpretations of existing data sources, explorations of the potential of remote sensing, and both the quantitative and qualitative capabilities of computers to provide new data types.

Inventory procedures used today by planning and management agencies have been developed using data that is routinely available. Now with an improved understanding of ecological systems and better equipment it is possible to specify environmental parameters that have not been directly or conveniently available in the past.

Test projects illustrating the potential of GISs have created interest in developing operational systems for provincial and regional applications. Some applications include:

1. planning for regional development, including transportation, recreation, preservation, new town development, location of mines, factories, and power generation plants (Dangermond and Smith, 1982);
2. location analysis for siting of radioactive waste deposits (Dangermond and Smith, 1982);
3. selection of land parcels to be made available by the government for sale to the private sector (Dangermond and Smith, 1982);
4. flood simulation and protection planning (Dangermond and Smith, 1982);
5. identification of agricultural land subject to urbanization (Marble and Peuquet, 1983);
6. updating forest inventories (Hegyi and Quenet, 1983); and

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7. design and layout of parks and wildlife refuges (Dangermond and Smith, 1982).

Some features that can be handled by a GIS include road networks (Plate 1:1), habitat potential (Plate 1:2), and land cover data derived from LANDSAT imagery (Plate 1:3), and many others depending on user specifications.

Plate 1:1 Road Networks

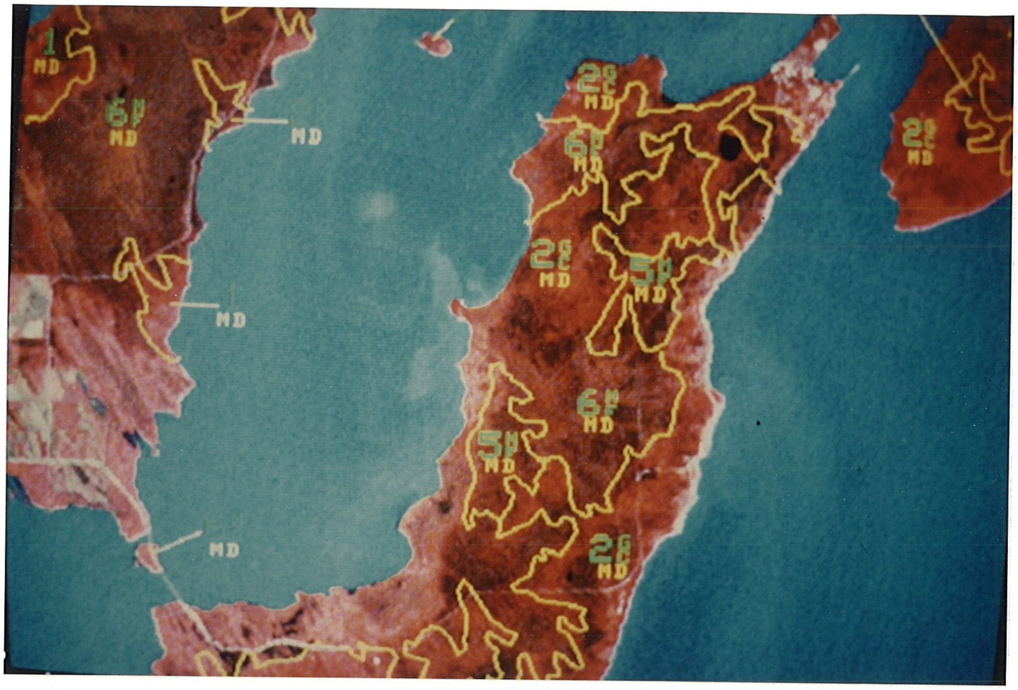

Plate 1:2 Habitat Potential

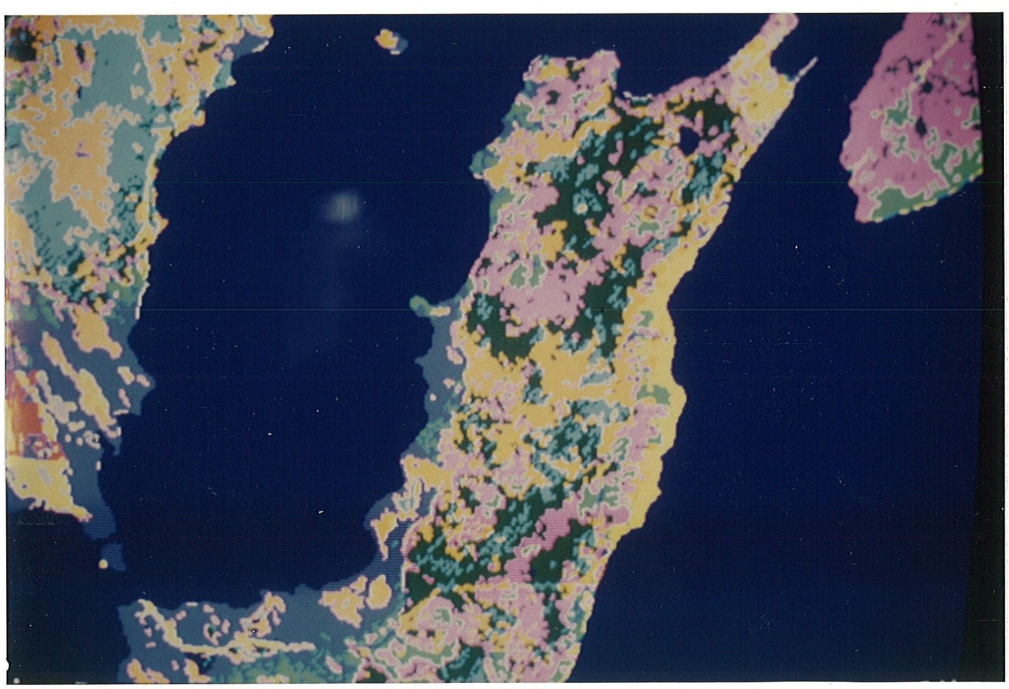

Plate 1:3 Land Cover from LANDSAT

Remote sensing provides a means of obtaining specific environmental data which can be utilized in a GIS. The value of this environmental data is dependent upon the sensor and its ability to produce timely and accurate information (Estes,1982). A GIS does not rely totally on satellite remote sensing input nor is it a prerequisite. Recognition is also given to other data sources such as aerial photographs, used to obtain land cover information, and maps indicating political boundaries and land titles. The information, obtained from aerial photographs and satellite imagery, useful to many users, should be determined. When the information is in a uniform format it will more easily be incorporated into a GIS.

The concern for integrating remote sensing and a GIS has arisen only in the past few years. Estes (1982) suggested a few reasons why there has not been a more concerted effort for integration:

-resource managers needed information systems that provide data rapidly. Only recently has remote sensing information been available in near time as processing techniques improved.

-automatic techniques of data extraction with remote sensing were not completely operational. Applications oriented data are now taking priority and the automatic techniques are now part of the data extraction process.

-remote sensing is not a contact method of data collection and this has resulted in somewhat lower accuracy than ground survey techniques. With a better understanding of classification algorithms and processing limitations, classification accuracy has increased.

-remote sensing was unspecific in what was collected. This resulted in an abundance of information that needed to be sorted out for further analysis.

-resource managers were skeptical of trying new techniques.

Now, the capabilities of remote sensing are beginning to be realized and utilized by many resource managers.

Before any inventory of natural resources can occur the resource manager must have a classification system available. "Classification is the ordering or arranging of objects into groups or sets on the basis of their relationships" and as such provides the resource manager with a structure for organizing their needed information (Kleckner, 1982).

Most resource classifications used today focus on single resources and are used for one limited purpose. Resource managers should now implement the concept of multiple use in land management. An integrated approach to resource classification is needed to fulfill multiple use mandates as stated in the <u>Roles and Missions Statements</u> of the Manitoba Department of Natural Resources (Manitoba, 1983).

When examining the role of remote sensing in developing a classification for a GIS, the spectral nature of the data should be considered to ensure that delineation is possible. There must be an exchange of ideas between data analysts and users (Merchant, 1982). Also, with computer classifications, Hoffer (1980) states that,

> Effective man/machine interaction is needed to develop classifications having the highest accuracy and reflecting the interests and needs of the users.

Thus, an efficient classification system should encompass the spectral nature of environmental parameters, the data users, and the capabilities of the processing hardware and software.

Cooperation and coordination with the federal government agencies concerned with resource information systems should not be overlooked when developing a provincial integration strategy (Starr and Anderson,1982). It is in a province's and nation's best interest to interact when developing a classification system, planning an inventory, deriving common terminology and sharing information (Kleckner, 1982)

The information system being considered in Manitoba was developed by the National Research Council (1980). This system (Figure 1:1) was built from the bottom up using the underlying components to attain the information indicated at the top.

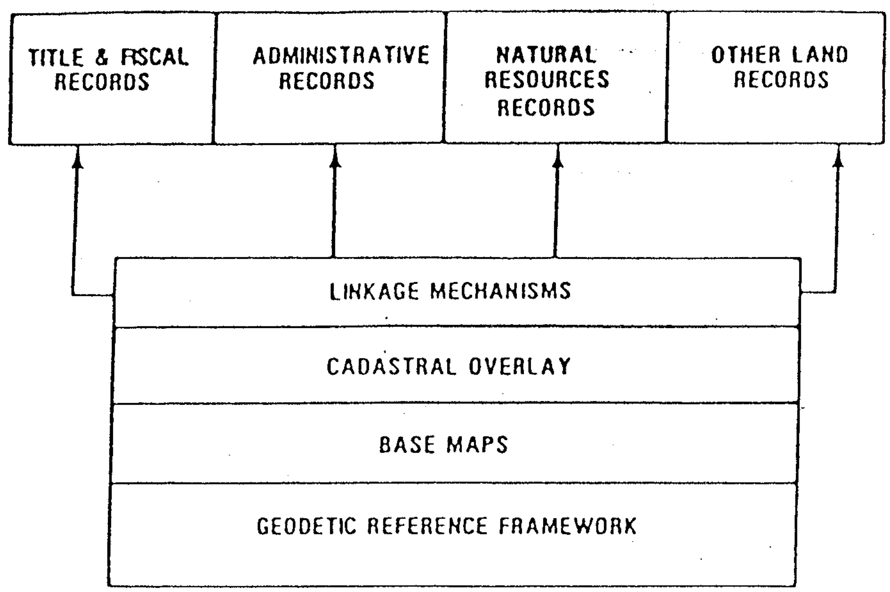

Figure 1:1 Envisaged Geographic Information System Model (National Research Council, 1980)

Geodetic Reference Framework

For all resource information to be valuable, it must be referenced to a location on the earth's surface. The reference systems used in Manitoba vary (Hicks, 1983 and Resources Data Task Force, 1977), making it difficult to link different data systems together. The Provincial Survey System Committee (Manitoba) is presently studying the need for a multipurpose referencing system including the design concepts for such a system.

Base Mapping

Base maps are used to display natural and man-made features with reference to a specific location on the earth. These base maps may be used by any agency to overlay their mapped information to create new maps with the various attributes they may desire.

Cadastral Mapping

The cadastral overlay permits collection, storage and analysis of data on individual parcels of land. Property ownership, assessment records and zoning information are examples of data that can be recorded in this layer.

Linkage Mechanisms

To link information from various land record files the system needs a linkage mechanism such as a standard index or a unique identifier (i.e. standard terms; procedures; data storage; and retrieval units). There is a lack of a standard indexing system which makes it difficult, if not impossible, to exchange information between systems operated by various user groups.

The Land Information Network Advisory Committee (previously called the Cadastral Mapping Committee) has been working towards the development of a Multipurpose Land Information Network for Manitoba. The Committee believes that a needs analysis will aid the development of an operational system (Cadastral Mapping Committee, 1984).

1.2 PROBLEM STATEMENT

Presently there is no program in Manitoba to integrate remotely sensed data with a provincial geographic information system. The lack of models utilizing an interaction between these technologies has isolated the design of remote sensing techniques, hardware and software from the concepts of GIS design and from the possibility for improved processing, interpretation and utilization that is offered by efficient information systems. Efficient information systems are important, in the area of resource management decision-making, to improve the resource manager's understanding and appreciation of the information drawn from data sources.

Integration of remote sensing and a GIS is dependent upon the realization that the potential of each cannot be achieved until they are fully integrated (Estes,1982). The Department of Natural Resources (Manitoba) is aware of this problem and is concerned with developing an integrated system for Manitoba.

A multiple use classification system is desired to enable integration of remotely sensed data with a GIS, but choosing or designing the optimal system depends upon knowing the needs of resource managers in Manitoba. An assessment of inventory needs and a review of past classification systems was conducted to determine alternatives open to Manitoba. When integration is accomplished, time, money and personnel will be used more efficiently.

1.3 OBJECTIVES

The objective of this study was to design a land classification system which would enable integration of remotely sensed data with a provincial geographic information system. The sub-objectives were:

- to identify the information needs (that could be provided by remote sensing technology) of resource agencies in Manitoba;

- to assess the role of federal government cooperation and coordination;

- to develop a classification system that will be capable of meeting the multiple demands of a variety of the resource agencies in Manitoba;

- to determine the rate at which the stored remotely sensed data should be updated; and

- to test the multiple use classification (derived from remotely sensed data) and determine its capability for integration with a provincial GIS.

1.4 METHODS

Provincial resource agencies' data needs that could be addressed more effectively through the use of remote sensing/GIS technology were identified. This is the first step in developing an integrated strategy (Merchant,1982 and Van Hooser,1982). This information was obtained with standardized questionnaire forms (Appendix A), interviews and a combination of both.

As the spatial resource information required by the province changes, it would be necessary to determine when the data information system should be updated (Hoekstra, 1982). The need for cyclical updating was considered when determining the needs assessment.

A classification system, entitled the Manitoba Land Classification System, was compiled using information obtained from resource agencies and from existing literature on classifications for regional and specific resource applications. Consideration was given to the concepts of classification, capabilities of remote sensing technology and geographic information systems.

After the classification system was compiled, it was tested in three areas of Manitoba. The three areas were chosen to represent a boreal, transitional and agricultural environment (Figure 1:2). The image analysis system at the Manitoba Remote Sensing Centre was used to analyze existing provincial computer compatible tapes (CCT). The multiple use application of the remote sensing classification was determined using an information quality test devised by Mead (1982) to assess its capability for integration with a GIS for Manitoba (Appendix B).

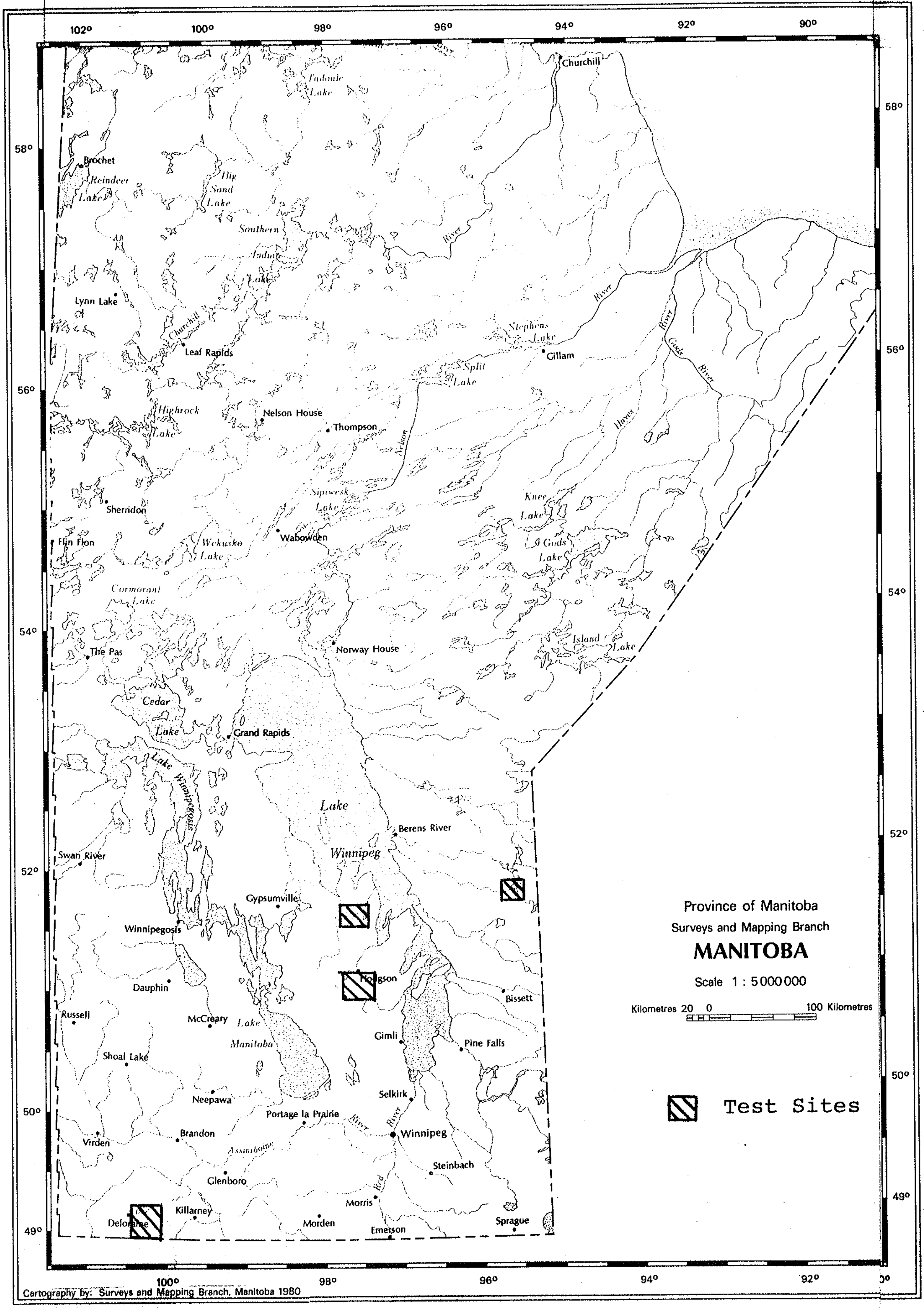

Figure 1:2 Location of Test Sites

1.5 IMPORTANCE OF THE STUDY

Over the past decade there has been an increased demand by resource managers for improved responsiveness both in generating and updating special purpose maps and statistical information. With the results of this study the Province of Manitoba can move toward the achievement of a long range goal. Timely production of data on natural resources that are spatially accurate and can be processed into information relevant to management decision-making should be the objective of this goal (Estes, 1982).

Integrated land classifications that are derived from remote sensing techniques and are compatible with a provincial GIS would decrease inventory costs and increase the manager's capability to generalize, to extrapolate research results and to share management experience (Kleckner,1982). This study should assist in determining the path Manitoba must follow to secure effective integration of remotely sensed data with a provincial GIS.

A GIS would not only benefit the Department of Natural Resources but would be an asset to all agencies that have a need for resource mapping and inventories. This would include the Manitoba Government Departments of Northern Affairs, Municipal Affairs, Agriculture, Highways and Transportation, and Manitoba Hydro, many private resource industries, consultants and educational institutions.

1.6 LIMITATIONS

This study has been restricted to Manitoba, however the information could be used to develop integration strategies for other provinces in Canada.

This study does not recommend an ideal GIS for the province; rather, it develops a standard remote sensing land classification to be used in a provincial GIS.

1.7 OUTLINE OF THE STUDY

The second chapter reviews the literature related to past and current attempts to develop classification systems for land resources and related information. The third chapter outlines the methods used to obtain the inventory needs of resource managers and the criteria for developing a classification system. The fourth chapter summarizes the results of the questionnaire and the user needs of resource managers working with Manitoba land data. Chapter five discusses the Manitoba Land Classification System developed for the incorporation into a provincial GIS Chapter six includes the conclusions, summary and recommendations based on the findings of this study.

Chapter II

REVIEW OF RELATED LITERATURE

2.1 INTRODUCTION

This chapter discusses classification system criteria, some of the problems encountered when designing a classification system, and the role remote sensing plays in the management of natural resources. Examples of specific and general operational classification systems used in the United States, Canada and some provinces illustrate the progress that has taken place over the last two decades. Findings of the Resources Data Task Force (1977) provide some goals that Manitoba should be attempting to achieve.

2.2 CLASSIFICATIONS

Sokal (1974) believes that the primary purpose of classifications is to describe the structure and relationship of similar objects or features. These relationships should be simple to allow general statements about classes in order to permit groupings of objects under a common nomenclature. The resulting classification would increase our knowledge of the world by allowing us to generate and test hypotheses.

Certain general principles and requirements for classifications have been put forward by resource managers. These include:

1. some classifications are more suited to general (multiple) use than others (Kleckner, 1982);
2. a classification should be designed for a specific purpose; seldom does it meet the requirements of two purposes (Kleckner, 1982);
3. a classification is never complete; it must be changed as more is discovered about the object being studied (Kleckner, 1982);
4. correlation with existing systems should occur (Ryerson and Gierman, 1975; Schubert, 1978; Parker, 1982); and
5. the classification should be simple to be used by those with minimum training (Hays, 1982).

Structural characteristics that have been suggested include:

1. mutual exclusivity between divided classes (Kleckner, 1982 and Hays, 1982);
2. hierarchical classification to be usable at different levels of resolution (Hays, 1982 and Parker, 1982); and
3. accommodation of component (an individual attribute) systems in the classification (Parker, 1982).

When considering technical aspects of the classification it is suggested that:

1. the descriptors and states of different classes should commonly be found in a region of the country (or province)(Hays, 1982);
2. the descriptors and states should be inexpensive to measure (Hays, 1982); and
3. the descriptors and states should have a minimum degree of seasonable variability (Hays, 1982) or be suitable for use with remote sensor data at different times of the year(Anderson, 1971).

Along with these criteria, the classification system should be flexible to permit application over a broad area (Kleckner, 1982).

