AN EVALUATION OF SITE SELECTION METHODS IN THE ASSINIBOINE DELTA REGION OF MANITOBA

BY

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

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Abstract

Resources that are devoted to the conservation of biodiversity are limited. Conservation planners are often faced with the challenge of preserving the maximum amount of biodiversity within a give minimum amount of land. Based on these circumstances, the extent to which protected areas are capable of representing elements of biodiversity will largely depend on the manner in which protected areas are selected and where they are located. This thesis focuses on the application of systematic selection methods in order to identify potential networks of protected areas that comprehensively represent enduring landscape features. Two conservation scenarios are explored: one takes into consideration the current level of conservation within the Assiniboine Delta region of Manitoba, and the other treats the study area as if no protected areas have been previously established within the region.

A greedy heuristic algorithm and a simulated annealing algorithm were utilized to select candidate areas for conservation that would fulfill specific conservation goals. The two algorithms were free to select sites from crown lands or a combination of crown lands and privately owned natural lands. Variations in the magnitude of spatial clustering and conservation targets were applied to the two algorithms as they selected candidate areas for the two conservation scenarios. The simulated annealing algorithm outperformed the greedy heuristic algorithm with regards to generating a selection set that was spatially compact, and was much closer at meeting conservation goals in the most efficient manner.

The results generated from this analysis contained some important implications for conservation planning in the Assiniboine Delta region. Most importantly, efficient ecosystem representation could not be achieved for this region. The reasons for this were that, first, in order to achieve full ecosystem representation, a much larger land base would be required than was available. Second, the presence of existing protected areas reduced the efficiency with which a network of protected areas could be established. The reason for this was that the manner in which the protected areas have been previously established resulted in the over representation of conservation features. Third, the manner in which the planning units were spatially distributed across the landscape did not adequately sample all of the enduring landscape features. If full ecosystem representation based on enduring landscape features is going to be accomplished, not only would conservation planners have to look outside crown lands to include privately owned lands, but they would also have to examine the options of restoration and rehabilitation.

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Chapter 1: Introduction

1.1 Background

The transformation of natural landscapes by human activities has resulted in the degradation of ecosystems on a global scale. In order to minimize the impacts of such loss, biological diversity and ecosystem functions must be preserved (Noss, 1995). One strategy, outlined by the United Nations Convention on Biological Diversity, is to "*promote the protection of ecosystems and natural habitats and the maintenance of viable populations of species in natural surrounds.*" (Environment Canada, 1997, p.4). Protected areas have been referred to as the 'backbone' of any strategy that tries to maintain regional biodiversity. In order to conserve regional biodiversity, protected areas should be as representative as possible of natural diversity at all levels, from ecosystems to genetic variation within populations (Willis *et al.,* 1996). Thus, in order to successfully conserve a region, protected areas must be selected with great care so that they contain samples of all natural diversity levels found within that region (World Resource Institute, 1992).

Historically, the selection of most protected areas has not been based on ecosystem conservation. Rather, nature conservation has been primarily based on the designation of selected areas, usually as national parks or reserves, and managed for the purpose of recreation, tourism, and the protection of charismatic flora and fauna (McNamee, 1993). This type of approach has resulted in the conservation of individual parcels of land scattered across the landscape (Pressey, 1994). A growing view among conservation biologists is that in many regions this approach to conservation will not be adequate on its own to ensure the long-term conservation of biodiversity and ecosystem processes (Noss, 1995). Other concerns center around this approach include: lack of ecosystem representation; hindrance that existing conservation networks may have on the selection and establishment of new areas for conservation; most areas by themselves are too small to maintain viable populations of species; and protected areas are not adequately protected from conflicting land use in the surrounding landscape (Bennett, 1997). In an effort to address these concerns, the conservation of a protected area has shifted from the protection of isolated parcels of land, the examination of relationships and connections between protected areas within the broader landscape (Noss, 1995).

The selection of areas which are worthy of long-term protection, and which make valuable additions to the existing system of protected areas is very intricate process. When one considers the social, economic, political, and ecological context of the landscape, the selection process becomes quite complex. To facilitate the selection process, different methods have been developed in order to identify areas that are required to achieve full ecosystem representation. A number of these methods utilize selection algorithms that are capable of identifying sites that meet the specific conservation objectives while taking into consideration the environment in which the sites are situated.

1.2 Study Area

The region under investigation for this thesis is the Assiniboine Delta region of Manitoba, which is located in the south-central region of the province. This region extends in a fan shape between the city of Brandon to the west and the city of Portage La Prairie to the east. The majority of this region is under private land ownership, which is occupied by various types of farming activities.

1.3 Statement of the Problem

The intent of this thesis is to explore how site selection algorithms can facilitate the identification and selection of networks of protected areas that comprehensively represent all habitat types in a spatial arrangement. Specifically, this thesis will compare the application of two systematic site selection methods in order to identify candidate areas within the Assiniboine Delta region of Manitoba that could potentially contribute towards the representation of biodiversity within this region. These two site selection methods are a greedy heuristic algorithm and a simulated annealing algorithm. In order to identify candidate areas in the region, two conservation scenarios will be examined based on different assumptions, constraints, and conservation goals. In the first scenario *(Existing Protected Areas)*, the current network of protected areas have been embedded into the analysis, thus the algorithms are forced to include existing protected areas as part of their site selection. In the second scenario *(No Existing Protected Areas)*, the reverse set of conditions is in place, the Assiniboine Delta study area is treated as a blank conservation canvas, that is, as if no protected areas had been previously established. Thus, the algorithms are free to either ignore or incorporate existing protected areas into the site selection process.

1.4 Objectives

The overall thesis objectives are as follows:

1. To examine the extent to which the current network of protected areas represents the biological diversity of the Assiniboine Delta, and to establish conservation goals for this region based on the result of this assessment.

2. To review, evaluate, and apply site selection methods in order to identify areas that can contribute towards the fulfillment of conservation goals for the Assiniboine Delta.

3. To evaluate the results produced by the greedy heuristic algorithm and simulated annealing algorithm.

4. To identify a spatial framework within which the different conservation scenarios for the Assiniboine Delta Region could be presented.

1.5 Organization of Thesis

This thesis is organized into six chapters. The first chapter introduces the purpose and objectives of the thesis. The second chapter provides a review of the conservation literature related to protected area selection and is divided into three main sections. The first section highlights Canada's conservation efforts, from both a national and provincial perspective. This is followed by a review of the concepts and criteria that must be taken into consideration when identifying sites for the purpose of conservation. Towards the end of this chapter a review of the issues relevant to the planning and design of a protected areas system is presented. The third chapter provides a review of site selection methods, along with their associated characteristics, strengths and limitations. Chapters two and three present the theoretical basis for the remainder of this thesis. The fourth chapter outlines the study methodology, including a description of the study area, and data sources. The fifth chapter presents the results of the analysis. The sixth and final chapter concludes with a discussion of the findings generated for each objective, along with overall conclusions and recommendations for future work.

Chapter 2: Review of the Literature

2.1 Introduction

The creation of some 30,000 terrestrial protected areas around the world has been one of the greatest conservation achievements of the twentieth century. Together, they cover approximately13.2 million square kilometres, which amounts to 8.4% of the Earth's land area (Davey and Phillips, 1998). Both the number and size of protected areas has expanded considerably in recent decades, resulting in two thirds of the protected areas being established within the last thirty years (Davey and Phillips, 1998).

The characteristics and contributions of existing protected areas as well as the selection methods used in identifying new areas are important factors that require careful consideration when selecting additional areas for conservation. For the purpose of this research, a protected area is defined as: "*An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means.*" (IUCN, 1994, p.6). This literature review will investigate the concepts and approaches related to the establishment of protected areas. More specifically, this chapter will begin with a review of the progress and achievements of landscape conservation in Canada, at both the federal and provincial levels. This will be followed by an assessment of the issues surrounding the establishment and management of protected areas, such as their functions and designations. The final section of this chapter will cover different aspects involved with the selection and design of protected areas.

2.2 Conservation in Practice

Protected areas are seen as part of a larger strategy to prevent the loss of biodiversity (Environment Canada, 1998). Within Canada, federal and provincial protected areas are now selected and established with the goal of conserving the diversity of Canada's natural heritage (Parks Canada Agency, 2000). However, this was not always the intent of protected areas. In the late 1800s and early 1900s, protected areas were established for the purpose of recreation and economic development (Wright and Mattson, 1996). The following section is intended to provide a review of past and present conservation initiatives and achievements, at both the federal and provincial government levels.

2.2.1 National Efforts: Past and Present

National parks are one of the oldest forms of conservation in Canada. The establishment of national parks began in 1905, when two Canadian Pacific Railway employees discovered the Cave and Basin mineral hot springs, near what is now the township of Banff (Canadian Heritage, 1997). Recognizing the value of these mineral hot springs, they sought to establish a claim over the area. However, the Canadian

Government decided to retain the hot springs and the surrounding lands as a 'national possession' (Canadian Heritage, 1997). That same year, the federal government established a 26 square kilometre protected area around the hot springs, which resulted in the establishment of Canada's first National Park (McNamee, 1993). Recognizing the opportunity for economic development and financial gain for both the federal government and the Canadian Pacific Railway, Banff National Park was established, in part to promote tourism and increase exposure to the new railway (McNamee, 1993). Influenced by the success of Banff National Park, the federal government continued to increase the number of parks within this mountainous region (McNamee, 1993). By 1911, five national parks in the Rocky and Selkirk mountains had been established, namely the Rocky Mountain Park, Yoho, Glacier, Waterton Lakes and the Jasper Forest Park.

As parks began to grown in popularity, the federal government recognized a need to protect and manage these newly established areas. In 1911, the Dominion Forest Reserve and Parks Act was passed. Under this legislation, two types of land use classifications were established for the purpose of conservation, namely Forest Reserves and Dominion Parks. Under this Act, the first national parks service was also established, known today as Parks Canada (McNamee, 1993). With the passing of this legislation, the size of many of the national parks was greatly reduced (Eagles, 1993). The reason behind this was in part a reflection of society's perception of protected areas at that time.

Parks were seen as places for recreation and tourism and, as such, they did not require such large expanses of land (Eagles, 1993).

In 1930, the National Parks Act was established with the dual mandate of conservation and utilization: "*The National Parks of Canada are hereby dedicated to all the people of Canada for their benefit, education and enjoyment....and shall be made use of in a manner that leaves them unimpaired for future generations*" (McNamee, 1993, p.27). Not only did this Act provide a set of rules for the operation and management of national parks, it also stated that no new parks could be established, or that any existing parks could be eliminated, or their boundaries changed without Parliament's approval (Eagles, 1993). Mineral exploration and development were also prohibited (McNamee, 1993). It was not until 1988, and again in 2001, that amendments were made to the National Parks Act. Today, Parks Canada's mandate focuses on the protection of ecological and cultural integrity (Parks Canada Agency, 2000).

By 1971, nineteen national parks had been established across Canada (Canadian Heritage, 1997). Until this time national parks had been selected and established in an ad hoc manner. "*They represented, rather, a collection of special places- created in some cases by heroic efforts, accidents of geography and political opportunism – that had been set aside for a variety of purposes that included protecting scenic areas for national and international tourist resorts, providing recreation areas, preserving habitat for wildlife, and stimulating flagging economies in areas of chronic underdevelopment.*" (Canadian

Heritage, 1997, p.3). Due to the unsystematic manner in which national parks were established, a national parks system plan was adopted to help guide the establishment of new national parks. The underlying principle behind this system's plan was to protect an '*outstanding representative sample of each of Canada's landscapes and natural phenomena*' (Canadian Heritage, 1997, p.10).

In order to accomplish this task, Parks Canada divided the country into thirty-nine terrestrial regions (Figure 2.1). These regions were based on physiography, vegetation, and environmental conditions. The intention was that at least one national park should be located in each natural region. Thus, if each natural region was adequately represented through the establishment of a national park, then Canada's biodiversity would be conserved right across the country (Rollins, 1993). The significance of adopting this approach was that Parks Canada moved away from making ad hoc decisions, and towards a more systematic based approach.

Between 1985 and the early 1990s, much effort was placed on conservation, both at the federal and provincial levels. In 1985, a federal Task Force on parks was established and appointed to examine new strategies that would facilitate the creation of new national parks. As opportunities to establish national parks were disappearing, the federal Task Force urged the federal government to complete the national parks system by the year 2000 (Nelson, 1993). In 1989, the World Wildlife Fund of Canada and the Canadian Parks and Wilderness Society launched their Endangered Spaces campaign.

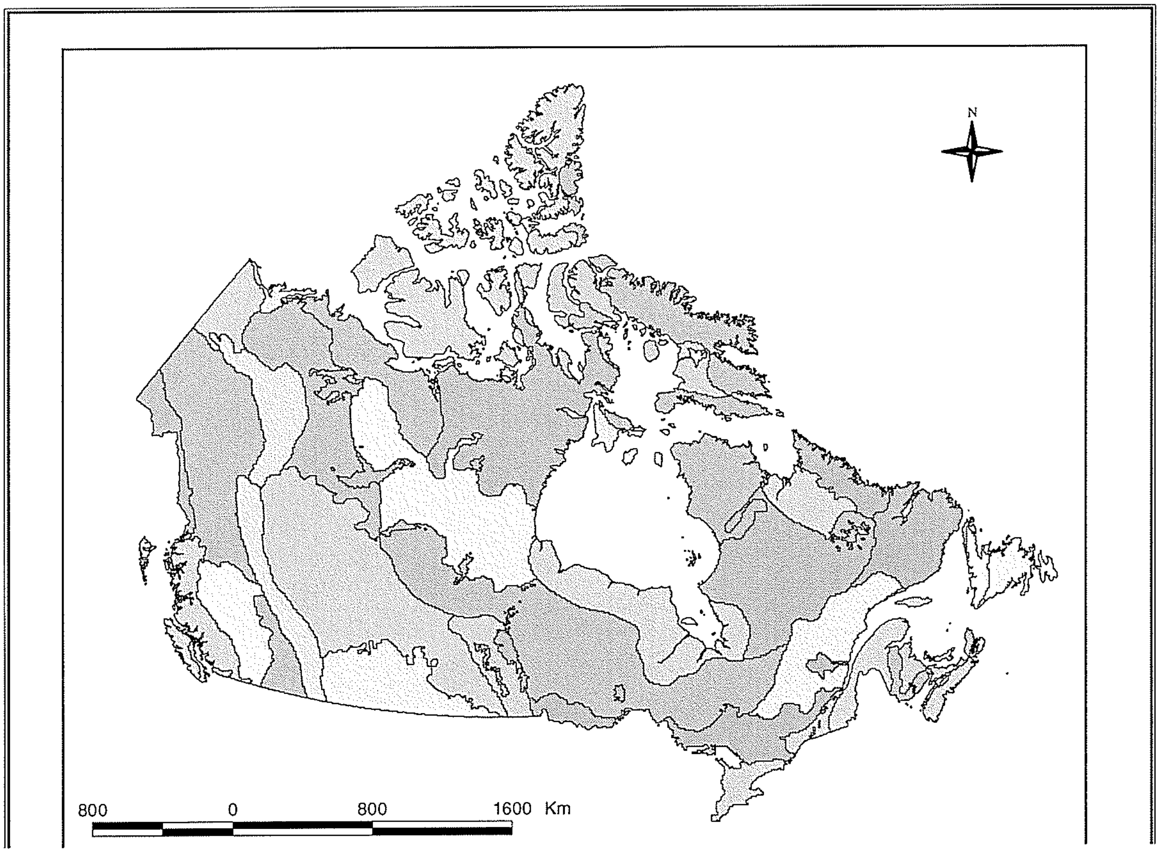


Figure 2.1 Parks Canada Terrestrial Regions

The campaign's goal was to have the federal, provincial and territorial governments complete their parks and protected areas system by the year 2000 (Hummel, 1989). It was estimated that once a sample of each of the nation's natural regions was protected, it would represent approximately twelve percent of Canada's land surface, a target that was recommended by the Brundtland Commission (World Commission on Environment and Development, 1987). When the Endangered Spaces Campaign was launched in 1989, just over fifty percent of Canada's National Park system had been completed. Twenty-one of the thirty-nine natural regions were represented by thirty-four national parks, with eight of those regions having more than one park (McNamee, 1993).

In 1992, Canada was the first industrialized country to ratify the United Nations Convention on Biological Diversity at the Earth Summit (Environment Canada, 1998). The Convention stimulated the federal government to assess the adequacy of current conservation efforts, and to develop strategies to prevent further loss of biodiversity (Environment Canada, 1998). Following the summit, Canada's federal, provincial and territorial Ministers responsible for Environment, Parks, and Wildlife, met to discuss Canada's networks of protected areas. They unanimously affirmed that Canada had a global responsibility to protect its natural heritage (Hummel, 1989). The federal, provincial and territorial governments all agreed in writing to achieve the Endangered Spaces goal of completing a network of representative protected areas by the year 2000 (Hummel, 1995). Today, national parks make up a large percentage of conservation lands, totaling forty percent of all Canada's protected areas (Parks Canada Agency, 2000).

This review has primarily focused on national parks and does not preclude the fact that the federal government has been actively involved in other conservation initiatives. Over the past one hundred years, Canada has played an important role in conservation both nationally and internationally. Listed in Table 2.1 are some of the major national and international conservation initiatives that the federal government has supported. Canada makes a major contribution to international conservation efforts through its federal and provincial park system. In addition, international agreements between countries have been solidified to ensure the continued conservation of habitat and species.

2.2.2 Provincial Efforts: Past and Present in Manitoba

The history of conservation in Manitoba dates back to the late 1800s, with the dedication of Riding Mountain as a Dominion Timber Reserve in 1906. This area was set aside to discourage homesteading and to prevent the agricultural use of unsuitable lands (Manitoba Natural Resources, 1990). Shortly after, in the early 1900s, Manitoba was the first province to establish protected areas to protect wildlife (Manitoba Natural Resources, 1990).

Table 2.1 Species base conservation involvement over the past 100 years

International Convention	Year
Migratory Birds Convention	1916
Western Hemisphere Convention	1940
Convention on Wetlands of International Importance (Ramsar Convention)	1971
Convention Concerning the Protection of the Worlds Cultural and Natural Heritage	1972
Polar Bear Convention	1974
The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	1975
Convention on the Conservation of Migratory Species of Wild Animals	1979
Antarctic Treaty	1988

Source: Eidsvik, (1993); Environment Canada, (1998) As the conservation of natural areas had great political and public support, Parliament passed the National Parks Act in 1930, which clearly stated that mineral development and exploration were prohibited in national parks and only limited use of timber was allowed. Prior to 1930, the federal government had full control of the nation's natural resources (Eagles, 1993). At this time there was a transfer of resource management from the federal to provincial governments (Eagles, 1993). Under this legislation, Riding Mountain Forest Reserve was re-designated and became the first national park in the province of Manitoba.

The 1960s brought dramatic growth in public concern over the environment as public and political expectations of protected areas began to shift from recreation areas to conservation areas (Dearden and Rollins, 1993). Within Manitoba, legislation was enacted to develop a comprehensive network of protected areas. The Provincial Parklands Act of 1960 resulted in the establishment of the Duck Mountain, Whiteshell, Turtle Mountain, Grand Valley, and Patricia Beach Provincial Parks. These parks were largely multi-use facilities, primarily oriented towards recreation (Manitoba Natural Resources, 1990). In 1973, the Ecological Reserves Act was enacted, which involved the selection of areas for the preservation of plants, animals, and natural landscapes without provisions for recreation (Manitoba Natural Resources, 1993). It was not until 1976, with the establishment of the first ecological reserve, Reindeer Island, that Manitoba began creating provincially designated lands that meet current protection standards. "*At a minimum, protected areas prohibit, through legal means, logging, mining (including* *aggregate extraction), and oil, petroleum, natural gas or hydro-electric development. Protected areas with this minimum level of protection still remain open for activities such as hunting, trapping or fishing. As well, protected areas respect First Nation's rights and agreements such as the Manitoba Treaty Land Entitlement Framework Agreement."* (Manitoba Conservation, 2002 p.4).

The Manitoba Provincial Parks Act was revised in 1989. At the same time the World Wildlife Fund launched their Endangered Spaces Campaign. The Endangered Spaces campaign was a ten-year challenge that set out to protect a minimum of 12% of each of Canada's ecosystems, by the year 2000. The predominant reason for this campaign was that in order to maintain biodiversity, networks of protected areas must be established that collectively represent Canada's natural regions in conjunction with the development of sound stewardship over the remaining landscape (Hummel, 1995). At the onset of the World Wildlife Fund Endangered Spaces Campaign in 1990, less that one percent of Manitoba's landscape met the campaign's standards. The World Wildlife Fund's conservation standards require protected areas to be free from commercial logging, mining, hydro, oil and gas development, and any other development which could adversely affect habitat (Whelan-Enns, 1995).

Manitoba was the first province to officially endorse the World Wildlife Fund's Endangered Spaces campaign. At that time, Riding Mountain National Park, and twelve ecological reserves, most of which were relatively small sites, were the only protected areas that satisfied the campaign's requirements. None of the twelve natural regions in Manitoba (Figure 2.2) were adequately protected (Whelan-Enns, 1995). In order to increase the number of protected areas within the province, the Manitoba government adopted the 'Natural Lands and Special Places Initiative'. This strategy, which provided the guidelines for the selection of protected areas, eventually became the policy foundation for Manitoba's Protected Areas

In 1993, the Manitoba government tabled a new Parks Legislation which was fully implemented in 1997. This legislation permitted provincial parks to contribute towards the network of protected areas for the first time. A new Conservation Agreements Act was also passed in 1997, which provided private landowners with the mechanisms to voluntarily apply long-term and binding protection to land they own, thereby allowing these lands to contribute to Manitoba's network of protected areas. Over the past ten years Manitoba has made some significant gains in the creation of new protected areas, including enhancing the protection of existing designated lands through legislation (Table 2.2). Between 1990 and 2000, an additional 200,000 hectares of land have been conserved within the province (Manitoba Conservation, 2001). Thus the percentage of land that is free from commercial logging, mining, hydro, oil and gas development, and any other development that could adversely affect habitat, has risen from 0.06% to 8.5% (Manitoba Conservation, 2001). An Enduring Feature Analysis Approach was adopted to help guide the selection of new protected areas in Manitoba.

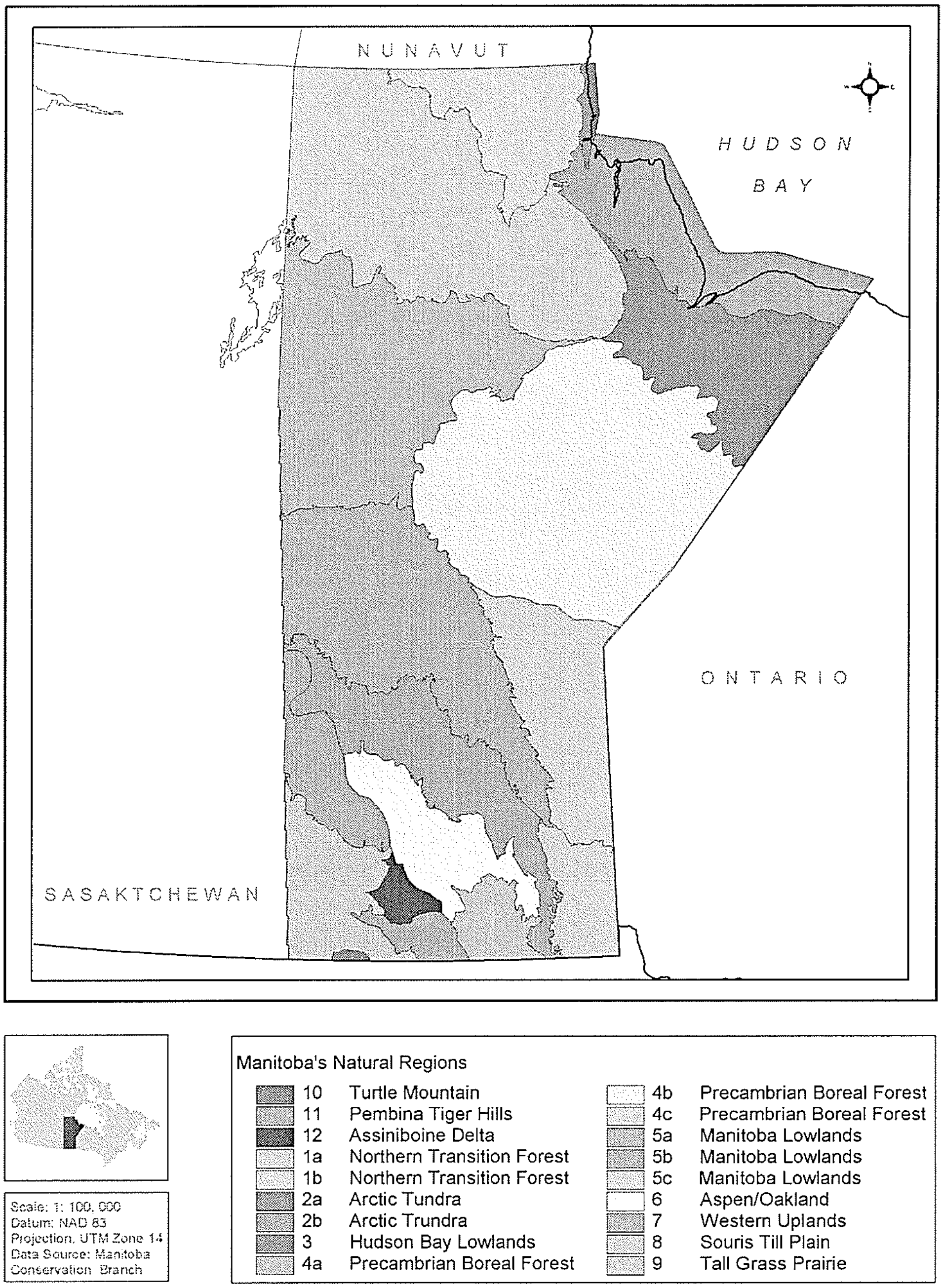


Figure 2.2 Manitoba's Natural Regions

Table 2.2 Conservation achievements within Manitoba (1990-2000)

Year	Percentage Protected	Area (hectares)	Milestones
1990 – 1991	0.6%	350,000	Manitoba Commits to a protected areas program
1991 – 1992	0.6%	350,000	Policy framework developed on protected areas
1992 – 1993	0.6%	350,000	Public consultations on protected areas
1993 – 1994	2.2%	1,440,000	Protected part of the Cape Churchill WMA
1994 – 1995	5.5%	3,590,000	Created four protected provincial parks
1995 – 1996	5.5%	3.590,000	Public consultations on changes to provincial parks legislation
1996 – 1997	6.8%	4,390,000	Created ecological reserves and protected portions of provincial parks and WMA's
1997 – 1998	6.8%	4,430,000	Protected additional WMA
1998 – 1999	8.1%	5,270,000	Created two new protected park reserves, one ecological reserve and protected a portion of Canadian Forces Base Shilo
1999 –2000	8.5%	5,550,000	Created three new protected parks reserves and protected 21 additional WMA

Source: Manitoba Conservation, 2001

2.3 Protected Areas

Protected areas have received a considerable amount of attention over the past two decades. The research that this interest has generated has led to an awareness of the important role and contribution that protected areas make to the overall conservation of biodiversity. The first section of this review will discuss the importance of protected areas, and how their contributions extend beyond that of conservation. The next section will cover the different conservation designations assigned to protected areas. This is an important consideration because not all protected areas have the same conservation goals. The type of designation will vary depending on the level of protection, and the types of activities that are acceptable. Due to the complexity of biodiversity, surrogates such as species or habitats have to be used as measures of biodiversity. Thus the final section will review the different methods used to represent biodiversity.

2.3.1. The Role of Protected Areas

The objectives behind the establishment of protected areas have changed over time. Traditionally, recreation and tourism guided the establishment of protected areas whereas today, protected areas are selected for the purpose of conservation (Wright and Mattson, 1996). Even though many protected areas are selected based on their contribution towards conservation, it is important to recognize that directly or indirectly, the role and benefits of protected areas extend beyond that of conservation. The different roles and objectives that protected areas can fulfill are discussed below.

Scientific Research: Protected areas act as *natural laboratories* in which information pertaining to biological diversity can be gathered (Dixon and Sherman, 1990). In addition, because protected areas have experienced minimum human impact, they also can serve as ecological benchmarks for measuring how natural systems respond to change, thus playing an important role in environmental monitoring (Dixon and Sherman, 1990).

Education: Protected areas contribute towards public understanding, awareness, and appreciation of the environment by serving as outdoor classrooms where the public can have the opportunity to learn from first hand experiences (IUCN, 1994).

Preservation of Species and Ecosystem: Protected areas tend to be viewed less as playgrounds, and more as 'green spaces' that perform vital ecological functions (IUCN, 1994). These areas serve to protect all levels of biodiversity, including the genetic makeup, species diversity, the ecosystem, and their associated processes. Thus, it is important to protect and maintain landscapes that have not been altered by humans so that ecosystems may continue to evolve. (IUCN, 1994).

Maintenance of Environmental Services: Protected areas may play important roles in conserving and maintaining ecological functions such as ecosystem stability, regulating water cycles and atmospheric gasses, absorbing pollutants, buffering against the spread of disease, and stabilizing populations (Dixon and Sherman, 1990).

Protected areas are often established with the intent of conserving environmental and cultural integrity is association of protected areas has lead to the protection and management of areas in such a manner that preserves ecological integrity (Parks Canada Agency, 2000) Protected areas are also established to conserve cultural landscapes. *"Cultural landscape reflects the net effects of a group's technology, values, beliefs, tools and goals on the natural environment"* (Jackson and Hudman, p. 28, 1996). Cultural landscapes are important in that they display the past and/or present occupancy of a cultural group and their interactions with the environment.

Sustainable Use of Resources from Natural Ecosystems: Protected areas in many parts of the world are not only managed for the purpose of conservation but are also managed as areas that can be used in a sustainable manner. For example, in many tropical regions, species are harvested for medicinal purposes (Dixon and Sherman, 1990).

Tourism and Recreation: Numerous protected areas were historically established for tourism and recreation, and in many parts of the world this has not changed.

However, in many of these areas, eco-tourism and ecologically sensitive forms of recreation have evolved and are viewed as positive sources of revenue (Dixon and Sherman, 1990). Therefore, there can be many benefits to having ecologically sound tourism and recreation within protected areas.

Maintenance of Cultural and Traditional Attributes: Parks and natural areas have been established through land claim agreements, particularly in northern Canada. These areas not only protect the biodiversity of a region, but preserve a landscape. Aboriginal people can continue to practice a host of traditional activities such as hunting, trapping, the gathering of traditional plants for medicinal or ceremonial purposes, as well as to pass on traditional skills and practices (Parks Canada Agency, 2000).

Generally, the establishment of protected areas is thought of as a positive form of land use however, it is worth noting that the Western concern with biological diversity conservation is not universally shared. In some parts of the world, wildlife conservation and protected areas are foreign concepts to the people who have coexisted with wildlife for many centuries (Crowe and Shryer, 2000). There also exist some ethical issues surrounding the setting aside of land for conservation. This is especially true in many countries where the western conservation philosophy is increasingly divorced from the social and economic realities of many third world countries (Crowe and Shryer, 2000).

It is important to recognize the many different roles that protected areas have come to play. For example, protected areas serve as sources of inspiration and, for many, have a spiritual value of their own. Public support for the preservation of existing protected areas, and the establishment of new areas follows the recognition of the important role protected areas play.

2.3.2 Systems of Protected Areas

Protected areas are typically established with the intent of preserving the biological diversity of a region, but not all protected areas are alike. The level of protection afforded to protected areas and the types of activities that are acceptable within their boundaries, is dependent upon the type of designation an area receives. The manner in which a protected area is designated serves to place protected area planning within the broader context of land use planning (Noss and Cooperrider, 1994). The following section is intended to provide a review of the different conservation categories found within Canada including international, national, and provincial designations.

International Conservation Designations

Various international classification systems have been developed which vary considerably with regards to their designation. The following section identifies a number of international conservation designations that are distinguished according to specific conservation mandates.

International Union for the Conservation of Nature and Natural Resources (IUCN) Protected Area Management Categories: Globally there are thousands of different conservation criteria, which vary from country to country. In order to assess the level of conservation globally, the IUCN has developed a system of common international standards for classifying the many different types of protected areas around the world. IUCN's goal was to provide internationally applicable guidelines by defining different categories based on multiple types of conservation and management objectives. The different categories as summarized in Table 2.3 have been developed according to different conservation and management objectives, and are used to facilitate regional, national, and international activities (IUCN, 1994).