In 1978, an Interagency Agreement Related to Classifications and Inventories of Natural Resources was reached by the United States Department of the Interior (USDI) Bureau of Land Management, the USDI Fish and Wildlife Service, the USDA Forest Service, the United States Department of Agriculture (USDA) Soil Conservation Service and the USDI Geological Service. The purpose of the Agreement was to improve coordination and avoid duplication of resource classifications and inventories (Powell, 1982). A terminology work group was organized to develop criteria for defining terms to be used in classification systems. The criteria are:

1. consideration given only to major terms;
2. terms should define acreages (or land units) that add up to 100 percent of the total area - no areas should be left unclassified or be left unclassified;
3. land cover should take precedence over land use;
4. terms will not be related to ownership, management or landforms; and
5. no succession related ecological terms will be used.

With all of these criteria stated for classification systems, it would seem that the ideal system should now be designed. However, the variety of problems that have arisen are numerous.

Problems of past classifications have arisen:

> . . .when we try to combine the results of different inventories conducted to measure a variety of resources for a common land base (Powell, 1982).

Another problem has occurred when classification systems encompass both land use and land cover categories. This will result in a total area calculation larger than the total land area inventoried. Overlap is inevitable in these situations because a land parcel may have more than one use. Reasonable and logical comparison cannot occur because there is no common theme or pattern in the inventories.

When a number of managers are brought together to develop a classification system, problems arise (Hays, 1982). These problems are caused by:

1. a nonaligned stand on an unchanging and clear purpose for the classification;
2. disagreement by the managers on a basic philosophical issue: is the classification being developed to reflect a presumed underlying principle or is it to be a tool based on what works best for an application, no matter how independent it is of general theories?;
3. an obscure statement of the scope of the classification;
4. a lack of criteria for acceptability of the classification;
5. a lack of a logical step by step action plan, and an inadequate documentation of results obtained in the classification process;
6. the introduction of new authors and reviewers who disturb the design process and have to be brought up to date after the project is underway; and
7. a lack of clear definition of critical words used in the classification.

Hays (1982) expounds further on the definition problem in his conclusion, saying, ". . .writing adequate definitions of the descriptors and their states is the hardest part of the design effort." Definitions can be either short and simple or long and complex. Each of these has their unique problem, the former are always vague and ambiguous and the latter are hard for the reader to comprehend. If either is attempted, Hays believes that the results will be undesirable. Therefore, an attempt to properly define classes should consider these problems, and try to find an acceptable middle ground using simple, easy to comprehend definitions that are clear and unambiguous.

When a classification system is designed and implemented, it usually provides the resource manager with a source of information which he uses to make decisions. However, a classification system is seldom designed for a one-time inventory. Resource maps and data must be kept up to date if effective planning, management and utilization of resources are desired.

2.3 REMOTE SENSING

A myriad of reports and articles have been published highlighting the capabilities and limitations of remote sensing, especially since the launching of the first LANDSAT satellite (ERTS-1) in 1972. Because of its sensors' ability to generate spatial data on land, water and environmental conditions, LANDSAT has been used extensively in resources management.

In assessing past achievements and future needs for remote sensing, Godby and Thie (1981) divide the natural resource management process into five phases:

1. objective/opportunity/problem definition phase;
2. inventory/information analysis phase;
3. planning/policy development phase;
4. implementation/operation phase; and
5. monitoring/controlling phase.

Remote sensing is expected to contribute in the inventory and monitoring phases. Resource managers require timely, accurate and cost efficient information from their inventories, or monitoring programmes. Natural resource managers must be able to classify their resources before they can inventory them, otherwise, every object would be recorded individually as a unique occurrence.

2.3.1 Updates

Milazzo (1982) suggests that the frequency of update is dependent not only on the dynamics of change and the availability of inventory funds but is related to:

> . . .the type of change, the relative importance of change, and to the location, concentration and amount of change . . . In addition, the ability to update is also dependent upon the availability of suitable remotely sensed source materials.

Update frequency can be based upon elapsed time (such as every 5-7 years for urban areas, or 15-20 years for more stable land areas) or upon land use change (where the occurrence of a certain amount or type of change creates a need for the frequency of update).

Milazzo recommends that current base maps, used for updating the status of resources, should provide adequate reference or control data. This is needed to ensure that the mapped data are accurate in relation to ground location.

2.3.2 Accuracy

Accuracy is usually an important consideration in mapping projects, however it has different meanings to different users of the mapped data. Accuracy is commonly represented as a percentage, however, it is usually insufficient to state a percentage without some type of qualification.

Two types of accuracy assessment procedures are commonly used: non-site-specific and site-specific (Mead and Szajgin, 1982). Non-site-specific accuracy is an expression of the comparison between the total number of hectares classified using LANDSAT imagery and the total number of hectares determined from reference or field data. Location is ignored. Site-specific accuracy compares how two spatially defined data sets are registered, as well as considering correctly classified pixels. The site-specific method is considered to be a more rigorous and informative appraisal of a map product.

A number of factors can affect the accuracy (site-specific or non-site-specific) of a classification. When conducting a mapping project, classification results can be affected first by the complexity of the classification system itself. For example, a two class system, such as land or water, would undoubtedly provide better results than a classification with one hundred classes. The higher the number of classes, the more likely it is there will be spectral similarity and thus more class confusion. Horn and Render (1984) state,

> The ability to accurately identify cover types varies with each individual cover type and is dependent not only on a cover type's spectral signature but also on the number of additional cover types included in the classification with similar spectral signatures.

Complexity of the surveyed environment increases the likelihood of mis-classification, as does quality of the imagery and its resolution.

Errors can arise in raster data (satellite imagery) in edge (or boundary) pixels. These are pixels that have a mixed signature because the land surface they fall on represents two land cover types that abut each other. Depending on the classification algorithm used, the pixel may or may not be included in the region of uniform cover (Crapper, 1980). Sometimes these edge pixels are included in a separate class of land cover different from either side of the boundary.

Biases can enter into the accuracy assessment when researchers express how similar the training areas (used for generation of classification statistics) are to the check-training areas (used for accuracy evaluations). By locating check training areas in places of known cover types, accuracy can be erroneously raised to 100 percent (Pokrant and Gaboury, 1983 and Kalensky, Moore, Campbell, Wilson, and Scott, 1981). The bias can be reduced by ensuring that the training data represent the variability present in the LANDSAT scene.

Confusion matrices have been used in Manitoba to demonstrate the correlation between classification results and check training areas (Pokrant and Gaboury, 1983, Horn and Render, 1984, Horn and Lahaie, 1984, and Dixon and Stewart, 1984). Errors in omission and commission can then be assessed. Elsewhere, standards in accuracy assessment have not been set for thematic maps (Mead and Szajgin, 1982 and Kalensky et al. 1981). Standards will become essential as LANDSAT classifications are used in geographic information systems.

2.4 OPERATIONAL CLASSIFICATION SYSTEMS

The Lands Directorate (Environment Canada) has produced a series of Working Papers addressing issues in Land Use. Working Paper No. 14 (Scace, 1981) deals specifically with a review of 46 Land Use Classification Systems. This review was conducted as a preliminary step to develop a Canadian Land Use Classification that could be used to measure land use change.

It is not the purpose of this study to reiterate completely this information but to utilize it and other sources as an aid to devising a land classification for Manitoba.

2.4.1 World

During the 8th General Assembly of the International Geographical Union, the World Land Use Commission expressed the need for a survey of land use throughout the world and proposed a World Land Use Classification. This colour based classification system is non-hierarchical but is intended to be enlarged to meet local needs (See Appendix C).

2.4.2 United States

Much of the attention given to land classification systems in the United States has centred around the United States Geological Survey (USGS) system developed by Anderson (1971) and later revised by Anderson, Hardy, Roach, and Witmer (1976). Anderson was previously concerned with the problem of developing a land use/land cover classification system which could be used with orbital imagery to make thematic maps. He realized that it was unlikely that one ideal classification would ever be developed but that a standardized approach has its advantages (Anderson, 1971). He proposed that:

1. the minimum level of accuracy from remote sensor data be 85 percent;
2. the accuracy of different categories or classes be about equal;
3. results should be repeatable by interpreters from one time to another;
4. the classification should be applicable over a wide area;
5. the categorization should permit land cover types to be used as surrogates for activity;
6. the classification should be suitable for use at different times of the year;
7. effective use of subcategories obtained from ground surveys or from larger scale or enhanced remote sensor data should be possible;
8. aggregation of categories should be possible;
9. comparison with future land use data should be possible; and
10. multiple uses of land should be recognized when possible.

The land categories in the USGS system are resource-oriented as contrasted with the people-oriented categories of the Standard Land Use Coding Manual (U.S. Dept. of Transportation, 1969). The people-oriented system (based on urban, transportation and recreation classes) accounted for less than 5 percent of the land area in the United States. It was the remaining 95 percent of land area that the USGS system hoped to classify in more detail.

Land cover is the basis for classifying land categories since remote sensing instrumentation which form thematic images do not distinguish between different activities conducted on the land surface. Land activities are derived from land cover when, "The interpreter uses patterns, tones, textures, shapes, and site associations . . ." (Anderson _et al_., 1976).

The USGS system is hierarchical and divided into four levels (Appendix D).

> Levels I and II would be of interest to users who desire data on a nationwide, interstate or statewide basis. More detailed land use and land cover data such as those categorized at level III and IV usually will be used more frequently by those who need and generate local information at the intrastate, regional, county or municipal level. It is intended that these latter levels of categorization will be developed by user groups themselves, so that their specific needs may be satisfied by the the categories they introduce into the structure.

The maps produced by the USGS using Anderson's (1976) classification are being digitized and incorporated into a digital base called the Geographic Information Retrieval and Analysis System (GIRAS). The main system is composed of three subsystems for: 1) data input; 2) data retrieval; and 3) data output (Hallam, 1979).

Input for the system is derived from land use and land cover maps; political unit maps; population census; county subdivision maps; hydrologic unit maps; federal land ownership maps; and state land ownership maps. Since land use/ land cover maps are produced in polygon form (boundaries on the map represent as closely as possible the boundaries of a feature on the ground) the GIRAS data structure was designed to handle polygon data. Some spatial data systems, however, require land information that is presented in grid cells (uniform parcels of land, not based on ground features), so a polygon-to-grid cell programme was designed to meet the needs of as many users as possible. The system is used by land managers at the federal, regional and state level.

As problems still exist in the United States, the Interagency Agreement Related to Classification and Inventories of Natural Resources is currently trying to develop a National Site (land) Classification System (Rivers, 1982). Four working groups were appointed to address identified areas of concern. The first is the classification group which is developing and implementing an interagency classification covering major categories of soil, vegetation, water and landforms. Second is the common terminology group which is developing consistent terminology for inventory methods and management information. Third, the inventory methods group is developing inventory techniques that allow consistent and compatible data to be generated. The last group is the information management group. This group is developing standards and methods that will facilitate data exchange.

Currently, two basic integrated resource classifications are in use in the United States (Bailey, Pfister and Henderson, 1978). One is the ecological approach which assumes that an association exists directly between topography, soils, and vegetation and indirectly with climate. The second is the component approach which regards the land as a combination of individual attributes which can be classified and then integrated (Merkel, Driscoll, Hagihara and Radloff, 1982).

The Interagency Agreement is examing the component approach to see if it can meet the needs of their respective agencies.

2.4.3 Canada

As a result of the World Land Use Classification, Canada (a member of the International Geographic Union) initiated a mapping program to survey systematically land use across the country using a system called the Canada Land Use Classification. A comparison with the World Land Classification can be seen in Appendix C.

However, in Canada, the Canada Land Inventory (CLI) is the best known land classification system. The CLI was created and implemented in 1963 under the sponsorship of the

Agricultural and Rural Development Act to obtain information for resource management problems. The Agricultural and Rural Development Act (ARDA) had been passed in 1961 as a result of land use problems and conflicts arising from competing land uses. The CLI was a reconnaissance, land capability and present land use survey which was initially performed by means of air photo interpretation (McLellan, Jersak, and Hutton, 1968).

In ten years the CLI surveyed 2.6 million square kilometers across Canada. Approximately 15,000 1:50,000 and 12,000 1:250,000 and 1:1,000,000 maps were compiled on land capability for forestry, agriculture, recreation, wildlife, fisheries and present land use (Thie, Switzer, and Chartrand, 1982).

Because of the vast amounts of data generated by the CLI project, a computer system (the Canadian Geographic Information System or the Canada Land Data System) was developed that allowed:

1. data to be digitized, stored and manipulated (in polygon form);
2. data handling at a high level of detail/resolution (map data are accepted at scales of 1:370 to 1:10^6 in the UTM projection and can produce maps at any scale in the UTM grid);

3. analysis of the data base on a national, provincial, regional, or local level; and
4. comparison and correlation of multidisciplinary resource information and socio-economic data.

Schubert, Thie and Gierman (1977) investigated the feasibility of using LANDSAT data as a means of mapping land use for the CLI. The computer classification techniques were evaluated to assess LANDSAT's desirability. They found that classification accuracies of the ten different land use classes present in the test areas differed significantly between the classes. They concluded that,

> . . .a technique combining human interpretation and computer recording of boundaries would . . . include the potential for directly recording interpretation results in the Canada Geographic Information System.

Ryerson and Gierman (1975) developed a two level land classification for application with remotely sensed data generated by satellite and high altitude sensors. The classification was designed using four elements: the concepts of classification; user needs; remote sensing imagery; and the existing CLI land use classification. They related their new classification system to the CLI system because land use demarcations would not be possible without compatibility to past land use classes. The classes, based on land cover rather than land use, are dependent upon the sensor's resolution and the scale of data rather than the user's data needs (Appendix E).

In 1977, the Lands Directorate of Environment Canada began developing a new land use classification (now presently in use) because it felt that the existing classification systems were not suitable for monitoring land use changes (Gierman, 1981b). The proposed ideal classification which separated land cover from land use was designed to be hierarchical; be independent of data gathering methods; take in all possible land cover and land use activities existing in Canada; ensure purity of classes; be compatible with the CLI land use classification system; and be coded to allow easy computer manipulation. As the classification was being developed, the author tried to prevent any biases towards any single discipline, their needs, or any one data gathering method.

A standard technique for classification (division of classes into more than two subclasses) was favoured over a binary technique (land classes always breaking down into two classes) to reduce the number of computer bytes required to digitize the same information and to decrease storage and user accessibility costs.

Factors that affect the efficacy of the classification were included to differentiate between the ideal and the operational situation:

> The particular operational subset will be dependent upon such factors as specific mapping scale, size of land units in an area, specific data sources, scale of source data, and recognition ability of a specific class (Gierman, 1981b).

The Ecological Land Survey (ELS), another nationally derived system for classifying and evaluating areas of land as ecosystems, has evolved over the last two decades. The land is regarded in a holistic sense, and recently, increased emphasis has been placed on soils, vegetation, and landforms.

Wiken (1978) reports some of the advantages of the ELS over single disciplinary surveys as being:

1. a reduction of redundant activities in data gathering;
2. the stress on the collection of more stable aspects of the environment;
3. the flexibility of the data base which accommodates many purposes;
4. the collection of report(s) and map(s) which are presented in one convenient package; and
5. the simplification of the environmental data into one common framework.

Some of the disadvantages of the ELS are:

1. the complex presentation of the data collected;
2. the need for a good scientific background to understand the highly technical terms associated with the system;
3. the data are insufficient for micro-planning;
4. the problems created when trying to classify water bodies; and

5. the overabundance of data for less sophisticated studies.

Murtha (as reported in Rubec, 1983) has provided a relationship between the level of ELS required (Ecoregion, Ecodistrict, Ecosection, Ecosite, or Ecoelement), mapping scales, and the remote sensing platforms that should be used. Panchromatic (black and white) aerial photography has been used most extensively in ELS but more and more colour and colour infrared photography or LANDSAT colour images are being used to supplement that panchromatic photography.

Factors that determine the optimal imagery for an ELS are the detail of the required data, the size of the territory to be surveyed, the time, money and staff available, and the necessity for current imagery (Rubec, 1983). These factors should also be considered for surveys other than Ecological Land Surveys. Thie, Chartrand and Mills (1978) found that when the ELS data are combined with a land information system like the Canada Land Data System, the efficiency of both is improved. They state, "The computer allows easy evaluation and mapping of complex and difficult to interpret map symbols and legends."

2.4.4 Provincial Systems

Many provinces have used remote sensing techniques to inventory resource information.

The Ontario Centre for Remote Sensing is currently operating a land cover mapping program based on LANDSAT data. "The philosophy of the program is to make the fullest possible use of existing satellite data and to provide comprehensive mapping of the province" (Pala, Ellis and White, 1981). It was not their intention to provide a new approach to the description of land use/land cover units so they have not compared their system to other existing systems.

The classification system used in their program provides for up to 16 themes to be employed on each map. The themes used generally fall within the CLI classification system. The major theme categories that they classify are:

1. URBAN AREAS;
2. AGRICULTURAL LAND;
3. WOODLANDS;
4. WETLANDS; and
5. WATERBODIES.

The LANDSAT data were classified by the maximum likelihood classification algorithm and then transformed into a hard-copy land use map by an Applicon plotter. The cost for this process is \$1.00 - \$1.50 (1981) per square kilometer, excluding overhead and development costs and profit.

No method exists for the hard-copy land use maps to be used in a GIS for Ontario, but training programs are offered to encourage resource planners to use the land use/land cover maps.

The Alberta Remote Sensing Center has LANDSAT digital analysis capacity and a flying program for aerial photography but does not have any program to integrate remotely sensed data into a provincial GIS (Canadian Advisory Committee on Remote Sensing, 1981). Several provincial departments have been developing smaller subsystems of their own.

In British Columbia the integration of image analysis information with geo-data base systems is expected to increase the desirability of satellite data (Canadian Advisory Committee on Remote Sensing, 1981). They have also approached the land data acquisition problem on a subsystem basis. Each resource discipline (water quality, forest inventory, soils, etc.) has established its own data system (Resources Data Task Force, 1977). Each system is growing as the quantity of users increases.

The Maritime Remote Sensing (MRS) Committee has been studying the question of interfacing remotely sensed digital data with a GIS. The MRS Committee thinks that this linkage is timely and important and that there should be a sharing of information in the Maritime Provinces (Maritime Remote Sensing Committee, 1983).

2.4.5 Manitoba

In Manitoba there have been a number of major remote sensing projects (both airborne and satellite) conducted mainly by the Manitoba Remote Sensing Centre (MRSC) and the Forestry Branch. Some of these include photography for forest inventory and highway construction programs (Canadian Advisory Committee on Remote Sensing, 1981); LANDSAT data projects for barrenland caribou habitat mapping (Dixon, 1981); Land use/land cover changes affecting the Dauphin Lake Fishery (Pokrant and Gaboury, 1983); and crop monitoring in the southern part of the province (Horn, Ryerson, Thiebault and Dobbins, 1984). Each of these projects has a specific classification for land units dependent upon the specific purpose of the project (Appendix F). There was no attempt to integrate the information obtained from these projects into a provincial land information system (B. Best, pers. comm. 1984).

An Ecological Land Survey of the remote northern and eastern part of the province was conducted in 1974 using aerial photography and ground truthing. However, the map scale was too small to serve many users in more detailed or site specific planning. Also, as many of the users were not experienced with the ELS, they found the complexities portrayed in the data difficult to comprehend (Borys and Mills, 1979).

In 1977, the Resources Data Task Force was created to examine various Departments' gathering, analysis, storage, retrieval and dissemination of land related information (Resources Data Task Force, 1977). Some of their findings indicate that:

1. map making, maintenance and distribution occurs in most government departments;
2. the province spends between $7-10 million (1977) on data collection and data support. Because the data collection is uncoordinated, much of this is wasted (approximately $1.2 million per year);
3. there are 93 geographic applications, many of which appear to be uncoordinated; and
4. there is a need to develop a system capable of automatically updating maps and to reproduce paper copies.

Conclusions related to land information or data indicate that:

1. it is very difficult to find out what information is available and how to obtain it;
2. there is no common set of standards for departments and agencies currently involved in their own information systems. This results in a variety of redundant systems and an emphasis on a single discipline approach to complex land use problems; and
3. there are variations in the data collected, such as:

   - different scales - metric or imperial;
   - the existence of eight different geo-referencing systems;
   - many different levels of accuracy; and

- inconsistent updating frequency - it is virtually impossible to assemble all data germane to a certain area with any degree of confidence that the available data are the most current for that given area.

The Task Force recommended that maps containing dynamic information (renewable resources) become a part of a computer assisted information system. This will permit automatic update for immediate use.

2.5 RESOURCE CLASSIFICATIONS

In this section some of the existing classifications related directly to a specific discipline will be examined.

2.5.1 Forestry

The Canadian Forestry Service of Environment Canada is responsible for national statistics on forest resources. Its major concerns are areas and wood volumes that are available for harvesting. In 1977, the development of the Canadian Forest Resource Data System (CFRDS) was proposed by the Forest Resource Data Program. The CFRDS provides the infrastructure for storing, manipulating and summarizing basic data which is referenced to a UTM grid and/or to geographic administrative units. Provincial forest inventories are the primary sources of information for the data base (Kalensky et al., 1981).

The principle of the system is utility. Bonnor (1982) indicates,

> Statistical data must serve a purpose . . . they serve primarily as baseline data, as a foundation for further studies and analyses such as general assessments of provincial, territorial, or national figures; comparative studies at various levels, including the international level; evaluations of specific attributes to identify problem areas or opportunities that require new management or policy plans.

The Canadian Forestry Service inventory is based on land classes (land or water), ownership, status, productivity, site quality, stocking, age and forest types (softwood, hardwood or mixed wood) as shown in Appendix G.

Kirby and van Eck (1977) state that multistage remote sensing sampling of forested areas may provide estimates at a considerably lower cost than conventional methods. In addition, they found that the multistage remote sensing inventories permit:

1. regional generalization for planning;
2. detailed inventory information when and where it is required;
3. concentrated sampling in high interest areas;
4. statistically valid measures of precision; and
5. identification of changed areas resulting from forest growth, cutting, fire and removal of forest land from competing uses.

By using LANDSAT images acquired at different times of the year, they were able to identify different classes. The spring image yielded classifications of mature softwood, water, black spruce bog types and grass shrub types with an 80 percent or better accuracy. Summer images produced good results with the exception of sedge bogs and poplar forests which were spectrally similar. The winter image provided over 80 percent classification accuracy in three classes: open areas with snow; mature softwood and mature spruce-poplar combined; and predominantly poplar forests. They believe that the best classifications will be obtained when the spectral signatures from two seasons are overlayed.