World Heritage Sites: In 1972, a Convention concerning the Protection of the World Cultural and Natural Heritage was adopted, which recognized "that the world's cultural and national heritage transcends national boundaries and must be preserved for future generations" (UNESCO, 2002). Under this convention, natural and cultural sites that meet specific criteria are identified and area given the special conservation status of World Heritage Site. Within Canada thirteen World Heritage Sites have been established to date.

Table 2.3 IUCN protected areas classification system Source: IUCN, 1994

Category	Name	Description
I	Scientific Reserve/Strict Nature Reserve	An area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species available primarily for research and/or environmental monitoring. A wilderness area is a large area of unmodified or slightly modified land and/or sea retaining its natural character and influence without permanent or significant habitation which is protected and managed so as to preserve its natural condition.
II	National Park	A natural area of land and/or sea designated to (a) protect the ecological integrity of one or more ecosystems for present and future generations; (b) exclude exploitation or occupation inimical to the purposes of the area; and (c) provide foundation for spiritual, scientific, educational, recreational, and visitor opportunities all of which must be environmentally and culturally compatible.
III	Natural Monument/Natural Landmark	An area containing one or more specific natural or natural/cultural feature which is of outstanding or unique value because of its inherent rarity, representative or aesthetic qualities or cultural significance.
IV	Nature Conservation Reserve/Managed Nature Reserve/ Wildlife Sanctuary	An area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species.
V	Protected Landscape or Seascape	An area with coast and sea, as appropriate, where the interaction of people and nature over time has produced an area with significant aesthetic, ecological and/or cultural value and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance and evolution of such an area.

United Nations Educational, Scientific, and Cultural Organization – Man and the Biosphere (UNESCO-MAB): In 1968, The Man and the Biosphere program (MAB) was launched by the IUCN and UNESCO. The goal of this conservation strategy was to establish areas where conservation of biodiversity and sustainable land use practices could co-exist (Noss, 1995). These areas contain natural, and cultural landscapes, which provide a setting for education, sustainable activities, scientific research, and monitoring of environmental change. As of 2002, 396 Biosphere Reserves had been established within 94 countries, 10 of which can be found in Canada (UNESCO, 2001) Within Manitoba, Riding Mountain has been designated as a MAB site.

Ramsar Sites: The Convention on Wetlands of International Importance was signed in 1971, also known as the Ramsar Convention (Eidsvik, 1993). The goal of this Convention was to ensure that wetlands are protected and included on a 'List of Wetlands of International Importance'. These sites play a critical role in the conservation of ecological processes, as well as the flora and fauna they contain. Wetlands that are listed acquire a status that is recognized at national and international levels. Within Canada, thirty-six wetlands have been added to the List of Wetlands of International Importance. Within Manitoba, Delta Marsh and Oak Hammock Marsh have been listed (Manitoba Conservation, 2001).

Federal Conservation Designations

The Canadian government recognizes the importance of conservation and has provided continued support through the establishment of different conservation initiatives, including a system of national parks, migratory sanctuaries, and other nationally designated areas. Table 2.4 provides a summary of the various conservation designations, with a focus on those found within the province of Manitoba.

National Park: National Parks are part of the federal system of protected areas. They have been established across Canada and represent natural areas of Canadian significance. There are currently thirty-nine national parks in Canada, two of which are located in Manitoba, namely Riding Mountain National Park and Wapusk National Park (Parks Canada, 1999). National parks have high levels of protection based on federal legislation, with a primary mandate to protect the ecological integrity of the ecosystems they represent (Parks Canada Agency, 2000).

National Historic Site: Part of Parks Canada's responsibilities is to ensure that Canada's human history is adequately represented (Parks Canada, 1999). These sites are selected to commemorate nationally significant places. Manitoba has a rich history, and to date six national historic sites have been established, including Lower Fort Garry, Prince of Wales Fort, Riel House, St. Andrew's Rectory, The Forks, and York Factory (Parks Canada, 1999).

Migratory Bird Habitat & National Wildlife Areas: The Canadian Wildlife Service, in conjunction with other agencies and organizations, manages a network of National Wildlife Areas and Migratory Bird Sanctuaries across Canada. The goal is to identify and preserve areas of national and international importance for migrating birds and other wildlife (Canadian Wildlife Service, 2002). Not only do these areas serve as sanctuaries for migrating species, they also provide places for educational and scientific research. As of 1998, these protected areas have conserved approximately 11.8 million hectares of land.

Canadian Heritage Rivers: The Canadian Heritage River System, established in 1984, was designed to '*give national recognition to Canada's outstanding rivers and to ensure long term management and conservation of their natural, cultural, historical and recreational values*' (Parks Canada Agency, 2002). To date there are thirty-eight Heritage rivers across Canada. In Manitoba, the Seal River and the Bloodvein River are designated under this program, with the Hayes River nominated for the program. (Canadian Heritage River Association, 2001)

Provincial Conservation Designations

In order to conserve the natural diversity found throughout Manitoba, different conservation criteria have been established. These criteria have been developed to reflect the whole spectrum of conservation requirements, throughout the province. Figure 2.3

Table 2.4 Land Management Categories for Conservation in Manitoba

Category	Name	Number of Sites in Manitoba	Number of sites in the Assiniboine Delta Region
International	Biosphere	1	0
	Ramsar Sites	2	0
	World Heritage Sites	0	0
National	National Parks	2	0
	National Historic Sites	6	0
	Migratory Bird Habitat	0	0
	National Wildlife Area	2	0
	*Canadian Heritage Rivers	2	0
Provincial	Provincial Parks/Park Reserves	25	1
	Ecological Reserves	16	1
	Wildlife Management Areas	32	3
	Provincial Forests	2	1
	Special Conservation Areas	3	1
	**Private Lands		

* This conservation program is run in cooperation with provincial/territorial and federal governments

**Landowners using Conservation Agreements can protect their land to these levels of protection if they wish.

Sources: Parks Canada Agency, (2001); IUCN, (2000); Manitoba Conservation, (2001)

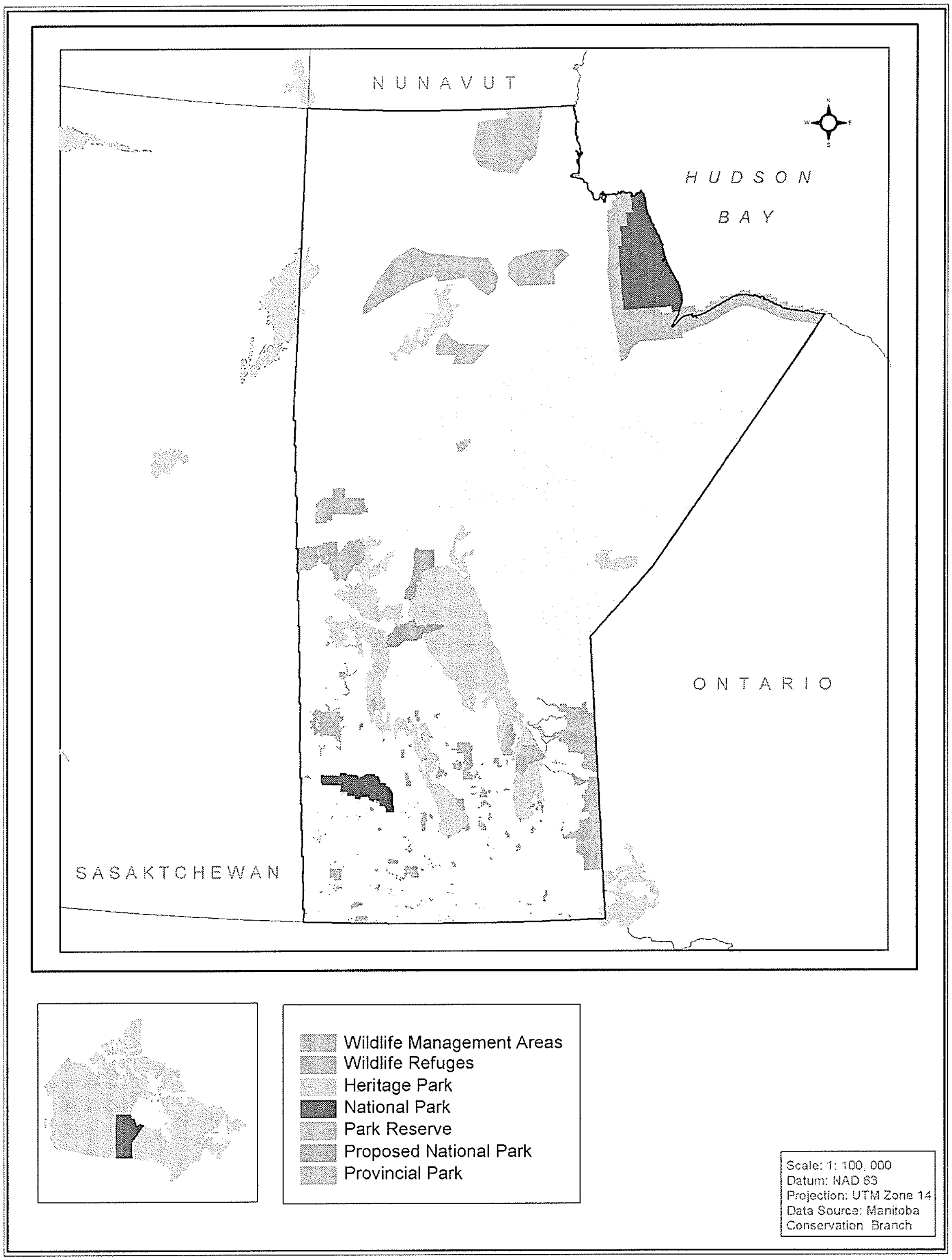


Figure 2.3 Protected Areas within Manitoba

represents all of the protected areas within the province of Manitoba. Protected areas within Manitoba prohibit, through legal means, such activities as commercial logging, mining, oil, petroleum, natural gas, or hydroelectric development. However, protected areas still remain open for activities such as hunting, trapping or fishing and traditional land use by First Nations (Manitoba Conservation, 2001).

In 1972, the Provincial Parks Act identified twelve categories of park designations: natural park, wilderness park, recreational park, recreational trail ways, parkways, recreational waterways, heritage park, wayside park, marine parks, access sites, information centres and seasonal dwelling units (Gill, 1996). The conservation categories that are included within Manitoba's Natural Lands and Special Places Policy Initiative are outlined in Table 2.5. These areas are legally protected from activities that may negatively impact the biodiversity of the region.

2.3.3 The Conservation of Biological Diversity

The conservation of biodiversity is the primary goal behind the establishment of protected areas. Biodiversity is defined as "the *variety of life and its processes, including the variety of living things within a particular area, the genetic differences among them, the communities and ecosystems in which they occur, and the ecological evolutionary processes that keep them functioning*" (Paehlke, 1995, p.80). Biodiversity is typically divided into three levels: genetic diversity, which refers to the difference in the genetic

Table 2.5 Manitoba Protected Area Designations

Conservation Designation	Description
Provincial Forests	Are established to reserve areas for perpetual growth of timber, preserve forest cover and provide for reasonable use of all resources in provincial forests. These forests have been zoned for different use including creating provincial parks, wildlife management areas and ecological reserves within their boundaries. Today there are approximately fifteen Provincial forests in Manitoba. Of those fifteen two have set aside areas within for conservation
Provincial Parks	Manitoba's parks are organized in such a way to allow for multiple land use activities, including recreational use, resource extraction and wilderness experiences. Of the 139 provincial parks found within Manitoba 25 meet the conservation criteria.
Wildlife Management Areas	Are designated for the management, conservation and enhancement of wildlife resources. They protect and provide for unique and critical habitats, preserve the integrity and aesthetics of natural lands and improve the capability of habitat to support a wide variety of species.
Ecological Reserves	Areas are set aside in order to preserve plants, animals and natural landscapes. They also serve as outdoor laboratories for research into biological processes, nature study and education. Areas that contain rare or sensitive habitats can be set aside as ecological reserves with greater restrictions on uses and activities so that the natural region features for which they are set aside endure for future generations.
Private Land	Private landowners using Conservation Agreements can protect their land to specific levels of protection. Private lands which are owned by conservation groups may also contribute to Manitoba's Network of Protected Areas.

variation that exists between individuals; species diversity, which is the most commonly used measure of biodiversity; and ecosystem diversity, which encompass the distinct collections of organisms that occur in different settings, such as a wetland or grassland (Paehlke, 1995). Due to limited knowledge and incomplete data sets, surrogate measures such as species or ecosystems are often used to represent the biodiversity of a region (Faith and Walker, 1996). The following section will review the strengths and limitations associated with the use of various surrogate measures, along with an overview of the surrogate ecosystem used by Manitoba's landscape conservation program.

Conservation biologists often use species or groups of species as surrogates to represent the biodiversity of a region (Caro and O'Dotherty, 1999). This has been referred to throughout the literature as a fine filter approach (Noss and Cooprrider, 1994). Typically, surrogate species are selected where their geographical distribution within the region are known, or have been estimated. Where possible, conservation biologists recommend using umbrella species to delineate the size of areas or types of habitats over which protection should occur (Caro and O'Dotherty, 1999). Umbrella species are specific species that require a wide range of habitats. By protecting important umbrella species and preserving its habitat, this will also protect a number of other species that depend on the same habitat. The concept of using umbrella species is that areas or sets of areas that are 'species-rich' for these groups may be rich in general, i.e. hot spots (Caro and O'Dotherty, 1999). Where species information is incomplete for a given region, statistical estimates are often produced (Meffe and Carroll, 1994). A fine filter approach such as the one described above, addresses one of the basic components of biodiversity, that is, species diversity. However, there are some limitations associated with this type of approach. For instance, the use of species as surrogate measures does not capture the broad ecological scales of biodiversity (Pressey, 1994). In some cases, indicator groups tended to favour different environments, and hot spots do not always overlap for different taxonomic groups (Prendegast *et al.,* 1993). It has also been noted that an approach focusing on the individual needs of a particular species does not address ecosystem structure and function (Hutto et al. 1987; Hunt 1989). In addition, when using a species-based approach, the regional landscape context such as habitat size, shape, configuration, juxtaposition, and configuration are all overlooked (Noss and Harris, 1986; Harris and Kangas, 1988). Finally, critical elements of multi-community diversity, such as gradients and mosaics, are not included in a species approach (Noss 1987; 1990).

Classifications at higher levels on the biological hierarchy, such as ecosystems, landscape types, or environmental domains, have also been used as surrogates to represent the biodiversity of a region (Williams and Humpheries, 1996). The basis for adopting a landscape or coarse filter approach is summarized by the following. "*Because organisms cannot long survive without their equally creative matrix of air-water-soil-sediments, the preservation of ecosystems 'at the landscape level' is the necessary practical approach for all those in land management concerned with biodiversity. This is the 'filter' that, if made sufficiently large, catches everything, whether we know it or not*" (Rowe, S. p.3 in Kavangah *et al.,* 1995). The main advantage of using a landscape-based approach is that information on the distribution of surrogates is clear-cut, and less expensive to acquire than species distribution data. This information is also available at a more consistent level of detail compared to species-based information (Belbi, 1993). Another advantage of using this type of approach for conservation is that patterns and processes, as well as the ecological interactions of different ecosystems can be captured (Turner, 1989). However, there are disadvantages to using landscape-based surrogates.

Limitations associated with land classes in conservation planning are as follows. First, the association of the predictive relationships between surrogates and target elements has often not been empirically tested (Pressey, 1994; Noss, 1990; Williams and Humphries 1996). Second, there is no accepted classification of communities or ecosystems that exists for landscape surrogates (Noss and Cooperrider, 1994). Third, even though it is generally agreed that representing community types rather than just species would do more to capture taxa not currently well inventoried; with regards to taxa that are patchily distributed within land classes, protecting a piece of land might miss many taxa (Williams and Humphries 1996). Fourth, land classes do not necessarily delineate or recognize areas of critical resources essential for maintaining populations in times of scarcity (Noss, 1990). The Nature Conservancy estimated that up to 90% of species could be protected by conserving examples of natural communities without having to inventory and manage each species individually (Noss and Cooperrider, 1994). However, because some species may not be captured using a coarse filter approach (i.e.

sensitive, localized and endangered species) a fine filter approach is still necessary and should be seen as complementary (Noss and Cooperrider, 1994).

As previously stated, surrogate data is often used to represent the biodiversity of a region when being considered for the purpose of conservation. In the absence of detailed species information, landscape classification categories are often employed. The use of enduring landscape features as a landscape-based classification system to represent biological diversity was widely advocated by the Canadian Council on Ecological Areas, the World Wildlife Fund and the Manitoba government (Gauthier 1992; Kavangah, *et al.*, 1995). Due to the fact that physiographic characteristics (topography, slope, aspect and substrate conditions), in conjunction with regional climate, are major factors that contribute to ecosystem formation and function and productivity, enduring landscape features were utilized as ecosystem surrogates (Gauthier *et al.*, 1995). "*Representation should be judged in relation to enduring features of ecosystems and not in relation to themes that can change rapidly, or are in high public profile at any given time. Consequently, landforms and soils and ecological patterns that they control, are viewed as the most enduring features of ecosystems and one on which the degree of representation can be evaluated best, at least at a 'coarse filter' level of analysis. Plant and animal assemblages can change with time, as can ecological processes, so they are not the best features to capture the most stable ecological basis for Canada's ecosystems.*" (Gauthier *et al.*, 1995, p. 6). Thus, if the enduring landscape features within a region are adequately protected, so will the biodiversity of that region.

2.4 Selection of Protected Areas

The underlying goal behind the establishment of protected areas is to conserve representative samples of the biodiversity that are found within a region. The extent to which protected areas within a region will be able to successfully meet this goal rests upon the manner in which protected areas are selected. The following section reviews issues relating to the development of conservation goals, the methods used to identify areas, and the concepts and criteria behind protected area design.

2.4.1 Conservation Goals and Criteria

The conservation goals and criteria that are used to identify areas for protection have evolved from a mixture of ecological and biological theory, land management and administration considerations and human values (Margules and Usher, 1981). Conservation goals and criteria require careful consideration as they pose a strong influence on which candidate areas are to be evaluated and potentially selected. A candidate area or site is defined as a contiguous area, which, if protected, would contribute towards the conservation goals for a region (Pressey, 1994). The following section is intended to provide a review of conservation goals and criteria that are most frequently taken into consideration when identifying areas for conservation.

Since the early 1970, the International Union for Conservation of Nature has advocated the establishment of a global system of protected areas of various categories, which should be representative of the full range of biogeographical variation found on the planet (Peterson and Peterson, 1991). Representation is defined as the degree to which a protected area or systems of protected areas captures the biological diversity of a region (Mondor, 1990). The attainment of full representation is seen as necessary in order to protect sample ecosystems in a natural state, maintain ecological diversity, environmental regulation, conserve genetic resources, and provide areas for education, research and environmental monitoring (IUCN, 1978). Sites should be selected in a manner that is efficient as possible. Efficiency, in this context refers to the degree to which the protected area selection strategies minimize unnecessary duplication of features by identifying sites that are highly complementary in terms of the features they contain (Pressey and Nicholls 1989; Bedward *et al.,* 1991; Pressey, 1994).

When beginning the process of ecosystem conservation, an assessment should be conducted to examine the extent to which the biological diversity of a region is represented within existing protected areas. Three general requirements must be met when assessing the representation of an area. First, it is important to select a classification or surrogate measure to represent the biodiversity of the region under consideration. For example, within Manitoba enduring landscape features are used to represent the existing ecosystems found within each region. Second, an inventory of existing protected areas within the region of interest must be completed. The third step requires an examination of the extent to which the existing system of protected areas adequately captures or represents the biodiversity of the region. Within Manitoba, the conservation strategy is based on an approach in which all examples of landscape diversity will be present within a system of protected areas (Manitoba Conservation, 2001). Thus, representation is the main goal, which the conservation strategy aims to achieve. Tables 2.6 and 2.7 provide a summary of criteria used by Manitoba's Special Places Initiative to assess the level of representation found within a region. Table 2.6 defines size and area requirements that pertain to achieving representation within a region of interest. The actual quantifiers that are used to assess the extent to which individual enduring landscape features are represented within a region of interest.

Successful representation is central to the conservation of biological diversity. However, a protected area system should not be designed solely on the extent to which biological diversity is protected. Other criteria that require consideration are the ecological and cultural attributes of the landscape. Even though the emphasis has been primarily placed on criteria with a biological basis, it is important not to overlook culturally based criteria when identifying areas for the inclusion of sites within a network of protected areas. *"A protected area that responds to human concerns can help bridge the gap and ease the conflicts between conventional development and strict conservation. By including human concerns in protected area planning, reserves can become more socially and politically viable."* (Noss 1995, p. 34)

Table 2.6 Criteria used to assess the level of representation for Enduring Features Source: Manitoba Conservation, 2000

Small (1-8,000ha)	Adequate representation may require that the entire enduring feature be protected. This is particularly true for enduring features that are less than 1,000 ha. One thousand hectares is considered the minimum area necessary for the maintenance of plants and small animal communities. For small enduring features that repeat across a natural region, it is preferable to have one or more complete units captured within a protected area. The character of small enduring features id often determined by the nature of surrounding landscapes. Adequate representation of small enduring features, therefore, requires that the protected unit be embedded within a larger protected area, to prevent edge effects and to preserve the character of the enduring feature being evaluated
Medium (8,000 – 400,000 ha)	Adequate representation may be achieved by setting aside a portion of the enduring feature in a manner that is consistent with guidelines related to edge effects, minimum size criteria, and spatial configuration. For enduring features that repeat across the region, adequate representation may be require that one complete unit is captured within a protected area. For enduring features at the upper end of this size category it may be sufficient to capture a significant portion of the unit within a protected area. Medium enduring features are less vulnerable to edge effects than small enduring features, and may sometimes lie along the inside boundary of a protected area. The protection of adjacent enduring features may be required for adequate representation, if there are significant spatial linkages that determine the character of the enduring feature being evaluated.
Large (> 400,000 ha)	Adequate representation may be achieved by setting aside a portion of the enduring feature in a manner that is consistent with guidelines related to edge effects and spatial configuration. For enduring features that repeat across the region, adequate representation generally only requires that a significant portion of a single unit be captured within a protected area. Large enduring features are much less vulnerable to edge effects that small or medium enduring features, and can thus generally lie along the inside boundary of a protected area. Large enduring features often have other smaller landscape units embedded within them. The protection of adjacent enduring features is not usually required for adequate representation of enduring features in question, unless there are significant spatial linkages that help to determine its character.

Criteria defined according to social or cultural interests that are used in the selection of candidate areas have traditionally guided protected area planning. In the past, protected areas were selected based on their scenic value, as well as their potential for recreation and tourism (Wright and Mattson, 1996). These types of areas were perceived as ideal candidates for conservation as they had strong tourism potential and were often perceived to embody a national identity (Wright and Mattson, 1996). The economic benefits associated with tourism have also been a strong influence in the establishment of protected areas. For example, the establishment of the first National Parks was driven by economic incentives (McNamee, 1993). Other culturally based attributes, such as the scientific and educational value of an area, or the cultural and historical significance of a site, have become increasingly important over the last couple of decades. The scientific and educational value of protected areas is important, in that protected areas can serve as outdoor classrooms and laboratories (IUCN, 1994). Protected areas that are culturally or historically significant also serve to protect our heritage (Park Canada Agency, 2000). These cultural attributes used in the selection of candidate areas for inclusion within a protected areas network are closely tied to roles and benefits of protected areas.

Ecologically based criteria are intended to serve as guidelines for the selection of areas for the purpose of conservation. As the selection of candidate sites for protection can be a spatial exercise, the protection of ecosystems is often based on criteria such as size, lack of roads, or watershed boundaries. (Margules and Pressey, 2001). A number of guidelines for site suitability have been identified by Noss and Cooperrider (1994), and are outlined below.

- Locations of roadless, undeveloped, or otherwise essentially wild areas of significant size. This criterion is relative to the condition of the region. In heavily developed regions, undisturbed areas that are as small as a few hectares may be of high value because of their rarity. Undeveloped areas, especially when inaccessible to humans, offer important refuges to species sensitive to human activities.
- Concentrated occurrences of rare species. On a regional or continental scale, centres of endemism are obvious 'hot spots' of biodiversity that should be included within reserves. Unfortunately, in most regional databases, data concerning rare species occurrences are incomplete.
- Areas of unusually high species richness. Centres of species richness may vary among taxa, but are more correlated with areas of high physical habitat heterogeneity or high-energy flow. Centres of species richness are areas where many species can be protected efficiently (Scott et al, 1993). As species richness for different taxa may not overlap, species richness may have to be plotted separately for each taxonomic group for which data are available (Saetersdal *et al.,* 1993).
- Unique and vital locations of rare or unusual plant or animal communities; important sites used during seral stages (such as old growth forest); or animal concentration areas such as bird or seal breeding sites, ungulate winter range or calving grounds, snake or bear denning areas. The survival of a number of species is dependent on areas such as the ones listed above.
- Resource hot spots such as sites of unusually high primary productivity, artesian springs, ice-free bays, outcrops of unusual parent material, mineral licks and watersheds of high value for anadromous fish or other aquatic elements. It is very important to conserve areas such as these because they greatly contribute to the

conservation of biological diversity, and with out without them, it may not be possible to achieve full biological diversity representation.

- Sites that are extremely sensitive to development such as watersheds with steep slopes or unstable soils, and aquifer recharge areas. The inherent value of sensitive areas as well as their unsuitability for development make them excellent candidates for conservation.
- Sites recognized as important by indigenous people. The value of traditional knowledge should not be underestimated. People who have inhabited a region for a long period of time often have a wealth of knowledge relating to the local flora and fauna and areas rich in wildlife. They also typically identify certain sites as sacred, which may require specific attention. Traditional knowledge is very complex and equally so when it comes to adding this type of information to conservation models.
- Sites that could be added to adjacent protected areas to form larger and more defensible protected areas, thus contributing towards the ecological integrity of an existing protected area.

Many ecological and cultural attributes have been proposed over time as guidelines in the selection of candidate sites and the selection of protected areas. It is highly unlikely that any single candidate site or group of sites would possess all of these attributes. Therefore, candidate sites should be selected so that the full range attributes are captured within protected areas, because these attributes reflect the relative importance of those areas in contributing to the overall conservation goal of a region.

2.4.2 Selection Methods

Over the past decade, conservation planners have developed a number of methods for identifying and selecting for conservation. Although these methods differ in their objectives, most of them are designed to select sites in an explicit, objective and repeatable manner (Pressey *et al.,* 1993). The following section will briefly introduce different selection methods that have been used in conservation planning. A more detailed review of selection methods has been provided in chapter three, where the strengths and limitations of the different protected area selection methods are discussed in detail.

A variety of site selection methods have been developed over the past thirty years. These methods have been developed in order to facilitate the identification of areas, which collectively achieve some overall protection of biodiversity in a region under study. Initially, these methods involved the ranking of areas according to criteria believed to reflect important or urgent needs for conservation action (Margules and Usher, 1981; Smith and Theberg, 1987).

More recently site selection has been done using GAP analysis developed in and adopted across the United States. Using geographic information systems (GIS) and prediction of species occurrence, areas are identified that contain unprotected species (Scott *et al.,* 1993). These gaps are then filled through the establishment of new protected areas or changes in land management practices. Within Canada, a similar initiative is underway to conserve Canada's biodiversity. Based on landscape features, an Enduring Feature Analysis Approach is being carried throughout province. The goal of this landscape-based approach is to have representative samples of all the enduring landscape features captured within protected areas (World Wildlife Fund, 1993).

The final group of site selection methods sets out to identify complete networks of areas. These methods involve the use of algorithms to identify candidate conservation sites (e.g. Kirpatrick 1983; Margules and Nicholls 1988; Margules 1989; Pressey *et al.,* 1993; Possingham *et al.,* 2000; Rebelo and Siegfried 1990; Williams *et al.,* 1991). These methods result in highly efficient representation of diverse elements found throughout a region. In other words, sites are selected based on the extent to which they complement areas that have been previously selected.

2.4.3 Protected Area Design

As a result of habitat fragmentation, the option of protecting the biological diversity of a region through the establishment of a single protected area no longer exists. Thus, if conservation efforts are to be successful, focus should be placed on designing a network of protected areas. *"Hypothesis behind reserve networks is this: if functionally connected, a system of reserves will be united into a whole that is greater than the sum of its parts. Although no single reserve may be able to support a long term viable* *population of species with large area requirements...reserves linked by corridors or other avenues of movement just might do so.*" (Noss, 1995, p.46). There are many elements to consider when designing a network of protected areas. Within the conservation literature, design issues relating to protected areas include protected area size, protected area shape, boundaries, connectivity between protected areas, protected areas zoning and heterogeneity, and landscape dynamics.

The actual size (i.e. how large a protected area should be) has yet to be determined. On a theoretical level, the minimum size requirement of a protected area has been defined as the *"Smallest amount of area required to ensure the long-term survival of a given species or community*" (Peterson and Peterson, 1991 p.26). Others have suggested that protected areas should be fifty to one hundred times larger than the largest size of an expected disturbance. For some ecosystems, this would translate into fifty to one hundred million hectares (World Wildlife Fund, 1993). Often, population viability models and the minimum area requirements derived from them are used to determine the size of a protected area. However, these measures are seen as largely hypothetical and can be uncertain (Noss, 1995). In reality, the total area available for conservation ends up as a compromise between competing social, economic and political interests (Pressey *et al.,* 1992), and the general consensus is that it is more beneficial to select larger areas than smaller areas (Thomas *et al.,* 1990). Larger protected areas tend to include more species, and are better able to maintain species biodiversity and ecological functions

(Meffe and Carroll, 1994). Larger protected areas are also more likely to recover from natural and anthropogenic disturbances than smaller protected areas (Noss, 1995).

Since it is no longer possible to protect the diversity of a region within one large protected area, another landscape design question is 'how much is enough' (Noss, 1995). There is little consensus concerning this problematic question, although estimates may be derived by closer inspection of initial conservation goals. It is also very important to take into consideration the social, cultural and economic aspects of the region that is under investigation. With regards to ecological factors, Noss (1995) has identified some general guidelines, which are outlined in Table 2.7. These guidelines can be used to facilitate the decision process with regards to determining how much of a region should be conserved. Since every conservation scenario is unique, one particular set of methods does not exist determining 'how much is enough'.

Another concern that is closely related to the size of a protected area is its shape. (Meffe and Carroll, 1994). Diamond (1975) recommended that protected areas should be as close to circular as possible to maximize the core area, and to minimize the impacts of edge effects which may produce changes in an area's microclimate, biological communities and ecological process. The exception to this is an elongated protected area that follows a river or coastline (Diamond, 1975). The shape of an area is typically measured using an area/perimeter ratio. If the area/perimeter ratio is high for a protected area, the average distance from any interior point to the nearest boundary point is large.

Table 2.7 Some important factors and considerations for determining the optimal scale of a reserve network Source; Noss (1995)

Guidelines	Description
Size of region	The size of the region will affect decision about how much land must be included within reserves and other zones. For example a small region containing features not represented elsewhere may have to be entirely protected.
Heterogeneity	Heterogeneity of physical habitats and associated species distribution will affect the area required to achieve adequate protection. Highly heterogeneous regions will require more area in reserves.
Hot spot coincidences	If hot spots of species richness are to be captured in a reserve network, each taxonomic group may need to be individually analyzed because centers of species richness may not coincide.
Classification	The more habitat or community types in a classification system, the more area will be required to represent them in a reserve network.
Replication	A greater degree of replication is ecologically advantageous, in that it will capture more within type variation, guard against catastrophic loss and foster metapopulation stability, but it will obviously require more area
Unit Size	The larger the reserve, the higher probability of within-reserve population viability and integrity of natural processes.
Area Requirements	In the design phase it is important to consider the area requirements and average population densities of the species found within that region. From this calculations can determine the area required to support a viable population.
Habitat Quality	Habitat of higher quality for a target species will greatly support a population of higher density, which will therefore require fewer overalls areas to be available. However habitat quality may vary from year to year.
Natural Disturbance Regimens	Reserves or reserve networks that are small relative to the spatial scale of disturbances may experience radical fluctuations in the proportions of different seral stages over time. Ideally a core reserve should be large enough that only a small part of its disturbed at any one time (Pickett & Thompson 1978)

In such cases, external processes may have an effect on internal processes. However, if the area/perimeter ratio is low for a protected area of the same size, the average distance from any point to the boundary decreases, resulting in a relatively large proportion of the area occurring within the *edge zone*. These areas are transition zones, and typically have different microclimates and contain different species than in interior areas (Meffe and Carroll, 1994). The total area contained within the edge zone of a protected area depends not only on the shape of the protected area but also on its size (Meffe and Carroll, 1994).It is advantageous wherever possible to select sites with a longer perimeter/area ratio in order to minimize the impact of edge effects (Schonewald-Cox and Bayless, 1986).