Beaubien (1980) conducted a study that showed LANDSAT data can provide information needed for general mapping of boreal forest vegetation cover. He identified and evaluated the following classes as components of a pattern in each unit (with a maximum of three vegetation cover types per unit):

-dense softwood (density 50 percent and +)
-open softwood (density 25-50 percent)
-open lichen-softwood (density 25-50 percent)
-mixedwoods
-hardwood
-shrub-forested heath (density 10-25 percent)
-lichen forested heath (density 10-25 percent)
-shrub heath (density 10 percent and -)
-lichen heath (density 10 percent and -)

-open peatland (bogs and string bogs)

-recent burns

The cost of forest inventories can be reduced considerably when the general information provided by LANDSAT is sufficient to permit identification of areas requiring more in-depth surveys. Beaubien (1980) has compared the approximate cost of classifying and mapping a 200,000 square kilometer area using both satellite imagery and aerial photography. He found conventional aerial photography techniques to be 15 times more expensive.

Kalensky et al. (1981) investigated the suitability of ARIES (A Resource Image Exploitation System - a digital analysis computer system) for categorizing northern forest land in Saskatchewan into classes that were compatible with the CFRDS. Major concerns were the delineation and tabulation of class areas. Various methodologies, accuracies and costs were discussed.

For northern forest lands that lack sufficient data, multistage remote sensing methodology may have merit. Kalensky et al. (1981) believe that satellite remote sensing (LANDSAT) could provide a reconnaissance survey of softwoods; hardwoods; mixed woods; regeneration; brush; recent burn; and muskeg in areas of low yield, difficult access and long distance timber transport. For forest lands with more productive capacity, the reconnaissance data, using multistage remote sensing, would make planning easier for a timber inventory than a survey using only aerial photography.

With the technology present in 1981, Kalensky et al. (1981) believe it is,"unlikely that a fully automated forest classification from remote sensing data will ever be possible." Tree canopy density, tree heights, understory and terrain topography, ground moisture conditions and differences in atmospheric attenuations are factors that they found limit the use of satellite imagery in forest inventories. However, operational applications will inevitably increase with the improved resolution of the Thematic Mapper (TM), the newest sensor on the fifth LANDSAT satellite.

In Manitoba, the provincial forest inventory is one of the most intensive inventories conducted for a resource. The provincial classification is used mostly for wooded and Aspen-Parkland areas and is not applied to the transition zone or tundra region (Manitoba, 1984), thus limiting its use in all parts of the province.

This provincial forest inventory delineates land parcels on the basis of land and water, forested or non-forested areas, and productive and non-productive areas (Appendix H). Productive forest land is further defined by cover type codes (softwood, two mixed wood codes, and hardwood), subtype (dominant species composition by percentage), site classification (using indicator plants to indicate growth potential),cutting class (based on size, vigor, state of development and maturity), crown closure (estimated from air photos by photo interpreters), and species composition (calculated to the nearest 10 percent). The forest information is obtained using a combination of aerial photography and ground verification. In recent years the Forest Inventory Section of Manitoba's Department of Natural Resources has inventoried more than 421,000 square kilometers (B. Lamont, pers. comm. 1984).

This information from the inventory is compiled on base maps to permit digitization and retention of permanent statistics. These maps are used by other agencies outside the Forestry Branch to assist in resource management problems.

The Forestry Branch is currently in the process of acquiring a computer system to automate provincial forest data. This system will allow the statistical and tabular data to be entered, edited and stored permanently for future analysis and output (both as statistics and maps).

The Inventory Branch of the British Columbia Ministry of Forests has incorporated satellite image analysis on an operational basis (Hegyi and Quenet, 1983). Annual monitoring includes the examination of 52.1 million hectares of forested land. Inventory maps must be updated because of changes resulting from harvesting, fire, site preparation, insect attack, regeneration and classification according to the existing provincial classification system. The satellite data have been integrated with a computer-assisted mapping system by converting satellite data files to Interactive Graphics Design System (IGDS) files. The IGDS can store a file or map on 63 levels, and can retrieve any of these individually or in sets to be combined. The resultant files are then displayed on the base-map or a graphic system that displays raster data.

Oswald (1982) has proposed a vegetation classification system for Canada to satisfy requirements for the Ecological Land Survey. Vegetation is classified into six levels with no bias towards any resource discipline. Satellite and ground survey data may permit classification on the first two levels (Tier I refers to type: trees, shrubs or herbs,Tier II refers to density). Aerial photography can be used to obtain information on the next three levels (Tier III refers to form, Tier IV specifies height, Tier V refers to groups of generalized assemblages of plant species). Tier VI classes (based on plant associations) are limited to on site examination. Phase modifiers (the last hierarchical level) reveal special features.

2.5.2 Wetlands

Carter (1982) states in her review of wetland classifications there are "no universally accepted definitions of a wetland because a wetland is a dynamic ecosystem with complex interrelationships of hydrology, soils and vegetation". However, that does not prevent definitions from being offered. Beets (1982) describes wetlands as,

> . . . lands that are wet enough or inundated frequently enough to develop and support a distinctive natural vegetative cover that is in strong contrast to the adjacent matrix of better drained lands.

The U.S. Army Corps of Engineers has a similar definition, but rather than differing from adjacent land cover, the vegetative cover is "typically adapted for life in saturated soil conditions"(Bussom, Samson and Rundquist, 1982).

The U.S. Fish and Wildlife Service defines wetlands as,

> . . .transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water (Cowardin, Carter, Gollet and LaRoe, 1979).

Wetlands defined by the Fish and Wildlife Service include at least one of the following: the presence of hydrophytes (at least periodically); undrained hydric soils; and inundated substrate at some time during the growing season.

Millar (1976) defines a wetland in Canada as,

> . . . that portion of a basin which is normally covered with shallow water for at least a portion of each year and, in an undisturbed state, supports wetland vegetation . . .

The wetlands of the United States were inventoried by the Fish and Wildlife Service in 1954. This was a single purpose inventory designed to assess the amount and types of valuable waterfowl habitat. The 20 wetland types and the results of the inventory have been illustrated by Shaw and Fredine (1954, reported in Cowardin et al., 1979) in the U.S. Fish and Wildlife Service Circular 39. This Circular has been commonly used, and is considered one of the most influential publications used to preserve wetlands (Stegman, 1976 as reported in Cowardin et al., 1979). Other wetland classifications have since been developed because of the Circular's emphasis on waterfowl habitat, which focused on vegetated areas.

Stewart and Kantrud (1971) attempted to create a classification to categorize natural ponds and lakes in the glaciated prairie region. The bases for classification in their system are the zonal patterns of the plant forms, the interspersion of emergent cover, and the species that are present. These factors are indicative of permanence, stability and waterfowl habitat quality.

Cowardin et al. (1979) developed a classification for wetlands and deepwater habitats in the United States. It has a hierarchical structure, based on five major systems (Marine, Estuarine, Riverine, Lacustrine, and Palustrine - Appendix I) that satisfy a national need for a wetland classification. These major systems are further divided into subsystems and classes. Marine and Estuarine systems are deep water, ocean related wetlands. Riverine systems are those wetlands contained within a channel not dominated by vegetation consisting of trees, shrubs, persistent emergents, emergent mosses or lichens or habitats with water containing ocean derived salts more than 0.5 percent. Lacustrine system wetlands are those located in a depression or dammed river channel. Palustrine systems are non-tidal wetlands that are composed of trees, shrubs, persistent emergents, emergent mosses or lichens. The Palustrine system contains wetlands that have been called marsh, swamp, bog, fen and prairie as well as ponds.

Zoltai, Pollett, Jeglum and Adams (1975) proposed a wetland classification for Canada based on four hierarchical levels. Level I considers "site features which either constitute or contribute to the physiognomy of the wetlands". The main classes include bogs, fens, marshes, swamps, and shallow open waters (Appendix J). Level II considers the surface morphology of the wetland, the distribution of the surface water, and depending on the class, the morphology of the confining basin. Level III further discriminates on the basis of vegetative characteristics. Level IV contains the most detail in the classification system. This level can be subdivided into classes based on need of the particular agency using the classification.

Millar (1976) developed a classification for wetlands in western Canada. He stated that vegetation is susceptible to water level fluctuations, therefore it cannot be the sole index for adequately assessing water permanence. Physical features are also required, in addition to vegetation, to assess the permanency of the water regimes. These physical features include size, depth of the basin and nature of the watershed. Although this system may be used by a variety of disciplines, the main use of the system is to aid land use planning and waterfowl management.

Beets (1982) designed a classification for wetlands that has no bias towards any one use. It is divided into four hierarchical layers: classes (shallow open water, marsh, fens, bogs, swamps, shrub-carrs, and wet meadows); subclasses; variants ; and plant associations.

Most of these classifications require extensive ground survey to classify to more specific levels. This undoubtedly is one of the reasons why Carter (1982) found no operational programs that utilized satellite data for wetland mapping. Bussom et al. (1981) have indicated that a production level project has been undertaken by the Remote Sensing Applications Laboratory (RSAL) at the University of Nebraska and the U.S. Army Corps of Engineers to provide baseline information on the location and areal extent of the wetlands in the Omaha region. A data management system was designed by RSAL to allow storage and retrieval of four wetland classes: open water, marsh, riparian, and sub-irrigated meadow.

Gilmer, Colwell and Work (1980a) used LANDSAT to evaluate waterfowl habitat in the prairie pothole region. Because the resolution of the LANDSAT multispectral scanner (MSS) is 0.4 ha. many smaller wetlands cannot be detected. Drewien and Springer (1969) and Millar (1969), as stated in Gilmer, Work, Colwell and Rebel (1980b), say that approximately 73 to 88 percent of prairie wetland basins were smaller than 0.4 hectares. When classifying vegetation, Gilmer et al. (1980a) stated,

> The classification categories included water, deep marsh vegetation, bare soil, row crops(corn and sunflower), small grain crops and range. These categories were potentially separable using multispectral techniques and were meaningful relative to waterfowl ecology.

However, they found that upland land use (cover) categories were more accurately classified than the wetland vegetation types.

Morrow and Carter (1978) concluded that wetland inventories can utilize data from digital analysis of LANDSAT only when conventional aerial photography cannot be used (due to accessibility, cost, etc.). Satellite data are restricted at the present time by spectral and spatial resolution. They suggest that LANDSAT's largest potential (given existing limitations) exists in detecting land cover changes and in updating wetland maps.

LANDSAT would become efficient for regional, state and national inventories when its nominal spatial resolution becomes 0.25 hectares or less (Carter, 1982).

2.5.3 Agriculture

The literature on agricultural applications of remote sensing is concentrated more on capability for identifying crop and land cover types, than on agriculture classifications. The classification systems that exist for agricultural land categories include the USGS system Anderson et al. 1976), the classification for present land use in the Canada Land Inventory (Canada, 1970), the Remote Sensing Compatible Land Use Activity Classification (Ryerson and Gierman, 1975), and the Agricultural Crown Land System (as reported in Horn and Lahaie, 1984).

The USGS system divides the Level I Agricultural Land into: Cropland and Pasture; Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas; Confined feeding Operations; and Other Agricultural Land.

The Canada Land Inventory subdivides its Agricultural Lands class into Horticulture, Poultry and Fur Operations; Orchards and Vineyards; Cropland; Improved Pasture and Forage Crops; and Rough Graze and Rangeland.

Improved Agriculture in the Remote Sensing Compatible Land Use Activity Classification (Ryerson and Gierman, 1975) is divided into: Cropped Land; Improved Pasture and Hay; Horticulture; and Farmsteads and Agricultural Buildings.

The Agricultural Crown Land System in Manitoba is divided into the least number of classes, those being: Arable Cropland; Tame Forage; and Abandoned Cropland (Horn and Lahaie, 1984).

References to remote sensing have previously concentrated on research areas, but more recently the efforts are being directed towards operational programs. In fact, agricultural managers may be one of the main potential users of the information provided (Gillot, 1980). This is due to the demand for regular information on crop status, area estimates and their sequence in time. Since information provided by remote sensing is accessible and surveys a large area, it will inevitably be used in the decision-making process.

Two areas that show promise for further development are rural land use/land cover monitoring projects and identification of crop types for area estimates (Bauer, Hixson, Davis and Etheridge, 1978). Land use/land cover mapping projects using remote sensing techniques are of interest to both agriculture and resource managers in that the data obtained allows them to determine area coverages for specific land categories. Land use/land cover monitoring also allows managers to assess whether or not land use practices are changing and at what rate, if any, the changes occur.

Pokrant and Gaboury (1983) found that agricultural land in the Valley River area of Manitoba has increased dramatically from 37 percent of the total area in 1948 to 60 percent in 1980. This was primarily at the expense of woodland and to a lesser extent pasture and wetland. They also found that cereal crops and sown forage crops could be identified with an accuracy of 92 percent using LANDSAT imagery and digital image analysis. Pastureland and summerfallow were also identified with an acceptable level of accuracy (87 percent and 95 percent, respectively).

When distinguishing between agricultural cover types it is necessary to consider two factors that will affect the accuracy of crop identification (Myers, 1983). These factors are: 1) the nature of the spectral variation between and within the various cover types of interest; and 2) the capability of the sensor to measure the spectral variation.

Ryerson, Sigman and Brown (1981) state that

> . . . any given temperate crop can be separated from all surrounding crops with LANDSAT MSS data . . . only if certain conditions about the absence of confusion crops, and date of imagery with respect to growing season (or crop's growth stage) are met.

They believe that finer spectral and spatial resolution (offered by the new TM and SPOT sensors) will not lead to improved performance in crop identification where the crops have similar spectral signatures (confusion crops), rather, a multitemporal approach may permit the delineation of confusion crops.

One of the earlier attempts in remote sensing for agricultural purposes was the Crop Identification Technology Assessment for Remote Sensing (CITARS) conducted from 1973 to 1975 (Myers, 1983). The purpose of the study was to assess LANDSAT's crop identification performances for corn and soybean. The project also attempted to assess the effects of various types of soils, weather, management practices, crop distributions, and field sizes (conditions that change in different regions of the country).

The results of the study showed that crop identification accuracy varied throughout the growing season, with the maximum classification accuracy occurring in late August. The study also showed that

> . . .relatively automatic data analysis procedures can be defined which produce repeatable results, are suited for processing relatively large data volumes, and incorporate, to a large degree, the judgement and expertise of experienced analysts (Myers, 1985).

In a joint Canada-United States agriculture project established to assess area estimation, vigor of growth and yield of spring wheat using LANDSAT-1 data, it was reported (Crosson, Peet and Wacker, 1974) that computer classifications of wheat, rapeseed/canola and summerfallow had limited success for early June imagery, but accuracy improved later in the season.

In another area estimation study in Kansas and Indiana, Bauer _et al_. (1978) described the techniques used to estimate winter wheat, and corn and soybeans. They concluded that LANDSAT data provided acceptable identification accuracies for winter wheat in Kansas, but proffered lower accuracy assessments of corn and soybeans in Indiana. These results reflect the large field sizes of winter wheat grown in Kansas and the unique time that winter wheat is growing and visible (its crop calendar). Corn and soybean fields in Indiana are smaller and the crop calendars are not markedly different from most other crops or cover types in the state. Another overall conclusion of the study was that computer-aided analysis techniques could be used to effectively obtain crop identification information from LANDSAT MSS data.

Brown, Ahern, Ryerson, Thomson, Goodenough, McCormick and Teillet (1980) found that rapeseed/canola could be reliably separated from other field crops when MSS data were used, but the accuracy of identification was dependent upon when the rapeseed/canola was in bloom or when the other field crops (peas and grains) were ripening and beginning to turn yellow.

In a comparison of high altitude photographs and LANDSAT imagery, multidate LANDSAT digital data produced better results than multidate high altitude photography (Jensen, Estes and Tinney, 1978). Improved accuracy is attributed to the signature extension problems associated with vignetting that is inherent with the high altitude photography. The authors endorse the use of LANDSAT data since its digital nature is already conducive to multidate crop identification, and would improve with the selection of optimal dates. A crop area estimate using remote sensing techniques was conducted in Manitoba (Horn et al., 1984). Results have shown that these techniques can be used to produce reliable area estimates for rapeseed/canola, summerfallow and cereal grains on a regional basis for Manitoba. These results were comparable to the National Farm Survey estimates.

A project to inventory land cover in the southwestern part of Manitoba provided valuable information needed for input into a water budget model. This model was used to calculate the total water requirements of the Assiniboine Aquifer (Horn and Render, 1984). LANDSAT imagery was used to delineate three specific crop types (canola/rapeseed, corn and potatoes) and one conglomerate of similar crop types (wheat, oats, barley, flax, and rye). The specific crop types were more accurately identified (93 percent, 90 percent, and 88 percent respectively) than were cereal crops (75 percent). Within the cereal crops category there was some confusion with mixed grassland/scrub forest and grassland/pasture categories.

Agriculture studies have shown that numerous classes can be delineated with acceptable accuracies. These include:

1. Cereal Crops and Specialty Crops;
2. Canola/Rapeseed;

3. Pasture; and

4. Summerfallow

The accuracy with which one may identify each of the preceding classes is dependent upon a number of factors. As previously mentioned, spectral variation is necessary to improve accuracy and prevent confusion. Cereal grains are spectrally similar (H. Pokrant, pers. comm. 1984, and Horn and Render, 1984) and the signature of this grouping of crops may overlap with the signature of woodlands.

Other factors that may affect the accuracy of any agricultural classification are the size of the fields of the target crops, the number of crops and cover types in the survey area, uniformity of soils, cloud coverage, and production practices (Bauer et al., 1978, and Horn et al., 1984).

Acceptable results can be secured by carefully selecting training fields (Crosson et al., 1974 and Bauer et al., 1978) and by using imagery obtained at a time when the crop is spectrally distinct from adjacent cover types (Crosson et al., 1974, Jensen et al., 1978, Brown et al., 1980, Ryerson et al., 1981, Horn et al., 1984).

2.6 THEMATIC MAPPER

The Thematic Mapper (TM) is the latest sensor to acquire resource information on the LANDSAT satellite series. The TM sensor has an improved spatial and spectral resolution, which are expected to increase classification accuracy and number of land classes that can be identified.

The spatial resolution should reduce the number of edge pixels, which degrade the image quality (Hyde and Vesper, 1983). The availability of additional spectral bands provides greater potential for deriving land cover information (National Oceanic and Atmospheric Administration, 1984).

Toll (1984) evaluated the use of simulated TM and MSS data to discriminate among suburban and regional land use and land cover. He found that not all seven TM bands were necessary for classification analysis. The TM simulator provided high classification accuracy in comparison to the MSS, especially in Level II classes such as rangeland, irrigated sod, irrigated alfalfa, and irrigated pasture.

Dottavio and Dottavio (1984) also compared TM simulator to the MSS when identifying wetland plant communities. They concluded that given large homogeneous land cover categories, the MSS and TM sensors are comparable for wetland community mapping. The middle infrared wavelength region was found to be suitable for distinguishing between two marsh communities. They believe the increased number of spectral bands may improve wetland mapping capabilities.

2.7 SUMMARY

It is evident that resource inventories and maps will continue to be essential tools to the resource manager, and that satellite imagery and aerial photography will be used more frequently as a primary source of data for a geographic information system, especially with technical advancements.

Literature on remote sensing, geographic information systems and classification systems indicate that a set of standards must be set to enable the integration of remotely sensed data with a geographic information system. The standards include:

1. a classification system based on similar land units - using either component or ecological criteria;
2. a clear definition of terms used in the classification;
3. an optimum period for collection of data (either at one time or multitemporally);
4. stated criteria for update frequency; and
5. a minimum level of accuracy.

Multipurpose classification systems reduce the amount of space required to store records and reduce the redundancy of gathering information.

Although federal standards may ultimately be used to establish land cover classification systems, regional variations in land cover will present problems. A land classification system designed for Manitoba, coupled with an appropriate GIS may be better suited for gathering, storing, analyzing and disseminating the information relevant to provincial natural resource management.

The review of classifications for specific resources has outlined the capabilities of remote sensing, specifically LANDSAT MSS data, to identify and delineate land cover types that may be incorporated into the classification system.

The next chapter will review the methods used to obtain the resource managers' needs for inventories and the criteria to develop and test a classification system.

Chapter III

RESEARCH METHODS

3.1 INTRODUCTION

Primary and secondary data sources were used to provide information for this study. Primary data were obtained through a survey of Manitoban resource managers. This enabled resource managers' needs to be identified. The secondary data consist of published literature, existing classification systems, and personal communication. These data were used to provide direction and prevent repetition of past mistakes.

3.2 SURVEY DESIGN

The survey method and questionnaire format (Appendix A) is described in the following subsections. The design closely followed those used by J.F. MacLaren Ltd.(1980),the Resources Data Task Force (1977) and Gierman (1981a).

3.2.1 Sample Description

The data were acquired from Manitoba based resource managers who had indicated a need for land-related information that could be surveyed from satellite and aircraft sensors.

A total of 50 managers were selected on the basis of their interest in using both remote sensing and GIS technology. Some interested resource managers had been identified in a previous study which examined Remote Sensing Renewable Resources Monitoring Needs in Manitoba (J.F. MacLaren, 1980). Others were chosen from the Departments of Natural Resources, Northern Affairs, Municipal Affairs, Agriculture, Highways and Transportation, and Environment and Workplace Safety and Health, Manitoba Hydro, and from private resource firms and universities in Manitoba. Data were collected from resource managers located in Winnipeg, Thompson, The Pas, Portage, Brandon, Steinbach and Saskatoon (Canadian Wildlife Service headquarters for waterfowl managers working with Manitoba data).