Theberge (1989) recommended that, wherever possible, the boundaries of protected areas should be based on the natural boundaries that exist within a landscape. In some cases *"natural boundaries may be worthy of protection in their own right, instead of being protected on one side but not the other, because they may be areas of high biological diversity and food chain interchanges."* (Theberge, 1989, p 698). However, protected areas are rarely established using natural features, either because of conflicting land use or because the boundaries of protected areas have been previously delineated by the edges of pre-existing land ownership (Schonewald-Cox and Bayless, 1986). Despite the constraints of practical and political realities, the ecological criteria used to propose boundaries are important. Theberge (1989) suggested the following ecological guidelines for the establishment of large protected areas such as national parks:

- Boundaries should not sever drainage areas.
- Boundaries should not leave out headwater areas.
- Boundaries should not cross active terrain.
- Boundaries should include, and not threaten, rare geomorphic and hydrologic features and processes.
- No area, or unique community, in the candidate natural area should be severed by a boundary.
- Boundaries should not sever highly diverse communities.
- Boundaries should not sever communities with a high proportion of dependent faunal species.
- Boundaries should not jeopardize the ecological requirements of either numerically rare or distributionally rare species.
- Boundaries should not jeopardize the ecological requirements of niche specialists.
- Boundaries should not jeopardize populations of spatially vulnerable species.
- Boundaries should not jeopardize populations of range-edge or disjunct species.
- Boundaries should take into account pollution susceptible species.
- Boundary delineation should take into special account the ecological requirements of ungulate species.

Connectivity between protected areas is an important design consideration when planning a regionally protected area network. Connectivity refers to the connection of protected areas through corridors, or strips of habitat connecting habitat patches (Meffe and Carroll, 1994). Over the past decade, the concept of connectivity and corridors has been met with mixed reviews. Criticisms have been centered on the lack of evidence that corridors actually work (Harris *et al.,* 1996). Generally, the clustering of sites is preferred; however, there can be compelling reasons to avoid clustering. Where catastrophes can impact large areas and cause local extinction, it may be better to conserve each species in at least two or three separate places thereby spreading the risk (Possingham *et al.,* 2000).

A number of conservation scientists agree that connected protected area systems are more viable for maintaining biological diversity than a disjointed collection of protected areas that have been isolated because of habitat fragmentation (Harris *et al.,* 1996). As animals normally move across both naturally and culturally fragmented landscapes, corridors may enable and enhance this process (Beier, 1995). There are also many other benefits associated with landscape connectivity. Corridors serve to maintain or facilitate key ecological processes and services, and improve the ability of species to disperse and migrate between protected areas (Meffe and Carroll, 1994). Corridors allow for gene flow between populations, therefore helping to minimize extinction. In addition, corridors allow for range shifts in response to catastrophic events or long-term environmental changes (Noss, 1995), and act as *stepping-stones* for migratory species (Margules *et al.,* 1994).

When designing a network of protected areas, the use of zoning has been identified as a useful method for integrating human activities with conservation (Noss, 1995). Zoning is also applied in the UNESCO Biosphere reserve, where a core area is surrounded by a buffer zone within which various activities are allowed but the land is still managed with the primary concern being to maintain biodiversity (Noss, 1995). As the types of land use within a buffer zone are less intense than those found within the general landscape, the buffer zone shields core-protected areas from harmful activities. The benefits of buffer zones include the minimization of edge effects, as well as in some instances, a decrease in wind, sun, exotic weeds, agricultural chemicals, noise, and opportunistic predators. Buffer zones can also provide connectivity between protected areas, allowing animals to move long distances. (Meffe and Carroll, 1994).

It is important to recognize that protected areas are influenced by both the patch dynamics within the protected area and by the context of the larger landscape (Meffe and Carroll, 1994). Thus, when selecting areas for inclusion within a network, one key requirement for maintaining functional networks is the maintenance of the natural heterogeneity of communities. Spatially and temporally heterogeneous areas are capable of accommodating disturbances better than homogenous areas, and therefore can offer species a diversity of habitats at any given time (Meffe and Carroll, 1994). *"The emphasis on habitat heterogeneity in conservation reserves is an outgrowth of the realization of the importance of process, rather than just patterns, in ecological systems. A patch dynamics approach fosters continuation of natural processes and change in a reserve.*" (Meffe and Carroll, 1994 p.277). Therefore, if conservation efforts are to be successful when designing a network of protected areas, it is important to protect the full range of ecosystem types. In doing so, ecological processes and species interactions that occur throughout the landscape will also be conserved (Harris *et al.,* 1996).

2.5 Summary

Canada has both a unique opportunity and responsibility to conserve the biological diversity found within its borders. Over the past hundred years, Canada has been fairly successful at meeting those obligations. Not only has Canada participated in a number of international projects, but has also initiated a number of conservation initiatives at the provincial level that focus on the conservation of areas of ecological and cultural significance. At all levels of government, the preservation of biodiversity has become an integral part of national and provincial mandates. Much of this can be attributed to the way society views the importance of conservation and the role of protected areas. Not only do protected areas serve to conserve the biological diversity of a region, their benefits often extend beyond their borders into areas of education, spiritual fulfillment, economic development, environmental services, and the continuation of cultural traditions.

This review has highlighted the complexity of the conservation of biological diversity. There are often numerous elements that need to be considered simultaneously. In particular, the identification of a measure with which to represent biodiversity presents numerous problems. Scientists have identified a number of surrogates that can be used to act as measures, but the level of confidence attached to these measures is questionable at times. Once surrogate measures have been identified, the next step is to assess the extent to which the diversity of a region has been captured within the existing protected areas. Based on the results of this analysis, conservation goals can then be defined. Following the establishment of conservation goals, the ecological and cultural characteristics of the landscape must be examined in order to identify areas that are suitable for conservation. In most instances it is not possible to protect every candidate site, and consequently, various selection methods must be used to identify which sites will be selected to meet conservation goals. The final step is to refine the selected sites by identifying core areas, establishing buffer zones and park boundaries. Conservation goals are unlikely to be met if the presence and impact of humans is not taken into consideration during planning. However, it is usually difficult to find a balance between ecologically sound design principles, and the economic, social, and cultural realities of the landscape in which they are situated.

Chapter 3: Conservation Area Selection

3.1 Introduction

Over the past decade, conservation planners have developed a number of methods for selecting areas in need of conservation. The traditional approach to conservation planning has been a species by species approach. However, a system of protected areas that is designed to be adequate for a single species is not likely to satisfy the requirements for all species (Noss, 1990). With the recognition that a single species approach to conservation was not sufficient to meet conservation goals, conservation planners expanded their focus to address the loss of biodiversity within a larger regional context. The adoption of a regional focus was based on the assumption that over the long term most species will become threatened, so the best approach to conservation is to set aside areas that protect the widest range of biological diversity (Kershaw *et al.,* 1995).

The purpose of a regional conservation strategy is to select a network of candidate sites for conservation that are representative of the natural diversity found within a region. This involves the identification of surrogate biodiversity indicators such as, species, vegetation, ecosystem or landscape units that are not currently protected within existing protected areas. This can present quite a challenge in that areas typically eligible for protection are often larger than the areas that can realistically be protected. Other issues such as budgetary constraints, inadequate or incomplete data sets, and conflicts with other land uses further complicate the selection of candidate sites. However, given their important role with regards to conservation, protected areas must be selected with great care from the range of alternatives to ensure that the natural diversity of the region is protected. A number of conservation planning approaches have been proposed over the past number of years. The intent of this chapter is to provide a review of these conservation planning methodologies.

3.2 Combinatorial Scoring

Combinatorial scoring procedures were developed in the 1970s and 1980s to facilitate regional conservation planning. Rather than selecting areas for conservation based on the requirements of a single species, combinatorial scoring procedures were designed to identify sets of areas for protection based on a multitude of conservation measures. Within this framework, areas were selected for protection based on their conservation value (Margules and Usher, 1981).

In order to determine the conservation value of an area, sites were assessed according to specific conservation criteria. The candidate areas that were under investigation were evaluated according to various criteria (Table 3.1). Based on these evaluations, a score was generated for each potential site. Typically this assessment

Table 3.1 A review of conservation criteria used in Combinatorial Scoring Approaches

Criteria		Margules & Usher Review of 9 studies	Smith & Theberge Review of 22 studies
1.	Accessibility	*	2
2.	Availability	1	1
3.	Biodiversity	8	20
4.	Buffers and Boundaries	*	4
5.	Conservation Effectiveness	*	2
6.	Cultural Resources	*	2
7.	Ecological Fragility	1	7
8.	Ecological / Geographic Location	1	2
9.	Educational Value	3	6
10.	Importance to Wildlife	1	6
11.	Level of Significance	*	4
12.	Management Considerations	1	*
13.	Naturalness	7	10
14.	Potential Value	1	*
15.	Productivity	*	3
16.	Rarity/Uniqueness	7	20
17.	Recorded History	3	6
18.	Recreation / Amenity Value	3	5
19.	Replaceability	1	*
20.	Representativeness / Typicalness	4	8
21.	Scientific Value	2	5
22.	Shape	*	2
23.	Size	7	11
24.	Vulnerability /Threatened Area	6	6

- The authors did not find the criteria in their survey.

Source: Marguels and Usher 1981; Smith and Theberge, 1987 involved assigning values to candidate sites based on their ecological, social and economic potential (Margules and Usher, 1981; Smith and Theberg, 1986). Once the assessment was conducted, scores were tallied, and candidate sites were then ranked in order of significance or conservation priority (Pressey and Nicholls, 1989).

The advantages of using combinatorial scoring procedures are that they are relatively quick and straightforward to implement. Scoring approaches are also quite flexible as different weights could be applied to sites according to ranked criteria. For example, if a rare species required a specific habitat type, this conservation criterion could receive a higher score to reflect this. However, this type of approach has not been widely adopted because of several inherent limitations. In particular, scoring procedures have been criticized for the following; their inability to efficiently represent conservation elements; the difficulty associated with defining explicit conservation targets; and the ambiguity and judgmental characteristics of conservation values that are derived from the various criteria.

Scoring approaches also have been criticized for their inability to efficiently achieve the basic conservation goal, that of representation (Pressey and Nicholls, 1989). Due to the fact that the selection of areas for conservation is based on a numerical score, there is no mechanism to guarantee that areas with the second or third highest score will not duplicate species, communities or habitats that have been successfully conserved by areas that were previously selected (Pressey *et al.,* 1993). Another problem with scoring approaches relates to where sites rank on a list. Often conservation planners must select quite a large number of sites from the list in order to represent all species, communities or habitats at least once (Margules and Austin, 1991).This can lead to the costly over representation of some features, and the detrimental under representation of others.

Scoring approaches have also been criticized for their inability to identify 'if and when' conservation targets have been reached. "*If sites are ranked according to some score, how far down the list is it necessary to go before the goal of adequate nature conservation is achieved? Are the top ten ranked sites sufficient, or the top fifteen?*" (Margules and Austin, 1991, p.346). This can be attributed to the difficulty in establishing definitive conservation targets, as well as problems related to the way conservation values are derived.

Combinatorial scoring methods have also been criticized for being overly subjective and ambiguous with regards to the way conservation criteria are defined, and in the manner in which conservation scores are calculated (Smith and Theberg, 1986; Margules, 1989). It is very difficult to evaluate areas based on their net contribution because the manner in which conservation criteria are evaluated is not explicit. Sites that are valuable with respect to one or more criteria may be overshadowed by low values for other criteria, thus the *true* conservation value of a site is often masked (Margules and Austin, 1991).

This can place conservation planners in a difficult position if they are required to demonstrate the rationale behind the selection of various sites (Margules, 1989). Based on the number of limitations associated with this approach, conservation biologists have turned towards the use of more explicit methods for the selection of areas for conservation.

3.3 GAP Analysis

The inability of species-based and combinatorial scoring approaches to adequately address the loss of biodiversity encouraged the scientific community to develop a variety of new conservation methodologies. One response was the development of a GAP analysis methodology that provides a well-organized approach for evaluating the protection status of biodiversity. GAP analysis uses geographic information systems (GIS) to identify gaps in biodiversity protection that may be filled through the establishment of new protected areas, or changes in land use practices (Scott *et al.,* 1993). There are two principles that drive the GAP analysis process, the first is that the best time to decrease the probability of species extinction is well before its population becomes endangered (Kershaw *et al.,* 1995). The second principle is that a dual focus which examines both habitat and species conservation is more likely to succeed than conservation programs focused on any single species (Scott *et al.,* 1993).

The objective of GAP analysis is to identify biotic elements that are either underrepresented, or not at all represented in the existing network of protected areas. Using GIS technology, vegetation maps and species distribution information are combined and overlain on maps of land ownership and management status (Scott *et al.,* 1993). The results of this analysis identify which elements are absent from existing protected areas. These areas are the 'gaps' within the conservation network that will require further protection (Scott *et al.,* 1993). This information can then be used to set conservation priorities such as designing future protected areas and planning land acquisition.

Although GAP analysis is based on a simple concept, the data required to run the analysis are quite complex. The types of data required to produce a GAP analysis include vegetation alliance maps, species distribution maps, and land use and management status maps (Scott *et al.,* 1993). Vegetation information is central to GAP analysis, and is viewed as the most fundamental layer (Noss and Cooperrider, 1994). Vegetation information is used to generate other layers of information, such as land management categories and wildlife distributions. Wildlife distribution maps are produced for various vertebrate species by linking range limits and habitat associations to mapped vegetation (Scott *et al.,* 1993). Vegetation is also used to determine species and natural community representation within existing protected areas (Stoms, 2000). Land ownership and management status information is collected and mapped according to classes such as private lands and agency managed public lands (Noss and Cooperrider, 1994).

The application of GAP analysis had an incredible impact on the conservation of biodiversity, and many benefits have stemmed from this conservation approach. Due to the broad scope of this conservation work, the results can provide conservation biologists with a road map of where to set conservation and land management priorities. GAP analysis has also greatly contributed towards more comprehensive land use planning within regions. Before GAP analysis, the impacts of individual management decisions were unknown, yet the cumulative effects of the various land management decisions were resulting in negative impacts (Crist, 2000). Thus, with the availability of land use and management status maps comes a more comprehensive understanding of how various land use practices affect biodiversity within a region (Crist, 2000). However, as with all conservation initiatives, there are also some important limitations associated with this type of analysis. The limitations of this approach centered around the errors associated with the types of information used, and with some of the assumptions that GAP analysis makes.

A particularly important issue in GAP analysis is the accumulation of errors. Errors can be introduced at various states of the analysis, such as when data sets are complied to produce the different layers of information, or when different data sets are overlain to produce conservation status maps (Flather *et al.,* 1997). Often, the amount of error that is introduced at these different stages is unknown (Flather *et al.,* 1997). Due to the uncertainty of error propagation, results produced from GAP analysis may be unreliable, resulting in sub optimal conservation decisions (Dean *et al.,* 1997).

GAP analysis has also been criticized for a number of assumptions. An early GAP analysis assumption was that species and vegetation maps would allow for the identification of biodiversity hotspots, that is, areas of maximum element co-occurrence (Scott *et al.,* 1993). These areas were initially seen as important for conservation because they represented opportunities to protect a large numbers of species (Noss and Cooperrider, 1994). However, more recent research has revealed that species richness for different classes of organisms do not necessarily co-occur (Prendergast, 1993). Thus, the emphasis has been replaced with the goal of identifying complementary sets of geographical units that could represent all conservation elements rather than hot spots (Williams and Humphries, 1996).

Another assumption of GAP analysis is that species data collected at coarse spatial and temporal scales provide a *first order* approximation to community and ecosystem representation (Conroy and Noon, 1996). This assumption has been criticized because *"species abundance distributions and species richness are poor surrogates for community and ecosystem processes and are scale dependent, thus, do not support its general applicability"* (Conroy and Noon, 1996, p.763). GAP analysis also makes the assumption that mapped vegetation accurately predicts the spatial distribution of terrestrial vertebrates (Edwards *et al.,* 1996). The concern centered on this assumption is that there exists uncertainty regarding the level of accuracy and sensitivity of the data sets that are used in the habitat relationship models to predict species occurrence (Dean *et al.,* 1997). As conservation science continues to change and evolve, so too will the assumptions and information used within GAP analysis. Prior to GAP analysis, there had been no broad-based assessment of the protection given to biodiversity within the United States (Scott *et al.,* 1993). Today, GAP analysis is seen as a powerful conservation methodology and has been implemented across the United States and parts of South America (Flather *et al.,* 1997).

3.4 Enduring Feature Analysis Approach

GAP analysis is a methodology that has been used extensively in the United States to identify gaps in the representation of biological diversity (Scott *et al.,* 1993). This conservation framework has been widely adopted within Canada. However, in place of vegetation communities and species distributions, landscape based features are used to represent the biological diversity of a region. This conservation planning approach, referred to as Enduring Feature Analysis Approach, has been embraced by the World Wildlife Fund of Canada, and has formed the foundation of a nation-wide conservation strategy (Hummel, 1995).

Enduring Feature Analysis Approach is used to identify and assess areas that are in need of conservation, with the end goal of developing a network of protected areas that are representative of the diversity found within a particular region (Schroder, 1993). Enduring Feature Analysis can be implemented in three stages. The first stage begins with the characterization of the landscape. This involves the 'delineation of landscape based units' in which enduring landscape features serve as biodiversity or ecosystem surrogates. Enduring landscape features are made up of physiographic features such as topography, slope, aspect, substrate conditions and regional climate that have been delineated using GIS technology (Watkins, 1994). The layers of information used to create enduring landscape features have been selected because they have been identified as major factors that influence ecosystem development (Gauthier *et al.,* 1995). *"The implicit assumption underlying the enduring landscape features concept is that if the variation in landforms and physiographic as well as soils are adequately represented in terrestrial ecosystems, then the environment and site conditions that support representative plant and animal species and communities will also be captured"* (Gauthier *et al.,* 1995, p.3). Thus, the representation of enduring landscape features in a system of protected areas serves as a natural way of protecting biodiversity (Gauthier *et al.,* 1995). The second stage involves an assessment of representation which is achieved by evaluating the extent to which enduring landscape features are already captured within existing protecting areas, and the extent to which they adequately reflect the biological diversity of a particular region. Based on the results of this analysis, gaps within the existing network of protected areas become evident (Gauthier *et al.,* 1995). The third stage of the process involves a more detailed often biological based investigation of the existing conservation gaps. This is achieved through the identification of candidate areas that are best suited for filling in the existing conservation gaps. In Manitoba, Areas of Special Interest are identified as candidate areas (Government of Manitoba, 2000). A fine filter analysis is applied to Areas of Special Interest in order to identify any rare or endangered species, areas of unusually high species diversity, areas that may be extremely sensitive sites, or areas that contain unique features that influence the biodiversity of a region (Government of Manitoba, 2000). Wherever possible, Areas of Special Interest are selected in a manner that will minimize resource allocation conflicts, while at the same time protect undeveloped areas (Government of Manitoba, 2001).

The criticisms centered on the application of the Enduring Features Analysis Approach have largely focused on the level of suitability associated with the use of enduring landscape features as biodiversity surrogates. In particular, concern has been focused on the issue of scale and accuracy. Enduring landscape features are mapped at a very coarse scale, and as a result are not suitable for fine level assessments. At this scale, many important details are not captured which may lead to a false representation of biological diversity. However, it is important to note that this coarse scale approach is complemented by a finer scale analysis, that is, on the ground surveys once candidate areas have been identified (Government of Manitoba, 2000). Within Manitoba the Enduring Feature Analysis Approach has received some criticism regarding the manner in which candidate areas are selected. The selection of candidate areas for protection occurs mainly on crown land and is often constrained by existing resource commitments. However, this limitation reflects the realities of the landscape and not the actual selection process (Government of Manitoba, 2000). There are many advantages associated with an Enduring Features Analysis Approach. In particular, one advantage is that it is a standard approach, making it possible for it to be applied across the entire province, thus providing conservation planners a measure of regional conservation progress. Another benefit associated with this approach is that it is relatively straightforward to understand and implement. Due to the inherent flexibility of this approach, conservation planners across the provinces and territories of Canada can modify and fine-tune this conservation tool to reflect and capture the ecological and cultural diversity of their landscapes.

3.5 Systematic Selection Methods

Many countries have committed to conserving significant amounts of their native biodiversity through the establishment of protected areas (McNeely *et al.,* 1990). However, the resources allocated to conservation are limited, and therefore protected areas must be located as efficiently as possible if they are going to adequately fulfill this commitment. One conservation strategy that has been developed to address this challenge is the use of systematic selection methods that employ the use of selection algorithms to choose areas for conservation.

Selection algorithms set out to identify the minimum, or near-minimum group of candidate areas which are required to fulfill a regional conservation goal. The types of conservation goals that are set can be defined as percentages, area-based targets, or the number of occurrences of elements such as biodiversity indicators. Commonly adopted surrogate measures include vegetation, species, ecosystems and landscape-based features (Pressey *et al.,* 1993). Once a conservation goal has been established, the algorithm examines and selects candidate areas with respect to those conservation goals. The selection algorithm proceeds by selecting a particular site. Once a site is selected, the conservation values for the region are recalculated and the selection process continues until the conservation goal has been met. By design, selection algorithms select areas in a manner that is complementary. Each site is selected based on the extent to which it complements previously selected sites by contributing the most new conservation elements that are not already captured (Pressey *et al.,* 1993). This approach greatly reduces the number of sites needed to represent the biological diversity of a landscape.

Three types of selection algorithms that have been used extensively in conservation planning include richness-based algorithms, rarity-based algorithms and simulated annealing algorithms (Possingham *et al.,* 2000). The first two selection algorithms proceed stepwise through a list of candidate sites, choosing the best candidates at each step according to explicit rules (Seatersdal *et al.,* 1993). Greedy or richness-based algorithms start initially by adding sites that contain the greatest amount of conservation elements, and sequentially include sites that add the most additional elements, taking into account those elements that have already been selected (Nicholls and Margules, 1993). Rarity-based algorithms begin by selecting the areas which contain the most rare element. Additional sites are sequentially selected which add the next most rare element, as well as taking into account those elements that have already been selected (Freitag *et al.,* 1996). Greedy algorithms are very fast and simple to implement. They also are very effective at finding the largest number of species that can be preserved when the number of sites allowed for protection is restricted (Kershaw *et al.,* 1995). Some studies have found that richness-based algorithms tend to be more effective than rarity-based greedy algorithms in finding the minimum number of sites necessary to represent all species at least once (Possingham *et al.,* 2000).

A simulated annealing algorithm is another selection algorithm that begins the selection process by generating a completely random system of protected areas (Possingham *et al.,* 2000). With each iteration the algorithm randomly selects sites and evaluates the overall change to the system. The site is then added or removed depending on the results of the evaluation (Stoms *et al.,* 1999). Initially, any change to the system is accepted, whether it increases or decreases the value of the system. As time progresses, the algorithm is more and more selective about which changes it accepts, rejecting those changes that would increase the value of the system by too large an amount (Stoms *et al.,* 1999). At the end of the simulated annealing run, only changes that improve the value of the system are accepted (Possingham *et al.,* 2000).

The use of selection algorithms in conservation planning has been criticized for their inability to guarantee optimal solutions (Lombard *et al.,* 1995; Underhill, 1994; Seatersdal *et al.,* 1993; Pressey *et al.,* 1995, Willis *et al.,* 1996; Custi *et al.,* 1997). As stated by Underhill (1994), to find the true optimal solution requires optimizing algorithms that are capable of evaluating a data set and producing what is *mathematically* considered to be a global optimum. Although these types of algorithms produce a guaranteed global optimum, they do have some associated limitations. For complex problems, that is, selection problems that have large data sets, optimizing algorithms often cannot find a solution (Pressey et al 1996; Custi *et al.,* 1997). In addition, optimizing algorithms cannot account for the spatial relationships among the sites selected, which often results in selection of fragmented protected areas (Possingham *et al.,* 2000). Another limitation of optimizing algorithms is that they cannot manage conservation targets that are proportional, that is, targets that are based on specific area goals such as two hundred square kilometers or a percentage of an area of land (Pressey *et al.,* 1999). Furthermore, a comparative analysis revealed that optimality algorithms were only ten percent more efficient (Lombard *et al.,* 1995; Pressey *et al.,* 1997), or in some cases only as efficient as heuristics (Seatersdal *et al.,* 1993; Willis *et al.,* 1996).

Although greedy, rarity and annealing algorithms tend to select a somewhat larger area than optimizing algorithms, they also tend to provide more appropriate methods for conservation planning (Pressey, 1999). Systematic selection methods provide conservation planners with tools that enable them to explore alternative sites selected quickly and easily and within reasonable limits of optimality (Nicholls and Margules, 1993). Systematic selection methods also have the advantage of being flexible, explicit, and efficient (Nicholls and Margules, 1993; Pressey *et al.,* 1993; Williams, 2000). Efficiency, in this context refers to the degree to which the protected area selection strategies minimize unnecessary duplication of features by identifying sites that are highly complementary in terms of the features they contain (Pressey and Nicholls 1989; Bedward *et al.,* 1991; Pressey , 1994). The degree to which systematic approaches efficiently achieve conservation goals is very important, as only a small proportion of land will be dedicated to nature conservation. Unless protected area networks are chosen efficiently, the chances of a network of protected areas representing all the elements of biodiversity is slim (Custi *et al.,* 1997). Another advantage of systematic selection methods is their inherent flexibility. The flexibility of systematic methods allows conservation planners to explore and compare the different conservation scenarios. In addition various spatial configurations can effortlessly be explored. The algorithms and conservation targets themselves can also be altered and refined. The types of modifications that are possible when selecting sites for conservation include changes to conservation goals or targets, the exploration of land use decision making through the inclusion or exclusion of specific areas, revisions and updates of data sets, and the modification of the algorithm itself through the alteration of selection rules (Margules *et al.,* 1994). Thus, the flexibility found within systematic approaches allows conservation biologists to explore the different options that exist within a landscape. An additional advantage of systematic selection methods is that they are explicit, and therefore can be readily justified and defended (Margules *et al.,* 1994). It is also important to be explicit so that other parties involved in land use planning can clearly understand how the results are derived (Margules *et al.,* 1994). From a scientific perspective, it is important that the results produced by systematic methods for conservation planning are unambiguous and repeatable, thus, as conditions change and new information becomes available, systems of protected areas can be readily re-evaluated and modified (Pressey, 1999).

Heuristic selection algorithms are powerful tools for conservation planning. In particular, what distinguishes systematic approaches can be attributed to their inherent flexibility, efficiency and explicitness. Their utility lies in their ability to quickly identify potential protected area networks based on specific conservation goals and restrictions. However, they are not capable of supporting all the decisions needed in conservation planning, and therefore it is important to link systematic approaches with GIS-based analysis and mapping.

3.6 Geographic Information Systems

Conservation planning is inherently spatial, and as such, the use of GIS has had a vital impact on the development of conservation planning methodologies. GIS technology is designed to address spatial questions, and can present the results using maps, graphs, charts, data tables and lists. In particular, GIS technologies incorporate a full set of tools for storing, analyzing and displaying geographic information, including links to various database management systems and support for geographic queries.

GIS technologies consist of five major components: data acquisition, preprocessing, data management, data manipulation and analysis product generation. One of the greatest strengths of a GIS is its ability to integrate many different data sources in many different forms. The key to data acquisition in a GIS is that the data must be inherently spatial. Once the data is entered into the system, the next step is preprocessing of the information. This involves the integration of various data sets into formats that can be used in the analysis. Data management refers to the collection, storage and management of information and in some instances modification. What distinguish GIS technologies from other mapping systems is their analytical capabilities. GIS technologies are capable of performing a variety of spatial operations and queries, and in addition have the capability to manipulate spatial data and their attributes in order to generate new information not explicitly stored in the dataset. The final component product generation produces the results of spatial analyses and queries, and displays them in a number of different formats including maps, graphs, tables and statistical reports.

3.7 Chapter Summary

The conservation of biodiversity through the establishment of protected area networks forms the foundation for most conservation strategies (Willis *et al.,* 1996). To be successful, protected area networks must contain samples of the natural diversity found within the region, and therefore protected areas should be selected with great care.

Different approaches have been developed over the past couple of decades to facilitate conservation planning. The information that is produced can be used to set priorities for the conservation actions, such as designing future protected areas, ecosystem restoration and planning land acquisition.

The first methods that were adopted by conservation planners were combinatorial scoring selection methods. In response to a number of inherent limitations with this approach, the scientific community developed a variety of new conservation methodologies. GAP analysis, Enduring Feature Analysis Approach and systematic selection methods have been proposed as new approaches to conservation planning. Of the three approaches, systematic selection methods have been the most widely adopted (Nantel *et al.,* 1998). Systematic selection methods are powerful decision support tools in conservation planning. In particular, what distinguishes systematic approaches is their ability to efficiently select areas for conservation in a manner that is most complementary, thus producing a selection of candidate areas that are representative of the diversity found within a region (Williams, 2000). Due to their inherent flexibility, efficiency and explicitness, systematic methods allow planners to appraise a wide range of options for networks in practical ways to achieve goals.

Chapter 4: Methods

4.1 Introduction

The following section provides an overview of the study area, as well as an outline of the methodology used in this thesis. Figure 4.1 identifies the main steps that were taken to carry out this research. The protected area selection process began with the preparation of base data for the analysis. This was followed by the selection of conservation features to represent the biodiversity of the Assiniboine Delta region. Once conservation features were selected and characterized, ecosystem representation goals were defined for each enduring landscape feature.

The protected area selection analysis was carried out for two landscape-based situations. Pressey and Nicholls (1989), noted that the establishment of conservation targets can easily be obscured by existing land use. They found that: *"When sites were selected iteratively in western New South Wales with the aim of representing all natural environment types, the efficiency of an iterative selection procedure was significantly reduced when the analysis was made with properties already acquired for conservation automatically included."* (Kershaw *et al.,* 1994, p.363). Following this, the first conservation scenario set out to examine how protected areas that had been previously established within the Assiniboine study area influenced the goal of ecosystem representation. In the first scenario existing protected areas were locked into the analysis,

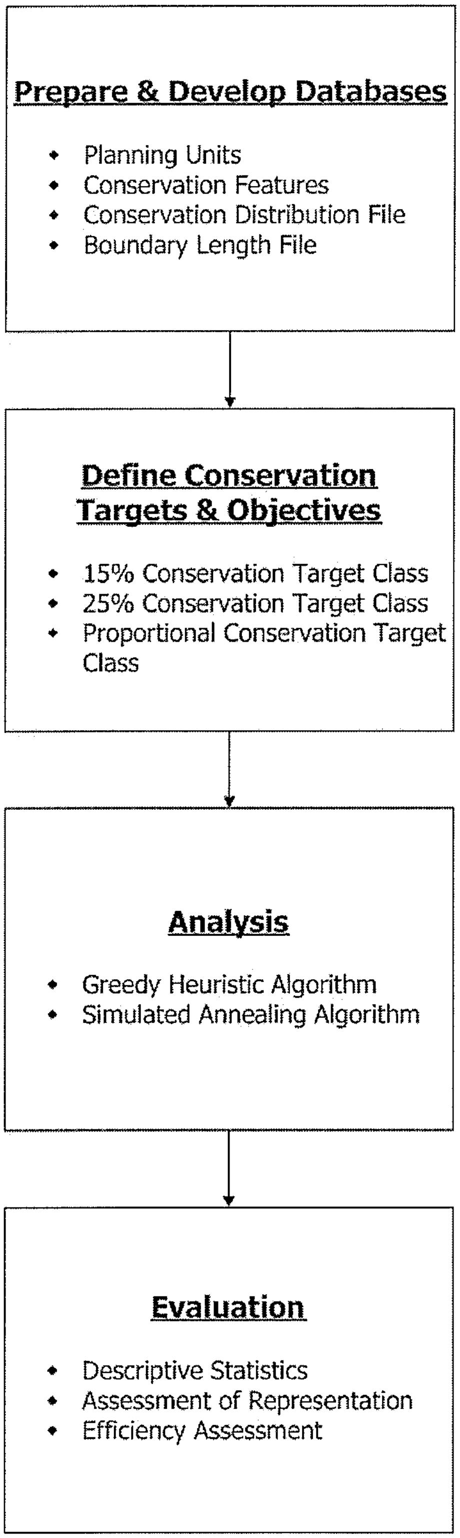


Figure 4.1 Required steps for the analysis

thus the algorithms were forced to include existing protected areas *(Existing Protected Area)* as part of their site selection. In the second scenario, the reverse set of conditions was in place. The Assiniboine study area was treated as a blank conservation canvas, as if no protected areas had been previously established *(No Existing Protected Areas).* Thus, the algorithms were free to either ignore or incorporate existing protected areas into the site selection process.