3.2.2 Questionnaire Process

The following were the steps involved in data collection with the questionnaire:

1. Resource managers were contacted by phone to explain the purpose of the study and to obtain their permission to send them the questionnaire.
2. When permission was obtained, the questionnaire was distributed by mail with a covering letter reiterating the purpose of the study. The questionnaire included an introduction that described remote sensing, geographic information systems and land classifica-

tions. The questionnaire was designed to ensure that the questions were clear and could be answered easily. The questionnaire was reviewed by the client, the Institute of Social and Economic Research (U. of M.), and the Natural Resources Institute (U. of M.) to ensure that useful information could be obtained. Space was provided for the manager's name, address and responsibility. The questions focused upon (see Appendix A):

- the use and purpose of their resource inventory activities
- the inventories they have conducted in the past and inventories currently being conducted
- the information, data or themes that were identified on their maps and their reasons for their inclusion
- the information, data or themes that would be necessary to obtain a solution for their management problems
- definitions of the information, data or themes required
- size of the area mapped
- scales of mapping projects
- update frequency of inventories
- desired final form of the data collected in the inventory
- future inventory plans and necessary information
- problems associated with past mapping and inventory projects
- suggestions for classification improvements

3. Within 1-2 weeks after the questionnaire was received by the manager, an interview was arranged, if it was required, to aid in completion of the questionnaire.
4. Interviews with the resource managers.
5. Follow-up contact by telephone to secure additional and more detailed information to clarify some answers.
6. The data were tabulated to assess the nature and purpose of resource inventories, to identify major overlapping needs, criteria and problems. Recurring themes that could be identified with remote sensors were given priority in the development of the classification system.

3.3 CLASSIFICATION DESIGN

3.3.1 Data needed

The tabulated data from the questionnaire were necessary to identify common needs that occur in Manitoba's inventory programs. The national and regional land classifications, and specific resource classifications were reviewed to determine their compatibility with provincial resource inventories.

3.3.2 Design Considerations

To design a classification system for multiple use, emphasis should be placed on the needs that have been identified by a number of resource agencies. Land themes or types that were identified as necessary by a number of users were considered as major elements in the classification design.

A component classification was used emulating the Canada Land Inventory, the U.S. Geological Survey and Ryerson and Gierman's (1975) Remote Sensing Compatible Land Use Activity Classifications. The criteria of mutually exclusive classes, hierarchy, regionally found classes, inexpensive measurements, minimum seasonal variability of classes, accuracy of identification above 85 percent using a confusion matrix, and equality of accuracy between classes was used as a basis for designing the classification.

Definition of each of the terms used for each class (land unit theme) is given to prevent misunderstanding by future users.

After the first draft of the Manitoba Land Classification System was completed (with definition of terms), it was reviewed by the client for comments and suggestions for revisions.

After the Manitoba Land Classification had been developed, its capability for multiple use was tested using CCT data from the LANDSAT satellite. Three areas, representative of different parts of the province (boreal, transitional and agricultural), were surveyed and the land categories classified. Classification was conducted using air photo interpretation techniques and digital image analysis of satellite data. The classified parcels were examined to determine the capabilities of the imagery, the classification system and to indicate problem areas.

The quality of the final classification system was determined for GIS integration using a test developed for GIS inputs (Mead, 1982).

3.4 SUMMARY

The primary data were obtained using a survey technique. A questionnaire was designed to obtain pertinent information that would assist in the design of a common land classification capable of meeting the demands of a variety of resource managers in the province. Secondary data, the existing information on classification systems, remote sensing and GISs, helped in the design process. Testing of the classification was conducted with multistage aerial photography and satellite imagery. When the final classification was completed, it was submitted with accompanying text, to the Manitoba Department of Natural Resources.

The next chapter will outline the questionnaire results of resource managers working with Manitoba land data.

Chapter IV

QUESTIONNAIRE RESULTS

4.1 INTRODUCTION

This chapter discusses the results of the questionnaire, the primary data source. The questionnaire was designed to obtain qualitative data on land resources which would allow for the identification of resource managers' needs. These needs are related specifically to land categories, size of area mapped, scales of maps, update frequencies, and desired final form of land information.

Secondary data sources, consisting of existing classification systems, literature and personal communication were important to the design of a classification system as some standards and definitions have already been set. Where possible the integration of presently used classification systems was attempted so that a variety of needs could be met.

There was an 80 percent response rate as 40 of the 50 resource managers approached returned the questionnaire. Two of the 40 managers who returned the questionnaire believed that their working responsibilities did not involve enough mapping and remote sensing utilization to contribute to the study.

4.2 QUESTIONNAIRE

4.2.1 Agency Category and Responsibility

The resource managers that were part of the sample were chosen from Manitoba-based resource agencies and educational institutions that have indicated a need for (or would like to use) land related information that can be surveyed from satellite or aircraft sensors. Thirty-five provincial, 5 federal, 5 university and 5 consultant company representatives were contacted and asked to participate in the study. TABLE 4:1 shows the response rate to the questionnaire.

TABLE 4:1 Agency Category and Responsibility

Responsibility	Provincial	Federal	University	Consultant	Total
Land Management (Env. and Municipal Planning)	5		2	2	9
Wildlife	5	4			9
Forestry	5				5
Crown Lands	3				3
Agriculture	3				3
Water	3				3
Recreation	2				2
Geological	1		1		2
Mapping	1		1		2
Fisheries	1				1
Transportation	1				1
TOTAL	30	4	4	2	40

The 4 university respondents were responsible for both research and teaching duties. The remaining respondents can be separated according to their management responsibility. Fifteen respondents could be considered a part of senior management (section chiefs, directors, superintendents, and presidents of companies) while the other 21 are responsible for planning as technicians, biologists, engineers or research scientists; all of these being responsible directly or indirectly for resource management.

4.2.2 Use of Remote Sensing Technology

Remotely sensed data is used by a majority of the surveyed resource managers. Remote sensing techniques were used or planned for future use by 82.5 percent of the sample while conducting their resource inventories. Fifteen percent of the resource managers said that remote sensing techniques were not utilized. These managers who do not use remotely sensed data have a responsibility for crown lands (dealing with land ownership and maintenance of registry records), wild rice management, fire management, water resources, hydro planning, and teaching of university courses (TABLE 4:2).

TABLE 4:2 Agencies that Use Remote Sensing Technology in their Resource Inventories

USED	30
NOT USED	6
PLANNED FOR FUTURE USE	11
OMITTED	2
*TOTAL	48

* Total is higher than the total of questionnaire responses because some managers answered either USED or NOT USED plus PLANNED FOR FUTURE USE.

4.2.3 Acquisition of Mapped Data

In Manitoba, the Department of Natural Resources (DNR) is the main source of mapped information that can be used by resource managers (combined total equals 82.5 percent). Within the DNR, the Surveys and Mapping Branch and the Forestry Branch have provided maps to 67.5 percent and 30 percent, respectively, of the resource managers surveyed (TABLE 4:3). The Department of Agriculture ranks second to the DNR in the provision of mapped data, having provided maps to 20 percent of the resource managers.

TABLE 4:3 Providers of Mapped Data

AGENCIES	No. of Resource Managers using Agency's Maps		
MANITOBA PROVINCIAL AGENCIES			33
Dept. of Natural Resources (Combined)		33	
Surveys and Mapping Branch	27		
Forestry Branch	12		
Lands Branch	7		
Wildlife Branch	5		
Water Resources Branch	4		
Parks Branch	3		
Fisheries Branch	3		
Fire Management	2		
Regional Services Branch	1		
Engineering and Construction Branch	1		
Dept. of Agriculture		8	
Dept. of Highways and Transportation		5	
Dept. of Energy and Mines		4	
Dept. of Municipal Affairs		4	
Dept. of Northern Affairs		1	
Dept. of Economic Development and Tourism		1	
Dept. of Historic Resources and Culture		1	
FEDERAL AGENCIES			22
Dept. of Energy, Mines and Resources		15	
Dept. of Environment		12	
Dept. of Agriculture		3	
Dept. of Indian Affairs		3	
Dept. of Fisheries and Ocean		2	
Dept. of Transportation		1	
OTHER			10
Private Contractors and Mapping Companies		6	
United States federal mapped data and satellite imagery		2	
Manitoba Hydro		2	
City of Winnipeg		1	
OMITTED			4

Federal government agencies also provided mapped data for the province. The Department of Energy, Mines and Resources is the main supplier, with 37.5 percent of the resource managers obtaining information from various branches within its jurisdiction. Environment Canada ranks second, supplying mapped data to 30 percent of the resource managers.

Less than half (40 percent) of the resource managers surveyed indicated that they obtain data from resource inventories that have been conducted with other agencies (TABLE 4:4).

TABLE 4:4 Cooperative Inventory Projects

Agencies that conduct inventories with other Agencies	16
Agencies that don't conduct inventories with other Agencies	21
Omitted	3
TOTAL	40

The cooperative inventories that have been conducted occurred between provincial agencies, between provincial and federal agencies and between provincial agencies and private companies (TABLE 4:5).

TABLE 4:5 Type of Cooperative Inventory Projects

Provincial Interagency Cooperation	9
Provincial - Federal (including 1 planned)	7
Provincial - Private	4
University - Provincial and Federal	1
TOTAL	21

4.2.4 Size of Area Inventoried

The resource managers were asked to indicate the size of the areas covered in past inventory projects. The answers illustrated a high degree of variability. No particular size was prevalent as area sizes ranged from 10 acres (24.71 hectares) to the whole province. A few respondents indicated more than one size of areal coverage due to the number of different projects being conducted by their agency. The responses were given both in hectares and acres and square kilometers and square miles (one may conclude that the metric system has not yet become fully assimilated).

4.2.5 Maintenance of Mapped Data

TABLE 4:6 shows how the resource agencies in Manitoba differ widely in the frequency in which they update their maps. In most cases the update is dependent upon the working budget, manpower and aerial photographs available or upon the need for information about a particular area. The update period for 20 percent of the respondents could not be specifically defined because updates are conducted irregularly as projects require them to be done. Another 22.5 percent stated that updating of maps is not a necessary function of their agency.

TABLE 4:6 Update Frequency

Frequency	No. of Respondents
0-1 years	7
2-3 years	1
4-5 years	6
6-10 years	3
11-15 years	1
16-20 years	2
Not Definite	8
Update not required	9
Omitted	3
TOTAL	40

The 0-1 year and 4-5 year periods for update occur most frequently. In the 0-1 year range, two respondents were from an agency concerned with forest resources and two were from wildlife agencies. In the 4-5 year range, four of the six represented wildlife agencies.

When asked how often a resource inventory for the province, based on remotely sensed data, should be updated the results are similar to previous actual updates (TABLE 4:7). The 0-1 year and 3-5 year update periods are chosen most often as the ideal period, however the 5-10 year responses are only slightly less than the 3-5 year responses. Some comments were given suggesting that isolated northern areas do not need as intensive study as more southerly locations which are subject to more change. The 3 responses in the 11-20 years range realize either the stability of their resource of concern (geological resources) or the time needed to inventory a resource that covers most of the province (forestry).

TABLE 4:7 Recommended Update Periods for a Provincial Remote Sensing Inventory

Frequency	No. of Respondents
0-1 year	14
2-3 years	6
3-5 years	12
5-10 years	10
11-20 years	3
Omitted	1
*Total	46

4.2.6 Inventory Type

Due to the variety of resource managers contacted, a variety of resource inventories can be expected. TABLE 4:8 illustrates the diversity of inventories conducted in Manitoba by the questionnaire respondents.

TABLE 4:8 Types and Number of Resource Inventories

TYPE	No. of Inventories
Wildlife	10
Land Use	10
Land Cover	9
Terrain	9
Forestry	8
Water Resources	8
Agriculture	5
Recreation	5
Transportation	1
Environmental Impact Assessment	1
Historic Feature Survey	1
** TOTAL	67

*TOTAL is greater than 40 because some respondents may have selected more than one update period.

** Total is greater than 40 because some respondents were engaged in more than one type of inventory.

4.2.7 Map Scale

The map scale of the products of previously conducted inventories varied from a very large scale of 1:1320 for forest potential studies to a very small scale of 1:1,000,000 for plotting geologic information and 1:2,000,000 for plotting acid rain data. This wide variation in map scale is probably due to its close relationship to the size of the area inventoried. However, the most popular scale used is 1:50,000, as indicated by 8 respondents. The next most common scales are 1:15,840 and 1:250,000 each used by four respondents.

The questionnaire respondents indicated a need to have both constant and varied map scales. Seven of the 13 respondents who stated that their inventory data were presented at a constant scale, provided reasons why it was constant. These included the need to establish consistency from area to area and from year to year; to correspond with existing maps; and to best represent the feature of interest (forest resources and hydrogeological framework).

Seventeen respondents stated that their map scales of past inventories varied due to different needs in amount and kind of detail that were specific to various regions; different applications; economics (cost of map production); the variety of project area dimensions; and the format of the available information. Ten respondents omitted the question since their information was not presented in map form.

When asked to indicate the mapping scales that would best suit their needs, the responses varied again considerably as seen in TABLE 4:9. Because of the varying responses, the results are displayed as continuous data. Responses indicated only three scales that are desired by four or more resource managers. The 1:50,000 scale was thought to best suit the needs of six managers while the 1:250,000 and 1:20,000 scales were best suited to five and four resource managers respectively. Four resource managers expressed a desire for flexibility in selection of the scale factor to meet the requirements of unknown future projects.

TABLE 4:9 Mapping Scales That Would Best Suit the Needs of Resource Managers.

SCALE	RESPONSES
under 1:20,000	9
1:20,000 - 1:49,999	9
1:50,000 - 1:99,999	10
1:100,000 - 1:249,999	2
1:250,000 - 1:1,000,000	8
Variable scales	4
Omitted	6
*TOTAL	48

4.2.8 Data Acquisition

The data sources used to compile the resource inventories consist of a variety of techniques. Aerial photographs are the most common source, used by 47.5 percent (19) of the respondents. Satellite data are used by 27.5 percent (11) of the respondents. Ground Survey is the third most popular method used by 25 percent (10) of the respondents. Other sources of data include existing maps such as the Manitoba Forest Inventory Maps, Canada Land Inventory maps, topographic maps, etc. and other remote sensors such as RADAR, aeromagnetic mappers, and airborne gradiometers.

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*TOTAL is greater than 40 because more than one scale may have been chosen

4.2.9 Information Format

The results of the resource inventory can be presented in map form, as statistics (computer outputs or tables and graphs), or as a report. Maps are produced by 55 percent (22) of the respondents. Statistics are produced by 27.5 percent (11) of the respondents and 12.5 percent (5) respondents produced reports on the inventory. Ten respondents produce both maps and statistics, but only three produce maps, statistics and a report.

There was considerable variation in the responses from resource managers when asked how they would like to have their inventory data presented. Inventory data in map form is desired by 77.5 percent (31), 50 percent (20) desire statistics, and 12.5 percent (5) stated a desire to have the data compatible with computer storage. All three formats are possible in a computer mapping-GIS.

4.2.10 Future Inventory Plans

The resource managers were asked what resource inventory projects (using remote sensing techniques) their agency intended to initiate in the future. The responses varied from specific to general inventories (based on the number of unique land cover types to be identified in the inventory).

General type inventories, for all land cover types, are planned by 40 percent (16) of the resource managers. These included 7 habitat assessment inventories (requiring a wide range of land cover types to be located), 4 respondents indicated a plan to inventory forest cover types for the provincial forest inventory and forest fuel type mapping. Other general land cover inventories identified include resource inventories in parks, impact assessments, land use mapping and land cover mapping.

Plans to conduct specific type inventories were indicated by 22.5 percent (9) of the resource managers. These include inventories conducted for a unique feature or purpose. Specific inventories would be conducted to identify wild rice, to map the extent of floods and analyze lake level changes, to survey wetlands, to monitor the extent of fires, to aid in the analysis of crop yields, to locate saline and eroded areas, and to identify geological features.

Fifteen respondents indicated that they had no inventories planned or were not aware of them. The remaining 4 respondents said the question was not applicable to them (TABLE 4:10).

TABLE 4:10 Future Inventory Plans

General	16
Specific.	9
None Planned.	15
TOTAL	40

Eleven of the respondents indicated that the techniques used in future inventories and mapping projects would differ little from present practices or would vary slightly with different projects. Seven omitted answering the question or said it was not applicable to them (this may be an indicator that no change was expected to occur).

Five respondents said that they will try new inventory techniques using LANDSAT, SPOT (a new French earth resource satellite) or SAR (Synthetic Aperture Radar) and other technology as it improves. The changes that were listed include improvements to forest site classification and age classification; more detailed classification of wetlands and cropland; and better fuel type definitions.

Summarizing the results of this question it is evident that resource managers are interested in inventory/mapping methodologies that will enable a reduction in costs or will provide more detailed information at the same cost.

4.2.11 The Value of LANDSAT Image Analysis

The resource managers were asked what was their perception of LANDSAT image analysis in their present inventories (TABLE 4:11). Wildlife, parks, forestry, and agriculture managers believe that it is a "very valuable" inventory tool. Image analysis is also perceived as being "very valuable" to wild rice management and university research.

One of the forestry managers indicated that his "very valuable" response was influenced by LANDSAT's potential, however he believes that at the present time it is "not very valuable".

"Valuable" responses were chosen by agriculture, forestry, fire management, wildlife and fisheries managers.

"Helpful, but not essential" responses were chosen by water resource, land, small area wildlife habitat and environmental managers.

The disciplines that perceive image analysis as "not very valuable" or "of no value" require larger scale inventories such as those conducted for land claims, highway, specific forest site analysis, small area wildlife habitat assessment, and ice monitoring.

TABLE 4:11 Perception of LANDSAT Image Analysis

Perceived Value	No. of Respondents
Very Valuable	10
Valuable	8
Helpful, but not Essential	9
Not Very Valuable	5
Of No Value	2
OMITTED	7
*TOTAL	41

*TOTAL is larger because one respondent indicated more than one answer

Seven respondents omitted the answer as they do not require information that is provided by LANDSAT imagery or because its use in the resource inventory depends on the size of the area and features to be delineated.

4.2.12 Classification Criteria

An existing or modified version of a land classification system is used by 75 percent of the respondents. Two classification systems are used extensively in Manitoba. The Canada Land Inventory System is used by most of the resource managers (17 of the 30 using an existing or modified version). The other commonly used classification system is the Provincial Forest Inventory (Manitoba) used by 10 of the 30 respondents who indicated they use an existing or modified version. Other classifications identified by resource managers included Millar's Wetland Classification (2 respondents), the Crown Lands Classification (1 respondent), Ecological Land Classification (1 respondent), classification by legal description and administrative records (1 respondent), geological classification system (1 respondent), Ontario Land Inventory for Outdoor Recreation (1 respondent), and a classification similar to the National Topographic Series system (1 respondent).

The land cover classes that are of interest to resource managers for specific disciplines may be divided into six classes using the original Canada Land Inventory Land Use

Classification as a base. The first level of land class descriptors includes:

1. URBAN;
2. AGRICULTURAL LANDS;
3. WOODLAND;
4. WETLAND;
5. UNPRODUCTIVE LAND; and
6. WATER.

Although the Provincial Forest Inventory is divided into only two classes at the first level (land and water, Appendix H), it has classes similar to the CLI. The classes compared are: "unclassified" for URBAN AREAS (CLI); "fields" for AGRICULTURAL LANDS (CLI); "forested" for WOODLAND (CLI); "marsh-muskeg" and "treed muskeg" for WETLAND (CLI); "barren-bare rock" for UNPRODUCTIVE LAND (CLI); and "water" for WATER (CLI).

When compared to other systems, such as the USGS (Anderson, 1976) and the Remote Sensing Compatible Land Use Activity Classification (Ryerson and Gierman, 1975) systems, seven common classes emerge (TABLE 4:12 compares major land cover categories).

TABLE 4:12 Comparison of the Canada Land Inventory (CLI) Land Use Classes to other Land Classifications.

CLI	RYERSON & GIERMAN	USGS	PROV. FOREST INVENTORY
URBAN	URBAN	URBAN OR BUILT-UP LAND	UNCLASSIFIED
AGRICULTURAL LANDS	IMPROVED AGRICULTURE	AGRICULTURE LAND	FIELDS (AGRICULTURE)
ROUGH GRAZING AND RANGELAND	RANGELAND & ROUGH PASTURE	RANGELAND	MEADOW
WOODLANDS	FOREST AND MATURE ORCHARDS	FOREST LAND	FORESTED
WETLAND	WETLANDS	WETLAND	MARSH-MUSKEG & TREED BOG
UNPRODUCTIVE LAND	BARREN AND EXTRACTIVE	BARRENLAND	BARREN-BARE ROCK
WATER	WATER	WATER	WATER
		TUNDRA	
		PERENNIAL SNOW OR ICE	

Ryerson and Gierman added an extra class 'RANGELAND and ROUGH PASTURE' to the first level of their classification. Anderson incorporated 'TUNDRA' and 'PERRENIAL SNOW AND ICE' classes for a national classification of the United States. As there is no perennial snow or ice in Manitoba, this class may be deleted from the first level for a Manitoba classification. TUNDRA (Shrub and brush, and herbaceous) is spectrally similar to RANGELAND or BARREN and may result in some confusion during analysis.

Thus, the seven common first level classes should include:

1. URBAN;
2. AGRICULTURE;
3. RANGELAND;
4. FOREST;
5. WETLAND;
6. BARREN; and
7. WATER.

Information on land classes was obtained in three questions. The first question asked what land cover types were included in past inventories. The second asked what land cover types the resource manager would like to see in a land information system using remotely sensed data. The third asked for the most important features that should be identified in the resource inventory. The specific land cover classes identified by resource managers may be aggregated into the seven major classes on the basis of the results of the three questions as seen in TABLE 4:13. These aggregations show the major concerns of the resource managers but should not be misconstrued as his or her main priority. The specific requirements for land cover classes as indicated in the three questions are illustrated in Appendix K.

TABLE 4:13 Identified Concerns at Level I

	1st Question	2nd Question	3rd Question
FOREST	17	20	12
WETLAND	11	15	14
AGRICULTURE	9	13	11
WATER	10	8	8
BARREN	7	9	6
RANGELAND	5	9	7
URBAN	2	3	3

The level of accuracy of an inventory project is an important consideration for resource managers. A minimum level of accuracy for the identification of land cover types of 86 percent or better is acceptable to 65 percent of the resource managers (TABLE 4:14). Twenty percent of the resource managers indicated that accuracy of classification may be below 85 percent depending on the nature of the resource problem.

TABLE 4:14 Minimum Level of Accuracy Acceptable to Resource Managers

Accuracy (Percentage)	No. of Respondents
<75%	1
75-80%	2
81-85%	5
86-90%	14
91-95%	8
96-100%	6
OMITTED	6
*TOTAL	42

*Total is higher than 40 because some resource managers have stated more than one level of accuracy that is acceptable, depending on the nature of their resource problem.

4.2.13 The Utility of an Operational Geographic Information System

An operational system that includes critical land categories, derived from satellite and aircraft sensors, presenting the data at an appropriate scale, with regular updating is believed to be very useful or more useful than present methods by 80 percent (32) of the respondents (TABLE 4:15). Two respondents believe this type of system will equal present methods. Only one resource manager thought that an operational system would be less useful (for geological applications) and none indicated that it would be of no use.

TABLE 4:15 Utility of an Operational GIS Using Remotely Sensed Data

Usefulness	No. of Respondents
Very Useful	18
More Useful than Present Methods	14
Equal to Present Methods	3
Less Useful	1
Of No Use	0
Omitted	4
TOTAL	40

4.3 SUMMARY

Remote sensing technology is used by many resource managers and its output products, especially maps and statistics, should be considered for integration with a GIS.

Presently, in Manitoba, there are more inventory projects being conducted by individual agencies than there are inventory projects conducted through a cooperative venture. There is an opportunity for further interaction among resource agencies to participate in interdisciplinary or cost-sharing projects.

There is no one inventory area size that predominates. This makes it difficult to recommend a particular grid, frame or window size for resource maps to be entered into a GIS. However, with edge-matching capability (the ability to match the overlapping features on the boundary of one map with the same features on an adjacent map) the size of the study area to be inventoried may be as large as the province if not larger.

The most frequent update periods for both actual and desired frequencies are every one and every five years. However, annual updates may prove to be unfeasible in terms of cost and time.

The scale of satellite imagery output can be useful to 25 percent of the respondents assuming the largest scale attainable is 1:100,000 or smaller. If the largest scale attainable is assumed to be 1:50,000 for satellite imagery it can be useful to 50 percent of the respondents. Aerial photography will provide a more feasible approach to produce thematic maps when a scale of less than 1:50,000 are desired, however, Thematic Mapper and SPOT satelite sensors have a better resolution than the LANDSAT MSS. The data from these satellite sensors will allow for the production of maps that are larger than 1:50,000. As far as perceptions are concerned, there appears to be a belief (by 43 percent of the respondents) that LANDSAT image analysis will be of value in resource inventories.

The classes of land cover that have been identified in past inventories and the classes that resource managers plan to identify follow a common line. The differences tend to be more in terminology or definition. This reinforces the need for standards in terminology and definitions to facilitate multiple use of the data, especially when there are more general land cover resource inventories planned than specific resource inventories.

The perceived utility of an operational GIS incorporating remotely sensed data is very high. Over 75 percent of the respondents believe that this type of automated system will be better than present methods.

Chapter V

THE MANITOBA LAND CLASSIFICATION SYSTEM

5.1 INTRODUCTION

This chapter discusses the land classification system developed for Manitoba which uses remotely sensed satellite data as the main data source. As previously stated, the land classification will attempt to adhere to:

1. user needs (from many disciplines);
2. the capabilities of remote sensing imagery;
3. existing land classifications;
4. the concepts of classification;

These first four guidelines have been used by Ryerson and Gierman (1975), but in this study consideration is also given to:

5. GIS development and limitations.

Resource managers in Manitoba have supported some of the findings of the Resources Data Task Force (1977) in their questionnaire returns. Some problems in existing inventories have been indicated. These include:

1. differing objectives of the inventories;

2. errors of omission (the result of single purpose inventories) and of commission, both of which can decrease the accuracy of the final product;
3. high costs of data collection;
4. lack of equipment, data or technical expertise;
5. difficulty in retrieving information obtained in the inventory; and
6. keeping the information current.

A sub-objective of this study is to develop a classification system that will be capable of meeting the demands of a variety of Manitoba's resource agencies. This requires that no preference be given to any particular agency. By setting objectives for a multipurpose inventory rather than a specific discipline, the first, second and third problems can be avoided or ameliorated. The fourth, fifth and sixth problems could be alleviated by having an inventory agency that is assigned with the responsibility of inventory, data collection, or data handling and dissemination.

5.2 DEVELOPMENT OF THE CLASSIFICATION

The accuracy of the delineation of land features is dependent upon the classes that are part of the system, their spectral qualities and the sensor's ability to detect spectral, radiometric and spatial differences. Digital analysis of LANDSAT MSS data allows the identification of all Level I classes of the CLI, USGS and Remote Sensing Compatible Land Use, Activity Classifications with proficiency, and in some cases satellite imagery can provide more detailed information of the Level II hierarchy in Manitoba (as illustrated in the Technology Enhancement Program projects in Appendix F). Satellite imagery will thus be the basic inventory method used to identify classes in the first and second level of the classification. Level III and IV classes providing finer levels of detail on land cover can be provided by medium and low altitude aerial photography.

By using the seven Level I classes identified previously, compatibility with existing classification systems is possible. The fact that Level II classes are also based on satellite imagery is unique to this classification system. All other previous land classifications for multipurpose use have relied upon, or have advised that high altitude photography (less than 1:80,000) be used for delineation of Level II classes. However, the Technology Enhancement Program projects have shown that computer analysis of LANDSAT imagery is capable of identifying land cover types at a finer level of detail. Jensen et al. (1978) have reported that LANDSAT imagery is more accurate than high altitude photography due to its digital nature and because the film image of aerial photography is subject to vignetting at high flying heights. Level III and IV will be open-ended, like the USGS system to allow the user flexibility to add additional data at a finer level of detail, but will still allow precise land information to be aggregated into more general classes.

5.2.1 Comparison with Existing Systems

In the FOREST class an attempt has been made to parallel the provincial forest inventory's classification at a general land class level (Manitoba, 1984), so that regional planning is facilitated using LANDSAT imagery. This will enable studies and analyses such as general assessments of provincial or national forest statistics; comparative studies at various regional levels; and evaluations of specific attributes to identify problem areas or opportunities that require new management or policy plans. All of these are concerns that should be capable of being managed using forestry statistics derived from LANDSAT. The productive and non-productive classes of the Provincial Forest Inventory and the Canada Land Inventory have been omitted since these are specific forest resource terms - what may not be productive for forestry purposes may be very valuable or productive for other purposes such as grazing or wildlife habitat.

The WETLAND classes were based on the guidelines for wetland classification of Zoltai et al. (1975). However, wetlands, when spectrally analyzed, present problems. In many cases wet meadow may be agricultural land that has become inundated. Open water in a wetland may be classified as water using computer analysis of LANDSAT imagery because wetland water is spectrally similar to water in a lake or river.

The AGRICULTURE class is based on the development of image interpretation and the spectral qualities of the classes at Level II. Some classes within the Level II cannot be consistently delineated using satellite imagery (i.e. pasture and cereal crops). Additional sources of information or multitemporal analyses may have to be used. Specific crop types are usually not included in Level II but since canola is spectrally unique at a certain time during the growing season it is included. Rangeland is not included in the Agriculture class as it was in the CLI Land Use Classification.

RANGELAND Level II classes have not been chosen based on any classification system, rather the classes have been selected on the vigor of the natural grassland.

The BARREN class is not intended to be a catch-all category. Unclassified, or unvegetated land is part of the Manitoba landscape and for an inventory of land cover to be complete, a classification must allow for all of the land surface to be identified. The BARREN classification is comparable to the CLI Land Use Classification and the USGS classification.

The WATER class is dependent upon the capabilities of imaging devices to spectrally differentiate among water types of varying qualities. Because water is a dynamic feature on the earth, stable features, such as water depth and stream turbidity, are used to identify Level II classes.

The classification of URBAN land has not received much attention in this study since most of the questionnaire respondents indicated that an URBAN class by itself would be sufficient for their needs (with the exception of cultural features and farm residences, that are too small to be identified consistently by LANDSAT image analysis). Also, although there are numerous small communities in Manitoba, they represent a very small proportion of the total land surface. It is therefore advised that URBAN areas be manually delineated on the imagery.

5.3 THE MANITOBA LAND CLASSIFICATION SYSTEM

The Manitoba Land Classification System is a land cover classification system designed for use by resource managers in Manitoba. Remote sensing technology (primarily LANDSAT imagery) is the component used to collect inventory data. Subsequent analysis permits land cover to be classified into its respective category (TABLE 5:1).

TABLE 5:1 The Manitoba Land Classification System

LEVEL I	LEVEL II
1. FOREST	11.Deciduous 12.Mixed 13.Coniferous 14.Shrub 15.Treed Rock 16.Burns
2. WETLAND	21.Marsh 22.Fen 23.Bog
3. AGRICULTURE	31.Cropland 32.Canola/Rapeseed 33.Pasture 34.Summerfallow
4. WATER	41.Turbid/Shallow Water 42.Clear Open Water
5. BARREN	51.Sand and Gravel 52.Saline Soil 53.Bare Rock
6. RANGELAND	61.Vigorous Rangeland 62.Non-Vigorous Rangeland
7. URBAN	--

5.4 DEFINITIONS

Definitions deserve commensurate attention so that users will better understand and utilize the Manitoba Remote Sensing Land Classification System. Definitions are provided so that future users may know what is included in each class. The basis of the definitions are those sources indicated by the respondents (CLI, technical reports, and the Provincial Forest Inventory), existing classifications (USGS, 1976, Zoltai et al. 1975 and Millar, 1976), and from Manitoba Statutes (The Agriculture Lands Protection Act, S.M. 1978, c.45, s.1., and An Act Respecting the Administration and Conservation of Forests in the Province, S.M. 1964, c. 19, s.1.).

5.4.1 Forest

This class is comprised of both productive and non-productive (in terms of harvesting) forest land on which trees and shrubs are growing, and have a tree-crown areal extent of approximately 10 percent* or more. The boundaries between this class and others such as shrub and rangeland may be hard to determine. Thus 10 percent areal density is provided as a means for approximating inclusion or exclusion

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* These percentages are meant as guidelines. An actual percentage calculation is a very subjective measure, that may be biased by cover types or interpretive errors. A pure tree stand or uniform crop cover is uncommon in the real world. The user of this information should consider this point when interpreting the output data.

within the classes.

Deciduous Forest includes all tree species that lose their leaves at the end of the frost-free season. These species include bur oak (Quercus macrocarpa), poplar (Populus balsamifera), American elm (Ulmus americana), Manitoba maple (Acer negundo), aspen (Populus tremuloides), and birch (Betula papyrifera). The Deciduous species should represent a minimum of 70 percent of the total tree-crown area.

Coniferous Forest includes all tree species which bear cones and have needle or scale-like leaves. Species included in this class are jack pine (Pinus banksiana), balsam fir (Abies balsamea), black spruce (Picea mariana), white spruce (Picea glauca), tamarack (Larix laricina), and cedar (Thuja occidentalis). The coniferous species should represent a minimum of 70 percent of the total tree-crown area.

Mixed Forest is a term used to describe all forest types where neither coniferous or deciduous species cover a minimum of 70 percent of the total tree-crown area.

Shrub includes tree species under 10 feet but higher than what otherwise might fall into the rangeland class. This class also includes very sparse deciduous tree cover.

Treed rock is the class used to describe a sparse distribution of forest tree species (either deciduous or coniferous) on rock outcrops. The tree coverage is less than 50 percent of the total land area. This class is unique spectrally because of the reflectance from the bedrock on which the trees are standing.

Burns are areas that have been subject to wild-fires or controlled burns. They are areas that are spectrally unique from surrounding areas. This class includes areas of sporadic regeneration and pockets of unburnt trees.

5.4.2 Wetlands

Wetlands are those areas where the water table is at or near the surface of the land, or areas that are normally covered with shallow water for a major part of the year. The water regime in these areas usually supports hydrophytic vegetation. Level II classes include bogs, fens, and marshes. Open water is included in the Water class. Areas that show evidence of grazing or hay cutting should be included in the Agriculture class.

Bogs are peat covered areas that have a high water table that is at or near the surface in the spring and slightly below for the rest of the year. The drainage system is usually poor and oxygen saturation is very low. Bogs may be sparsely treed with low shrubs and stunted larch and black spruce. They are usually covered with a subsurface carpet of mosses (Sphagnum species) and may support sedges (Carex species). The surface of the bog is usually level with or raised above the surrounding terrain.

Fens are peatlands that have surface layers of partly to moderately decomposed peat, and are covered by a dominant component of sedges and some grasses and reeds. Sphagnum is not usually present, but there is often a low to medium height willow shrub cover and at least a sparse distribution of trees. Drainage is restricted and oxygen saturation is usually low. The sod covering in fens is more consolidated than in marshes.

Marshes are wet grass and sedge areas periodically inundated. The fluctuating water levels may expose drawdown areas of decayed vegetation and mud flats. The vegetation consists of non-woody emergent plants such as rushes, reeds and sedges.

5.4.3 Agriculture

Agricultural land is land that is used primarily for farming (to produce food and fibre). This area is situated outside a city, town or village. Often it may be difficult to determine exactly where this class begins and another ends (as in the case of marsh and agriculture land) since the boundaries fluctuate throughout the year. Therefore, land will only be delineated as agriculture when the production of crops is not seriously affected by another adjacent class.

Cropland is a term used for the class that includes all crops that are not spectrally unique. This Level II category includes cereal crops (consisting of wheat, oats, barley, flax and rye), and specialty crops (consisting of sugar beets, sunflowers, corn and potatoes).

Canola/Rapeseed is a spectrally unique crop whose characteristic yellow flower (present during a certain portion of the year) makes discrimination possible.

Summerfallow fields are bare exposed soils in agricultural regions that support no vegetation. The purpose of this practice is to catch and hold as much of one season's precipitation as possible and to retain it for use in the following year. They are spectrally unique from the surrounding agricultural crops due to the low reflectance of infrared radiation.

Pasture is upland and lowland grass utilized for grazing or the production of hay and other cultivated forage crops. It does not include land being cleared for pasture as this area will have a different spectral signature.

5.4.4 Water

The Water class includes all bodies of standing and running open water. Large open bodies of water in wetlands will also be included because the computer cannot distinguish between them and small lakes unless there are some internal quality differences reflecting different spatial signatures. This class includes clear and turbid/shallow open water. These classes were chosen because of their inherent spectral qualities, therefore, no distinction was made between standing and running water.

Clear Open Water includes all natural standing and free-flowing water, man-made reservoirs and channels that are relatively free of suspended sediments or nutrients.

Turbid/Shallow Water includes all natural standing and free-flowing water, man-made reservoirs and channels that have a high content of suspended sediments, nutrients or high stream velocity. Shallow open water along the shoreline of lakes and rivers, that do not have a steep sloped bottom are also included.

5.4.5 Barren

The Barren class includes those land areas that have a limited capability to support vegetation or areas that have been stripped of their natural vegetation. These are areas of poor soil formation, nutrient deficiencies, or extreme limiting factors for vegetative growth.

Sand and Gravel includes all beaches that have accumulations along shorelines; sand that has accumulated as a result of wind and water deposition; and gravel areas that have been exposed by man as a result of quarrying or other activities.

Saline soil are areas where salts have reached the surface and have exacerbated growing conditions to the point where only extremely salt-tolerant plants will grow. These areas appear white due to the high salt concentrations. Wetlands that have dried up completely in late summer may fall into this category.

Bare Rock includes all areas of bedrock exposure, quarries and other areas of where rock is exposed as a result of natural and human processes.

5.4.6 Rangeland

Rangelands are natural grasslands that are covered mainly with grasses, sedges, lichen, scrub/brush or abandoned farmland, whether that farmland is used for grazing or not. Trees may cover up to 10 percent of the area. The Level II classes are based on the vigor of the vegetative cover rather than on species or locational features such as upland or lowland.

Vigorous Rangeland includes all the herbaceous rangeland and abandoned areas which were once cropped or grazed and are experiencing ideal growing conditions due to moisture and nutrient conditions and land management practices. The vigor of the vegetation is evidenced by its high spectral reflectance.

Non-Vigorous rangeland includes all herbaceous rangeland and abandoned areas which are experiencing less than ideal growing conditions due to moisture and nutrient deficiencies or poor land management practices.

5.4.7 Developed Areas

Urban areas are areas that show considerable evidence of man's activities. These areas include land with structures such as residential, commercial, industrial, and recreational buildings and land that is used for transportation and utility purposes. These areas should be input manually using supplementary data indicating boundary limits of the Urban class. Manual identification is recommended for satellite imagery analysis because of the wide array of spectral values that can be reflected by numerous features in an urban environment (trees, buildings, roads, grass, and water).

5.5 TEST RESULTS

5.5.1 Study Areas

The study area for this project is Manitoba, however it was unfeasible to attempt to test the classification for the whole province. Therefore, four subareas were selected as test sites. These areas were chosen on the basis of available computer compatible tapes, existing aerial photography and township mosaics, and forest inventory maps. To avoid a repetition of some cover types and the exclusion of others, two test sites were chosen from boreal regions, one on the eastern side of the province and one on the west side of Lake Winnipeg. A second area was chosen in a transition zone in the Interlake region of Manitoba. The last was chosen in the agricultural region of the Rural Municipality of Morton.

5.5.2 Objectives of the Test

The objective of this exercise was to test the devised land classification's reliability for use with satellite imagery. Another concern was to identify weaknesses within the classification, so that modifications could be made to improve it.

5.5.3 Data Acquisition

LANDSAT computer compatible tapes from previously conducted projects were provided by the Manitoba Remote Sensing Centre. A brief visual survey of the image showed areas of diversity that would be suitable for classification testing. Three CCTs were selected:

Region	Track	Row	Image Date	ID Number
Boreal	32	24(+12)	June 13/81	LANDSAT 2
Interlake and Boreal	31	24	Aug. 17/83	LANDSAT 4
Agricultural	35	25	May 19/81	LANDSAT 2

Reference data consisted of aerial photographs, township maps from the Manitoba Air Photo Library (Department of Natural Resources), and forest inventory maps and legends from the provincial Forestry Branch. The reference data were used to locate training areas (these are areas that contain pixels representative of only one specific cover type).

5.5.4 Image Analysis

Image analysis was conducted at the Manitoba Remote Sensing Centre. An Applied Resource Image Exploitation System (Aries-II) was used to complete three stages: image preprocessing; supervised classification; and post classification filtering. These project methods are similar to remote sensing projects previously conducted in Manitoba (Horn and Lahaie, 1984, Horn and Render, 1984, Pokrant and Gaboury, 1983 and Dixon and Stewart, 1984).

5.5.5 Discussion of Test Results

Boreal Regions

The first region examined was the Family Lake region east of Lake Winnipeg on the Canadian Shield. This Precambrian terrain is covered mostly by coniferous tree species (jack pine - *Pinus banksiana* and black spruce - *Picea mariana*) with some deciduous tree species, commonly trembling aspen (*Populus tremuloides*)

One of the major apprehensions about LANDSAT classification in this area was the accuracy of the mixed wood class. Two classifications were conducted to assess the feasibility of using the mixed wood class: the first without a mixed wood class; and the second with a mixed wood class. The mixed wood class was omitted from the first classification because of the dominance of sparsely treed rock, burned areas and bogs, which have similar spectral signatures to mixed wood. This classification resulted in much of the actual mixed wood land cover being classified as deciduous tree cover (Plate 5:1).

The second classification produced reasonably accurate results for the area and for the mixed wood class (Plate 5:2). Burned areas were identified in the classification to a finer level of detail than is currently available for this region.