Each conservation scenario was taken a step further to examine how a network of protected areas would be defined for the Assiniboine study area when only specific areas were eligible for selection. The two sets of lands that were identified as available for conservation were crown lands and relatively undisturbed privately owned lands. Part of Manitoba's conservation mandate is to select candidate areas for protection that are located within crown lands (Government of Manitoba, 2000). However, with the recognition that the goal of ecosystem representation may not be fulfilled based on crown lands alone, one must look outside government managed lands and consider private lands. Hence, crown land, and the combination of crown lands and undisturbed private lands formed the foundation from which the algorithms were permitted to select candidate sites for conservation. For each planning unit scenario, conservation targets and spatial configurations were also examined. Three series of conservation goals were defined for each enduring feature. In addition, because it was desirable for a protected area network to be both compact and contiguous (Andelman *et al.,* 1999), changes were made to the boundary length modifier in order to influence the spatial configuration of the selected candidate sites.

The next phase of the analysis involved the evaluation of the results produced from the analysis. This was achieved by examining the summary information generated by each algorithm, and importing the best results into a GIS environment for further spatial assessment. Since constraints exist on the amount of land that can be set aside for nature conservation, it was important that candidate areas were selected as efficiently as possible. Therefore, the results produced from the various selection algorithms were also evaluated against measures of efficiency and summed irreplaceability.

4.2 Study Area

The Assiniboine Delta region falls within the transition zone between the tall grass prairie and the boreal forest ecosystem. This transition zone, known as the Aspen Parkland, extends along the Alberta foothills and continues across Saskatchewan to the south-east side of Lake Agassiz basin in Manitoba. Within Manitoba, the Assiniboine Delta natural region is located in the south-central region of the province and contains two watersheds: the Assiniboine River and the Cypress River. This region extends in a fan shape and encompasses a sparsely populated area situated between the city of Brandon to the west, and the city of Portage La Prairie to the east. Figure 4.2 provides a

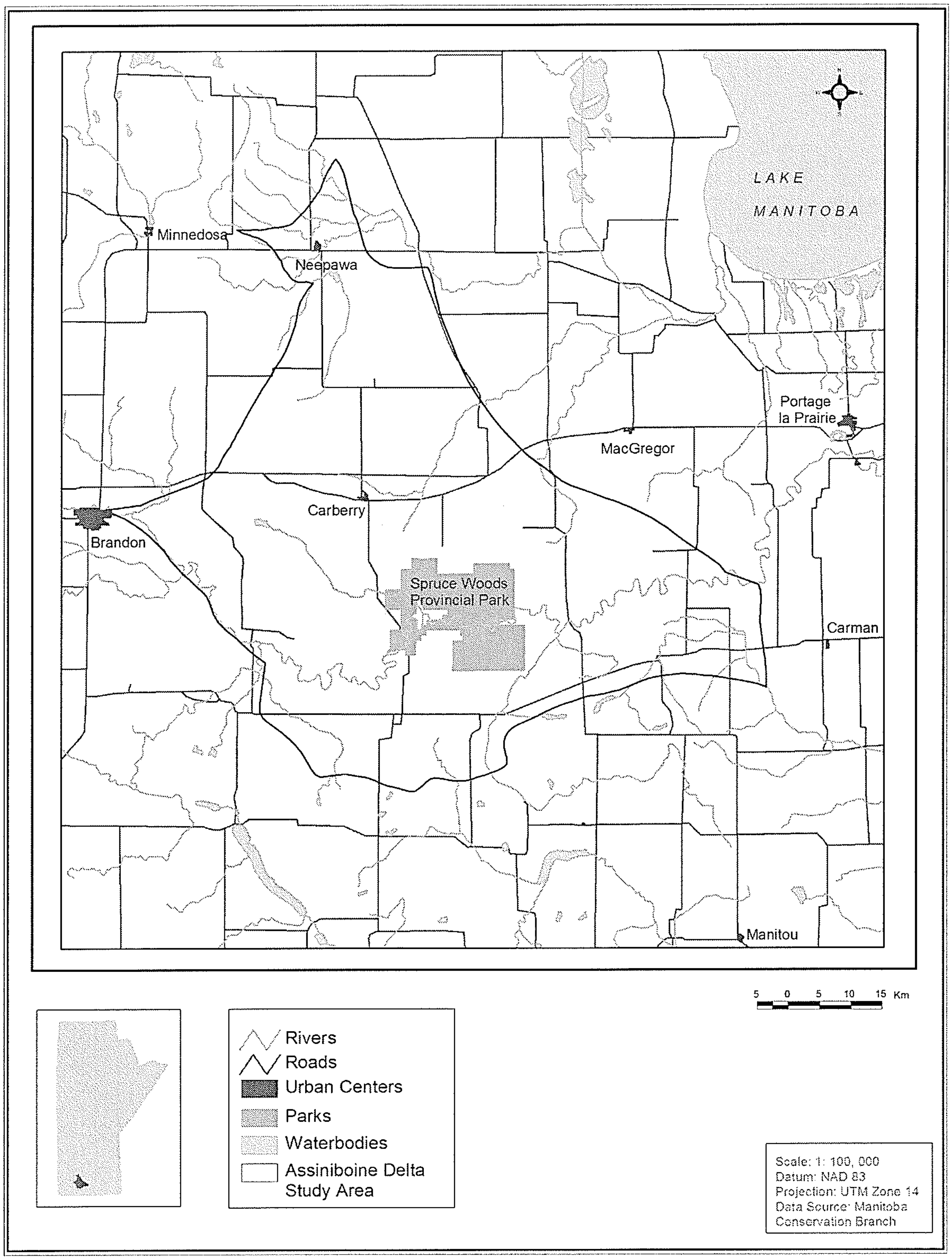


Figure 4.2 Overview of Assiniboine Delta Region

contextual view of the Assiniboine Delta region and surrounding landscape. The Assiniboine Delta region, much like the rest of southern Manitoba, has been heavily altered by human activity and is presently dominated by private land ownership.

European settlement began in the Assiniboine Delta region before Confederation (Lehr, 1996). During this period, most of the land was owned by the Hudson's Bay Company, and was used primarily for fur trapping. Trading forts were established along the Assiniboine River, and operated in the area until the early 1830s. In 1870, the land was then transferred to the Dominion of Canada (Bird, 1961). This political event marked the end of fur trading and the beginning of agriculture in this region (Bird, 1961). In the late1800s, as the transcontinental railroad spread across Canada, a great number of settlers came to the prairies. In order to accommodate the large influx of settlers, the land was subdivided into one-mile quarter-sections (Bird, 1961). As the area became increasingly populated, additional roads were built, and the landscape was transformed into a 'checkerboard' pattern. Today, agriculture has become the dominant social and economic feature of this region, while other human activities in the area focus on recreation and military training at the Shilo Military Reserve (Carlyle, 1996).

The Assiniboine Delta region, like most regions in southern Manitoba, was formed by the most recent Pleistocene glaciations and by the lacustrine deposits of glacial Lake Agassiz (Corkery, 1996). The existing landforms in the region were shaped by the subsequent rising and falling of Lake Agasszi. The sediments which characterize the

Assiniboine Delta were left behind when Lake Agasszi retreated for the final time in 7900 BC (Corkery,1996). As a result of glacial processes, over two-thirds of the soils of the region are rich, well-drained, black chernozems on loam and clay sediments (Scott, 1996). The remaining soils are sandy or loamy regosols commonly found in well to imperfectly drained riparian zones (Scott, 1996). In addition, there are also sheets of large non-glaciated gravel deposits (Scott, 1996). The resultant topography provides a diversity of abiotic substrates for the development of a variety of ecosystems and habitats (Scott, 1996).

The land cover in the region includes forest, declining mixed grass prairie, open sand dunes and agriculture crops. Figure 4.3 displays the extent of land use within the Assiniboine Delta region. The Spruce Woods Provincial Park and Forest Reserve supports a large area of Aspen forest, and includes a unique stand of White Spruce with an under-story of mixed grasses and ground cedars (Bird, 1961). Jack Pine, Tamaracks, and other soft-woods are also present. An additional mixed grass prairie community of considerable size exists within the Shilo Military Reserve (Carlyle, 1996). The open dune sand hills are a unique feature found within this region. This dune area is considered to be one of the most important in Canada because of the volume of sand and the proportion of active sand dunes that are present (Scott, 1996).

The climate in the region shifts from the dry Saskatchewan Plain in the southwest, to the more humid Manitoba Plain in the northeast (Blair, 1996). There is a gentle

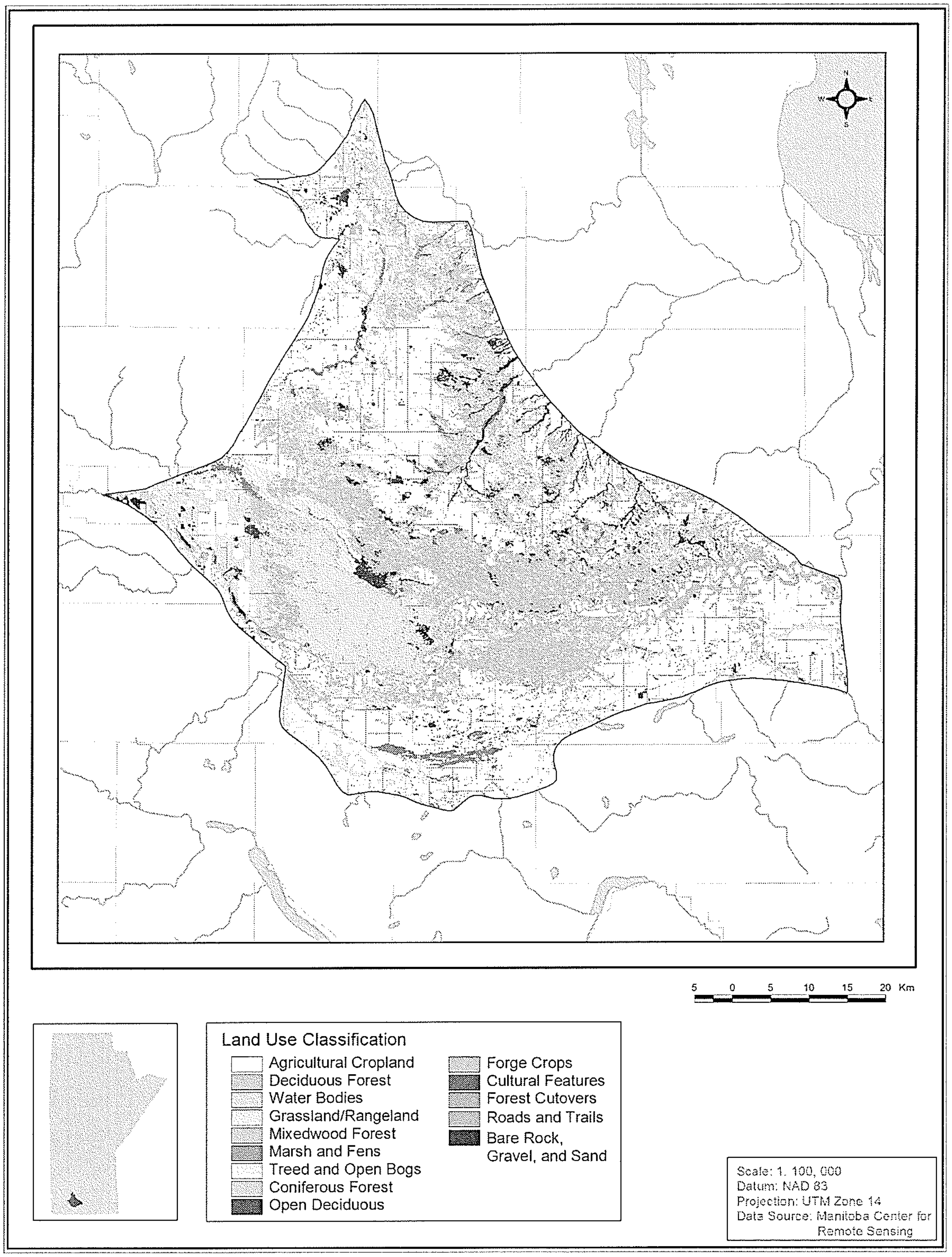


Figure 4.3 Land use in the Assiniboine Delta Region

variation in the Assiniboine Delta region's topography, with the exception of Riding Mountain, which bounds the Delta to the north, and the Tiger Hill Uplands which define the southern border. The eastern area is generally level and the central area is comprises mainly of agricultural lands, while the east-central area contains steep hills. The western area has hummocky sand dunes and flat lands. The average elevation for the entire area is 366 metres above sea level (Corkery, 1996).

4.3 Base Data Preparation

The selection process, which was used to identify sets of candidate conservation networks, required a wide variety of ecological and cultural data. The following section will outline how various data sets were collected, cleaned and harmonized to produce the necessary databases to run the analysis, including the identification of base data sets, the definition of spatial data layers that were derived from existing data sets, and the development of a spatial database that was required to run the analysis.

Seventeen digital spatial data sets were identified to form the base layers for the study. They included parks and protected area boundaries, provincial forests, a land use classification system, surrogate conservation features, Manitoba's natural regions, rural municipalities, townships, roads, rail networks, power networks, rivers, lakes, and urban centres. Appendix One provides an overview of each of these data layers. All databases that were used in the study were geographically referenced to the North American Datum (NAD 83), and projected to the Universal Transverse Mecator projection, zone fourteen.

The parks and protected areas spatial database contained information that was very important. This GIS layer, which was obtained from the Manitoba Conservation Branch, contained the accurate spatial location for the legal boundaries of all protected areas within the Assiniboine Delta region. This layer was essential for the formulation of conservation targets, as well as for the identification of planning units that were required to run the *Existing Protected Areas* landscape assessment scenario. Figure 4.4 displays the extent of each type of protected area found within the study area. Information regarding land use in the area was obtained from the Manitoba Centre for Remote Sensing. This raster land use classification data set consisted of sixteen different land use classes and vegetation types that were present within the study area. As this data set was in a different database format, it had to be converted from a raster data set into a vector data set. This was done using a raster to vector conversion script. The types of land use that occur within the Assiniboine Delta region are displayed in Figure 4.3. Enduring landscape features were selected to represent the biodiversity of the Assiniboine Delta region. The Manitoba Conservation Branch uses this spatial data layer to identify and provide a scientific basis for reporting on the adequacy of protected area representation throughout the province (Manitoba Conservation Branch, 2000). The Manitoba Conservation Branch originally developed the enduring landscape features data layer that was used in this study. This spatial data layer was produced based on data describing soil

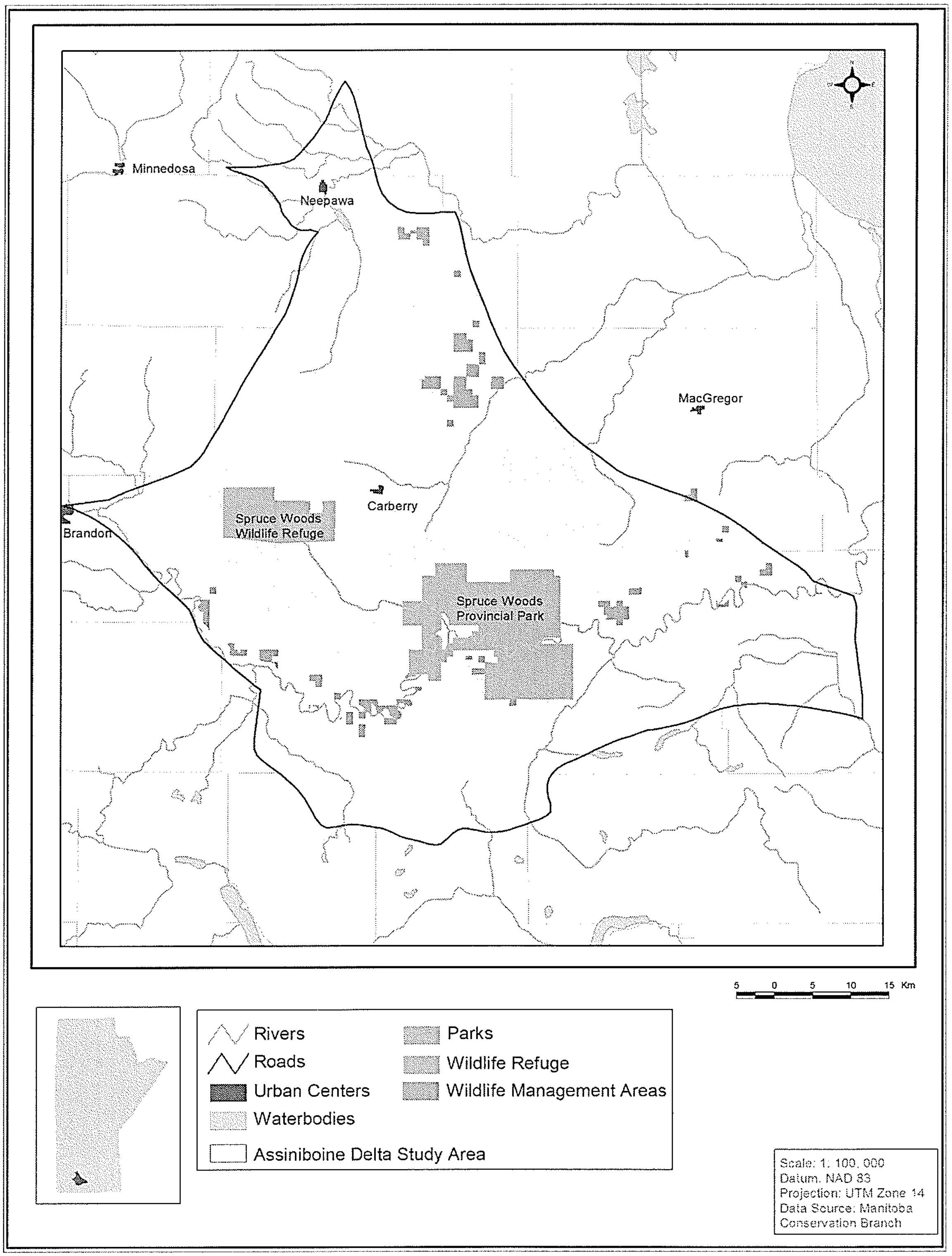


Figure 4.4 The Distribution of Protected Areas within the Assiniboine Delta Region

landscapes, topographic relief, surficial geology, as well as climate and physiographic data (Figure 4.5) (Watkins, 1994). Within the Assiniboine Delta Study area, there were seventeen enduring landscape feature classes (Figure 4.6 and Table 4.1) that summarize each enduring landscape feature. The remaining nine themes included Manitoba's natural regions, rural municipalities, townships, roads, rail networks, power networks, rivers, lakes and urban centres which were acquired from the Manitoba Conservation Branch website and required no additional manipulation.

After organizing all the base data layers, additional spatial data sets that were required to fill in existing data gaps were generated. The data sets that had to be generated included planning units, land use, land ownership and landscape suitability. Table 4.2 summarizes the base data sets utilized, along with the GIS processing steps taken to develop each of the required spatial data layers. Planning units form the building blocks of the reserve system (Margules *et al.,* 1994). They consist of individual polygons, which the algorithm examines while stepping through the selection process. For the purpose of this study, planning units follow the township survey system with each individual planning unit consisting of sixty-four hectare polygons.

The land use layer was created in order to identify privately owned lands that were relatively undisturbed. This information was utilized to produce the basis of planning units from which the second landscape scenario *No Existing Protected Areas* was to select candidate areas. Land use coverage for the study area was available in four

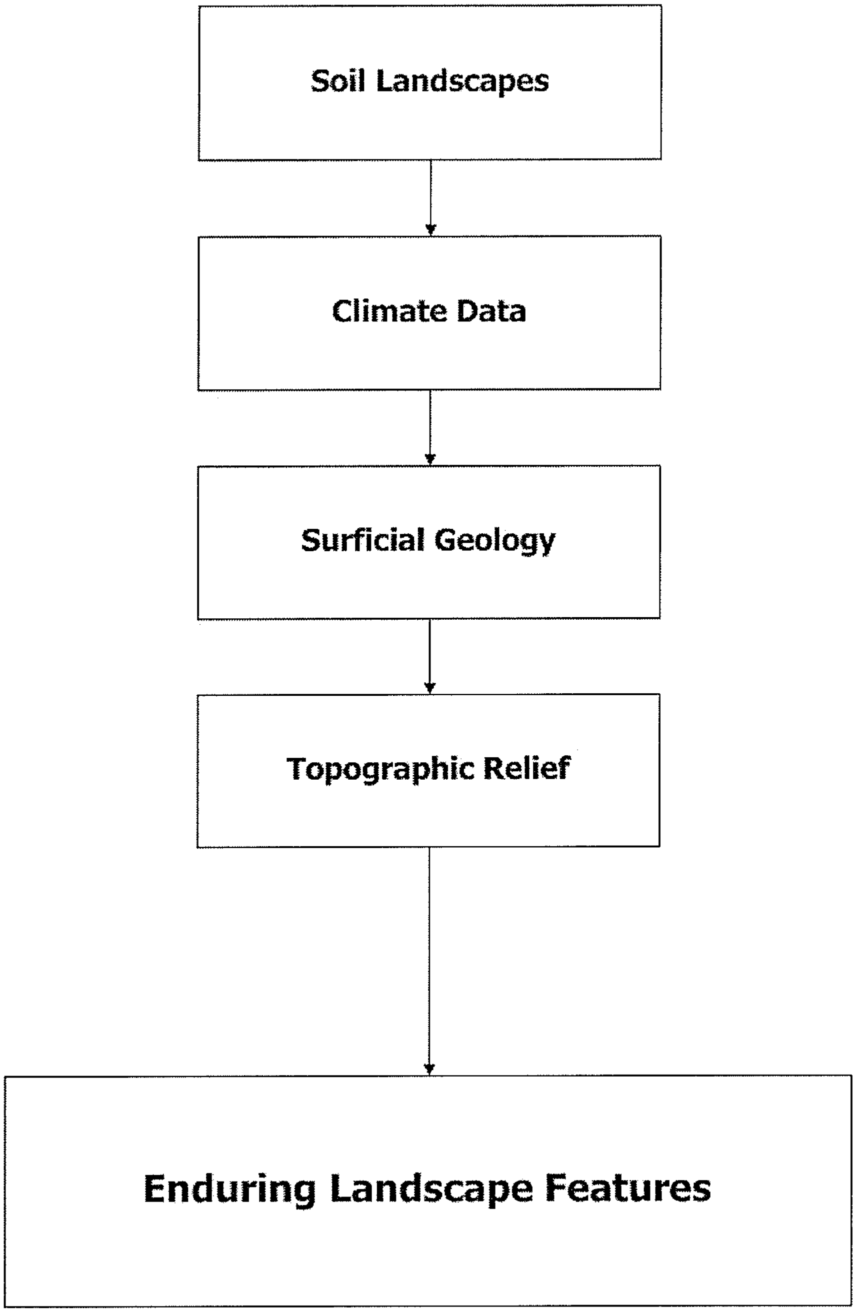


Figure 4.5 Components that make up Enduring Landscape Features

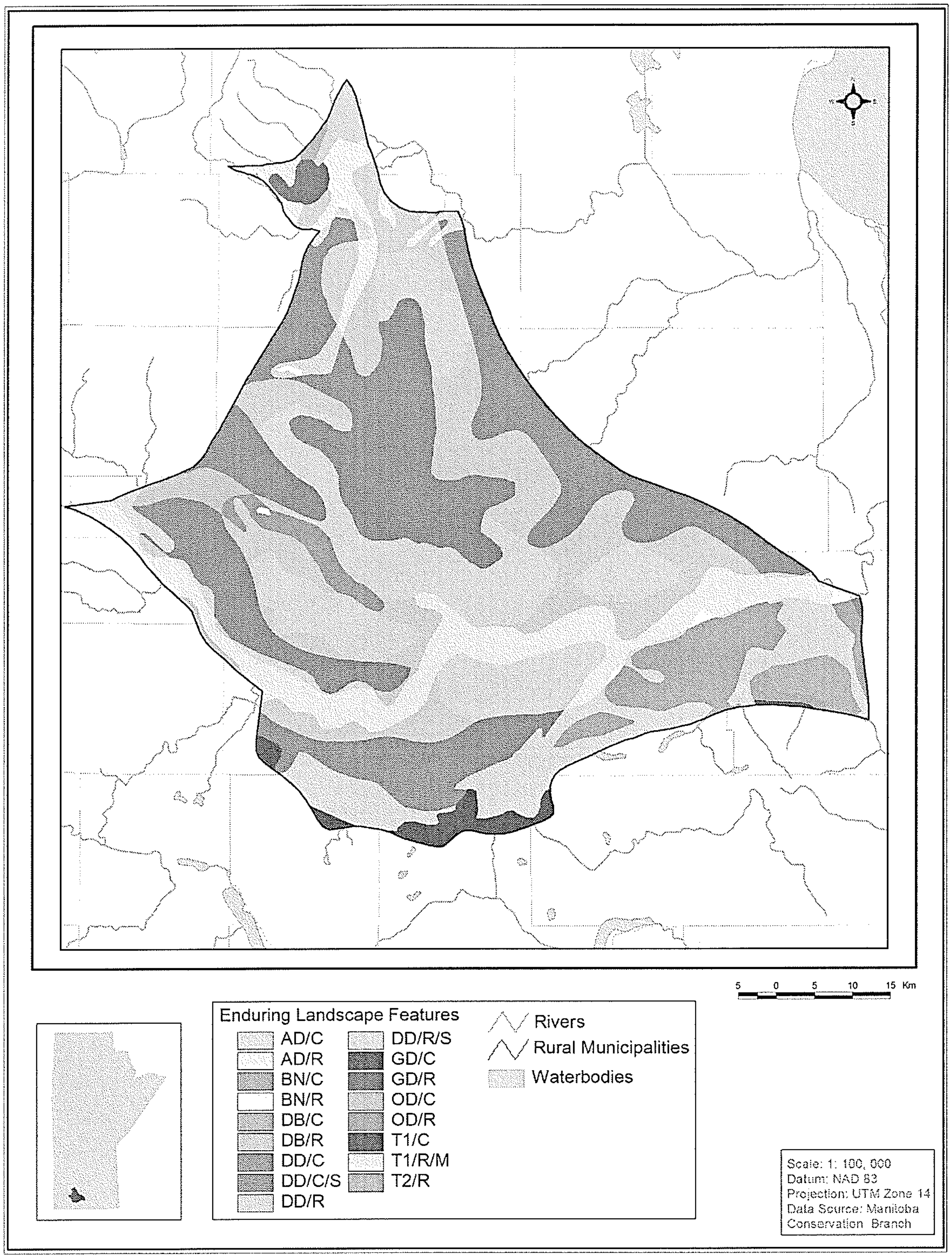


Figure 4.6 Enduring Landscape Features

Table 4.1 Enduring Landscape Feature Description

Enduring Landscape Feature	Description
AD/C	Alluvial Deposits / Black Chernozem
AD/R	Alluvial Deposits / Regosols
BN/C	Beach and Nearshore Deposits / Black Chernozem
BN/R	Beach and Nearshore Deposits / Regosols
DB/C	Deep Basin / Black Chernozem
DB/R	Deep Basin / Regosols
DD/C	Deltaic Deposits / Black Chernozem
DD/C/S	Deltaic Deposits / Black Chernozem / Sand Dunes
DD/R	Deltaic Deposits / Regosol
DD/R/S	Deltaic Deposits / Regosol / Sand Dunes
GD/C	Glaciofluvial Deposits / Black Chernozem
GD/R	Glaciofluvial Deposits / Regosol
OD/C	Organic Deposits / Black Chernozem
OD/R	Organic Deposits / Regosol
T1/C	Glacial Till Derived from Palaeozoic Rock / Black Chernozem
T1/R/M	Glacial Till Derived from Palaeozoic Rock / Regosol / Moraine
T2/R	Glacial Till Derived from Mesozoic Rock / Regosol

Table 4.2 Derived GIS Data Layers

Data Layers / Databases		GIS Processing
Land Use	Natural Region Twelve Manitoba Land Use Classification Imagery	• Define land use classes • Merge land use imagery together • Reclassify image into three land classes • Clip reclassified image to cover only Natural Region Twelve • Run descriptive statistics
Land Ownership	Paper maps of all the quarter section for each of the thirteen rural municipalities located within the study area	• Identify each parcel of crown land on hard copy maps • On screen digitizing of each crown land parcel • Enter attribute information for each crown land parcel
Planning Units	Township Rural Municipalities Quarter-section grids	• Identify all quarter sections that fall within the study area • Correct each data layer to make sure that they are topographically correct • Merge all of the quarter section grids together to from one large grid system • Assign each polygon an unique ID
Landscape Suitability	Roads Railway Urban Centers Transmission Lines Reclassified Land Use	• Extract all major roads, railways, urban centers and transmission lines from existing GIS data layers • Place a 500m buffer around each of the above data layers • Merge land use with the buffers produced for roads, railways, urban centers and transmission • Run descriptive statistics

raster-based files. Using a GIS, they were merged together and then clipped so that only the land that fell within the study area was left. This data set was then reclassified from sixteen land use classes down to three land use classes: cultural, natural and water. Figure 4.7 illustrates the reclassified land use GIS data layer.

The third spatial database that was required for the analysis identified the location of all the public and crown lands within the study area. Given that this information was only available in hard copy format from the Crown Lands Classification Committee, this dataset was very labour intensive to produce. The locations of all crown lands were digitized from paper maps using on-screen techniques for the thirteen rural municipalities contained within the Assiniboine Delta study region. Figure 4.8 displays all the crown land planning units located within the study area.

The mapping of landscape suitability for the Assiniboine Delta region was developed by following general guidelines and principles of conservation biology. In a GIS environment, factors known to constrain or have potential negative impacts on protected areas were spatially manipulated to produce a site suitability data layer. Within the study area, the spatial data sets that were utilized to define landscape suitability included land use, roads, railways, transmission lines and urban centres. These five data sets were identified as factors that represented unsuitable land use because of the potential negative impact they may have on many species, for example, noise, edge

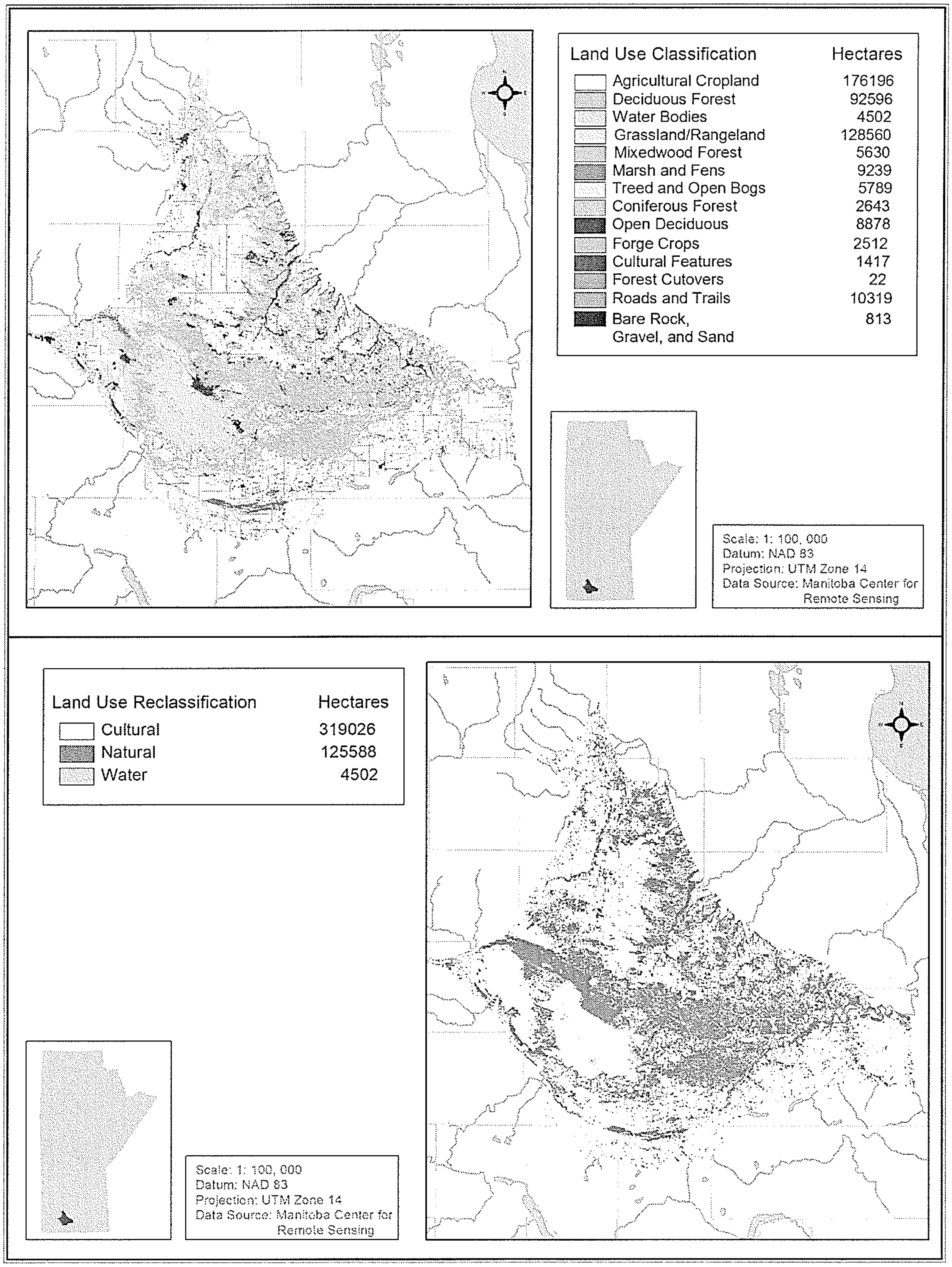


Figure 4.7 Reclassified Land Use in the Assiniboine Delta Region

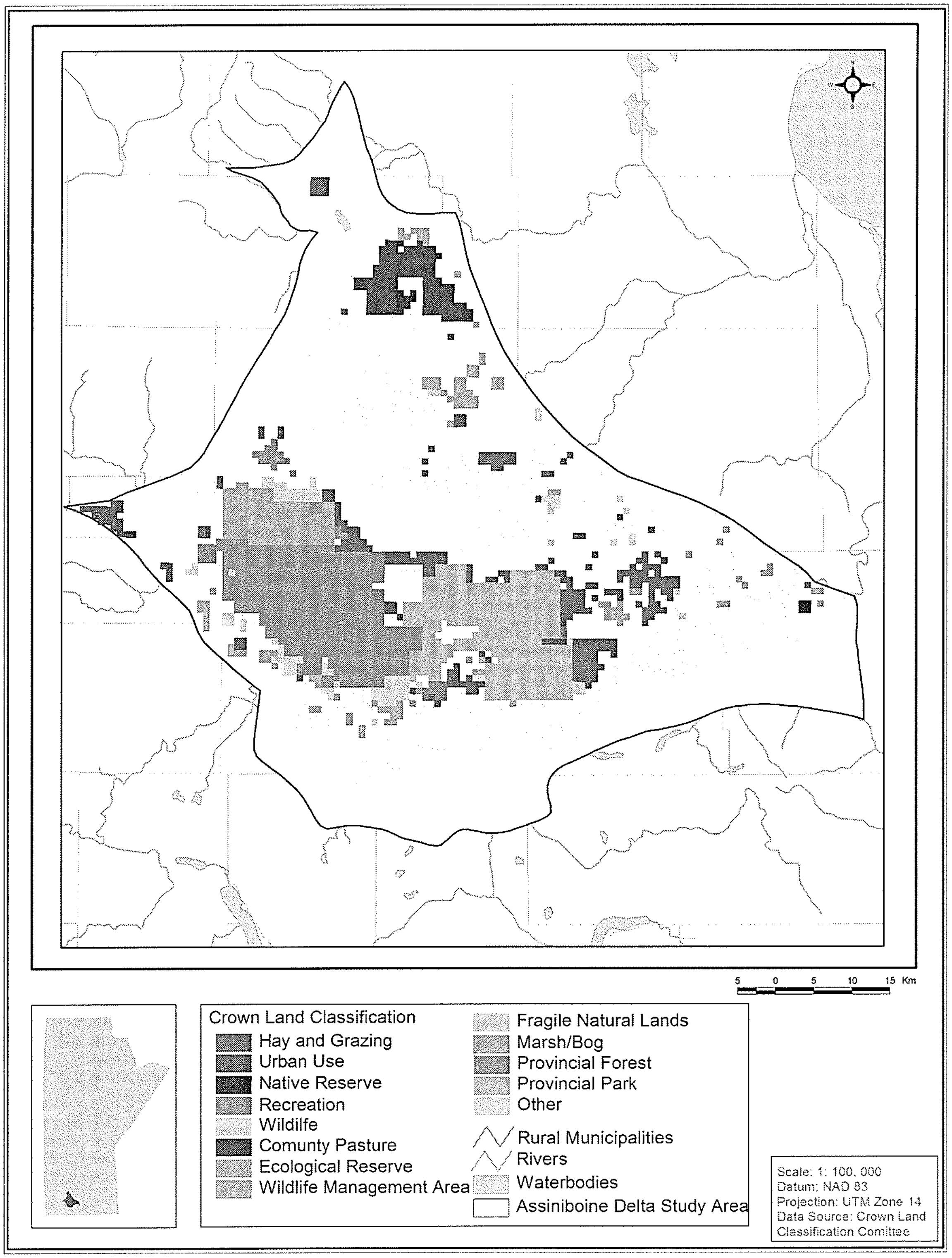


Figure 4.8 The Distribution of Crown Lands within the Assiniboine Delta Region

effects, the spread of disease and invasion by exotic pests (Meffe and Carroll, 1994). Figure 4.9 represents the landscape suitability of the study area.

4.4 Database Requirements for the Analysis

The databases required to run the selection algorithms were created in a GIS environment using a number of the existing and derived spatial data layers. The databases that were developed to run the selection analysis included planning units (the basic selection units), conservation features (enduring landscape features), a conservation feature distribution database and the boundary length modifier database. Table 4.3 outlines which GIS data layers were used to bring these databases together.

The study area was divided into 7300 candidate sites i.e. planning units, with each planning unit forming a sixty-four hectare cell. A planning unit was defined as a contiguous area, which if protected, would contribute towards meeting the conservation goals of the protected area networks. The planning unit database contains the planning unit id, the cost associated with each planning unit, the status of a particular unit that is whether or not it was locked in or out of the analysis, as well as the x and y coordinates for each polygon. Two sets of planning units were developed for the analysis in order to run each conservation scenario, one of which contained only crown land planning units and the other which included both crown land and undisturbed private lands. The

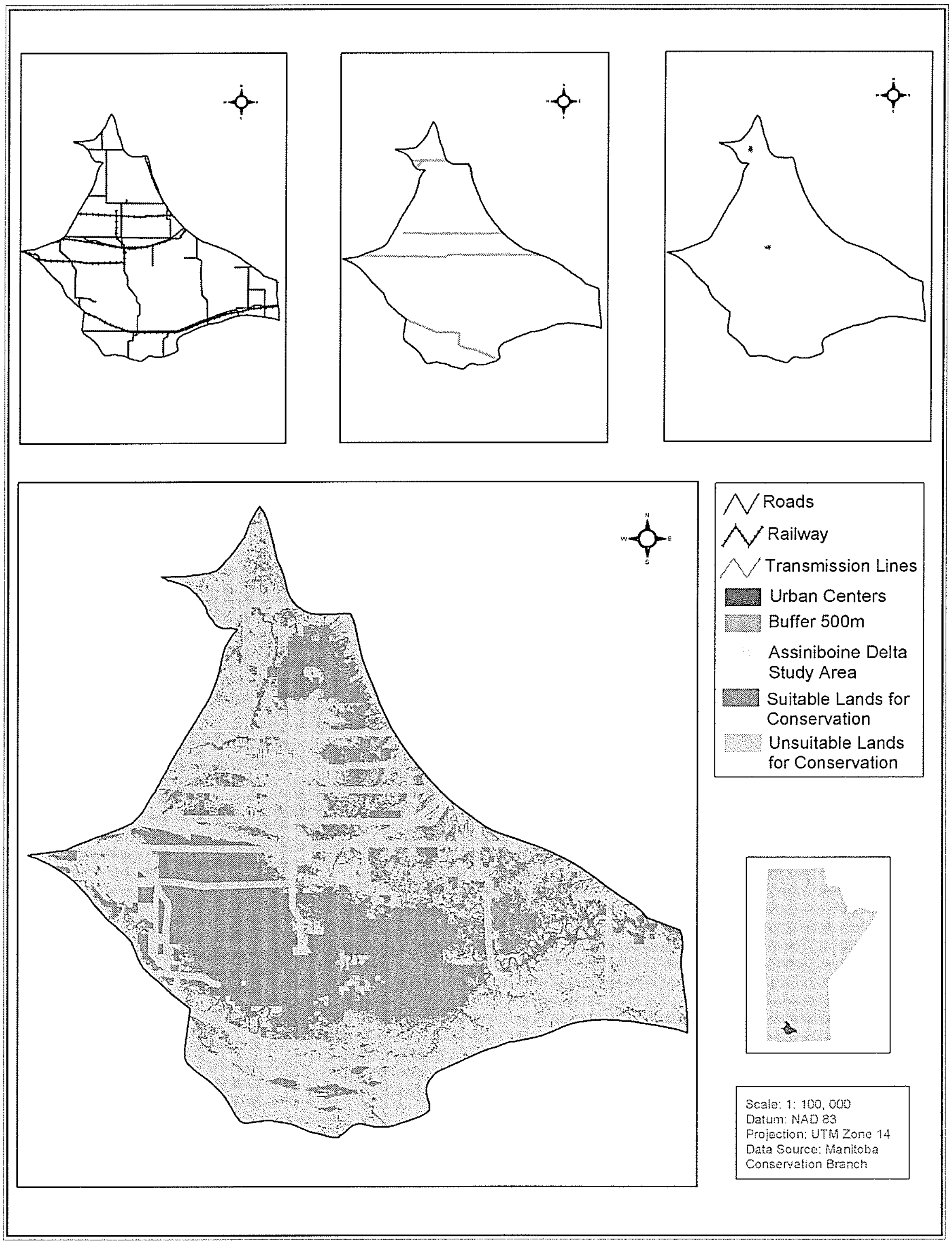


Figure 4.9 Landscape Suitability within the Assiniboine Delta Region

Table 4.3 Database Requirements for Selection Analysis

Database Name	Data Layers / Databases	GIS Processing Steps
Planning Units	Crown Land Landscape Suitability Classification Protected Areas	Combine crown land, protected areas and landscape suitability to define which areas were suitable for conservation purposes. Assign each polygon a unique ID value, and then export into the proper database format for the analysis
Conservation Features	Enduring Landscape Features	All the information pertaining to the conservation targets was produced for this data set. Three separate versions of this database were developed which corresponded to each set of conservation goals. Unique ID values had to be assigned to each enduring feature, along with conservation goals, and penalty factors. This data was then exported into the proper database format for the analysis.
Conservation Distribution File	Planning Units Enduring Landscape Features	Enduring landscape feature data layer was overlaid on top of the planning units data layer. Information was extracted for every occurrence that the two data layers overlapped. Two versions of this database were developed for both the 'Existing Protected Areas' and 'No Existing Protected Areas' conservation scenarios. This data was then exported into the proper database format for the analysis.
Boundary Length Modifier	Planning Units	Run script to make sure that the data layer was topologically correct and correct any problems. Then run a script to calculate all polygons, which share common boundaries and record their association. From there, boundary lengths of each polygon had to be calculated. This data was then properly formatted to run the analysis.

landscape suitability spatial data layer was used to identify and exclude all planning units that fell within areas that were deemed unsuitable for conservation purposes.

The conservation feature database controls all the information for each enduring landscape feature, with the exception of their distribution across planning units. The sets of information that were prepared for this database include enduring landscape feature id, the conservation goal for each enduring landscape feature, as well as any penalty factors associated with that conservation value. Three separate conservation feature databases were developed in order to run the analysis for the various conservation goals.

The third database that was required to run the analysis was the conservation feature distribution file. This file contained information on the spatial distribution of enduring landscape features across the planning units. Within the GIS environment, the planning unit data layer was superimposed on top of the enduring landscape features data layer. This resulted in a new data layer, which contained the spatial extent of each enduring landscape feature that fell within the planning units. This spatial processing was produced for both the *Existing Protected Areas* and *No Existing Protected Areas* conservation scenarios.

The final database that was required to run the analysis was the boundary length modifier database. This database describes the spatial relations of the planning units and the amount of shared boundary between each pair. The function of this database was to enable the modification of the amount of spatial aggregation in each conservation planning scenario. The higher the boundary length modifier, the more clustered the selection of planning units would become. This database was produced within a GIS environment by running a script that calculated all shared boundaries for each planning unit as well as the area of each planning unit.

4.5 Conservation Objectives and Targets

Once base data sets were developed, the next phase of the conservation planning process involved defining conservation goals, objectives and targets. This required the identification of conservation features to serve as biodiversity indicators. Conservation goals (i.e. representation targets) had to be defined for the area, and the extent to which these conservation goals had been previously satisfied by the current protected areas network required further investigation.

The first step in the development of a protected areas network involved the selection of conservation features to represent the biodiversity of the landscape. For this study, enduring landscape features were selected as the appropriate set of indicators. The reason for this selection was two-fold. First, enduring landscape features as a classification system to represent biological diversity had been widely advocated and adopted by the Canadian Council on Ecological Areas, the World Wildlife Fund and Manitoba Conservation Branch (Gauthier, 1992; Kavangah, *et al.,* 1995; Government of Manitoba, 2000). Thus, by using enduring landscape features as surrogates for ecosystem representation within the Assiniboine Delta study region, assessment of conservation based activities were compared at both provincial and national levels. Secondly, southwestern Manitoba lacks comprehensive biological data, which is further complicated by the small size, and isolation of remaining undisturbed lands. In the absence of such data, enduring landscape features were selected to represent the ecological diversity of the region. Before conservation targets were established for the Assiniboine Delta study region, it was important to first understand and explore how the enduring landscape features were spatially distributed across the study region. After examining the spatial distribution of the enduring landscape features, the next step was to develop conservation targets that were meaningful, and that reflect the biodiversity of the landscape. Appendix Two displays summary statistics as well as the spatial distribution of each enduring landscape feature within the Assiniboine Delta study region.

Once conservation features were identified, the next step was to define the conservation targets for the study area. This required translating the goal of ecosystem representation into quantitative targets for operational use. The importance of setting conservation targets was that they allow for the clear recognition of how existing protected areas contribute towards achieving regional conservation goals (Williams, 2000). They also provide an overview of how different conservation features may vary throughout the study area. In addition, conservation goals present a means for measuring the conservation value of different areas during the area selection process, and provide a benchmark of how successful a particular selection algorithm was in selecting a set of candidate sites (Williams, 2000). Three sets of conservation targets were defined for the Assiniboine Delta study area. Two sets of targets were defined as percentages of the total enduring landscape features, (15% and 25%). Watkins (1994) suggested that the proportional, and spatial arrangement of biodiversity elements in the network of protected areas should be relative to their proportional and spatial arrangements in the landscape. Thus, the third conservation target was defined according to the proportional landscape distribution. Table 4.4 illustrates the three sets of conservation targets which the selection algorithms must achieve.

The third step in this process involved running a conservation gap analysis. Within a GIS environment, protected areas were overlain on top of the enduring landscape features. The areas where the two layers intersected represented enduring landscape features, which were protected within the existing protected areas. Enduring landscape features that did not fall within protected areas represented the 'gaps' in the network of protected areas. The importance of running this analysis was that it provided some direction with regards to conservation efforts. First, it was important to examine the extent to which the sets of conservation targets had already been met by the existing protected areas network. Second, the results obtained from this analysis were required to re-adjust the original set of conservation goals for the analysis in order prevent enduring

Table 4.4 Original Conservation Targets

Enduring Landscape Features	Conservation Goals (hectares)		
	Proportional	15%	25%
AD/C	4,341.48	6,623.24	11,038.74
AD/R	5,406.97	7,391.44	12,319.06
BN/C	1,272.50	3,585.76	5,976.27
BN/R	1.90	138.39	230.65
DB/C	70.10	841.59	1,402.65
DB/R	2.17	148.08	246.79
DD/C	31,173.40	17,747.79	29,579.65
DD/C/S	1,091.97	3,321.68	5,536.13
DD/R	14,612.31	12,150.99	20,251.65
DD/R/S	13,549.37	11,700.70	19,501.16
GD/C	15.66	397.82	663.04
GD/R	18.42	431.47	719.12
OD/C	47.94	696.02	1,160.03
OD/R	97.49	992.50	1,654.16
T1/C	63.80	802.91	1,338.18
T1/R/M	7.67	278.34	463.91
T2/R	1.26	112.98	188.30
Total	71,774	67,361	112,269

landscape features from being over-represented in the *Existing Protected Areas* landscape conservation scenario. The results of the gap analysis were also mapped (Figure 4.8) to enable visual examination. Once conservation targets had been defined and further refined by the gap analysis, the next phase was to run the site selection algorithms.

4.6 Analysis

In order to identify conservation lands that collectively represent viable examples of all enduring landscape features, the reserve design software MARXAN, designed by Ball and Possingham (2000) was utilized. MARXAN not only draws on a variety of selection algorithms to produce solutions to the reserve selection problem, the algorithms have also been designed to allow conservation planners to place controls on the spatial configuration of the areas selected. Using MAXRAN, the greedy heuristic algorithm and simulating annealing algorithm were run with the objective of selecting a series of candidate sites that would satisfy the conservation goals for the Assiniboine Delta study region.

At the core of the protected areas selection problem was the goal of minimizing the spatial extent of the protected areas while meeting conservation targets (Bedward *et al.,* 1991; Pressey *et al.,* 1997). This was based on the notion that conservation planning must often compete against social, economic and management constraints (Possingham *et*

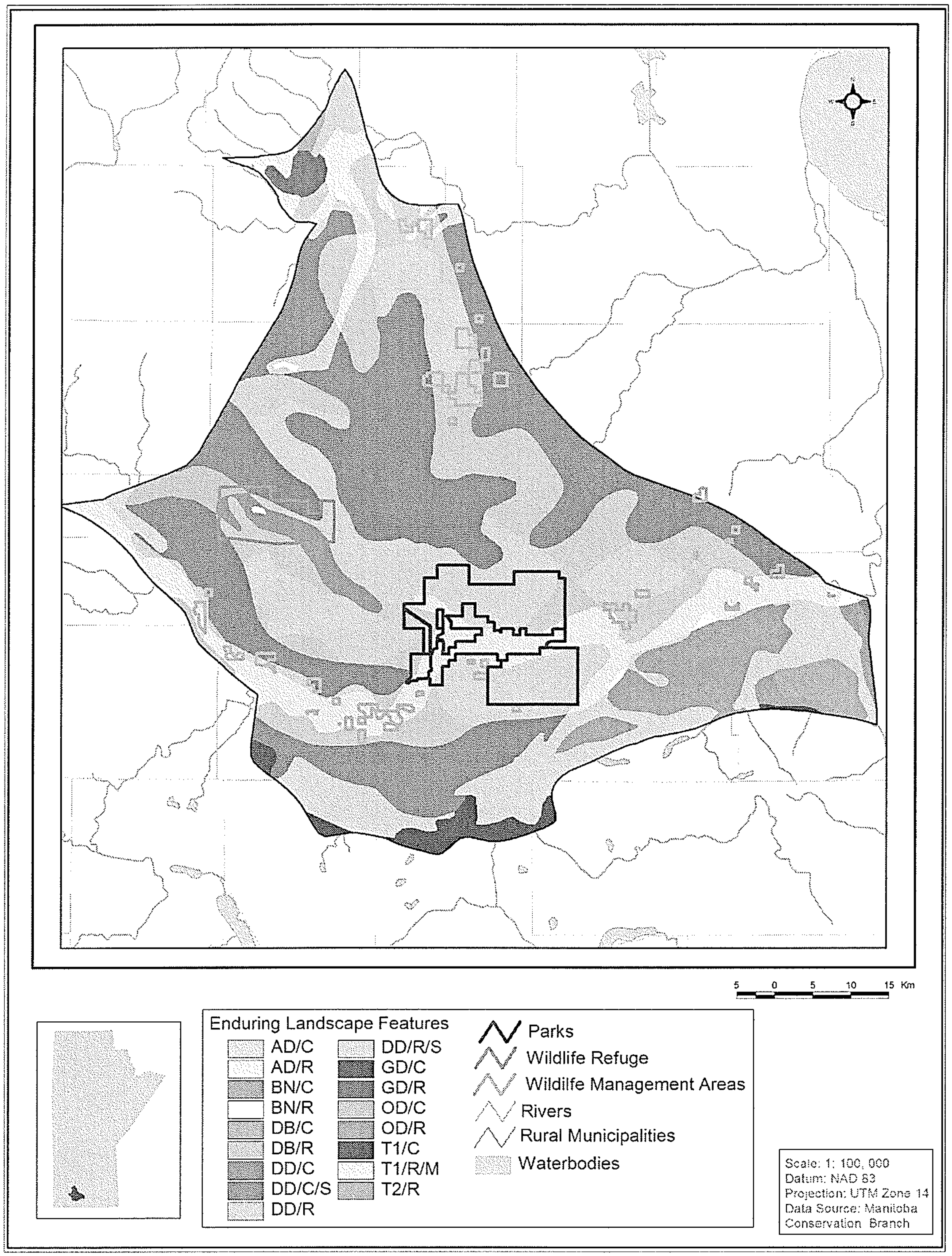


Figure 4.10 Gap Analysis map for the Assiniboine Delta Region

al., 2000). This constraint was included in the algorithm so that the objective of the selection process would be to minimize the 'cost' of the protected areas network while ensuring that both the primary goal of representation and secondary goal of spatial configuration were fulfilled (Possingham *et al.,* 2000).

The algorithm seeks to minimize the 'total cost' by selecting a set of planning units which cover as many conservation features as possible and as *cheaply* as possible, in as compact a set of sites as possible. (Possingham *et al.,* 2000). The objective function of the algorithm that influences how the algorithms reduce the selection cost was based on the following equation (Ball *et al.,* 2000).

$$\text{Total Costs} = \sum_{i} \text{cost site } i + \sum_{j} \text{penalty cost for element } j + w_b \sum \text{boundary length}$$

Total cost of Protected Areas Network = (cost of selected sites) + (penalty cost for not meeting the stated conservation goals for each element) + (cost for spatial dispersion of the selected sites as measured by the total boundary length of the portfolio).

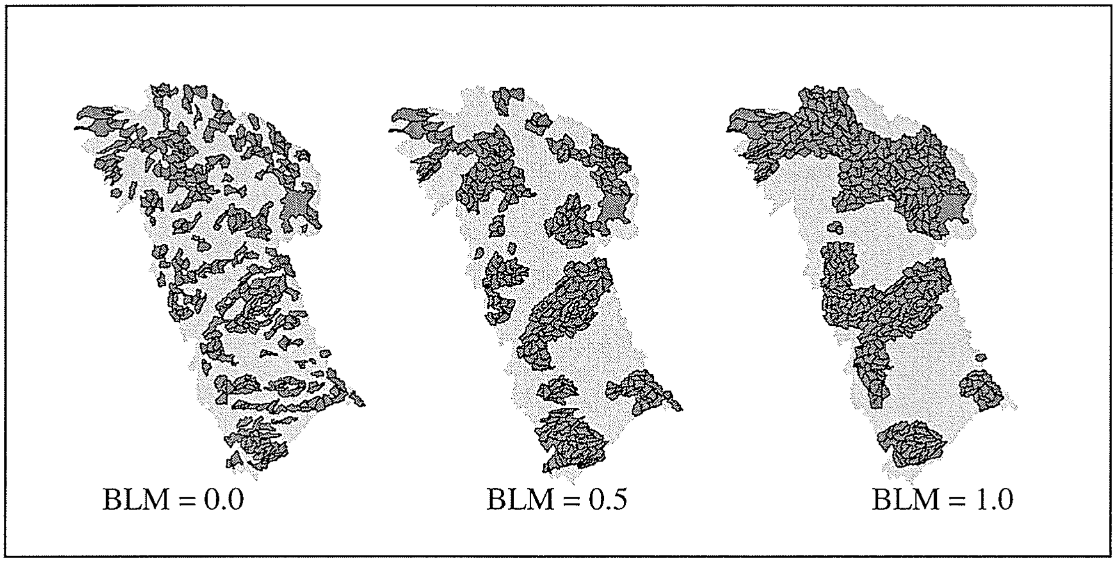
Total cost of the candidate areas (conservation targets) relates to how much of a particular feature must be included in the protected areas network. Conservation targets were expressed as the proportion of each enduring landscape feature, and 15%, and 25%

of each enduring landscape feature. Once a conservation target was reached, the algorithm would not try to collect any more of that particular feature, though in some cases more sites may have been acquired while collecting other features (Pressey *et al.*, 1996). For the purpose of this study, the area measurement of the planning unit was used as an estimate of cost. As all planning units were the same size, they all had the same associated 'cost'. Thus *site cost* was measured by how much area was required to meet conservation targets.

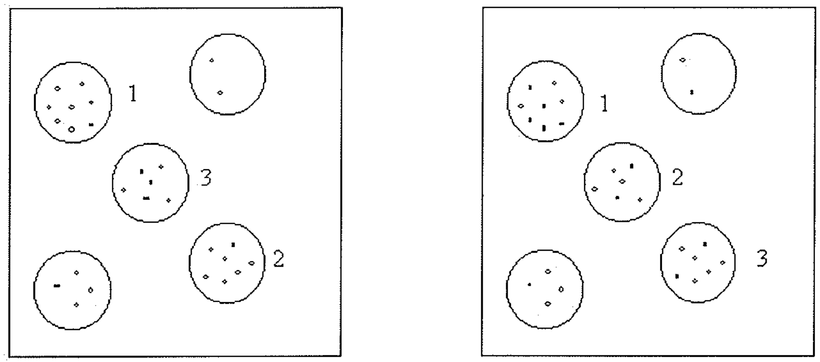
In order to determine how much 'cost' would be associated with not reaching the pre-defined conservation targets for the enduring landscape features, conservation feature penalty values were utilized. This was based on the principle that if a conservation feature was below its target representation level, then the penalty should be close to the cost for raising that conservation feature up to its target representation level (Ball *et al.*, 2000). This factor decreased as the conservation target was approached, based on an estimation of the 'cost' required to fully meet the features conservation target (Ball *et al.*, 2000). For the purpose of this research, the conservation feature penalty values were set to one.

Spatial design requirements were incorporated into the analysis by changing the boundary length modifier (BLM). The BLM was used to determine the relative importance placed on minimizing the boundary length relative to minimizing the area. For instance, an increase in the BLM gives preference to the inclusion of sites that minimize the overall perimeter, thereby clustering the sites and generating a well-connected reserve system. A BLM that is set to 0.0 does not exert any emphasis on the spatial arrangements of planning units (Figure 4.11). Thus, the shorter the total boundary length around selected planning units, the more compact the network of protected areas. Alterations to the BLM were made in order to adjust the relative importance placed or the 'cost' of the reserve perimeter. For the two conservation scenarios, the BLM were set at 0, 0.5 and 1.0.

Figure 4.11 Visual Changes in the Boundary Length Modifier



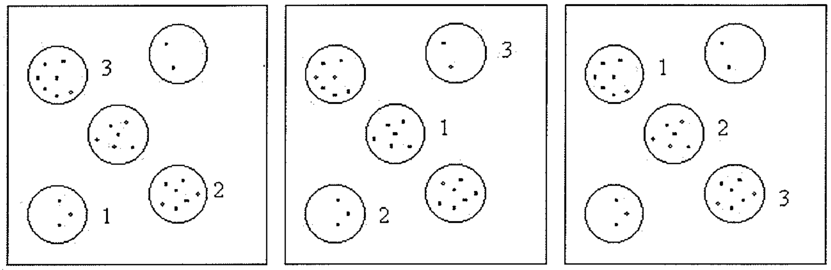
For each problem, one hundred independent runs of the greedy heuristic algorithm and simulating annealing algorithm were performed for each planning scenario. The conservation targets and the boundary length were adjusted for both sets of candidate planning units i.e. crown land, private and crown lands. As illustrated in the Figure 4.12 when the BLM is set to 0.0 no emphasis is placed on the greedy heuristic algorithm, thus the algorithm selects sites according to how many conservation features they contain. However, when the BLM is set to 1.0 there is an increased emphasis placed on selecting sites that are spatially compact. Thus the greedy heuristic algorithm tries to select sites that are closer together and may not always select the next site with the largest amount of conservation features if one with less conservation features is closer. As for the simulated annealing algorithm, because this algorithm randomly generates sets of candidate sites and then selected the best one, as illustrated in Figure 4.13 the BLM of 0.0 does not have any influence on the manner in which sites are selected. However, when the boundary length modifier is set to 1.0, the simulated annealing would keep the iteration, which contained the most compact spatial selection of sites. In total, this provided 36 different reserve system design problems for each algorithm. Table 4.4 outlines the various conservation scenarios in which the greedy heuristic algorithm and simulated annealing algorithm were run for.



BLM = 0.0

BLM = 1.0

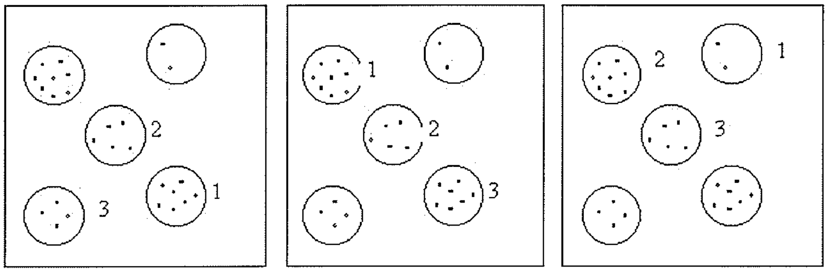
Figure 4.12 The influence of the boundary length modifier on a greedy heuristic algorithm



BLM = 0.0
Iteration # 1

BLM = 0.0
Iteration # 2

BLM = 0.0
Iteration # 3



BLM = 1.0
Iteration # 1

BLM = 1.0
Iteration # 2

BLM = 1.0
Iteration # 3

Figure 4.13 The influence of the boundary length modifier on a simulated annealing algorithm

Table 4.4 Analysis Scenario Matrix

Conservation Scenario *Existing Protected Areas*	Conservation Scenario *No Existing Protected Areas*

Greedy Heuristic Algorithm

Crown Lands					All Lands			Crown Lands					All Lands		
CT		P	15 %	25 %	P	15 %	25 %	CT		P	15 %	25 %	P	15 %	25 %
BLM	0.0							BLM	0.0						
	0.5								0.5						
	1.0								1.0						

Conservation Scenario *Existing Protected Areas*	Conservation Scenario *No Existing Protected Areas*

Simulated Annealing Algorithm

Crown Lands					All Lands			Crown Lands					All Lands		
CT		P	15 %	25 %	P	15 %	25 %	CT		P	15 %	25 %	P	15 %	25 %
BLM	0.0							BML	0.0						
	0.5								0.5						
	1.0								1.0						

4.7 Evaluation

MAXRAN generated summary data for each run of the analysis. The summary information generated included the objective function score, the number of planning units selected, and the overall boundary length. The best selections of candidate areas were identified as the solutions with the lowest cost. These solutions were then returned to the GIS environment for further analysis and visualization. Solutions with the lowest cost may not always represent the ideal reserve system (Possingham, 2000), thus requiring the alternative use of measures to evaluate the different sets of results.

In order to evaluate the spatial configuration of the top scenarios, the results were imported into a GIS environment where they were further processed. Total area, boundary length, and a series of summary statistics were calculated. These spatial analyses were repeated for the best selection sets generated for each problem. The level of representation for each enduring landscape was also examined within the GIS environment. As previously stated, because the solution with the lowest score may not always be the most desirable or practical solution, it was important to evaluate the candidate protected areas system configurations against other criteria such as efficiency (Pressey and Nicholls, 1989), and summed irreplaceability (Ball and Possingham, 2000).