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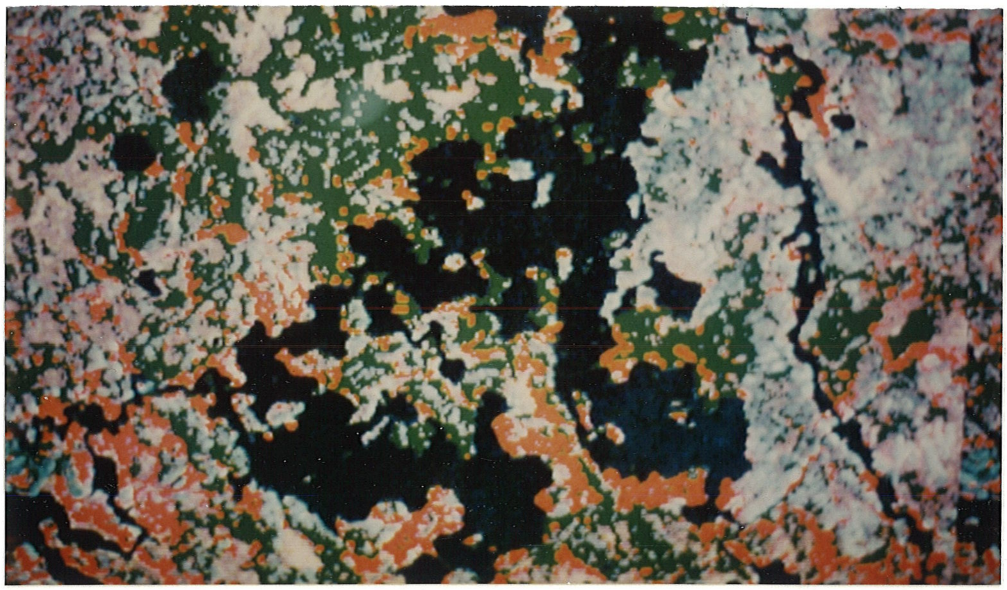
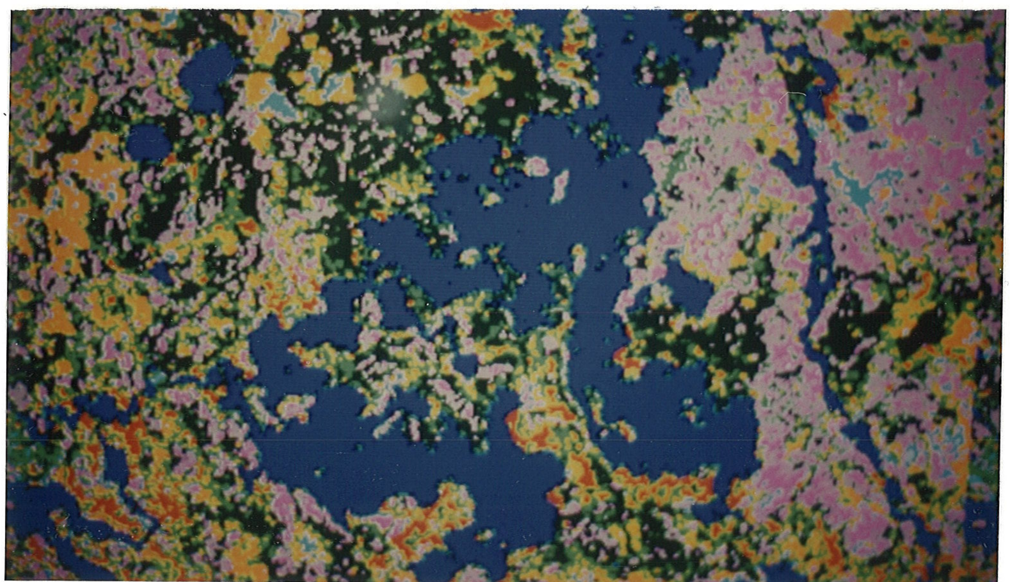


LEGEND

Red : Deciduous Green : Coniferous

Plate 5:1 Boreal Region - No Mixed Wood Class
Family Lake, Manitoba



LEGEND

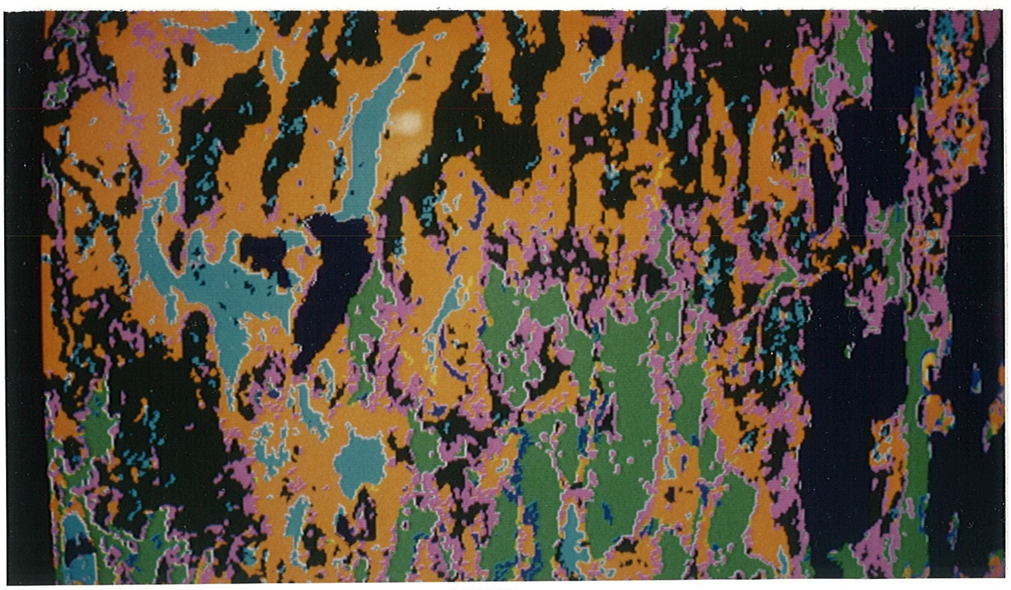
Dark Green	: Conifer	Grey	: Burn
Light Green	: Mixed	Orange	: Bog
Light Blue	: Fen	Red	: Deciduous
Magenta	: Treed Rock	Blue	: Water

Plate 5:2 Boreal Region - Mixed Wood Classified

The results of the boreal classification may vary throughout Manitoba. In an area to the west of Lake Winnipeg

LANDSAT classification produced results that are comparable with the Provincial Forest Inventory coniferous, deciduous, mixed wood, marsh and bog classes (Plate 5:3 and Plate 5:4).

Plate 5:3 Boreal Region (Interlake) Unclassified



LEGEND

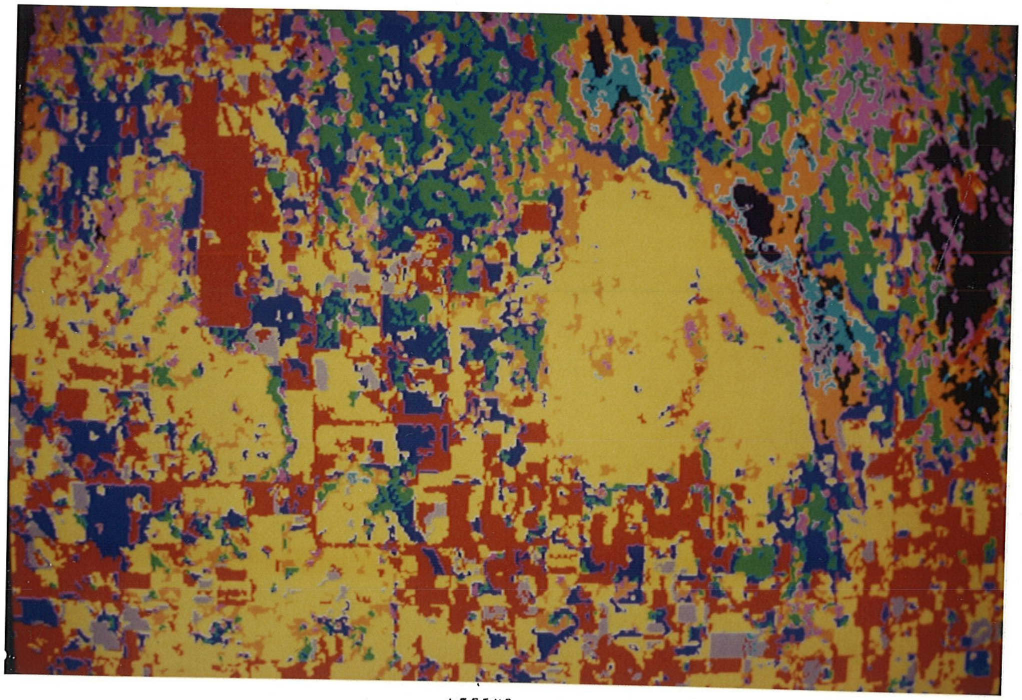
Red	: Agriculture	Orange	: Bog
Yellow	: Rangeland	Medium Blue	: Marsh
Light Green	: Deciduous	Light Blue	: Fen
Magenta	: Mixed Wood	Dark Blue	: Water
Dark Green	: Coniferous	Grey	: Barren

Plate 5:4 Boreal Region (Interlake) Classified

Transitional Regions

The transitional region examined was located in the Interlake region of Manitoba, west of Lake Winnipeg. The land cover in this region is diverse, being comprised of forest, rangeland, agricultural, barren, water and wetland classes (Plate 5:5 and Plate 5:6). Some road allowances were classified as agriculture because of the similarity between the allowances and crops.

Plate 5:5 Transitional Region Unclassified



LEGEND

Red	Agriculture	Orange	Bog
Yellow	Rangeland	Medium Blue	Marsh
Light Green	Deciduous	Light Blue	Fen
Magenta	Mixed Wood	Dark Blue	Water
Dark Green	Coniferous	Grey	Barren

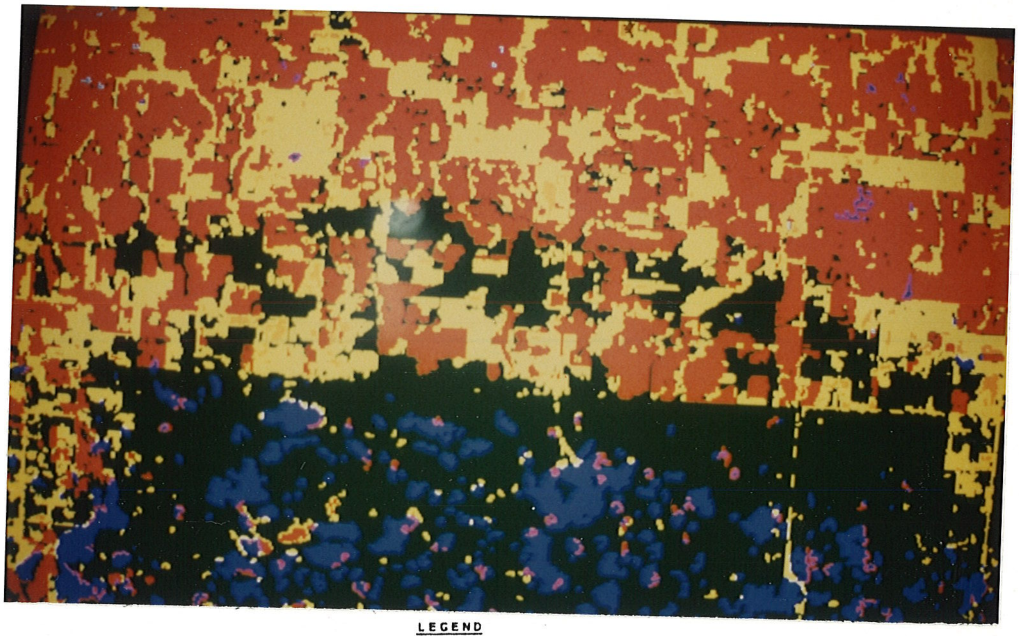
Plate 5:6 Transitional Region Classified

Agricultural Regions

The agricultural region examined was in southwestern Manitoba, directly north of Turtle Mountain Provincial Park (Plate 5:7). The LANDSAT image used for classification was taken in the spring. This enabled Rangeland separated from Agriculture cover types, but did not enable an assessment of whether or not crop types could be delineated. Plate 5:8 illustrates a classified LANDSAT image for Level I classes. Plate 5:9 illustrates how the classes can be further defined to Level II classes in the Rangeland and Forest classes.

Forest classes can be divided into deciduous and sparse wood (or shrub). Rangeland can also be further divided into vigorous or non-vigorous rangeland.

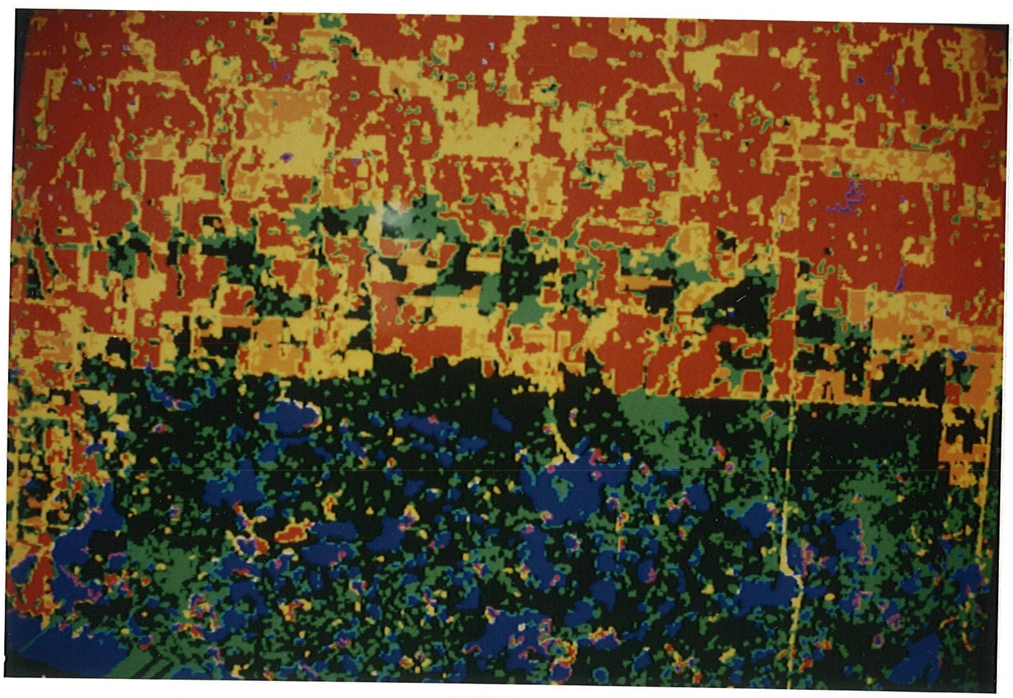
Plate 5:7 Agricultural Region Unclassified



LEGEND

Orange : Agriculture
Yellow : Rangeland
Green : Forest
Blue : Water

Plate 5:8 Level I Classification



LEGEND

Dark Orange : Agriculture
Light Orange : Vigorous Rangeland
Yellow : Non-vigorous Rangeland
Dark Green : Deciduous
Light Green : Shrub
Blue : Water

Plate 5:9 Level II Classification

5.5.6 Test Limitations

Rangeland

The rangeland classes originally selected for the Manitoba Land Classification System had included an upland meadow, a scrub/brush, and a tundra category. None of these categories are capable of being consistently separated by spectral data alone. The test results showed that rangeland can be subdivided spectrally on the basis of plant vigor, but the reasons for why some areas are growing better than others cannot be determined. Plate 5:10 is an air photo and LANDSAT image classified for rangeland in the agricultural region north of Turtle Mountain.

The classified image for rangeland corresponds with native and improved pasture, but in other areas this correspondence is related to upland and lowland rangeland. The pink areas represent vigorous (or improved) rangeland and the yellow represents all non-vigorous (or native) rangeland.

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HOWEVER, THE CHART AND OVERLAY DO NOT "LINE UP" PROPERLY,

THEREFORE, IN ORDER TO PRODUCE THE MOST LEGIBLE IMAGE, THE FREQUENCY CHART IS FIRST FILMED ALONE.

THE OVERLAY IS THEN PLACED ON THE FREQUENCY CHART AND BOTH ARE FILMED TOGETHER.

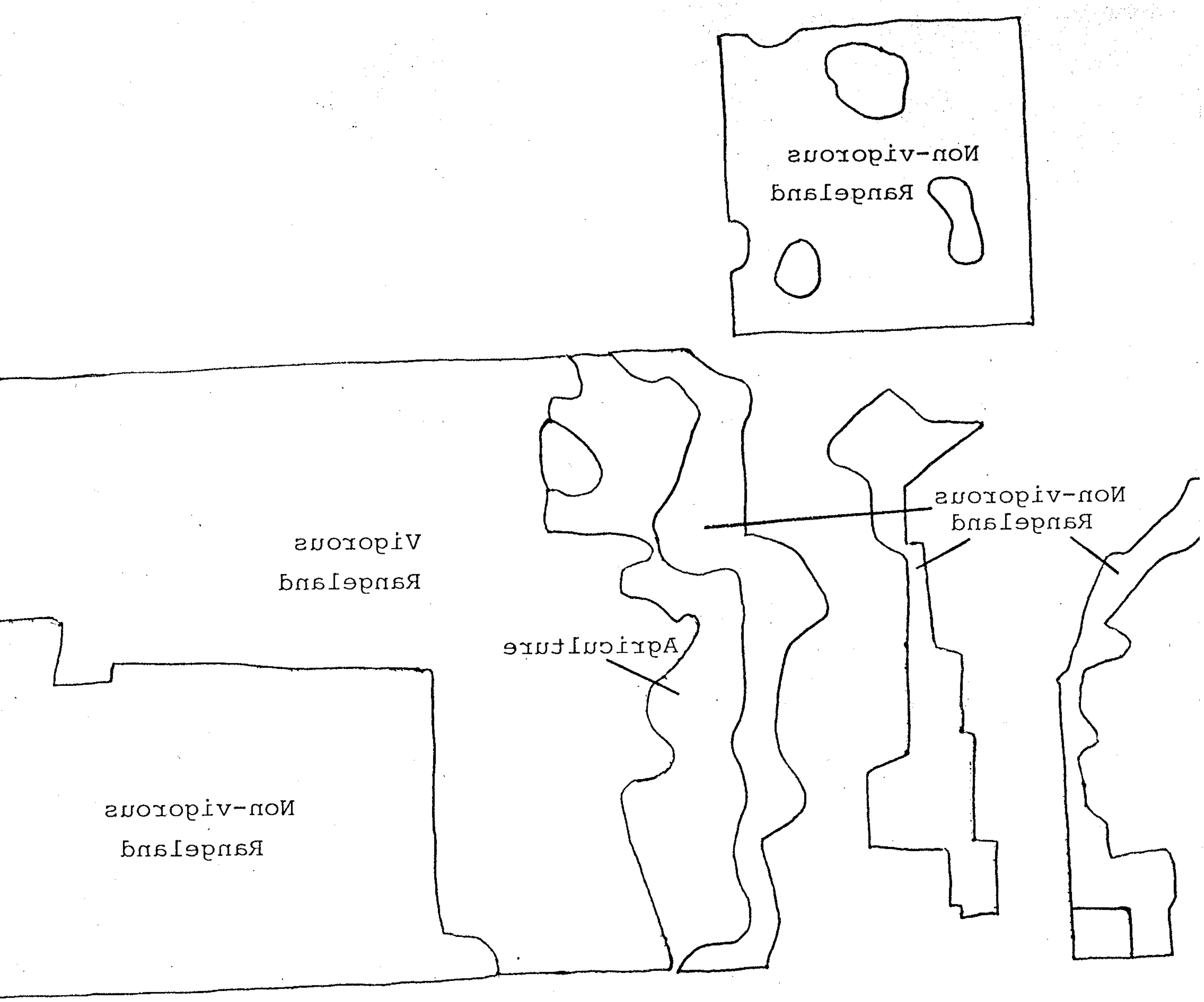
AVIS

ICI ET LA, DANS CETTE THESE, IL Y A DES TRANSPARENTS QUI SONT SUPERPOSES A DES GRAPHIQUES DE FREQUENCE.

TOUTEFOIS, LE GRAPHIQUE ET LE TRANSPARENT NE CORRESPONDENT PAS PARFAITEMENT.

EN CONSEQUENCE, POUR AVOIR UNE IMAGE LE PLUS CLAIR POSSIBLE, LE GRAPHIQUE DE FREQUENCE EST FILME A PART.

LE TRANSPARENT EST ENSUITE PLACE SUR LE GRAPHIQUE DE REQUENCE ET LES DEUX PIECES SONT ALORS FILMEES ENSEMBLE.


Non-vigorous
Rangeland
Non-vigorous
Rangeland
Vigorous
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Agriculture
Non-vigorous
Rangeland

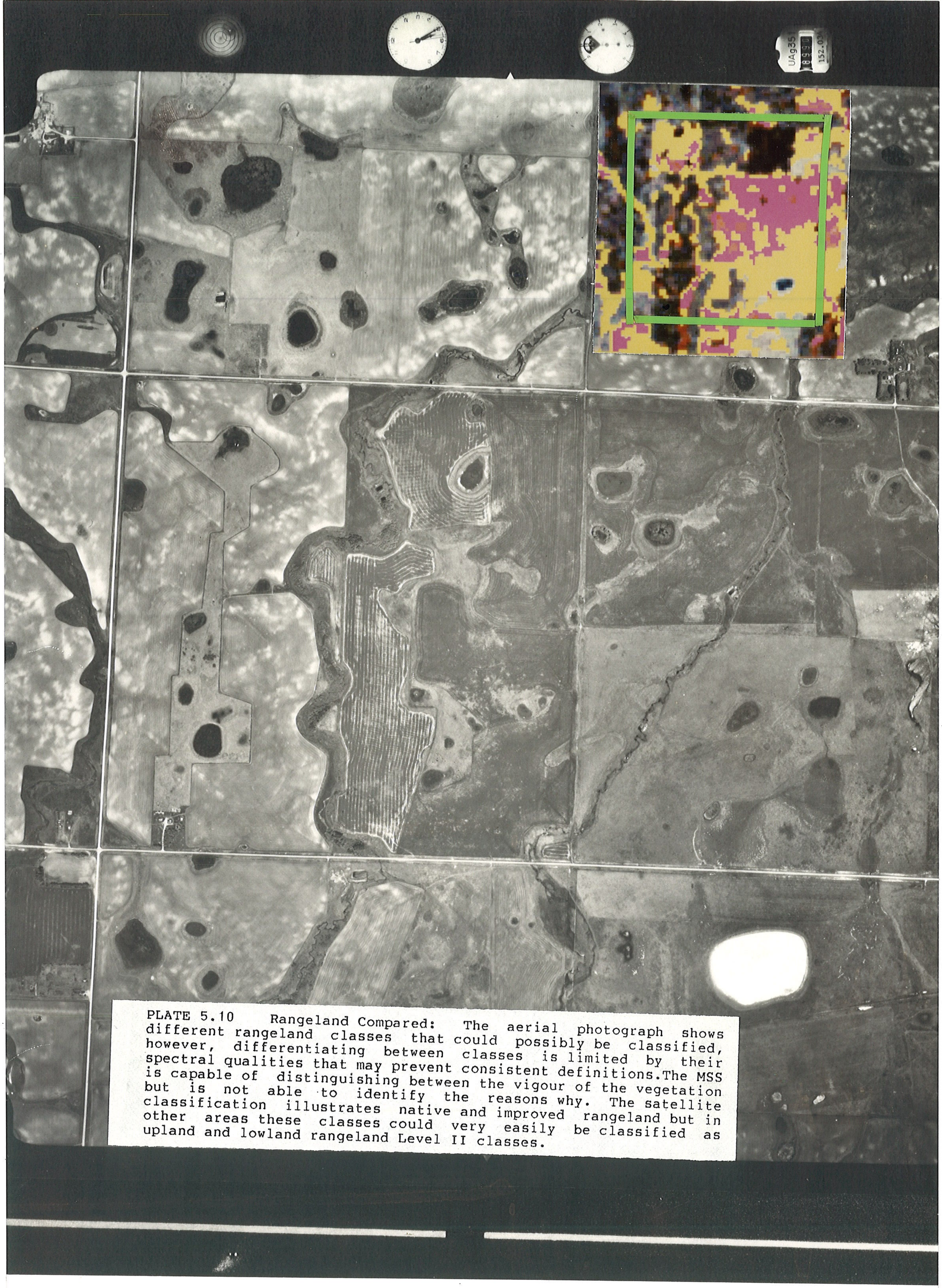

PLATE 5.10 Rangeland Compared: The aerial photograph shows different rangeland classes that could possibly be classified, however, differentiating between classes is limited by their spectral qualities that may prevent consistent definitions. The MSS is capable of distinguishing between the vigour of the vegetation but is not able to identify the reasons why. The satellite classification illustrates native and improved rangeland but in other areas these classes could very easily be classified as upland and lowland rangeland Level II classes.