Efficiency was used to demonstrate the relative effectiveness of alternative approaches to protected area selection. It refers to the degree to which the protected area selection strategies minimize unnecessary duplication of features by identifying sites that are highly complementary in terms of the features they contain, thus selecting the least number of sites required for conservation (Pressey and Nicholls 1989; Bedward, 1991; Pressey R.L, 1994). Efficiency was expressed by 1-(X/T) where X was the number of sites needed to achieve a representation target, and T was the total number or area of sites (Pressey and Nicholls, 1989). Efficiency varies from one to zero with zero being the most efficient solution.

Summed irreplaceability was used to examine how necessary each planning unit was with regards to achieving the conservation targets for each enduring landscape feature (Ball and Possingham, 2001). Since there were many possible protected area networks, which could be generated using MAXRAN, it was useful to have a general understanding of how individual planning units contribute towards the overall conservation strategy. The non-unique occurrence of many indices of biodiversity meant that there was often more than one way to achieve conservation goals (Possingham *et al.,* 2000). In addition, some planning units were likely to make a more valuable contribution than others so the options for replacing them with alternative sites were greatly reduced (Pressey, 1993).

Chapter 5: Results

5.1 Objective One

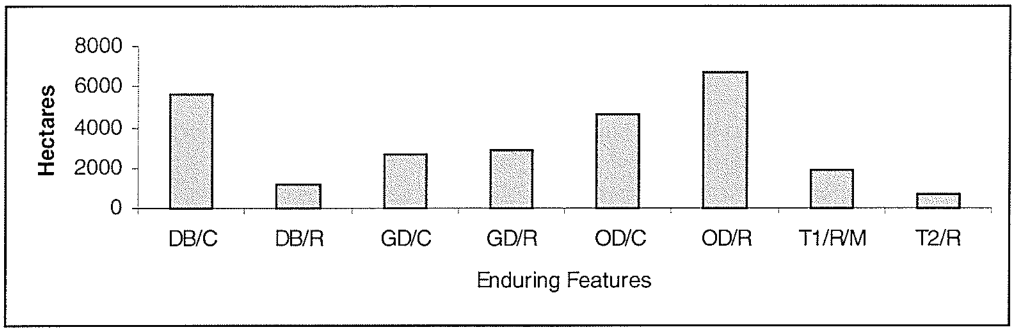
The first objective of this thesis was to evaluate how well the current network of protected areas was capable of representing the biological diversity of the Assiniboine Delta, and to establish conservation goals for this region based on the result of this assessment. To satisfy this objective, the following questions were posed. (1) What is the minimum area and percentage required to represent all surrogate ecosystems within the study area? (2) How well does the current network of protected areas reflect the biological diversity found within the study area? (3) What do the new conservation targets based on this assessment of representation look like, and how have they changed from the original set of conservation targets?

1. *What is the minimum area and percentage required to represent all surrogate ecosystems within the Assiniboine Delta Region*?

The spatial extent of the enduring landscape features within the Assiniboine Delta study area first had to be examined before the minimum area and the percentage required to represent all conservation features could be calculated. Table 5.1 presents a summary of the spatial distribution of the seventeen enduring landscape features that were used to represent the biodiversity of the study area. The table splits up the conservation features

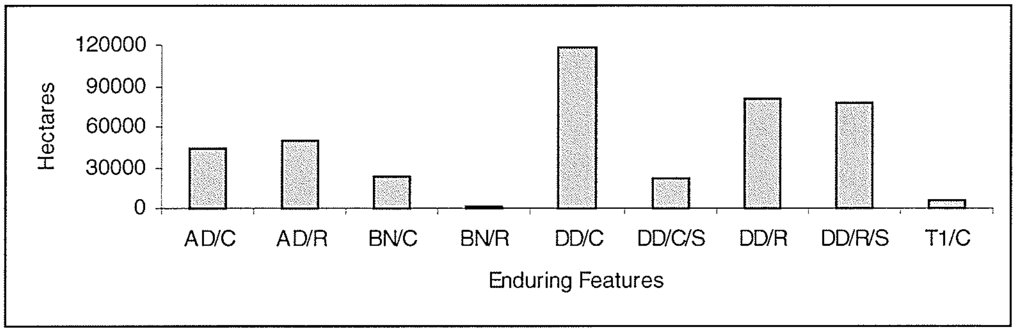
Table 5.1 Spatial Distribution of Enduring Landscape Features in the Assiniboine Delta Region

Single Occurrence Enduring Landscape Features



Enduring Landscape Feature	Hectares	Percent of Study Area
DB/C	5,632	1.25%
DB/R	1,152	0.26%
GD/C	2,688	0.60%
GD/R	2,880	0.64%
OD/C	4,672	1.04%
OD/R	6,720	1.50%
T1/R/M	1,856	0.41%
T2/R	704	0.16%
Total	26,304	5.85%

Multiple Occurrence Enduring Landscape Features



Enduring Landscape Feature	Hectares	Percent of Study Area
AD/C	44,160	9.83%
AD/R	49,344	10.98%
BN/C	24,064	5.36%
BN/R	768	0.17%
DD/C	118,080	26.28%
DD/C/S	22,144	4.93%
DD/R	80,640	17.95%
DD/R/S	78,272	17.42%
T1/C	5,568	1.24%
Totals	423,040	94.15%

into two categories, single occurrence and multiple occurrence features. Single occurrence features have a limited spatial distribution, and only occur in one particular location, where as multiple occurrence features have a much broader spatial distribution and can be found throughout the study area. There were seven single occurrence enduring landscape features within the study area. These features represented a total of 26,304 hectares of land, which is less than 6% of the study area. The remaining nine multiple occurrence features cover over 432,040 hectares of land and represent just over 94% of the study area. Of these multiple occurrence enduring landscape features, *deltaic deposits / black chernozem* was the largest, with its total area covering over 26% of the study area. The second and third largest features were *deltaic deposits / regosol* and *deltaic deposits / regosol / sand dunes,* which together cover just over 17% of the study area. Altogether, these three enduring landscape features represent close to 62% of the study area.

Conservation targets were calculated based on the spatial extent of the enduring landscape features within the Assiniboine Delta. The targets were used to define the total area required to represent each enduring landscape feature within the study area. Figures 5.1, 5.2 and 5.3 summarize conservation targets for the conservation target classes of 15%, 25% and proportional. The initial conservation target classes that were calculated for the 15%, 25% and proportional conservation targets totaled 67,402 hectares, 112,336 hectares and 71,610 hectares respectively. When a conservation target for an enduring landscape feature was less than 1000 hectares, the conservation target was adjusted wherever possible so no conservation targets would be less than 1000 hectares. This

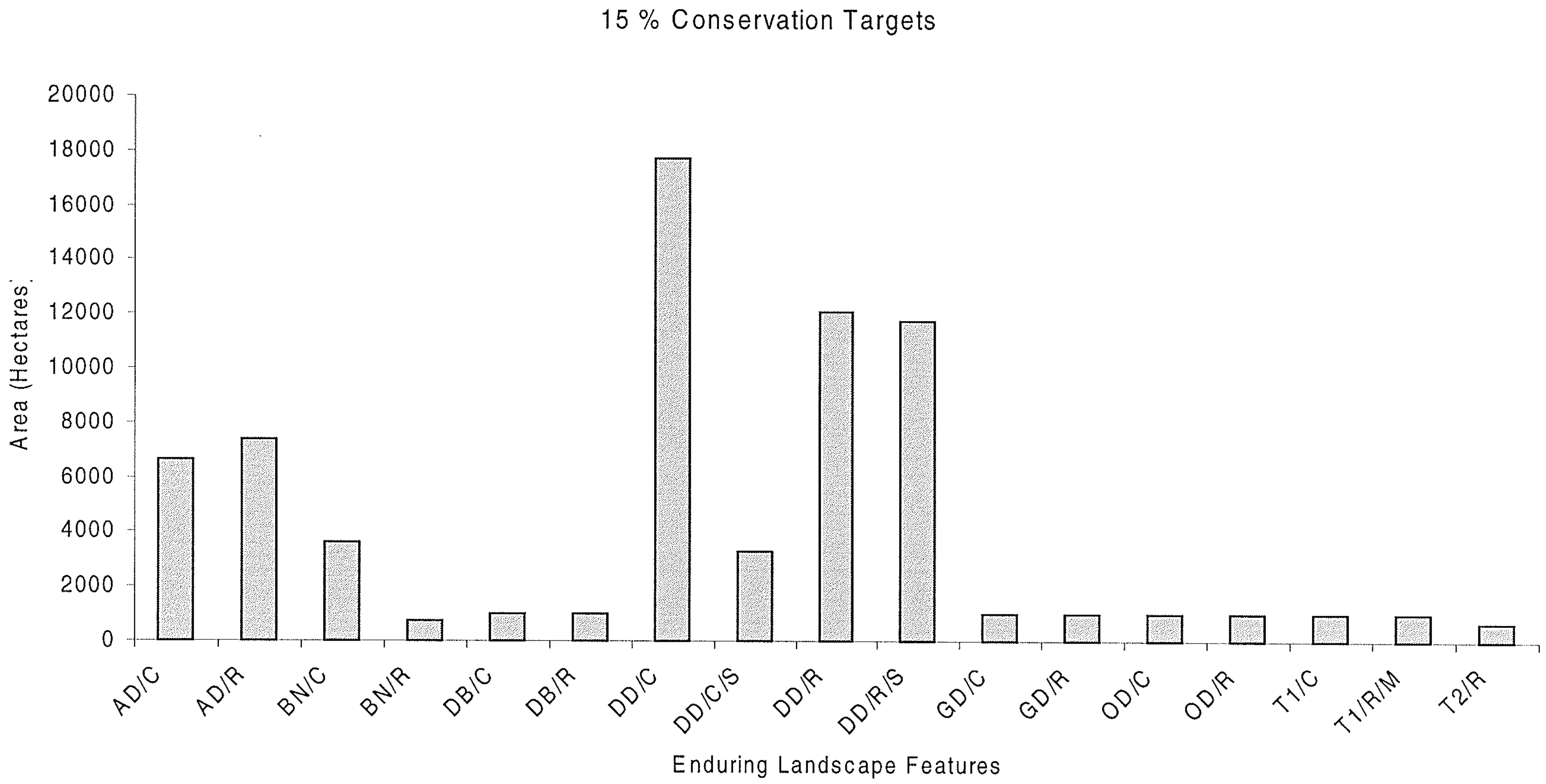


Figure 5.1 15% Conservation Target Class

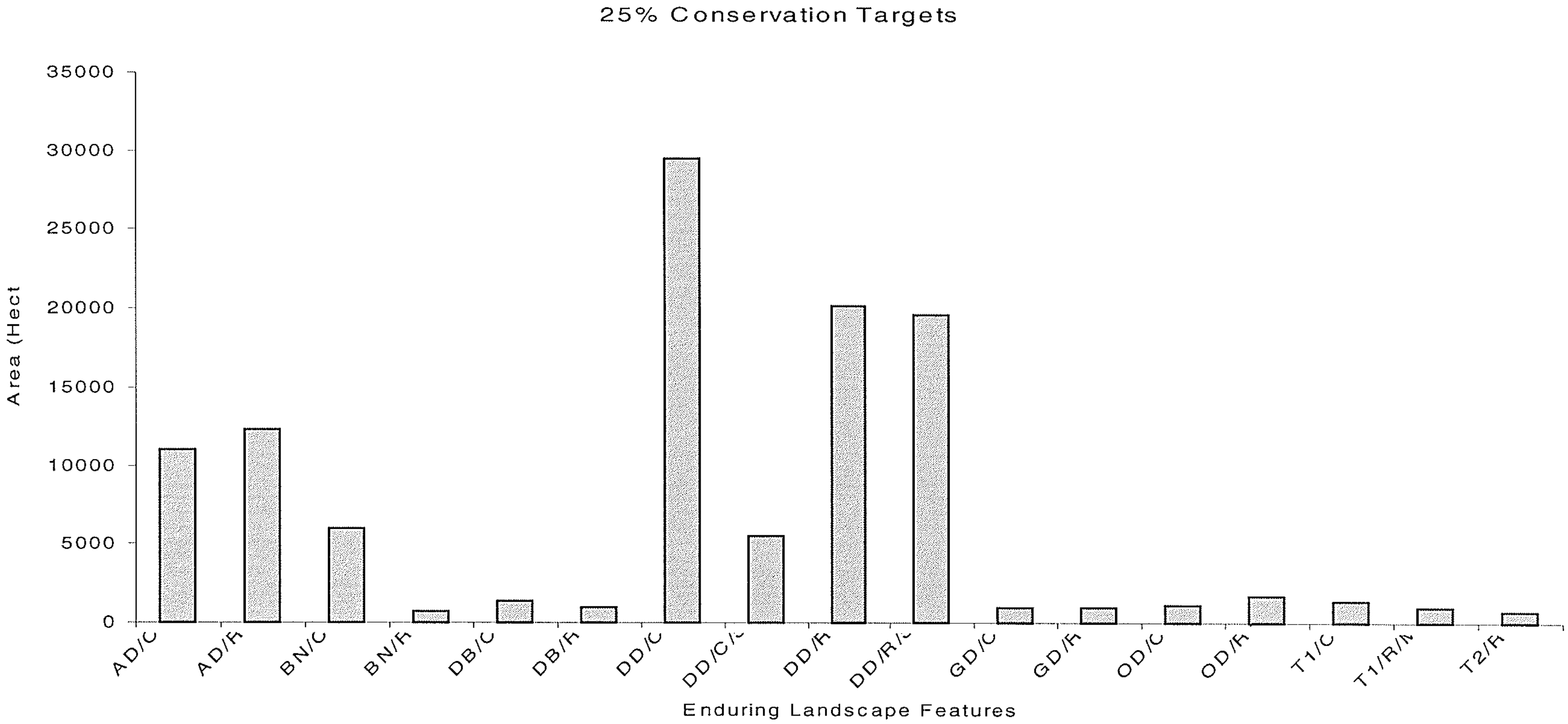


Figure 5.2 25% Conservation Target Class

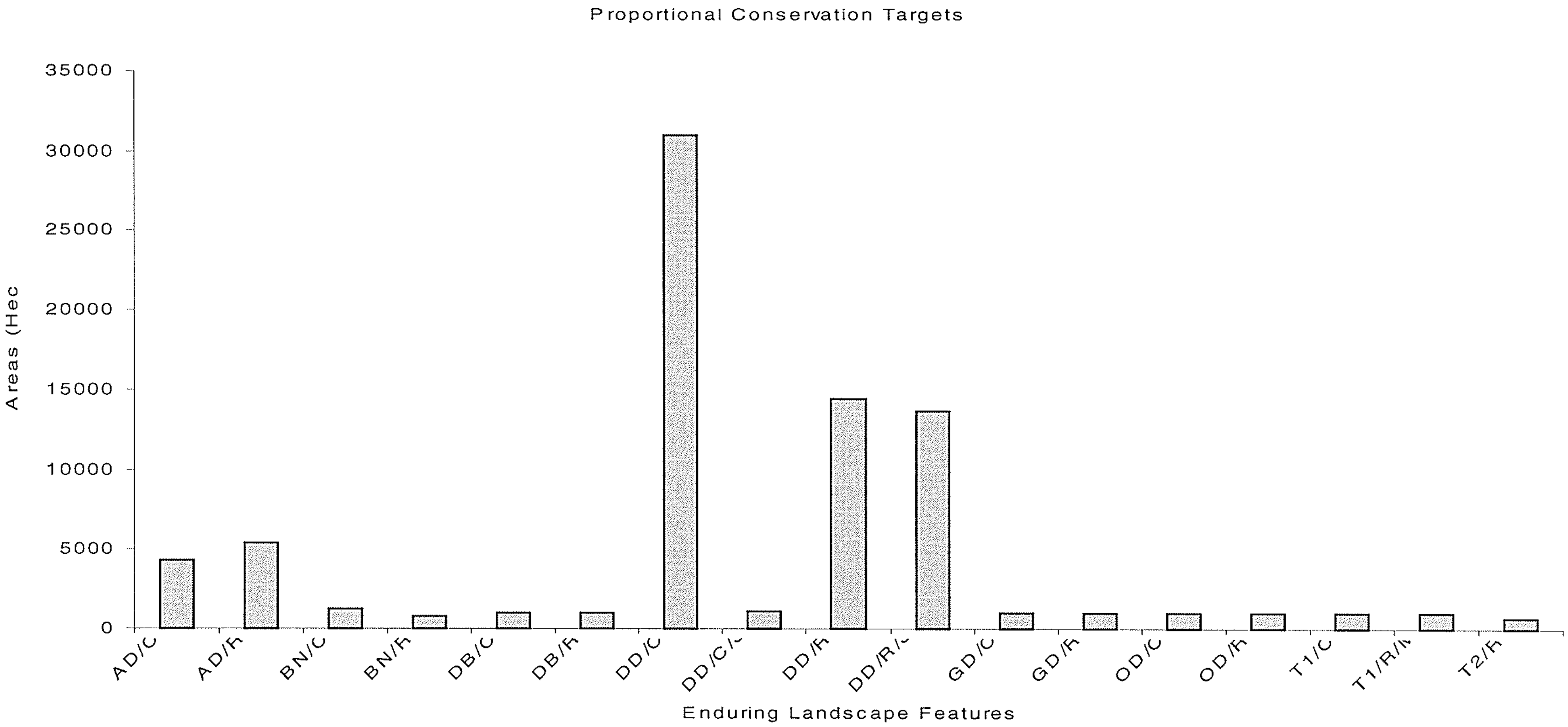


Figure 5.3 Proportional Conservation Target Class

adjustment added an additional 4,556 hectares (15% conservation target), 2,960 hectares (25% conservation target) and 1,935 hectares (proportional conservation target) to each conservation target class. This increased the 15% conservation target class to71,985 hectares of land, the 25% conservation target class to 115,296 hectares of land and the proportional conservation target class to 80,746 hectares of land.

2. How well does the current network of protected areas reflect the biological diversity found within the Assiniboine Delta region of southwestern Manitoba?

A gap analysis was undertaken to assess the extent to which the existing network of protected areas adequately captured the conservation features within the Assiniboine Delta region. The overall results of the gap analysis are summarized in Table 5.2. The existing conservation network conserved a total of 42,176 hectares of land. This contributed towards the overall conservation targets by fulfilling 39% of the 15% conservation target, 52% of the 25% conservation target and 48% of the proportional conservation target. The enduring features represented in the current conservation network are identified in Table 5.3 and Figure 5.4.

After reviewing the extent to which representation goals had been satisfied by existing protected areas, conservation goals for the study area were further refined. Information on the level of representation obtained from the gap analysis was assessed

Table 5. 2 Summarized gap analysis results for the 15%, 25% and Proportional Conservation Target Class

Conservation Target Classes	Conservation Targets Total (Ha)	*Percent Target Reached	**After Gap Target Total (Ha)
15%	71,985	39%	44,008
25%	115,296	52%	55,536
Proportional	80,746	48%	41,589

* Percentage of conservation target that has been protected by existing protected areas
**Number of hectares of enduring landscape features that still require protection

Table 5.3 Enduring Landscape Features that are Currently Represented in the Existing Network of Protected Areas

Enduring Landscape Features	Provincial Parks (ha)	Wildlife Management Areas (ha)	Wildlife Refuge(ha)	Gap Analysis Results(ha)
AD/C		256		256
AD/R	6,592	2,496		9,088
DD/C		1,664	512	2,176
DD/C/S		64	896	960
DD/R	3,648	2,560	2,176	8,384
DD/R/S	15,104	1,088	1,344	17,536
OD/R			3,776	3,776
Total	25,344	8,128	8,704	42,176

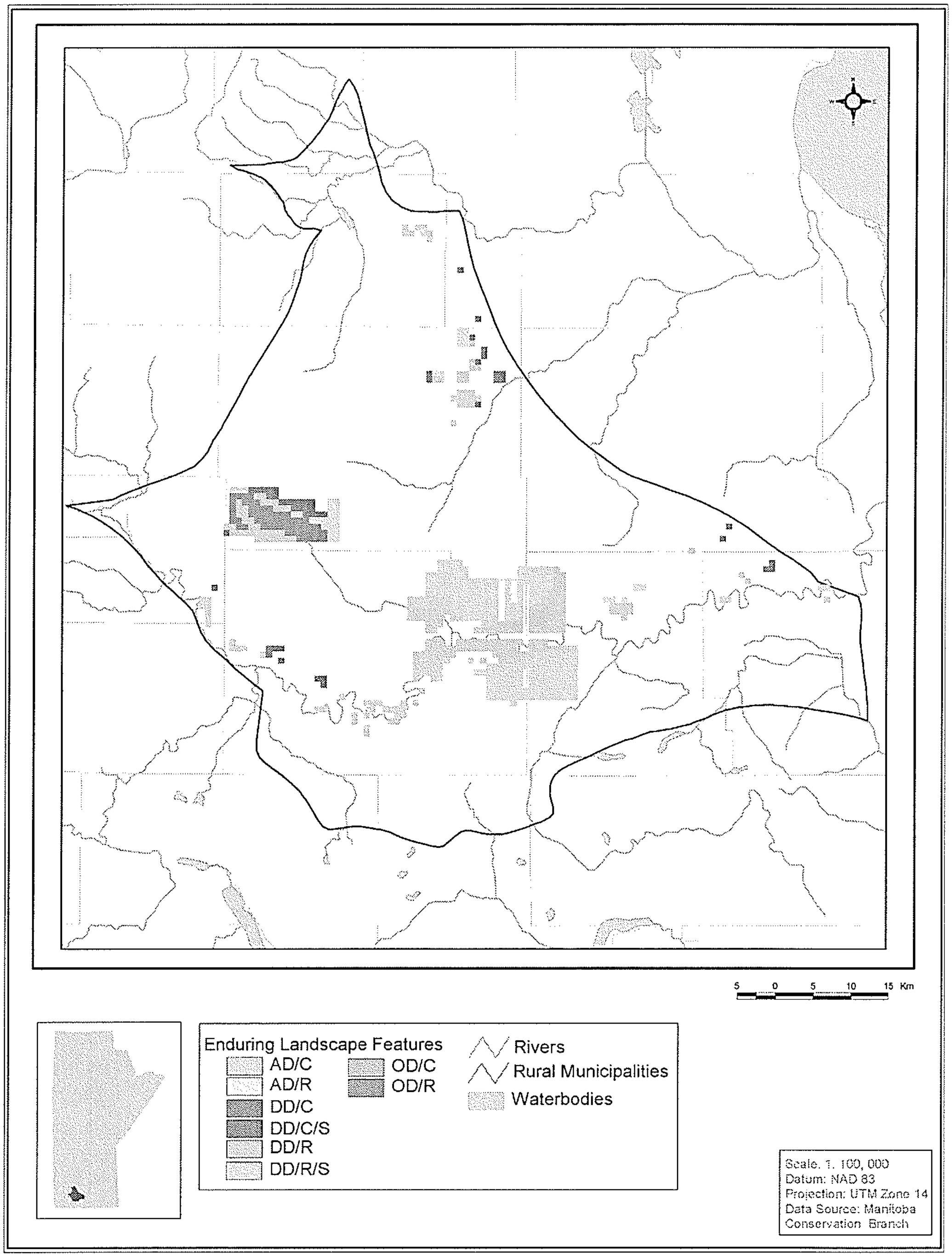


Figure 5.4 Enduring Landscape Features that are Currently Represented in Existing Protected Areas

Table 5.4 Criteria used to assess the level of representation for Enduring Features

Level of Representation	Assessment Criteria	Description Assessment Criteria
Not Captured	0% - 24%	No part of the enduring landscape feature is included within the boundaries of a protected area
Partially Captured	25% - 49%	Only minor parts of the enduring landscape feature are included within boundaries of existing protected areas.
Moderately Captured	50% - 89%	A significant portion of the enduring landscape feature is included within one or several protected areas
Adequately Captured	90% - 100%	A sufficient proportion of the enduring landscape feature in included in existing protected areas
Over Representation	101% - +	Enduring landscape features conservation requirements have been exceeded within existing protected areas

according to Table 5.4 and is presented in Table 5.5 and Figure 5.5 for all three conservation target classes. For the three different conservation target classes, the 25% conservation class was the only one that achieved adequate representation for deltaic deposits / regosol / sand dunes. For both the 15% and proportional conservation target classes, alluvial deposits / regosols, deltaic deposits / regosol / sand dunes and organic deposits / regosol were protected above their targets levels. With regards to the 25% conservation target class, only one conservation feature, organic deposits / regosol was

Table 5.5 Representation that was Achieved for the 15%, 25% and the Proportional Conservation Target Class

Enduring Landscape Features	Conservation Target 15% (ha)		Conservation Target 25% (ha)		Conservation Target Proportional (ha)	
AD/C	Not Captured	6,368	Not Captured	10,784	Not Captured	4,083
AD/R	Over Representation	0.00	Moderately Captured	3,248	Over Representation	0.00
BN/C	Not Captured	3,609	Not Captured	6,016	Not Captured	1,288
BN/R	Not Captured	768	Not Captured	768	Not Captured	768
DB/C	Not Captured	1,00	Not Captured	1,408	Not Captured	1,000
DB/R	Not Captured	1,00	Not Captured	1,000	Not Captured	1,000
DD/C	Not Captured	15,536	Not Captured	27,344	Not Captured	28,853
DD/C/S	Partially Captured	2,361	Partially Captured	4,576	Moderately Captured	131
DD/R	Moderately Captured	3,712.	Partially Captured	11,776	Moderately Captured	6,087
DD/R/S	Over Representation	0.00	Adequately Captured	2,032	Over Representation	0.00
GD/C	Not Captured	1,000	Not Captured	1,000	Not Captured	1,000
GD/R	Not Captured	1,000	Not Captured	1,000	Not Captured	1,000
OD/C	Not Captured	1,000	Not Captured	1,168	Not Captured	1,000
OD/R	Over Representation	0.00	Over Representation	0.00	Over Representation	0.00
T1/C	Not Captured	1,000	Not Captured	1,392	Not Captured	1,000
T1/R/M	Not Captured	1,000	Not Captured	1,000	Not Captured	1,000
T2/R	Not Captured	704	Not Captured	704	Not Captured	704
Total		27,977		68,952		39,156

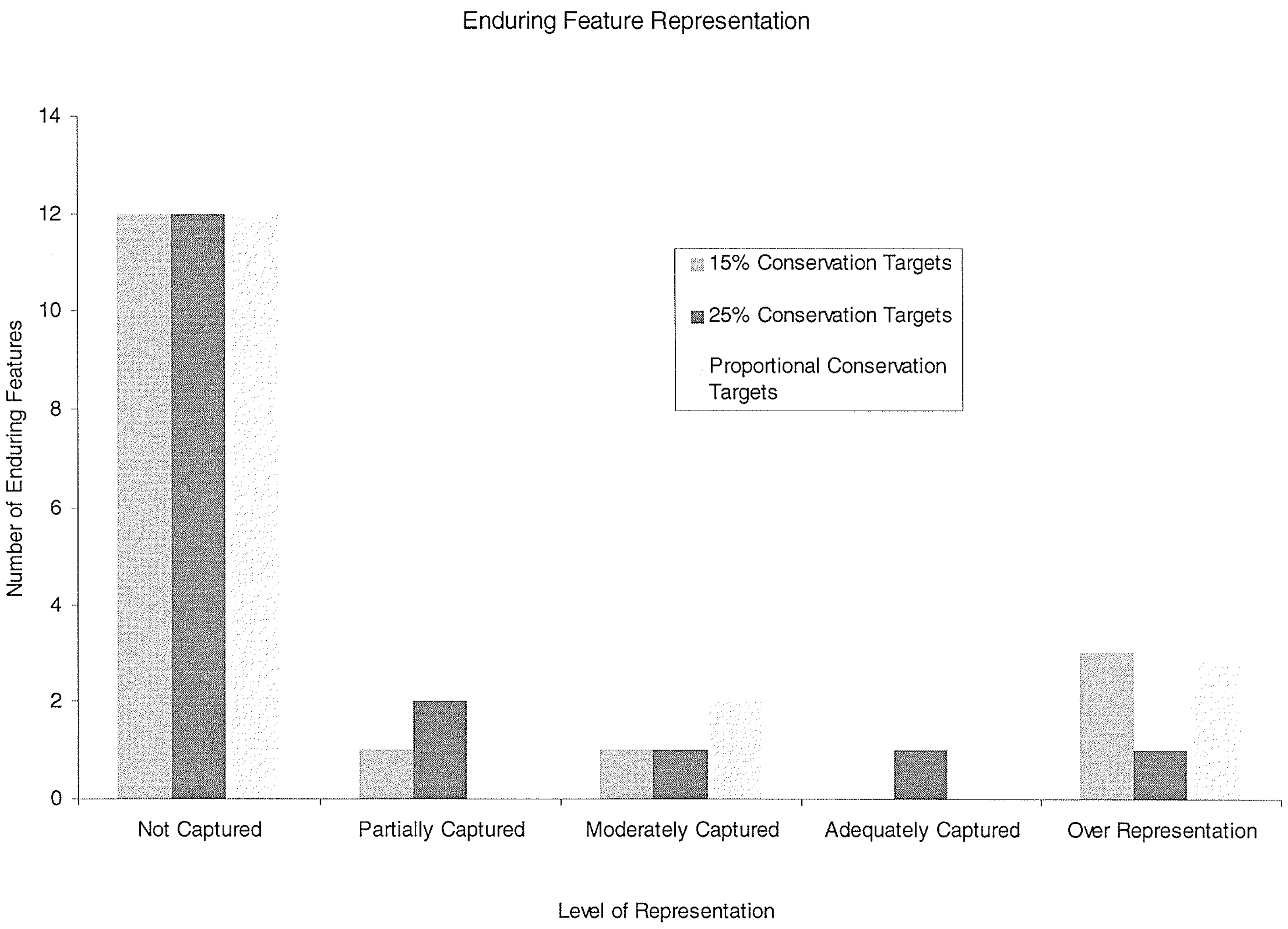


Figure 5.5 Representation Achieved for 15%, 25% and Proportional Conservation Target Classes

protected above the required target level. All three conservation target classes managed to moderately capture different sets of conservation features. However, only the 15% and 25% conservation target classes managed to partially capture deltaic deposits / black chernozem / sand dunes and deltaic deposits / regosol even though seven enduring landscape features were captured within the existing network of protected areas. Since only a small percentage of alluvial deposits / black chernozem and deltaic deposits / black chernozem were conserved, they were classified as not captured. Therefore, for all three conservation scenarios, twelve enduring landscape features were classified as not captured.