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Water

There was no attempt to classify water categories in the Level II hierarchy of the classification. The water features on Plate 5:11 show that a number of lakes have different spectral qualities (shown by the different shades of blue). A lake with turbid water is spectrally similar to shallow open water.

Plate 5:11 Evident Spectral Qualities of Water

A river or stream flowing into a larger body of water can affect how the water body could be classified. In the upper corner of Plate 5:11, the relatively clear water of the river can be seen to affect the water tone of Lake Winnipeg. This represents the sediment content in the water more than it represents water depth. Other lakes in the region show variation in spectral qualities, indicating water bodies with different sediment loads or water depths.

5.6 OTHER CONSIDERATIONS

This section is included to discuss various issues that could create problems when attempting to integrate remotely sensed data (using a standard land classification system) with a GIS. Implementation will be facilitated if these issues are addressed with commensurate attention.

5.6.1 Timing

The time that a remote sensing inventory is conducted is important because the 'visibility' of certain cover types varies throughout the year. This is especially evident in Agriculture classes. Spring images are ideal for identifying pasture and rangeland but not crop types as they may not emerge until later in the growing season. During summer, pasture and rangeland may be confused with some agriculture classes. Further research should be conducted to determine whether a single date inventory is adequate. A multitemporal procedure may be required to provide more information. The timing of either the single or multidate approach must be addressed to improve the quality of the information in the inventory.

5.6.2 Frame Connection

It would be impossible for all of the information on Manitoba land classes to be collected by LANDSAT's MSS at one point in time. This is due to the nature of the LANDSAT satellite which moves over the earth as it records spectral data on the land. Different frames (LANDSAT scenes) representative of different areas in the province are taken on different days. Also, it seems that a remote sensing inventory of the province could not be completed at one time, due to the computer and manpower time required to process the data. Therefore, a method must be devised to ensure that the edge of one LANDSAT scene or GIS frame concurs with the adjacent frames that may have been acquired during different years. Concatenation can be achieved by using an edge-matching capability incorporated into a GIS for Manitoba.

5.6.3 Minimum Size

The minimum size of the land polygons that will be delineated is dependent on two things: the spatial resolution of the MSS scanner; and the scale of the presentation of the final output (if presented in map form). These factors will affect the resolution attainable for various uses.

5.6.4 Accuracy

Consistent methods of assessing accuracy should be devised so that misinterpretation of data is avoided. A confusion matrix has been used in previous remote sensing studies in Manitoba (Pokrant and Wilson, 1984, Pokrant and Gaboury, 1984, and Horn and Lahaie, 1984). Methods for sampling and statistical analysis techniques must also be outlined to maintain uniformity of information throughout the province. In doing so, Manitoba would be one of the first in North America to standardize accuracy assessments of remotely sensed data.

5.6.5 Inventories Requiring More Detail

The Manitoba Land Classification System cannot meet all the demands of all resource managers in the province. Some inventories are conducted at a finer level of detail, requiring the identification of specific land categories (Level III or IV). These inventories should be made compatible with the Manitoba Land Classification System by incorporating some means of referencing to a level II class. This could be achieved by insisting that an identifier be attached to the specific land category identified on the map (i.e. Dense spruce [Conifer] , String Bogs [23], or irrigated tomatos [31-Cropland]). This would enable aggregation of inventory data into a form that is capable of being used in a GIS.

5.6.6 Thematic Mapper Data

Just recently Thematic Mapper (TM) data has become available. It has an improved spectral (7 bands) and spatial resolution (30X30 metres), but at an increased cost as compared to MSS data. The cost, however, is still substantially less than using aerial photography. The finer spatial resolution of the TM will be important for delineating small features on the land (Ryerson et al., 1981). Small wetlands, farm residences, stream networks and residential patterns are visible on the TM data and enable definition of finer levels of detail. As knowledge of its capabilities becomes more widespread, it may be necessary to modify the Manitoba Land Classification System so that a finer level of data can be incorporated into the GIS.

5.7 LIMITATIONS TO INTEGRATION

The main limiting factor in this study is that an operational multipurpose GIS does not exist in Manitoba at this time. Even though many agencies have automated systems for storing and handling their own information, none have the capability of combining other data sets for solving problems. Therefore the LANDSAT data arranged according to this proposed classification system cannot yet be combined with other sources of information in a proper GIS test. A GIS proves its worth when various sources of data can be combined, to provide decision-makers with valuable information.

Chapter VI

CONCLUSIONS, SUMMARY AND RECOMMENDATIONS

6.1 CONCLUSIONS

1. A Manitoba Land Classification System was developed to enable the integration of remotely sensed data with a provincial GIS. The classification design process involved consideration of user needs, the capabilities of remote sensing, existing land classifications, the concepts of classification, and GIS development and limitations. The quality of the classification system is suitable for a GIS.
2. A survey of resource agencies in Manitoba was conducted to identify information needs that can be met with remotely sensed data. Commonly identified land classes did not take precedence over the need for a land class that is only required by a few agencies, especially if that class is the main concern of the agency.
3. The federal government role was to promote remote sensing in Manitoba through the Technology Enhancement Program (TEP). This program was designed to promote the use of satellite data in the province, but the land classes identified in the TEP projects

did not follow a standard classification system. The classes identified were defined by the users of the image analysis system and were based on project requirements. The Lands Directorate is promoting the Canada Land Inventory classifications and had released a land cover and land activity classification in 1981, but this system was not specifically designed for remotely sensed data. The Canada Land Data System uses CLI data and encourages outside agencies to make use of the system. The data to be used for analysis must be provided by the resource manager, and does not require any standard format for the classification of land data.

4. The Manitoba Land Classification System was intended to be a multiple use system with no particular bias for any resource discipline. Transfer of information between resource agencies and cooperative inventory projects are facilitated, especially since more general land cover inventories are planned for the future.
5. A 5 year update period is feasible in terms of cost and manpower and to satisfy user groups.
6. Testing, using computer techniques for classifying land from LANDSAT indicate that the Level I and Level II classes are capable of being delineated. Data derived from remote sensors, presented in a standardized form using the Manitoba Land Classification Sys-

tem will decrease storage demands and facilitate use of the GIS. A test on a GIS has yet to be conducted, but this is because there presently is no operational system existing in Manitoba that will enable integration of LANDSAT imagery and classification results.

6.2 SUMMARY

This study supports the findings of Anderson (1974), in that the standardized land classification will:

1. provide necessary information for land planning and conservation in Manitoba;
2. ensure that present and future trends in land management are capable of being identified;
3. enable resource inventories to be conducted at a rate that is optimal (temporally) and feasible (financially);
4. identify regions that warrant more detailed examination for that land's potential for development or need for conservation. This limits the effort that would normally be expended in more intense provincial inventories; and
5. provide a method of resolving potential land use conflicts.

The Manitoba Land Classification System proceeds to the second level of hierarchy and allows users flexibility to input their own data at a third or fourth level. This standard method for presenting land cover data eliminates redundancy in inventory costs and enables the integration of remotely sensed data with a provincial geographic information system.

6.3 RECOMMENDATIONS

The main purpose of the Manitoba Land Classification System is to act as a tool to assist resource managers in the province. It was for this reason that they were involved in the planning process rather than devising a system that was solely dependent upon the capabilities of remote sensing. For the system to work efficiently, some additional steps are required. I therefore recommend that:

1. since the Manitoba Land Classification System for remotely sensed data is suitable for a GIS, it be used by all resource managers in Manitoba;
2. the potential users of a system (resource managers) be informed about the system;
3. the purpose of the system should be explained, including its capabilities and limitations; and
4. communication lines be developed to discuss problems and possibilities for the future.

The following technical recommendations should improve the quality of the system. Further study should be directed:

1. to determine the date(s) for either a single or multitemporal inventory;
2. to record the areas of Manitoba that are being inventoried more frequently so that a more concentrated effort can be applied where needed;

3. to develop consistent methods for assessing classification accuracy;
4. to review Thematic Mapper data to allow for incorporation of a finer level of detail if possible;
5. to determine the cost and manpower requirements for an operational system; and
6. to avoid frequent changes which will frustrate the data user and data collectors.

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APPENDICES

APPENDIX A

AN ASSESSMENT OF MANITOBA RESOURCE INVENTORIES TO DEVELOP A COMMON LAND CLASSIFICATION SYSTEM

Individual User Needs Questionnaire

Agency Name ____________________

Address ____________________

Telephone No. ____________________

Resource Manager's Name ____________________

Position ____________________

Responsibilities ____________________

____

____

____

(1) Does your agency conduct resource inventories using remote sensing techniques? (i.e. aerial photography interpretation or analysis of LANDSAT imagery)

YES _____ , NO _____ , PLANNED FOR FUTURE USE _____

(2) From which agencies do you acquire supplementary mapping information?

PROVINCIAL: Department - Branch | FEDERAL: Department - Branch

OTHER:
______________________, ______________________,
______________________, ______________________,

(3) Does your agency currently obtain data from resource inventories that have been conducted with other agencies? (i.e. cost sharing of the project)

YES _____ , NO _____

With which agencies? ______________

(4) How frequently does your agency need to update its maps? (Please be specific)

(5)In the following space list the purpose and use of resource inventory activities (conducted by remote sensing techniques) as they are related to your agency's responsibilities (see example below).

Inventory Type	Purpose

Example:

Deer habitat inventory	-to assess the impact of land clearing on wildlife habitat and animal popul-tions - used to counter land clearing activities

(6) In order to develop a land classification system for a Land Information System, it is essential to determine the mapping needs of resource managers. Please list the inventories that you have conducted over the past two or three years, the land cover types that have been classified, the mapping scales, the size of the area mapped, the source of data, and output products resulting from these inventories (see example below).

Inventory	Cover Types	Map Scale	Size of Area	Source of Data	Output Product

Example:

Inventory	Cover Types	Map Scale	Size of Area	Source of Data	Output Product
Deer Habitat	Coniferous Forest Deciduous Forest Mixed Forest Water , Pasture Crops , Fallow	1:8000	150sqKm	AirPhoto -Ground Survey	Color Map -Stats

(7) Does your agency use an existing or modified version of a land (or water) classification system? (i.e. Forest Inventory, or Canada Land Inventory)

YES _____ , NO _____

If yes, which classification system?

____

(8) What are some of the major problems that you have encountered with past (a) Inventories?

____

____

____

____

(b) Land Classification Systems?

____

____

____

____

(9) How do you think land classification systems could be improved to better meet your needs?

____

____

____

____

(10) When your resource inventory data were presented in map form did the map scale vary between projects (depending on specific requirements) or did it remain at a constant scale?

____

Why?

____

____

____

(11) Were ground truth checks conducted to assess the accuracy of the classification of land cover types?

YES _____ , NO _____ , NOT SURE _____

(12) What is the desired final form of the data collected in the inventory? (i.e. colour maps, statistics only, etc.)

____

____

____

(13) What resource inventory projects (using remote sensing techniques) does your agency intend to initiate in the future?

____

____

____

____

____

(14) How will your agency's future inventory and mapping projects differ from present practice (in terms of essential land cover types)?

____

____

____

____

(15) What is your perception of the use of LANDSAT image analysis in your present resource inventories? (check one)

_____ Very valuable
_____ Valuable
_____ Helpful, but not essential
_____ Not very valuable
_____ Of no value

(16) Do you think that remotely sensed data can serve as a valuable input into a Land Information System?

YES ______ , NO ______ , MAYBE ______

Comments: ____

____

(17) If a resource inventory of Manitoba, using remote sensing and a common land classification system, becomes operational, and integrated into a Land Information System;

(a) What land cover classes would you like to see included?

____

____

____

____

____

(b) What mapping scale would best suit your needs?

____

(c) How often should the resource inventory be updated? (check one)

_____ Every Month
_____ 1 month--6 months
_____ 6 months--1 year
_____ 2 years--3 years
_____ 3 years--5 years
_____ 5 years--10 Years
_____ 10 years--20 years

(d) How useful would this operational system described above, be to your agency?

_____ Very Useful
_____ More Useful than present methods
_____ Equal to the present methods
_____ Less Useful
_____ Of no use

(18) Of the previous land cover types, delineated in your inventories, (question #6) what are the most important land features that are to be identified in the resource inventory.

______________,
______________,
______________,
______________,
______________,
______________,
______________,
______________,
______________,
______________,

(19) What is the minimum level of accuracy acceptable for the land cover types that you have identified as absolutely necessary? (check one)

____ <75%
____ 75-80%
____ 81-85%
____ 86-90%
____ 91-95%
____ 96-100%

(20) (a)Do you have standard definitions for each of these essential land cover types listed in question #18?

YES _____ , NO _____ , NOT SURE _____

(b)If "yes", where are the definitions derived from?

____

If "no" or "not sure" could you provide definitions for the essential land cover types?(see next page)

DEFINITIONS OF LAND COVER TYPES

If more room is needed please add additional definitions on the back of this page or on an extra sheet(s) of paper.

APPENDIX B

A Quality Test for Data to be Used in a GIS

Mead (1982) surveyed 23 managers of GISs to determine data attributes that affect data quality. He believes that data quality is more than a measure of data accuracy or precision, it is an indicator of data utility or versatility. Data quality can be considered a measure of how many different, appropriate uses the data has.

The attributes identified in his survey include:

1. Age of data;
2. Areal coverage;
3. Map scale;
4. Map resolution;
5. Accuracy (position and content);
6. Format;
7. Accessibility;
8. Data costs; and
9. Degree of modification.

These attributes were then used to develop a rating system for evaluating data quality. The rating system enables determination of the suitability of data for state or provincial GIS input. The scores for the test may range from 100 to -60. A score of 70 or above indicates suitability of the data for inclusion in a state (provincial) GIS. Scores between 40-70 may not be ideal due to a deficiency in one or more areas but may be used because of economic, political or temporal considerations. Data with scores below 40 are precluded from use in a GIS.

This rating system is a screening device and does not deal with the question of which data types are most important or most needed.

Data Parameter	Rating
Data age	
Determine the year(s) in which the basic data (including aerial photographs) were obtained, not the date of map or data publication.	
0-2 years	10
3-5 years	8
6-10 years	6
11-20 years	2
20 + years	0
Areal coverage	
Statewide - complete coverage	10
Statewide - 60 percent coverage	8
Regional - complete coverage	6
Regional - 60 percent coverage	2
Local	0
Map scale	
Determine the largest scale at which the data are available	
1:12,000 or larger	10
1:12,001 - 1:25,000	8
1:25,001 - 1:100,000	6
1:100,001 - 1:250,000	2
Smaller than 1:250,000	0
Map resolution	
Determine the smallest unit shown on the map	
1 acre or less	10
1-5 acres	8
6-10 acres	6
11-40 acres	2
40 + acres	0
Positional accuracy	
Determine to what extent the location of features shown on the maps accurately reflect their true locations	
Intensive field checking indicates that the maps exceed National Mapping Standards (NMS)	10
Field checking indicates that the maps meet NMS	8
The maps do not meet NMS, but are considered by past users to be generally reliable	6
Accuracy is unknown or variable	0
Accuracy is known to be unacceptable for most uses	- 10
Accuracy of map contents	
Determine whether the maps accurately depict the true situation on the ground	
Extensive ground checking has shown a statistical reliability of 95 percent ± 3 percent or better	10
Ground checking has determined a statistical reliability of 85-95 percent ± 5 percent	8
Ground checking has determined a statistical reliability of 75-85 percent ± 10 percent	6
The maps are believed to be reliable, but statistical accuracy has not been determined or accuracy is less than 75 percent ± 10 percent	0
Map accuracy is unknown	- 10
Data format	
The maps are digitized or the data are available on computer tapes in an acceptable format and include geographic referencing	10
The maps use an acceptable projection and are geographically referenced	8
The maps are of unknown projection *or* are not geographically referenced	4
The maps are of an unknown projection *and* are not geographically referenced	0
The maps are of unknown projection and scale is unknown or variable. There is no geographic referencing	10
Accessibility of data	
Determine whether there are any restrictions on data use	
Completely accessible to all parties	10
Accessible to any government agency	8
Accessible to any state agency	6
Accessible only to a few state agencies	2
Accessible only to one government agency	- 10
Cost of using existing data	
Estimate the costs associated with acquiring the data and converting it to a form and format that will be compatible with other data in the system. Relate this to an estimate of the cost of acquiring new data	
Less than 10 percent of cost for new data	10
11-25 percent of cost of new data	8
26-40 percent of cost for new data	4
41-60 percent of cost for new data	0
More than 60 percent of cost for new data	- 10
Extent of data modification	
Determine to what extent the data have been manipulated, modified, classified or interpreted before or during the mapping process	
The data are available in a raw, unclassified and uninterpreted condition	10
The data have been subjected to a detailed classification (more than ten categories) but not interpreted	8
The data have been broadly classified (less than ten categories), but not interpreted	6
The data have been broadly classified with some modification or interpretation of the basic data reflected in the maps	2
The data have been subjected to significant modification or interpretation before or during the mapping process	- 10

	Total Score
Highly desirable - should be included in a state information system.	80 +
Desirable - should probably be included in any comprehensive information system	70-80
Potentially useful - significant deficiency may be outweighed by special need.	60-70
Possibly useful - severe deficiencies normally preclude use.	40-60
Undesirable - should only be considered under unusual circumstances	30-40
Highly undesirable - should not be considered for inclusion.	< 30

The quality of the Manitoba Land Classification System for incorporation into a GIS was assessed by the author and by a member of the Manitoba Remote Sensing Centre. The scores were comparable, 74 and 76 respectively, and indicated that land information presented in the Manitoba Land Classification System format is desirable, and should be included in any comprehensive information system.

The main weakness of this information is the largest scale at which the data are available. Assuming that only satellite data will be used, the map scale score is at best 2, but if additional information from aerial photographs is used, the score can be increased to its maximum of 10. This would increase both scores to 82 and 84, making information presented in the Manitoba Land Classification System highly desirable for a provincial information system.

APPENDIX C

World Land Use Classification and Canadian Land Use Categories (Scace, 1981)

WORLD LAND USE CLASSIFICATION	CANADIAN LAND USE LEGEND
Settlements and associated non-agricultural lands (dark and light red)	Urban (red) a. Industrial (dark red) b. Commercial (bright red) c. Residential (medium red) d. Recreation (light red) e. Associated non-agricultural land (pale pink)
Horticulture (deep purple) Tree and other perennial crops (light purple)	Tree Fruits and Horticulture (purple) a. Horticulture (dark purple) b. Vineyards (medium purple) c. Orchards (light purple) d. Other - blueberries, hops, etc. (pale mauve)
Cropland a. Continual and rotation cropping (dark brown) *b. Land rotation (light brown)	Cropland (brown) a. Hay (dark brown) b. Grain (light brown) c. Other - oil seeds, potatoes (medium brown) d. Other - tobacco etc. (medium brown)
Improved permanent pasture - managed or enclosed (light green) Unimproved grazing land a. Used (orange) b. Not used (yellow)	Pasture a. Improved pasture (light green) b. Open grassland - unimproved grazing land, used** (orange) c. Scrub grassland - unimproved grazing land, unused** (yellow)
Woodlands a. Dense (dark green) b. Open (medium green) c. Scrub (olive green) *d. Swamp forests (blue green) e. Cut-over or burnt-over forest areas (green stipple) f. Forest with subsidiary cultivation (green with brown dots)	Woodlands (green) a. Dense (dark green) b. Open (medium green) c. Scrub (olive green) d. Cut-over and burnt-over (dark green stipple)
Swamps and marshes, fresh- and salt-water, non-forested (blue)	Water (blue) a. Water (blue) b. Swamps and marshes (light blue)
Unproductive land (grey)	Unproductive (grey)

APPENDIX D

The USGS Land Use and Land Cover Classification System for use with Remote Sensor Data (Anderson *et al.*, 1976)

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

APPENDIX E

A Remote Sensing Compatible Land Use Activity Classification (Ryerson and Gierman, 1975)

LEVEL I*	CLI LAND USE CLASSES**	LEVEL II***
Water	2	
Urban	B O	Low density residential[5] (single family, duplex and rooming houses)
		Medium-density residential (row housing condonminiums, low rise apartments)
		High density residential[6] (high rise apartments)
		Commercial[7] (retail, strip development, shopping centres)
		Industrial (large factories, oil storage and associated land)
		Commercial and Industrial[8] warehousing, areas of mixed uses, small factories)
		Transportation and Utilities (rail yards, 4-lane highways, interchanges, harbour facilities and power installations)
		Open space and recreation[9] (parks, golf courses, ski hills, large playing fields, cemeteries, other open land)
Improved Agriculture[1,10]	A P H	Cropped land (grain, corn and other field groups)
		Improved pasture and hay
		Horticulture (vegetable crops, market gardening)
		Farmsteads and agricultural buildings (barns and other buildings associated with farm or agricultural use)
Rangeland and Rough Pastureland[11]	K	
Forest and Mature Orchards[2]	U T G	Coniferous
		Deciduous and mature orchards[12]
		Mixed
Wetlands[3,11]	M	
Barren and Extractive[4]	S L E	Sand, gravel and other open pit extractive
		Sand
		Slag and tailing piles (associated with mining and basic refining)
		Exposed bedrock

* For use with satellite imagery. Suggested mapping scale of 1:250,000

** Used originally with low- to medium-altitude airborne imagery

***For use with high-altitude airborne imagery 1:100,000 and mapping scale of 1:50,000. Unless complexing or point symbols are used, the smallest area that can be mapped is 4.5 hectares, thereby removing most single buildings.