The results of the gap analysis in which the 15% conservation target class was applied, are summarized in Table 5.6 and Figure 5.6. None of the seventeen enduring landscape features were adequately represented within the existing conservation network. Three enduring landscape features, alluvial deposits / regosols, deltaic deposits / regosol / sand dunes and organic deposits / regosol did exceed their conservation targets by 23%, 49% and 175% respectively. Deltaic deposits / black chernozem / sand dunes was partially represented (29%) and deltaic deposits / regosol was moderately represented (69%). Only a very small percentage of deltaic deposits / black chernozem (4%) and deltaic deposits / black chernozem (12%) were conserved within the existing conservation network, thus they were classified as not captured. The remaining ten enduring landscape features were not present within any of the existing network of

Table 5.6 Gap analysis results for the 15% conservation target class

Enduring Landscape Features	Enduring Features (Ha)	Conservation Target 15%	GAP Analysis Results	Representation
AD/C	44,160	6,624	256	4%
AD/R	49,344	7,401	9,088	123%
BN/C	24,064	3,609	0.00	0%
BN/R	768	768	0.00	0%
DB/C	5,632	1,000	0.00	0%
DB/R	1,152	1,000	0.00	0%
DD/C	118,080	17,712	2,176	12%
DD/C/S	22,144	3,321	960	29%
DD/R	80,640	12,096	8,384	69%
DD/R/S	78,272	11,740	17,536	149%
GD/C	2,688	1,000	0.00	0%
GD/R	2,880	1,000	0.00	0%
OD/C	4,672	1,000	0.00	0%
OD/R	6,720	1,008	3,776	375%
T1/C	5,568	1,000	0.00	0%
T1/R/M	1,856	1,000	0.00	0%
T2/R	704	704	0.00	0%
Total	449,344	71,985	42,176	

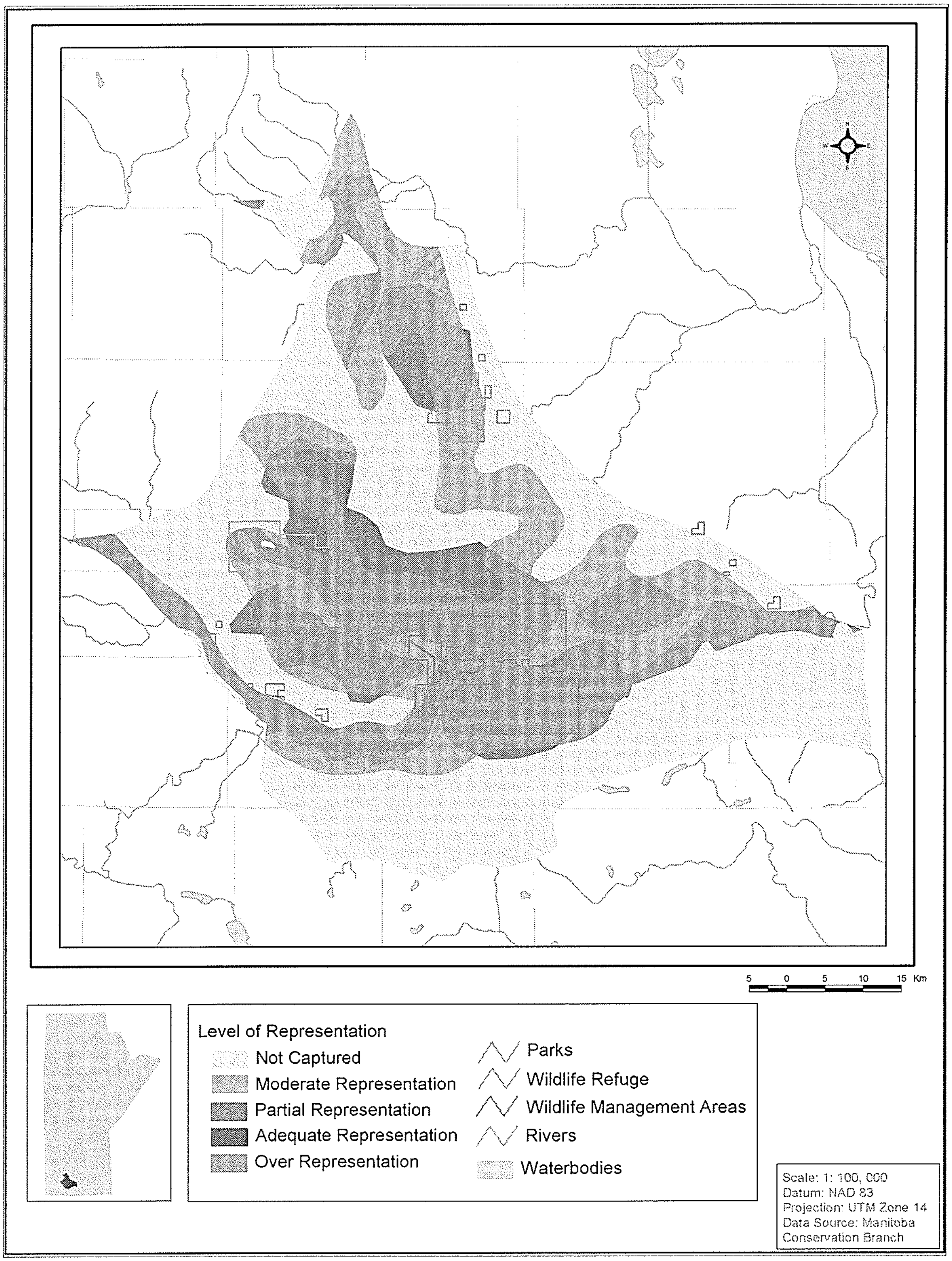


Figure 5.6 Gap Analysis results for 15% Conservation Target Class

Table 5.7 Gap analysis results for the 25% conservation target class

Enduring Landscape Features	Enduring Features (Ha)	GAP Analysis Results	Conservation Target 25%	Representation
AD/C	44,160	256	11,040	2%
AD/R	49,344	9,088	12,336	74%
BN/C	24,064	0.00	6,016	0%
BN/R	768	0.00	768	0%
DB/C	5,632	0.00	1,408	0%
DB/R	1,152	0.00	1,000	0%
DD/C	118,080	2,176	29,520	7%
DD/C/S	22,144	960.00	5,536	17%
DD/R	80,640	8,384	20,160	42%
DD/R/S	78,272	17,536	19,568	90%
GD/C	2,688	0.00	1,000	0%
GD/R	2,880	0.00	1,000	0%
OD/C	4,672	0.00	1,168	0%
OD/R	6,720	3,776	1,680	225%
T1/C	5,568	0.00	1,392	0%
T1/R/M	1,856	0.00	1,000	0%
T2/R	704	0.00	704	0%
Total	449,344	42,176	115,296	

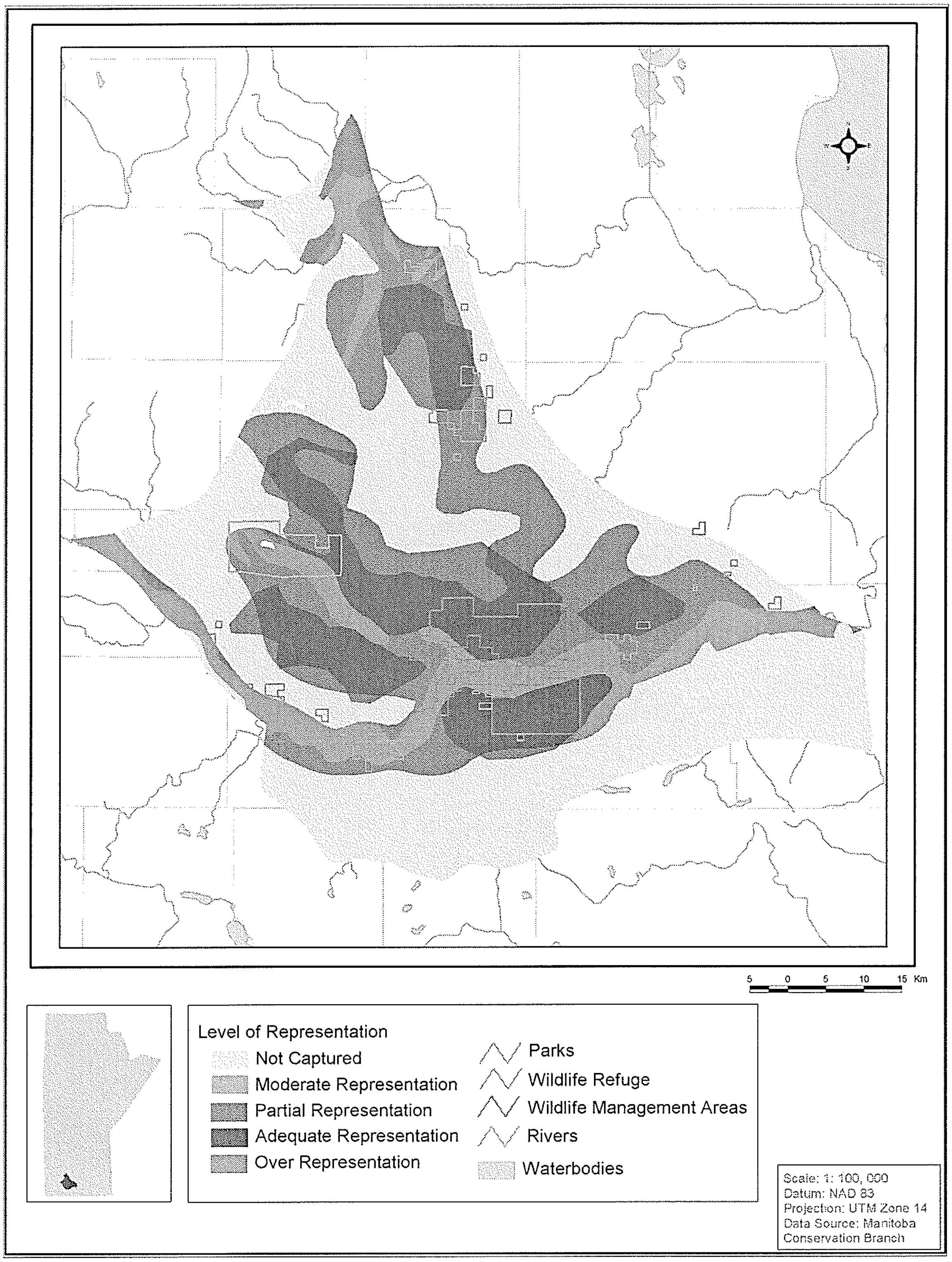


Figure 5.7 Gap Analysis results for 25% Conservation Target Class

protected areas. The results of the gap analysis, which used the 25% conservation target class, are shown in Table 5.7 and Figure 5.7. Of the seventeen enduring landscape features, twelve were classified as not captured within the existing network of protected areas. Even though a small portion of alluvial deposits / black chernozem and deltaic deposits / black chernozem were located within the conservation network, they were still classified as not captured because only 2% of alluvial deposits / black chernozem and 7% of deltaic deposits / black chernozem were represented. One conservation feature, deltaic deposits / regosol / sand dunes was classified as adequately captured. The enduring landscape feature organic deposits / regosol, was over represented by 125% of its required conservation target.

The results of the gap analysis, which used the proportional conservation target class, are summarized in Table 5.8 and Figure 5.8. Adequate representation was not achieved for any of the conservation features. The three enduring landscape features alluvial deposits / regosols, deltaic deposits / regosol / sand dunes and organic deposits / regosol were over represented within conservation targets by 68%, 29% and 278% respectively. Both deltaic deposits / black chernozem / sand dunes (88%) and deep basin / regosols (58%) were moderately captured within the existing network of protected areas. The remaining twelve conservation features were classified as not captured. However two of those twelve, alluvial deposits / black chernozem with 6% and deltaic deposits / black chernozem with 7%, had their conservation targets met by the existing conservation network.

3. What do the new conservation targets based on this assessment of representation look like, and how have they changed from the original set of conservation targets?

The results of the gap analysis identified which enduring landscape features were captured within existing protected areas. Table 5.9 lists the results of the gap analysis *existing protected areas* that were assessed against the initial conservation targets for each enduring landscape feature. Once the conservation target for an enduring landscape feature has been reached, there is no longer the need to search for any other candidate sites to represent that conservation feature. After running the gap analysis, both the 15% and proportional conservation target classes, were adjusted to zero for enduring landscape features alluvial deposits / regosols, deltaic deposits / regosol / sand dunes and organic deposits / regosol. Likewise, in the 25% conservation target class, the conservation target for organic deposits / regosol was also set to zero. As for the rest of the enduring landscape features, conservation targets were re-adjusted to reflect the extent to which conservation targets have already been satisfied by the existing protected area network. This resulted in a decrease in the amount of land required to reach each conservation goal compared for all three conservation target classes. As for the other set of conservation goals, they did not take into consideration the existing conservation network *no existing protected areas*, thus no adjustments to the conservation targets were made.

Table 5.8 Gap analysis results for the proportional conservation target class

Enduring Landscape Features	Enduring Features (Ha)	GAP Analysis Results	Conservation Target Proportional%	Representation
AD/C	44,160	256	4339	6%
AD/R	49,344	9,088	5418	168%
BN/C	24,064	0	1288	0%
BN/R	768	0	768	0%
DB/C	5,632	0	1000	0%
DB/R	1,152	0	1000	0%
DD/C	118,080	2,176	31029	7%
DD/C/S	22,144	960	1091	88%
DD/R	80,640	8,384	14471	58%
DD/R/S	78,272	17,536	13634	129%
GD/C	2,688	0	1000	0%
GD/R	2,880	0	1000	0%
OD/C	4,672	0	1000	0%
OD/R	6,720	3,776	1000	378%
T1/C	5,568	0	1000	0%
T1/R/M	1,856	0	1000	0%
T2/R	704	0	704	0%
Total	449,344	42,176	80,746	

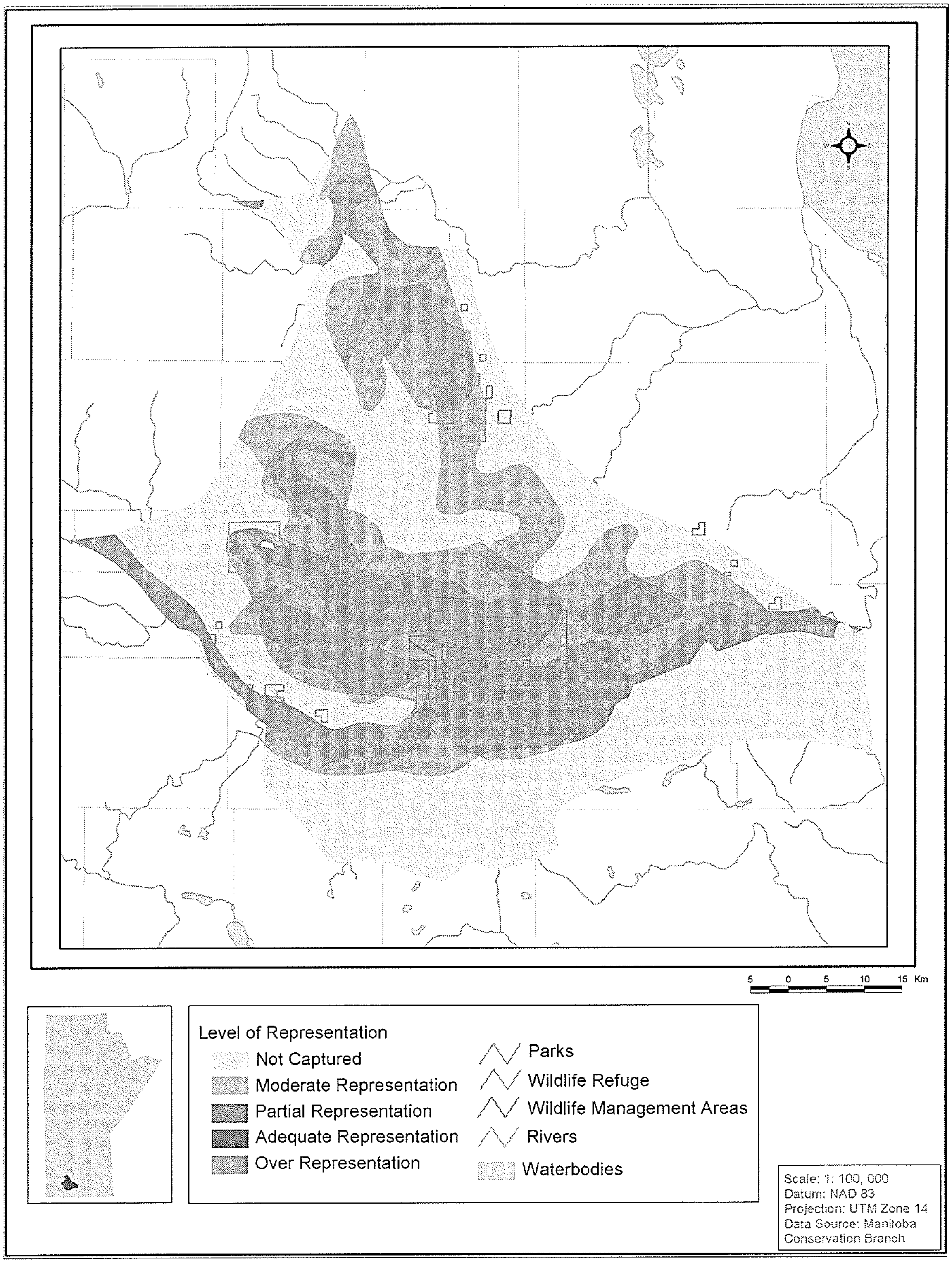


Figure 5.8 Gap Analysis results for Proportional Conservation Target Class

Table 5.9 Conservation Targets for Existing Protected Areas Conservation Scenario and No Existing Protected Areas Conservation Scenario

Enduring Landscape Features	Existing Protected Areas Conservation Targets			No Existing Protected Areas Conservation Targets		
	15%	25%	Prop%	15%	25%	Prop%
AD/C	6,368	10,784	4083	6,624	11,040	4,339
AD/R	0.00	3,248	0.00	7,401	12,336	5,418
BN/C	3,609	6,016	1,288	3,609	6,016	1,288
BN/R	768	768	768	768	768	768
DB/C	1,000	1,408	1,000	1,000	1,408	1,000
DB/R	1,000	1,000	1,000	1,000	1,000	1,000
DD/C	15,536	27,344	28853	17,712	29,520	31,029
DD/C/S	2,361	4,576	131	3,321	5,536	1,091
DD/R	3,712	11,776	6087	12,096	20,160	14,471
DD/R/S	0.00	2,032	0.00	11,740	19,568	13,634
GD/C	1,000	1,000	1,000	1,000	1,000	1,000
GD/R	1,000	1,000	1,000	1,000	1,000	1,000
OD/C	1,000	1,168	1,000	1,000	1,168	1,000
OD/R	0.00	0.00	0.00	1,008	1,680	1,000
T1/C	1,000	1,392	1,000	1,000	1,392	1,000
T1/R/M	1,000	1,000	1,000	1,000	1,000	1,000
T2/R	704.00	704	704	704	704	704
Total	27,977	68,952	39,156	71,985	115,296	80,746

5.1.1 Objective One Summary

After examining the spatial extent of the enduring landscape features within the Assiniboine Delta region, the minimum area required to represent the enduring landscape features varied between the three sets of conservation targets. The total amount of land required to adequately fulfill the conservation requirements for the 15% conservation target was 71,985 hectares. For the 25% conservation target the total amount of land required to fulfill this conservation goal equaled 115,296 hectares. For the proportional conservation target, 80,746 hectares of land was required to adequately fulfill this conservation target.

The current network of protected areas, covering a total of 42, 178 hectares of land captured seven enduring landscape features. This contributed towards fulfilling portions of the three conservation targets. The 25% conservation target had the largest percentage of its conservation target fulfilled (53%), the proportional conservation target was second with 48% of the required area fulfilled and the 15% conservation target had the least amount of its conservation goal fulfilled (39%). After reviewing the extent to which the level of representation had been satisfied for the three conservation goals the results indicated that for all three sets of conservation targets, organic deposits / regosol was over-represented. Where as alluvial deposits / regosols and deltaic deposits / regosol / sand dunes were over-represented for the 15% and the proportional conservation targets. As for fulfilling the individual conservation feature targets, the 25% conservation target class was the only one to adequately represent one enduring landscape feature (deltaic deposits / regosol / sand dunes).

5.2 Objective Two

The second objective of this thesis was to review, evaluate, and apply systematic site selection methods. In order to fulfill this objective, the following questions were asked. (1) What are the different site selection methods that have been developed? (2) How do the various selection methods operate? (3) What are the strengths and limitations of these various selection methods? These first three questions were thoroughly evaluated in chapter three. Based on this, a greedy heuristic and a simulated annealing selection algorithm were utilized to run the analysis. The following section will review the results of the two site selection methods.

5.2.1 Greedy Heuristics

Existing Protected Areas Conservation Scenario

A summary of the top scores for the *existing protected areas* conservation scenario generated by the greedy heuristic algorithm is displayed in Table 5.11 and Figure 5.9. This is illustrated for all three sets of conservation target classes and boundary length modifiers (BLM) in which the selection algorithm had the freedom to select candidate sites from both crown and private lands. For all three conservation target classes, the objective function score was the lowest when the BLM was set to 0.5. This indicated that the algorithm had a less difficult time fulfilling the conservation targets based within the existing constraints. Even though there was a difference in the objective function score when the BLM of 0.0 and 1.0, the results generated for the total cost, and boundary length were relatively the same.

Table 5.10 Greedy Heuristic Algorithm - Existing Protected Areas in which all lands are included in the selection process

		Run Number	Objective Function Score	Cost (Planning Unit)	Boundary Length (m)
Conservation Target 15%					
Boundary Length Modifier	0.0	25	6.46E+20	1,036	204,000
	0.5	28	2.39E+23	1,087	153,600
	1.0	24	4.77E+23	1,087	152,800
Conservation Target 25%					
Boundary Length Modifier	0.0	10	6.46E+20	1,312	240,000
	0.5	3	2.39E+23	1,354	177,600
	1.0	52	4.77E+23	1,354	186,400
Conservation Target Proportional					
Boundary Length Modifier	0.0	1	6.46E+20	1,151	250,400
	0.5	1	2.39E+23	1,208	186,400
	1.0	27	4.77E+23	1,207	187,200

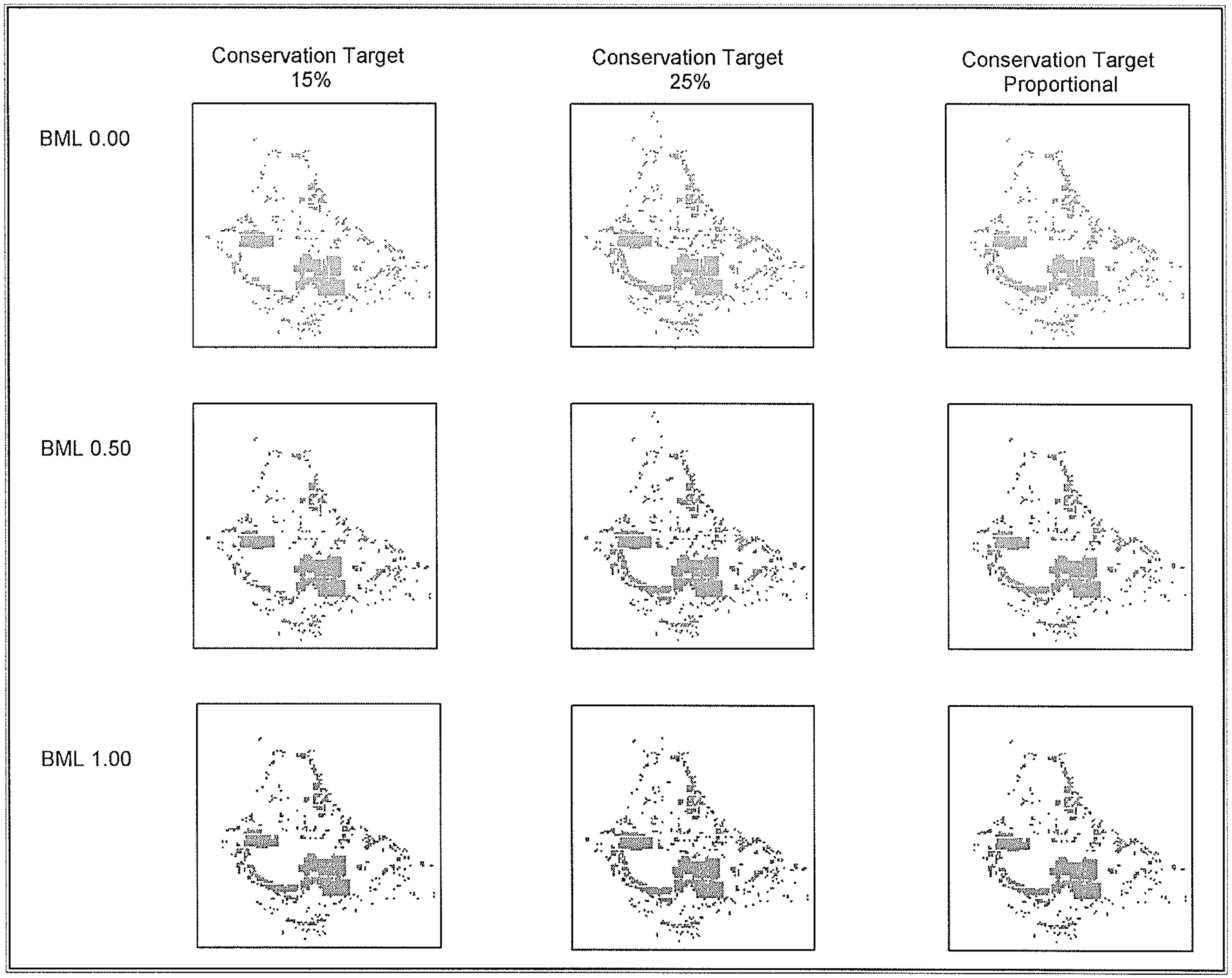


Figure 5.9 Greedy Heuristic Algorithm - Existing Protected Areas in which all lands are included in the selection process

Table 5.12 and Figure 5.10 display the top results for the greedy heuristic algorithm for the conservation scenario where existing protected areas are locked into the analysis. This is summarized for all three conservation targets and BLM where the selection algorithm was confined to select areas within crown lands. For all three conservation targets, the BLM of 0.0 generated the lowest cost; however, this modifier produced the largest boundary length. For the 15% and proportional conservation targets the objective function scores were the lowest when the BLM was set to 1.0. The results generated for the total cost, and boundary length were relatively the same for the 0.5 and the BLM of 1.0 for all three conservation targets.

Table 5.11 Greedy Heuristic Algorithm - Existing Protected Areas in which Crown lands are included in the selection process

		Run Number	Objective Function Score	Cost (Planning Unit)	Boundary Length (m)
Conservation Target 15%					
Boundary Length Modifier	0.0	1	2.51E+21	809	98,400
	0.5	1	9.04E+23	821	88,800
	1.0	1	1.81E+24	821	90,400
Conservation Target 25%					
Boundary Length Modifier	0.0	1	3.24E+21	896	87,200
	0.5	1	1.17E+24	905	81,600
	1.0	5	2.33E+24	905	82,400
Conservation Target Proportional					
Boundary Length Modifier	0.0	1	1.99E+21	786	107,200
	0.5	1	7.15E+23	802	94,400
	1.0	1	1.43E+24	802	94,400

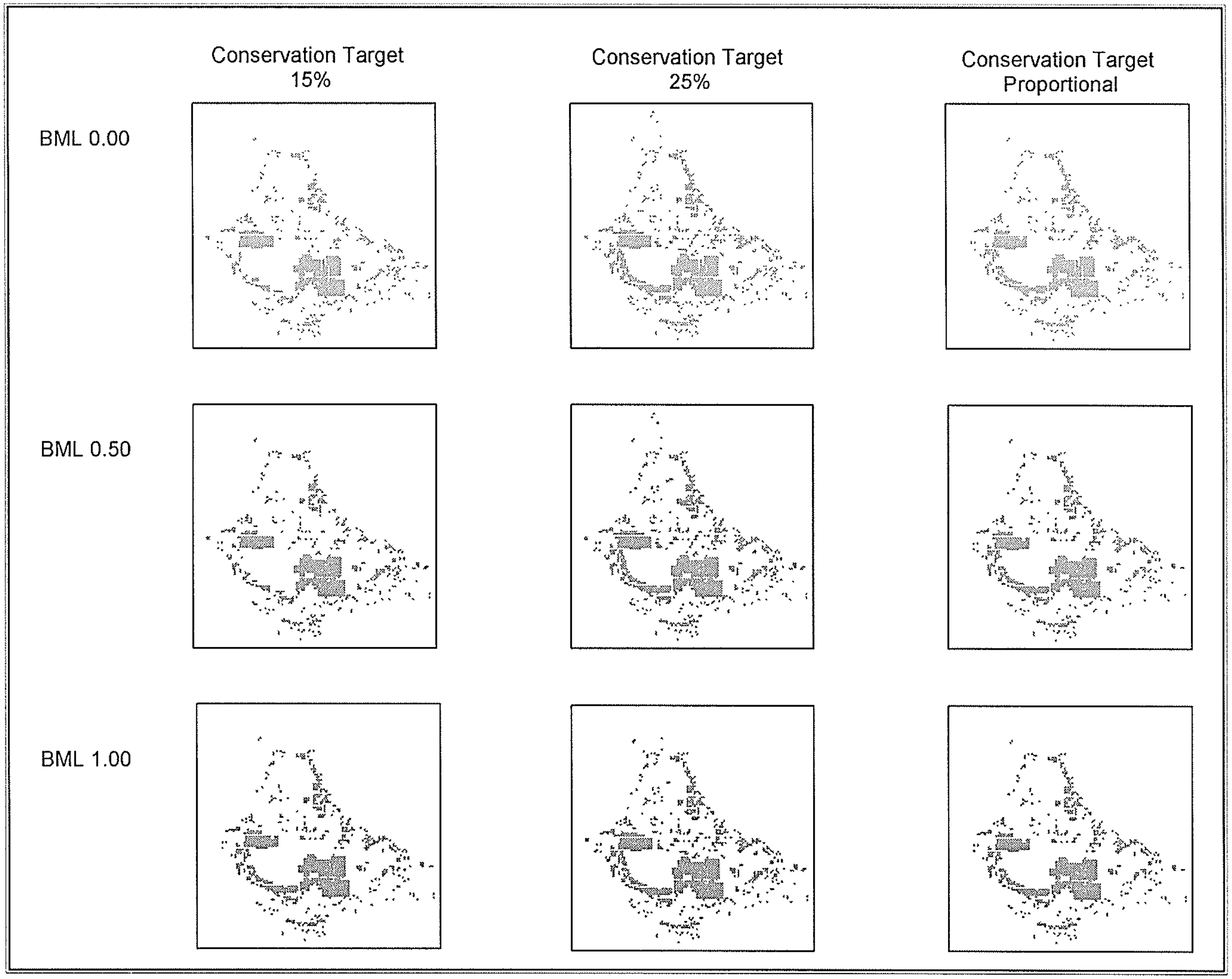


Figure 5. 10 Greedy Heuristic Algorithm - Existing Protected Areas in which Crown lands are included in the selection process

No Existing Protected Areas

A summary of the top scores where *no existing protected areas* have been locked into the system and the greedy heuristic algorithm had the option to select candidate sites from both crown lands and private lands are displayed in Table 5.13 and Figure 5.11. For all three conservation target classes, the smallest objective function score was generated when the BLM was set to 0.0, indicating that the algorithm had less trouble generating those solutions. For the 15% and 25% conservation targets, the cost and the total boundary length were the smallest. For the proportional conservation target, the BLM of 0.0 had a very large boundary length, indicating that the solutions were scattered. However, the total cost of the reserve system was largest for the BLM that was set at 1.0.