APPENDIX F

Manitoba Remote Sensing Project Classifications

Vegetation Mapping the Barrenground Caribou Winter Range in Northern Manitoba Using LANDSAT (Dixon, 1981)

When supplemented with aerial photography digital enhancement of LANDSAT data enabled the identification and delineation of 15 cover types(12 vegetation and 3 burn types). Specific definitions of the cover types were provided.

Vegetation Cover Classes

1.SUBARCTIC FOREST	a) Upland Closed Spruce Forest b) Upland Open Spruce Forest c) Upland Open Spruce-Lichen Forest d) Upland Open Birch e) Lowland Closed Spruce Forest f) Lowland Open Spruce Forest g) Fens
2.SUBARCTIC FOREST-TUNDRA TRANSITION	a) Upland Lichen Heath b) Upland Heath Complex c) Rock Barrens d) Lowland Sedge/Cottongrass e) Lowland Heath Complex
3.BURNS	a) Recent Burn b) Revegetated Burn c) Revegetated Burn with Residual Forest

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Land Use Monitoring with LANDSAT Digital Data in Southwestern Manitoba (Rubec and Thie, 1978).

The authors of this study concluded that certain land use classes can be reliably classified to permit "operational and accurate land use monitoring at a detailed scale of 1:50,000 particularly for wooded cover."

Land Classification System

1. Rangeland
2. Agriculture/Improved Pasture
3. Wooded Land
4. Water - Lakes and Ponds
   - Wetlands
5. Urban and Bare Ground

Accuracy for classified categories was in excess of 80 percent for wooded, water and agriculture areas relative to the total areas derived from airphotos.

MRSC Technology Enhancement Program Projects

1. Remote Sensing to Assess Land Use/Land Cover Changes Affecting the Dauphin Lake Fishery (Pokrant and Gaboury, 1983)

For this study eight land cover types (modified from the Canada Land Inventory) were selected for the classification.

Land Classification System

Classification Code	Description
A: AGRICULTURE	All land in cereal crops and sown forage crops
W: WOODLAND	Includes deciduous and conifer classes (productive and non-productive)
S: SUMMERFALLOW	Tilled fields bearing no crops
P: PASTURE	Improved grazing and/or hay cutting areas(native grasses)
K: ROUGH GRAZE	Rough, unproductive areas which may be used for grazing. May contain up to 25 percent scrub bush
WL: WETLANDS	Low lying areas and fringes of lakes supporting aquatic vegetation
L: LAKES	All open water bodies
U: URBAN	Town locations

The accuracy of the classification was assessed with a confusion matrix. Digital image classification of LANDSAT data resulted in an accuracy of 87 percent or better for all classes, whereas the calculated accuracy of the air photo interpretation was 95 percent or better. Confusion occurred between rough graze and woodland and between improved pasture and cropland when an unsupervised digital image analysis technique was used. A supervised technique was used as it was considered more favourable to class delineation.

2. Moose Habitat Analysis in North Central Manitoba from LANDSAT Data (Bowles *et al*., 1984).

This study was conducted to ascertain the value of computer analyzed LANDSAT digital data in habitat inventories. If use of computer analyzed LANDSAT data was successful, the results would be used to develop a methodology for conducting a moose habitat inventory for the Northern Flood Agreement Resource Area.

Land Classification System

DECIDUOUS MIXED DECIDUOUS/CONIFER CONIFER BOG(includes fen,muskeg) MARSH OPEN WATER	(No specific definitions were given)

Accuracy of the results were compared to Forest Inventory data for the province. Some discrepancies were found in the non-merchantable(700) class and in the mixed wood category of the provincial Forest Inventory. Classification accuracy of the computer analysis was dependent upon the accuracy of the Forest Inventory. Proposed aerial census flights will provide information for cover mapping to compare accuracy further.

3. Rangeland Mapping in Agro Manitoba with LANDSAT (Horn and Lahaie, 1984).

The Crown Lands Branch (Manitoba) wished to obtain land cover maps of the study area and to determine if satellite data could be used to estimate the amount of rangeland affected by flood conditions. The cover type classification used was derived from the Agricultural Crown Lands System.

Land Classification System

Level I	Level II
1 WOODLAND	a) Open to closed Woodland b) Sprayed Deciduous Woodland
2 UPLAND MEADOW	a) Unmodified Rangeland b) Modified Natural Uplands c) Abandoned Cropland
3 LOWLAND MEADOW	a) Midland Natural Vegetation b) Sedge Meadows c) Abandoned Cropland
4 WETLAND	a) Marshes
5 AGRICULTURE	a) Arable Cropland b) Tame Forage
6 UNPRODUCTIVE	a) Rock, Saline, Roads
7 WATER	a) Lakes, Rivers, Ponds

Accuracy of classification for Level I classes ranged from 61 percent (Lowland Meadow) to 98% (Upland Meadow and Unproductive Land). Lowland Meadow was often confused with water, unproductive land, wetland and woodland. The project showed that LANDSAT data analysis of land cover types can be used for regional planning by the Agricultural Crown Lands Branch.

4. Parkland Selection in Manitoba Utilizing LANDSAT computer Classification (Pokrant and Wilson, 1984)

Classes chosen for this study were based on a literature search of forestry mapping projects conducted in boreal areas.

Classification System

Level I	Definition
1. DECIDUOUS	-includes all hardwood species forming a component of 50 percent or more. Dominant species are trembling aspen, balsam poplar, and white birch.
2. TREED ROCK	-Areas of exposed bedrock with less than 50 percent tree cover. Jack pine is dominant with occasional scrub.
3. WATER	-All open water surfaces - lakes, rivers, streams and ponds.
4. SPRUCE	-Dense stands of black spruce comprising 75 percent or more of the canopy cover
5. BARE ROCK	-Exposed areas of bedrock with little or no vegetation.
6. MARSH	-Grassy wet areas with standing or slowly moving water. Grass or sedge sods with interspersed water.
7. TREED BOGS	-Peat-covered or peat-filled depressions with a high water table, a moss carpet, and 25 percent or more canopy cover by trees that are more than one meter tall.
8. BURNS	-All areas having been recently burned over by wildfires. Includes areas of sporadic regeneration and pockets of unburnt trees.
9. PINE	-Dense stands of jack pine comprising 75 percent or more of the area.
10. CUTOVER	-Areas where commercial timber has been completely or partially removed by logging operations.
11. URBAN	-Built up areas resulting from community development.

An unsupervised classifier was used on both single and multi-date LANDSAT imagery. Separations of the softwoods was not possible using the unsupervised classification technique. A supervised technique allowed black spruce and jack pine discrimination with an accuracy of 75 percent and an over all accuracy of 87 percent.

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5. Land Cover Mapping from LANDSAT to Aid in Hydrologic Budget Evaluation on the Assiniboine Delta Aquifer (Horn and Render, 1984)

Five classes in this study were chosen to represent a Level I classification. These five classes were then divided into 10 classes in the second level to provide more detail to water resource managers.

Land Classification System

Level I	Level II
1. AGRICULTURE	a) canola/rapeseed b) corn c) potatoes d) cereals
2. EXPOSED SOILS	a) summerfallow, roads and sand dunes
3. WOODLAND	a) woodland/conifer b) woodland/mixed
4. GRASSLAND	a) mixed grassland/scrub b) natural grassland/pasture
5. WATER	a) rivers, lakes, ponds

Accuracy ranged from 63 percent for exposed soils to 94% for water. The overall accuracy of the classification in the project area is 87 percent.

APPENDIX G

Canada Forest Resource Data System (Bonnor, 1982)

DATA SOURCE

6 Undetermined 9 | Inventory Types 1 2 3 4 | CLI* 5 | Satellite 6 | Other 7

LAND AND WATER

7 Undetermined 9 | Land 1 | Water 2

LAND CLASS

8 Undetermined 9 | Forest 1 | Nonforest 2

OWNERSHIP

9 Undetermined 9 | Federal 1 | Provincial 2 | Private 3 | Municipal 4

STATUS

10 Undetermined 9 | Nonreserved (Assigned** 2 | Retained** 3 | Other 4) | Reserved 1

PRODUCTIVITY

11 Undetermined 9 | Productive 1 | Unproductive 2

SITE QUALITY

12 Undetermined 9 | Site Classes 1 2 3 4 3 5 6 7

STOCKING

13 Undetermined 9 | Stocked 1 | Nonstocked 2

DISTURBANCE

14 Undetermined 9 | Cutover 1 | Burn 2 | Pest 3 | Other 4

AGE

15 Undetermined 9 | Regeneration 1 | Immature 2 | Mature 3 | Overmature 4 | Uneven-aged 5

FOREST TYPES

16 Undetermined 9 | Softwood 1 | Mixedwood 2 | Hardwood 3

*CLI – Canada Land Inventory
**Crown land only
Note: The numbers in the left-hand column refer to the Field as in Appendix 3. The numbers in the body of the chart refer to the CFRDS codes given each class in these fields.

APPENDIX H

Manitoba Forest Inventory Hierarchical Classification (Manitoba, 1984)

Productivity

The following diagram indicates the productivity breakdown to be followed:

(Map Type No) — (Code)

- TOTAL AREA
  - Land (1-899)
    - Forested (1-799)
      - Productive (1-699)
        - Softwood 'S' (01-39)
        - Softwood-Hardwood Mixedwood 'M' (40-79)
        - Hardwood-Softwood Mixedwood 'N' (80-89)
        - Hardwood 'H' (90-99)
      - Non-Productive (700-799)
        - Treed Muskeg (700)
          - Black Spruce Treed Muskeg (701)
          - Tamarack Larch Treed Muskeg (702)
          - Eastern Cedar Treed Muskeg (703)
          - Taiga (Northern Transition Forest) (704)
        - Treed Rock (710)
          - Jack Pine Treed Rock (711)
          - Black Spruce Treed Rock (712)
          - Hardwood Treed Rock (713)
        - Willow/Alder (720)
          - Willow (721)
          - Alder (722)
          - Dwarf Birch (723)
          - Shrub (724)
          - Shrub/Prairie (725)
        - Protection Forest (730)
          - Recreational Sites (731)
          - Small Islands (732)
          - Precipitous Slopes/Fragile Sites (733)
          - Shelter Belts (734)
    - Non-Forested (800-899)
      - Barren-Bare Rock (800)
        - Barrens-Tundra (801)
        - Bare Rock-Igenous (802)
        - Bare Rock-Sedimentary (803)
        - Open Sand Dunes (804)
      - Fields (Agriculture) (810)
        - Hayland (811)
        - Cropland (812)
        - Pastureland (813)
        - Land Clearing (815)
        - Abandoned Land (816)
      - Meadow (820)
        - Dry Upland Ridge Prairie (821)
        - Moist Prairie (822)
        - Wet Meadow (823)
        - Sand Prairie (824)
      - Marsh-Muskeg (830)
        - Muskeg (831)
        - String Bogs (832)
        - Marsh (835)
        - Mud/Salt Flats (838)
        - Sand Beaches (839)
      - Unclassified (840-859)
        - Townsites/Residential Sites (841)
        - Airstrips (842)
        - Roads/Railroads (843)
        - Transmission Lines/Pipelines (844)
        - Gravel Pits/Mine Sites (845)
        - Fence Lines (Community Pastures) (846)
        - Drainage Ditches (847)
        - Beaver Flood (848)
        - Dugouts/Water Holes (849)
        - Oil Fields (851)
  - Water (900)
    - Lake Winnipeg (991)
    - Lake Manitoba (992)
    - Lake Winnipegosis (993)
    - Red River (994)
    - Assiniboine River (995)

APPENDIX I

United States Wetland Classification System (Cowardin *et al.*, 1979)

WETLANDS AND DEEP WATER HABITATS

System / **Subsystem** / **Class**

- Marine
  - Subtidal
    - Rock Bottom
    - Unconsolidated Bottom
    - Aquatic Bed
    - Reef
  - Intertidal
    - Aquatic Bed
    - Reef
    - Rocky Shore
    - Unconsolidated Shore
- Estuarine
  - Subtidal
    - Rock Bottom
    - Unconsolidated Bottom
    - Aquatic Bed
    - Reef
  - Intertidal
    - Aquatic Bed
    - Reef
    - Streambed
    - Rocky Shore
    - Unconsolidated Shore
    - Emergent Wetland
    - Scrub-Shrub Wetland
    - Forested Wetland
- Riverine
  - Tidal
    - Rock Bottom
    - Unconsolidated Bottom
    - Aquatic Bed
    - Rocky Shore
    - Unconsolidated Shore
    - Emergent Wetland
  - Lower Perennial
    - Rock Bottom
    - Unconsolidated Bottom
    - Aquatic Bed
    - Rocky Shore
    - Unconsolidated Shore
    - Emergent Wetland
  - Upper Perennial
    - Rock Bottom
    - Unconsolidated Bottom
    - Aquatic Bed
    - Rocky Shore
    - Unconsolidated Shore
  - Intermittent
    - Streambed
- Lacustrine
  - Limnetic
    - Rock Bottom
    - Unconsolidated Bottom
    - Aquatic Bed
  - Littoral
    - Rock Bottom
    - Unconsolidated Bottom
    - Aquatic Bed
    - Rocky Shore
    - Unconsolidated Shore
    - Emergent Wetland
- Palustrine
  - Rock Bottom
  - Unconsolidated Bottom
  - Aquatic Bed
  - Unconsolidated Shore
  - Moss-Lichen Wetland
  - Emergent Wetland
  - Scrub-Shrub Wetland
  - Forested Wetland

APPENDIX J

Wetland Classification (Zoltai et al., 1975)

	Class
1. Well-defined wetland basins in which at least 75% of the area is occupied by central expanses of permanent open water less than 2 m in depth	*Shallow Open Water*
1. Wetlands where permanent open water is restricted to scattered small pools occupying less than 75% of the area, or where standing water is present only seasonally or not at all	*Other Wetlands* - 2.
2. Predominantly ombrotrophic wetlands, developed on acid peat forming a level, raised, or sloping surface with elevated hummocks and wet hollows, usually overlain by a continuous carpet of spongy moss dominated by *Sphagnum*, and supporting a layer of Ericaceous shrubs, with or without trees ..	*Bog*
2. Predominantly minerotrophic wetlands on less acid peat or mineral soil, without a continuous moss substrate and with a water table persisting seasonally at or very near the surface. .	*Fen, Marsh and Swamp* - 3.
3. Open wetlands with level or depressional surfaces except for low hummocks or ridges, and dominated by sedges and grasses. Pools of open water or drainage tracks may be present	*Fen and Marsh* - 4.
3. Wooded, non-bog wetlands usually with a flat or hummocky surface and supporting about 25% cover of trees or tall shrubs more than 1.5 m in height. Associated with stream courses, lake edges, subsurface drainage, glacial depressions, and bog margins	*Swamp*
4. An open, relatively uniform and consolidated surface occasionally with subparallel ridges or elevated islands, linear drainage features, and a dispersion of small pools. Surface vegetation consists of sedges and grasses and a sparse layer of shrubs and trees	*Fen*
4. An unconsolidated open, flat to depressional surface with clumps of emergent sedges, grasses, and reeds interpersed in standing water with occasional small pools and channels, or patches of bare soil exposed during seasonal water drawdowns. Often associated with open water in streams, flowage lakes, glacial depressions, or on marine terraces	*Marsh*

APPENDIX K

Specific Land Cover Classes for Manitoba Identified by Resource Managers in the Questionnaire

Land Cover Identified in Past Inventories

LEVEL (1)	LEVEL (2)	ADDITIONAL SUBCLASSES
FOREST	Coniferous Closed Mixed forest-mixed vegetation Deciduous Burns (fire)	open -species
WETLAND	Basins (grazed,normal,burned,wooded) Margins (grazed,normal,burned,wooded)	muskeg bog -treed bog -swamp bog fen marsh -shallow water marsh -lowland marsh aquatic vegetation
AGRICULTURE	Crops Summerfallow Pasture,Tame forage,Hayland	cereal row specialty
RANGELAND	Native Pasture,Grassland Heath	prairie upland midland
BARREN	Bedrock Exposure,Rock,Outcrops, Treed Rock Magnetic Susceptibility	structural features (5 classes)
WATER	Lakes Rivers	oxbows scroll bars
URBAN	Cultural features Abandonned	roads railroads buildings towers
OTHERS	Glacial Deposits,Physiogrpahy Soils Geology Wildlife Habitat Units Ground Water	depth

Land Cover Classes that Resource Managers would like to see included in a Remote Sensing-GIS Operational System.

FOREST	Coniferous Mixed Deciduous Fire Cutovers Disease Infestation Shrubland Productive and Unproductive classes	species identification species identification species identification all classes in the Prov. Forest Inv.
WETLAND	Marsh Bog Fen Swamp Wet meadow	Water plant types (Emergent or submerged)
AGRICULTURE	Crops Summerfallow Domestic Grassland (pasture)	special crops fodder crops cereal crops
RANGELAND	Native Grasslands, Native Pasture Rough Pasture Brush and Scrub	upland meadow lowland meadow
BARREN	Sand and Gravel Bedrock,Rock,Rock Outcrops	beach wet beach quarry
WATER	Lakes Streams	
URBAN	Cultural Features	roads road allowances
OTHERS	Slope Zoning Codes Land Use Cadastral Overlay Geological Classifications Soil	 glacial surficial erosion moisture

<u>Most Important Land Cover Features to be Identified</u>

FOREST	Deciduous Mixed Coniferous Fire	by species
WETLAND	Wet Meadow Bogs Fens Swamps Sloughs Muskeg Marsh	treed bog open water (permanent) vegetated (temporary) willow sedge cattail
AGRICULTURE	Crops (fields) Summerfallow Pasture Rural Residential	
RANGELAND	Grassland, Native Pasture	upland prairie lowland
BARREN	Gravel Ridges Sand Outcrops,Bedrock	- beaches
WATER	Lakes Waterways	shorelines (levels)
URBAN	Special Features Uses	roads railroads polelines towers buildings
OTHER	Potential Agricultural Land Habitat Types Inundation Risk Geology Topography(slope) Soil	lineaments,glacial deposits salinity depth erosion

APPENDIX L

GIS Configurations

This information is included to provide the reader with an improved understanding of how remote sensing may be incorporated into a GIS.

Data Input

There are four ways that a system may be designed to handle digital data (Computer Science Corporation, 1978). These four techniques used to interface LANDSAT with a GIS include:

1. manually entering the photointerpreted LANDSAT image data;

2. digitally classifying land cover, geometrically correcting and producing hard copy thematic maps - these are then manually entered;

3. digitally classifying land cover, and producing categorized images and geometrically correcting them to be automatically entered; and

4. geometrically correcting, and registering of raw LANDSAT material to be automatically entered into GIS files.

Marble and Peuquet (as reported in Colwell, 1983) stated that maps were the main source of spatial information in almost all of the currently operational geographic information systems. There apparently has been little use of the raw digital data (especially data obtained by satellites) as a direct data input.

Spatial data may be captured and encoded either by manual or automatic digitization. The design for a GIS should consider both, as the most efficient method of data capture is probably a balance between the two processes. It is essential that interactive display and edit are components so that clean data may be produced.

Johnson and Dueker (1979) have described four basic approaches to encode geographic data:

1. Information systems data are converted from image form (map) into pixel by electric scanning. These

data are then overlaid on LANDSAT derived data and computer analyzed using digital image processing procedures. Two problems exist with this technique. First, exact registration is necessary for analysis (similar to the problem encountered when trying to register satellite data from two dates). Second, the ancillary data are disaggregated to pixel size grid cells. This implies a level of spatial resolution in the ancillary data which may or may not exist (especially if the ancillary data are derived from large areas).

2. Another technique is to aggregate LANDSAT land cover data to a common analysis area (i.e. legal description or municipalities). Percentages of land cover occurring in each analysis area are recorded. The statistical quality of the data is retained with this technique, however, the spatial resolution is reduced from pixel size to the size of the analysis area.

3. A third method involves the use of a grid cell retaining a constant size and configuration for the surveyed area. Data stored in the grid cell is based on the dominant value that occurs there. An advantage of this technique is that overlay of different data sets is an easy task. A disadvantage is that some statistical and spatial detail is lost (depending on the size of the grid cell).

4. The last technique is polygon encoding in which the boundaries of each class are recorded and stored. In this technique the detail of the original data is maintained. Data files in this format are difficult to overlay but may be converted to grid cell files at the time of overlay.

Remote Sensing - GIS Relationship

Remote sensing is often seen as an input to geographic information systems but seldom does the reverse happen. At this time GIS operators consider the classified remotely sensed data as the raw material to be entered into the GIS for further processing with other data sets. This contrasts with the remote sensing technologist who sees the digital remotely sensed data as the raw material. These data are then processed into a classified image which becomes the refined understandable output product.

There is only an infrequent use of GIS data when digitally processing remotely sensed data. The classification accuracy could be markedly improved if GIS ancillary data are used in the classification process.

Data Handling

Tomlinson and Boyle (as reported in Colwell, 1983) have stated that typical map handling capabilities should include:

1. data manipulations;
2. generation of points, lines and polygons;
3. data extraction - with measurements;
4. comparison of overlays; and
5. interpretation to determine optimum location, suitability, and desirability.

Most operational GISs use a vector data structure and therefore, must use vector based algorithms to allow internal manipulations. Peuquet (as reported in Colwell, 1983) has found that there is less use of raster based algorithms in GIS, even though they are better known on a formal basis, since many of them are used in the image processing field. Marble and Peuquet (as reported in Colwell, 1983) stated that there was insufficient information on which to base a decision to choose between the two data structures (vector or raster). This will depend upon research on spatial data handling algorithms and changing data needs.

Design Process

Harding (1980) has outlined briefly a five year program for implementing a state GIS using remote sensing in Washington, U.S.A. In the first year data needs are identified for the State's natural resource managers. The second year plan requires the selection and/or development of procedures and techniques for a total system. During the third, fourth and fifth years the geobase will be built.

A structured GIS design model has been developed by Calkins [(1972) and further modified by Reed (1976) and Johnson (1981), as stated in Colwell, 1983]. The model is separated into four stages:

1. Description of objectives and specifications for the GIS;
2. Definition of organizational resources and constraints toward the system's development;

3. Generation and evaluation of alternative system designs; and

4. Overall evaluation of costs and benefits for the system selection.