Table 5.12 Greedy Heuristic Algorithm – No Existing Protected Areas in which All lands are included in the selection process

		Run Number	Objective Function Score	Cost (Planning Unit)	Boundary Length (m)
Conservation Target 15%					
Boundary Length Modifier	0.0	89	3,454	880	91,200
	0.5	98	129,763	974	111,200
	1.0	32	241,853	882	77,600
Conservation Target 25%					
Boundary Length Modifier	0.0	78	2,211	1,406	88,000
	0.5	33	241,718	1,410	124,000
	1.0	54	474,635	1,409	116,000
Conservation Target Proportional					
Boundary Length Modifier	0.0	1	1,219	660	1,028,800
	0.5	46	228,405	889	74,400
	1.0	14	448,405	894	70,400

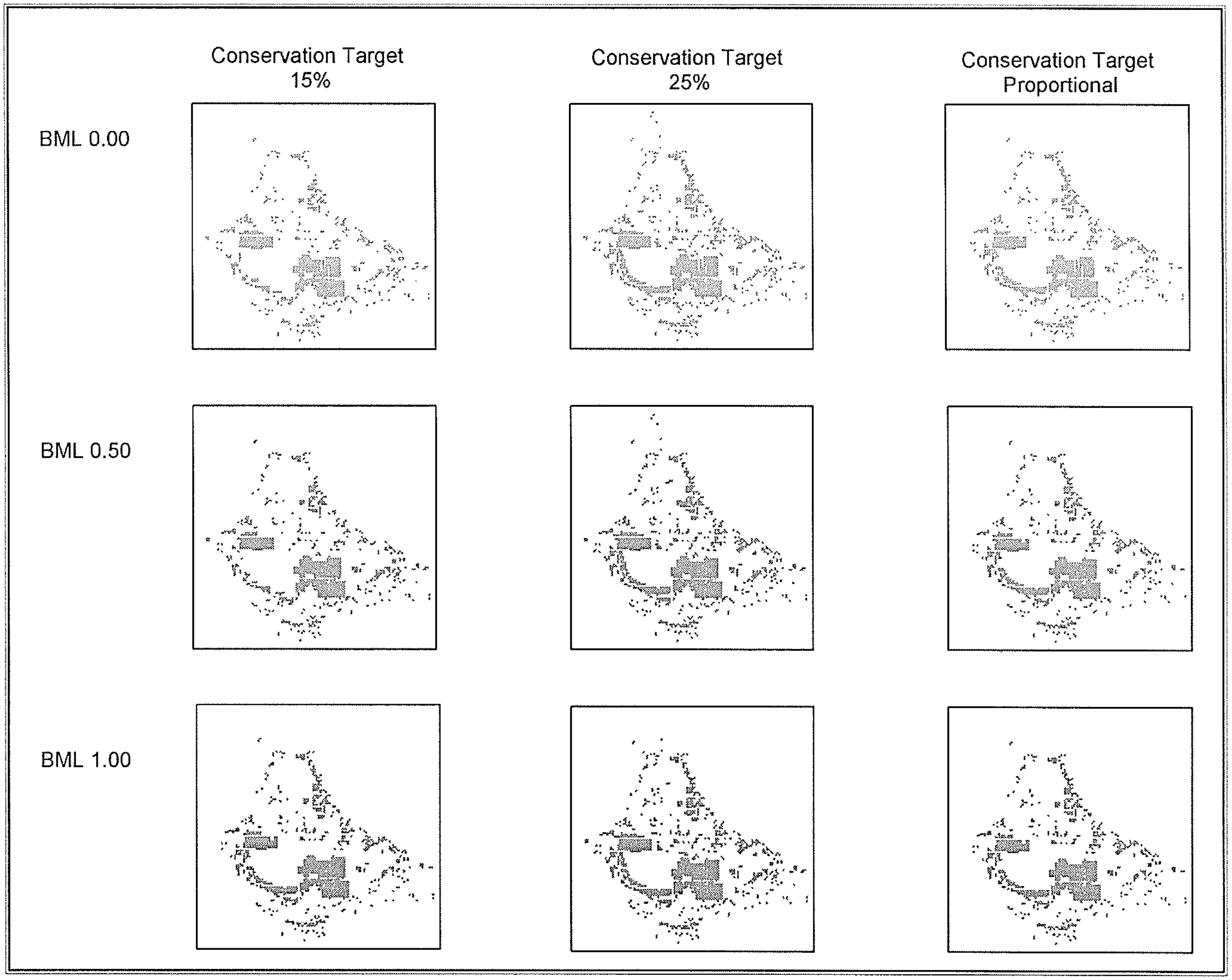


Figure 5.11 Greedy Heuristic Algorithm – No Existing Protected Areas in which All lands are included in the selection process

Table 5.14 and Figure 5.12 display the top results generated by the greedy heuristic algorithm where *no existing protected areas* area locked into the analysis and the algorithm's search radius is confined to crown lands. The cost calculated for the BLM of 0.5 and the BLM of 1.0 were identical within each conservation target. However, for all three conservation target classes, the BLM of 0.5 had the smallest boundary length. This was indicative that the BLM generated the most compact solutions for this particular analysis

Table 5.13 Greedy Heuristic Algorithm – No Existing Protected Areas in which Crown lands are included in the selection process

		Run Number	Objective Function Score	Cost (Planning Unit)	Boundary Length (m)
Conservation Target 15%					
Boundary Length Modifier	0.0	1	2.51E+21	898	88,000
	0.5	16	9.04E+23	907	83,200
	1.0	4	1.81E+24	907	79,200
Conservation Target 25%					
Boundary Length Modifier	0.0	1	3.24E+21	1,086	107,200
	0.5	1	1.17E+24	1,086	106,400
	1.0	1	2.33E+24	1,086	107,200
Conservation Target Proportional					
Boundary Length Modifier	0.0	1	5.59E+20	894	216,800
	0.5	3	7.15E+23	915	85,600
	1.0	13	1.43E+24	915	86,400

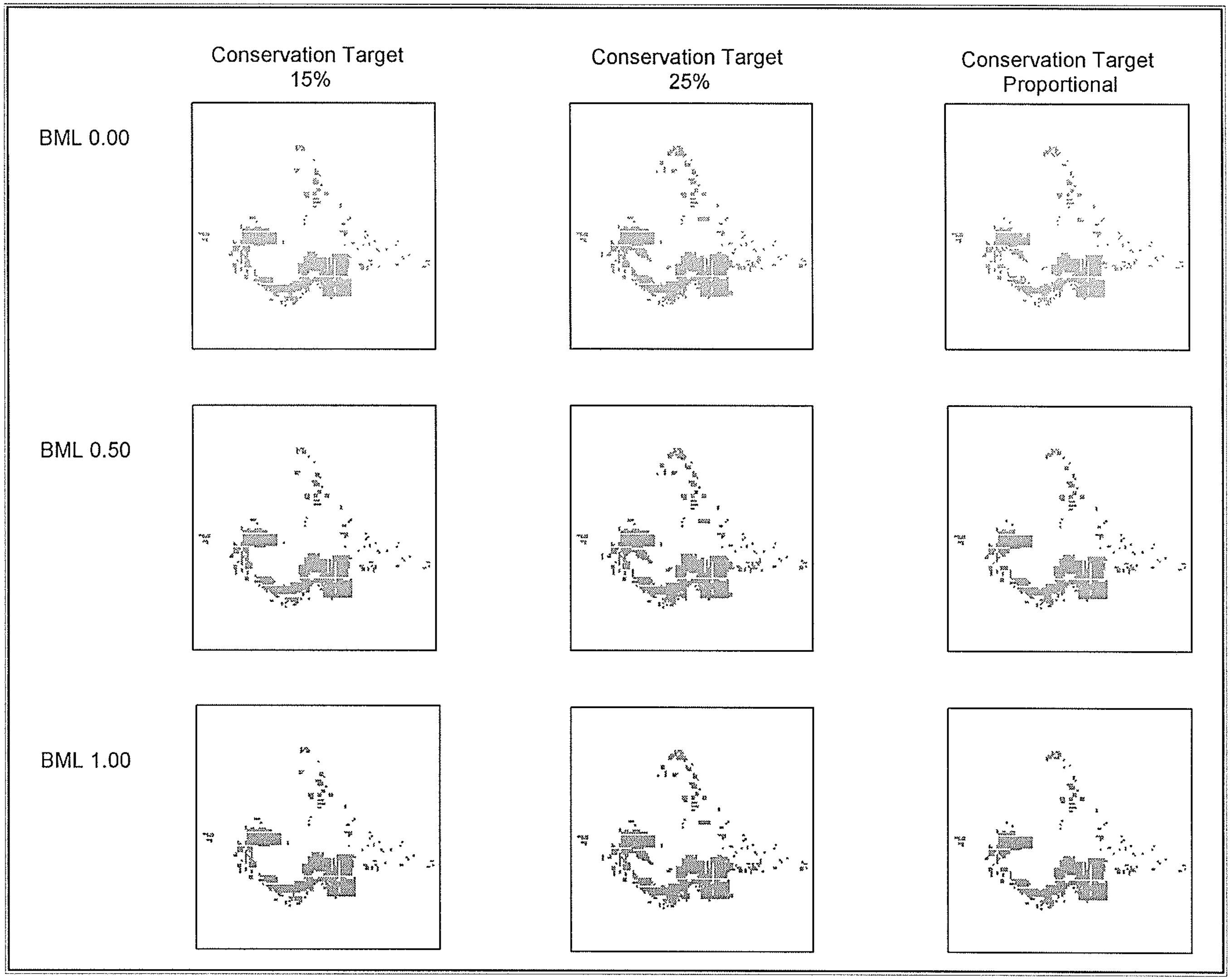


Figure 5.12 Greedy Heuristic Algorithm – No Existing Protected Areas in which Crown lands are included in the selection process

5.2.2 Simulated Annealing

Existing Protected Areas

The top solutions generated by the simulated annealing algorithm in which the algorithm was free to select candidate sites from a combination of crown lands and private lands where *existing protected areas* were accounted for are listed in Table 5.15 and Figure 5.13.The algorithm had the easiest time generating solutions for all three conservation target classes when the BLM was set to 0.5, thus generating the smallest objective function score. However, the 15% and proportional conservation target classes had the shortest boundary length when the BLM was set to 1.0

Table 5.14 Simulated Annealing Algorithm –Existing Protected Areas in which all lands are included in the selection process

		Run Number	Objective Function Score	Cost (Planning Unit)	Boundary Length (m)
Conservation Target 15%					
Boundary Length Modifier	0.0	12	6.46E+20	1,035	322,400
	0.5	11	2.39E+23	1,084	210,400
	1.0	13	4.77E+23	1,084	208,000
Conservation Target 25%					
Boundary Length Modifier	0.0	6	6.46E+20	1,310	324,000
	0.5	64	2.39E+23	1,350	222,400
	1.0	36	4.77E+23	1,351	226,400
Conservation Target Proportional					
Boundary Length Modifier	0.0	3	6.46E+20	1,151	264,000
	0.5	11	2.39E+23	1,084	210,400
	1.0	77	4.77E+23	1,206	192,800

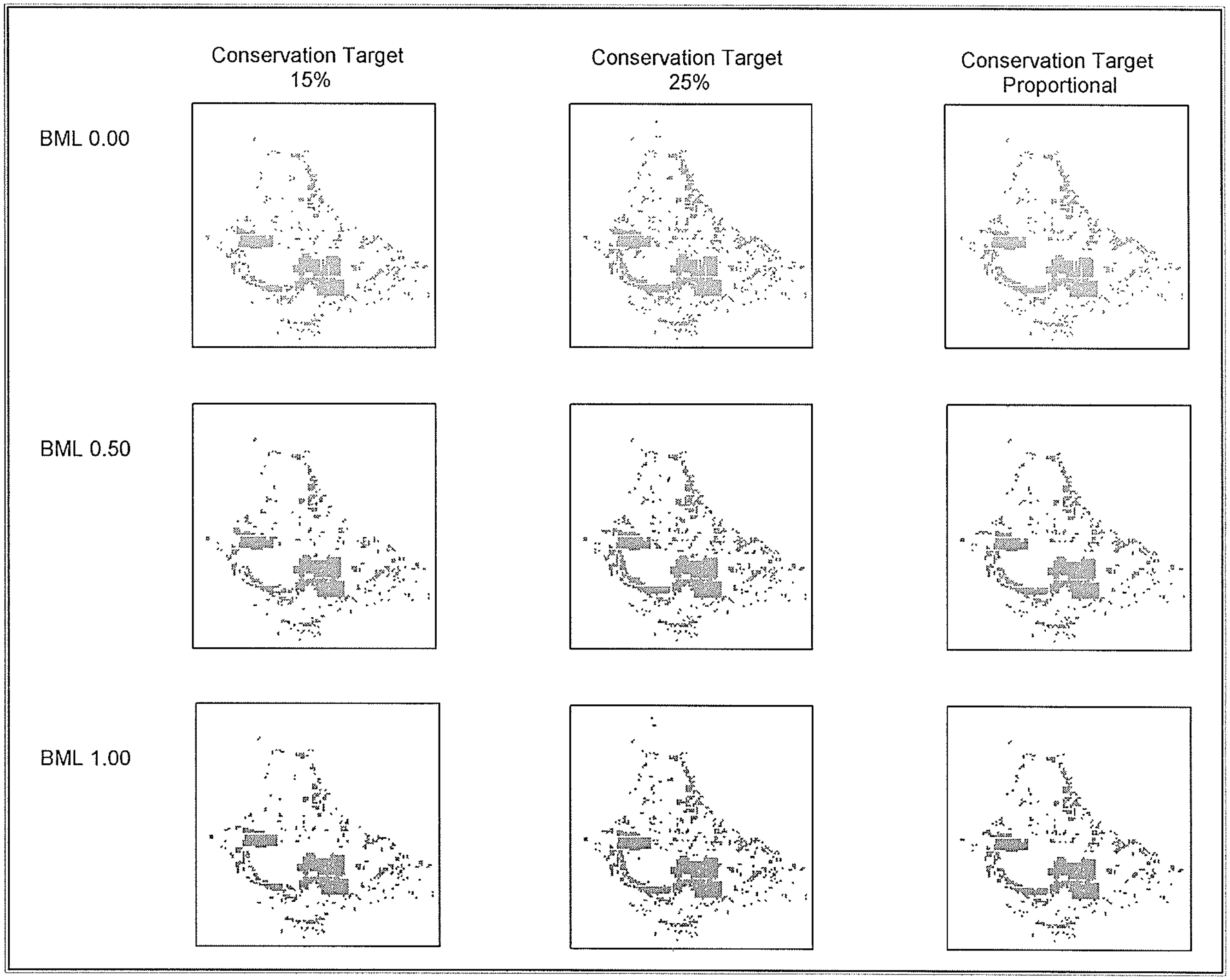


Figure 5.13 Simulated Annealing Algorithm –Existing Protected Areas in which all lands are included in the selection process

The top results for the *existing protected areas* conservation scenario where the simulated annealing algorithm was limited to selecting candidate areas within crown lands are displayed in Table 5.16 and Figure 5.14. The cost was the lowest for each conservation target class when the BLM was set to 0.0. However, different objective function scores and boundary lengths were generated for each target class. The largest boundary length was generated when the BLM was set to 0.0 for all three conservation classes.

Table 5.15 Simulated Annealing Algorithm –Existing Protected Areas in which Crown lands are included in the selection process

		Run Number	Objective Function Score	Cost (Planning Unit)	Boundary Length (m)
Conservation Target 15%					
Boundary Length Modifier	0.0	1	2.51E+21	808	111,200
	0.5	13	9.04E+23	820	96,800
	1.0	51	1.81E+24	820	94,400
Conservation Target 25%					
Boundary Length Modifier	0.0	6	3.24E+21	893	175,200
	0.5	11	1.17E+24	900	139,200
	1.0	9	2.33E+24	900	131,200
Conservation Target Proportional					
Boundary Length Modifier	0.0	1	1.99E+21	786	107,200
	0.5	1	7.15E+23	802	94,400
	1.0	1	1.43E+24	802	94,400

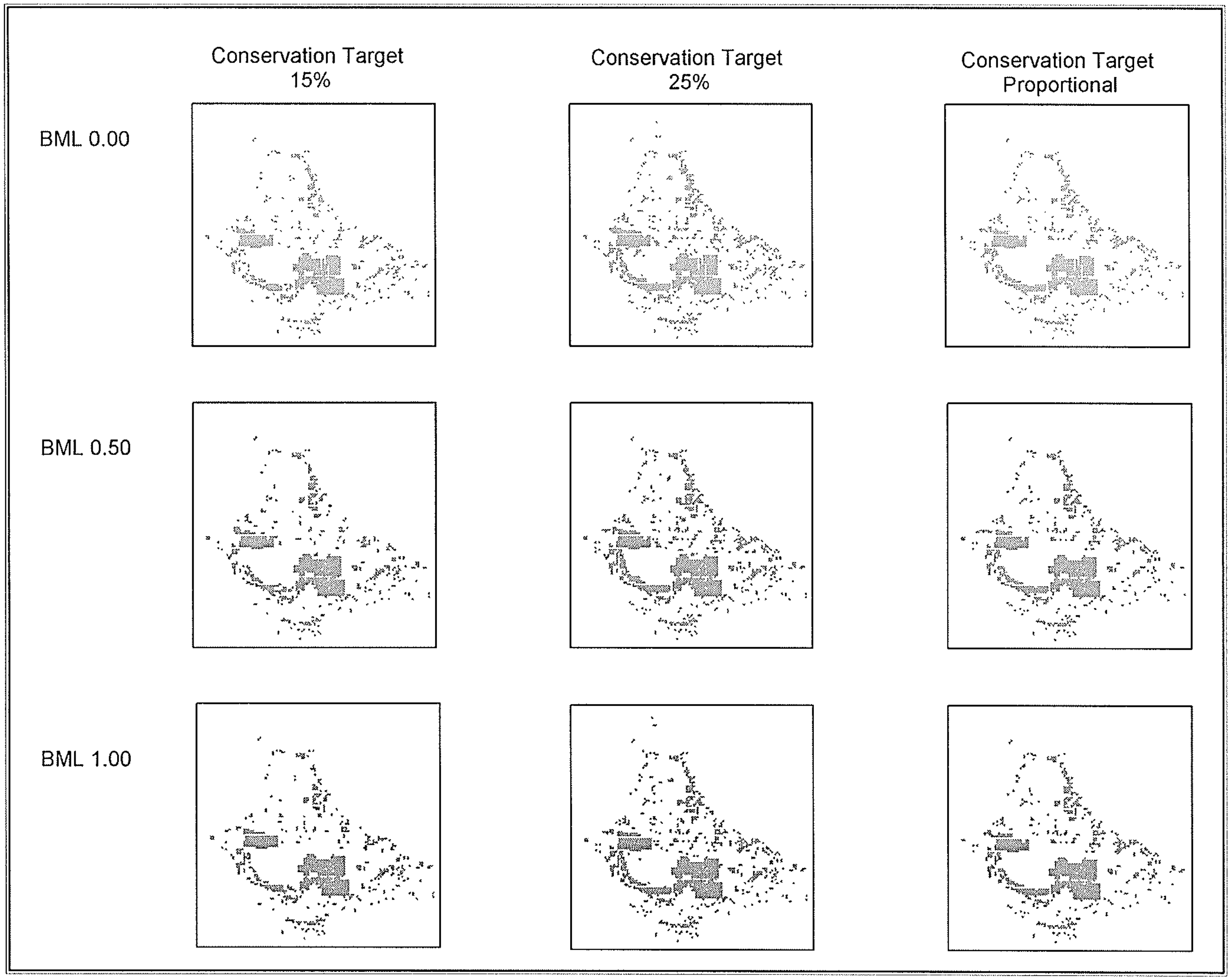


Figure 5.14 Simulated Annealing Algorithm –Existing Protected Areas in which Crown lands are included in the selection process

No Existing Protected Areas

A summary of the top scores for the *no existing protected areas* conservation scenario generated by the simulated annealing algorithm is displayed in Table 5.17 and Figure 5.15. This table shows the results that were produced for all three sets of conservation targets and BLM in which the selection algorithm had the freedom to select candidate sites from both crown lands and privately owned lands. For all three conservation target classes the lowest objective function scores were generated for the BLM of 0.0, however only the 15% conservation class had the smallest boundary. For the 25% and proportional classes, the BLM of 0.0 generated much larger boundary lengths.

Table 5.16 Simulated Annealing Algorithm –No Existing Protected Areas in which all lands are included in the selection process

		Run Number	Objective Function Score	Cost (Planning Unit)	Boundary Length (m)
Conservation Target 15%					
Boundary Length Modifier	0.0	14	1,203	983	53,600
	0.5	42	92,493	1,065	57,600
	1.0	92	122,233	1,140	57,600
Conservation Target 25%					
Boundary Length Modifier	0.0	2	2,102	1,493	108,000
	0.5	42	92,493	1,065	57,600
	1.0	22	304,683	1,621	71,200
Conservation Target Proportional					
Boundary Length Modifier	0.0	31	1,219	830	1,141,600
	0.5	59	96,336	1,236	51,200
	1.0	31	213,816	1,343	73,600

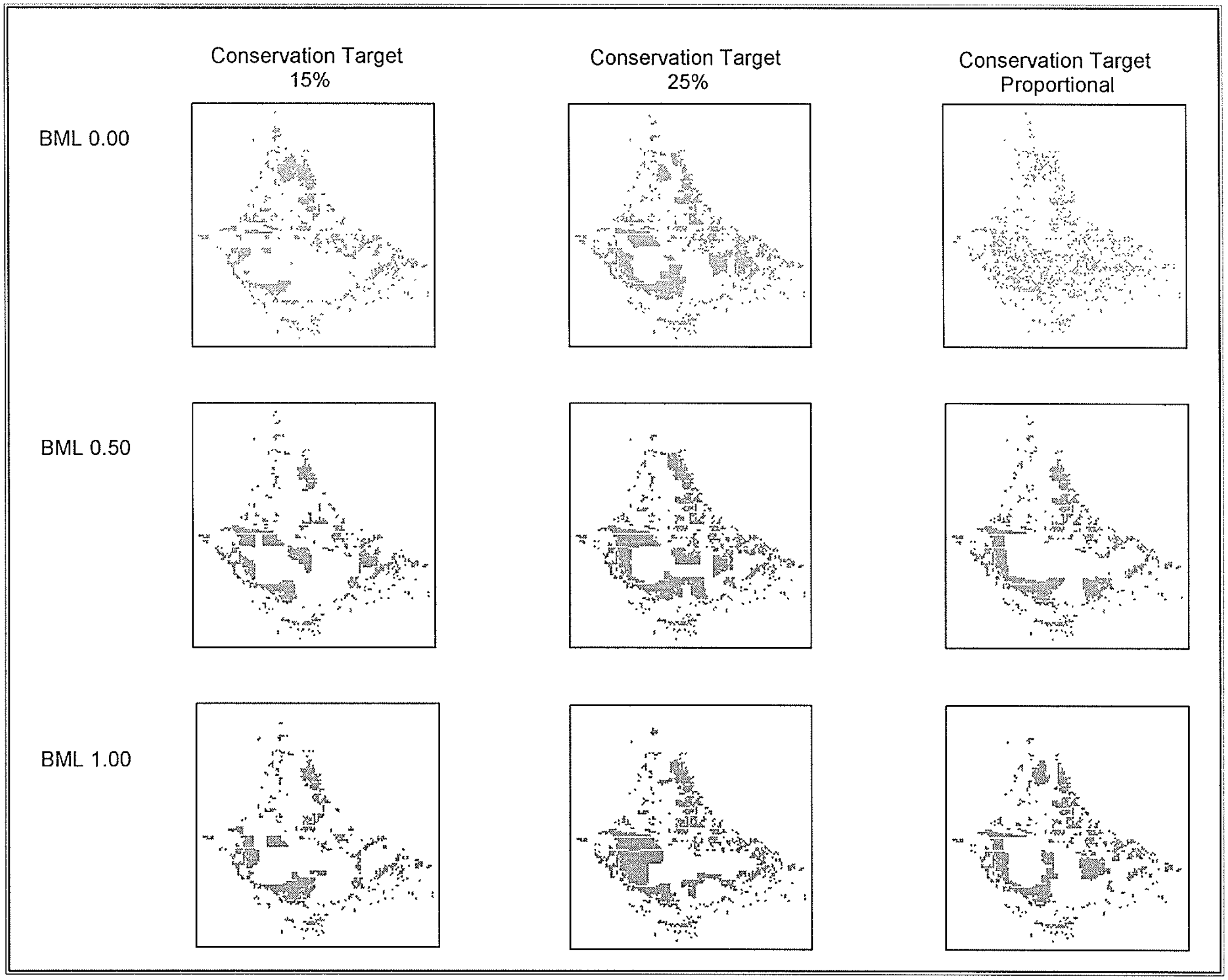


Figure 5.15 Simulated Annealing Algorithm –No Existing Protected Areas in which all lands are included in the selection process

Table 5.18 and Figure 5.16 display the top results for the simulated annealing algorithm, which was applied to the no existing protected areas conservation scenario. This is summarized for all three conservation targets and BLM where the algorithm's search radius was confined to select areas on crown lands. The lowest boundary lengths were generated by the BLM of 0.5 for all three conservation target classes. However, for the 15% and the proportional conservation target classes a BLM of 0.5 resulted in high objective function scores, indicating that the algorithm had a difficult time generating this solution set.

Table 5.17 Simulated Annealing Algorithm –No Existing Protected Areas in which Crown lands are included in the selection process

		Run Number	Objective Function Score	Cost (Planning Unit)	Boundary Length (m)
Conservation Target 15%					
Boundary Length Modifier	0.0	38	2.51E+21	894	181,600
	0.5	8	9.04E+23	902	134,400
	1.0	6	1.81E+24	903	147,200
Conservation Target 25%					
Boundary Length Modifier	0.0	1	3.24E+21	1,086	177,600
	0.5	1	1.17E+24	1,086	124,800
	1.0	1	2.33E+24	1,086	127,200
Conservation Target Proportional					
Boundary Length Modifier	0.0	56	1.99E+21	900	122,400
	0.5	25	7.15E+23	909	97,600
	1.0	22	1.43E+24	908	98,400

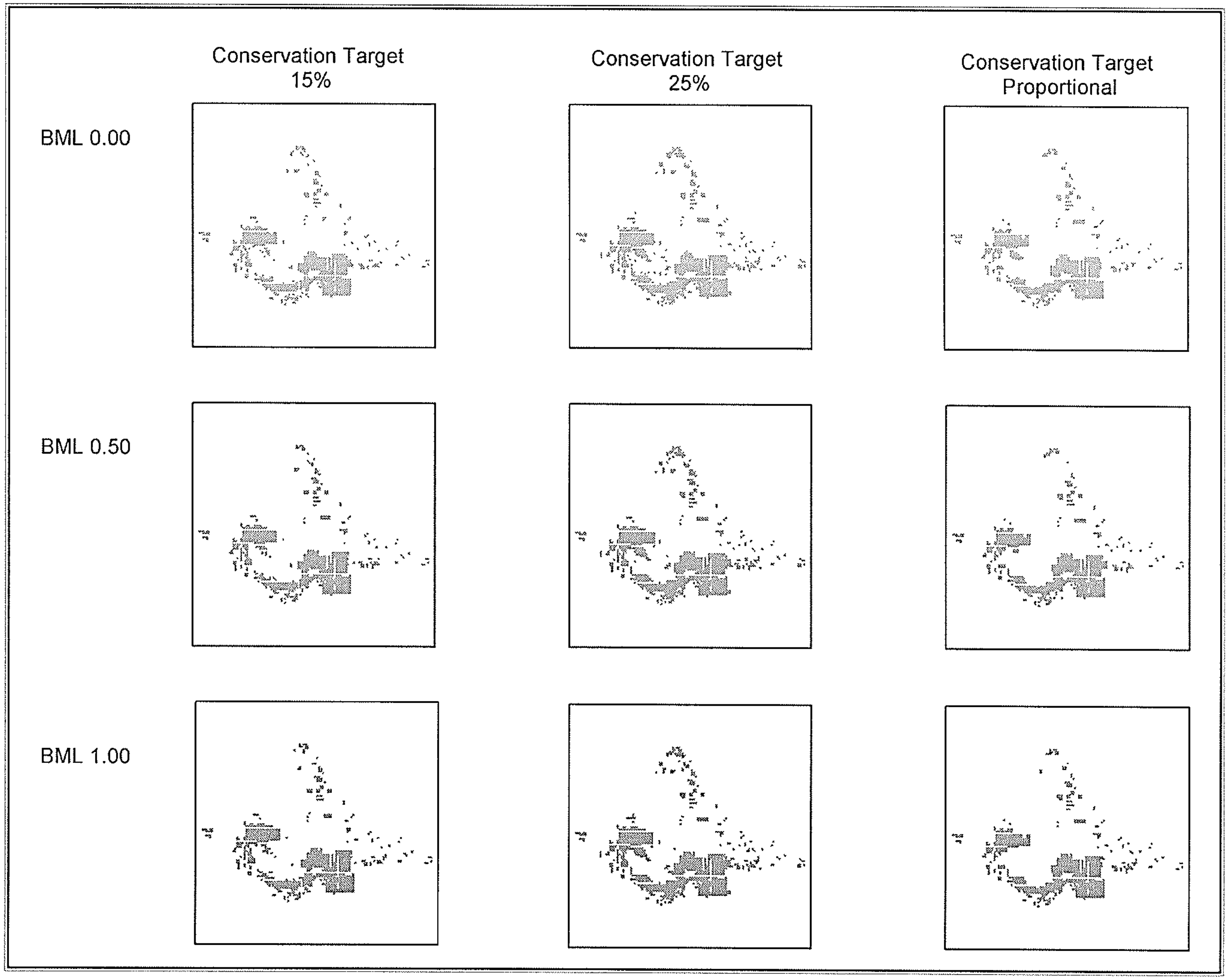


Figure 5.16 Simulated Annealing Algorithm –No Existing Protected Areas in which Crown lands are included in the selection process

5.2.2 Objective Two Summary

Both selection algorithms were capable of generating acceptable selection sets. The same objective function scores were generated when the two algorithms had their search radius confined to crown lands. The reason for this was that the selection of planning units available within crown lands was limited. Overall, the simulated annealing had an easier time generating solution sets, even when there was an increase emphasis placed on the boundary length modifier. However, the boundary length modifier did exert an influence on the two algorithms, which varied between the two conservation scenarios. For the *existing protected areas* conservation scenario, the two algorithms had an easier time with the selection of sites when there was an increase in the boundary length modifier. As for the *no existing protected areas*, when there was no emphasis placed on the spatial constraints (BLM 0.0) the two algorithms had an easier time selecting candidate sites.

5.3 Objective Three

The third objective of this thesis was to evaluate the results produced by the greedy heuristic algorithm and simulated annealing algorithm. In order to fulfill this objective, the results were evaluated by examining the following: (1) spatial and descriptive statistics (2) the level of representation that was achieved for each selection set (3) and the efficiency of each set of selected candidate sites. The following section will review the results produced by the greedy heuristic and the simulated annealing algorithms.

5.3.2 Spatial and Descriptive Statistics

In order to evaluate and compare the selection results, a series of spatial and descriptive statistics were generated in a GIS environment. Specifically, statistics were generated which summarize the total area of each selection generated, the number of candidate areas that were selected, their mean size, the total edge, edge density, and the average weighted mean shape index.

Existing Protected Areas

A summary of the top results for the *existing protected areas* conservation scenario generated by the greedy heuristic algorithm and the simulated annealing algorithm are displayed in Table 5.19. This is displayed for all three sets of conservation targets and BLM in which the selection algorithms had the freedom to select candidate sites from both crown lands and privately owned lands. The amount of land selected by the two algorithms varied according to the conservation targets. For the 15% and proportional conservation targets, the simulated annealing algorithm had a tendency to select larger amounts of land. As for the 25% conservation target, the greedy heuristic

Table 5. 18 - Existing Protected Areas Conservation Scenario - Summary Statistics for both Greedy Heuristic and Simulated Annealing Algorithms which all lands were included in the selection process

Boundary Length Modifier	Total Area Selected (ha)		Number of Candidate Sites Selected		Mean Size of Candidate Sites (ha)		Total Edge (m)		Edge Density (m/ha)	
	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing
Conservation Target 15%										
0.0	66,304	66,240	294	282	225.52	234.89	1,651,200	1,604,800	24.90	24.23
0.5	66,304	69,888	294	264	225.52	264.73	1,651,200	1,620,800	24.90	23.19
1.0	69,568	69,760	305	276	228.09	252.75	1,716,800	1,649,600	24.68	23.65
Conservation Target 25%										
0.0	83,968	83,840	351	357	239.23	234.85	2,086,400	2,099,200	24.85	25.04
0.5	86,656	86,400	357	349	242.73	247.56	2,115,200	2,112,000	24.41	24.44
1.0	86,656	73,664	362	281	239.38	262.15	2,136,000	1,748,800	24.65	23.74
Conservation Target Proportional										
0.0	73,664	86,464	281	361	262.15	239.51	1,748,800	2,134,400	23.74	24.69
0.5	77,312	77,376	292	290	264.77	266.81	1,817,600	1,816,000	23.51	23.47
1.0	77,248	77,184	291	284	265.46	271.77	1,812,800	1,800,000	23.47	23.32

algorithm selected a greater amount of land. On average, the greedy heuristic selected a greater number of candidate sites, which had a larger mean size, total edge, and edge density. For the simulated annealing algorithm, as the BLM increased from 0.0 to 1.0, there was an increase in the total area, and mean site size for the 15% and the 25% conservation targets, but an overall decrease in the number of candidate sites selected, total edge, and edge density. The greedy heuristic algorithm selected a greater number of candidate sites whose mean size and total edge increased as the BLM increased from 0.0 to 1.0.

The top solutions generated by the greedy heuristic algorithm and the simulated annealing algorithm for the *existing protected areas* conservation scenario are summarized in Table 5.20. When the algorithms were limited to selecting sites on crown lands, in most instances the greedy heuristic algorithm selected greater amounts of land. However, with regards to the actual number of candidate sites selected, the simulated annealing algorithm had a tendency to select a greater number of sites. This algorithm on average also had an overall larger boundary length and edge density. The BLM of 0.5 and 1.0 did not influence the amount of area that the simulated annealing algorithm selected for all three conservation targets. As for the greedy heuristic algorithm, there was no change in the amount of land that was selected for BLM of 0.0 or 0.5 for the 25% and proportional conservation targets. For both algorithms, as the BLM increased from 0.0 to 1.0 there was an increase in the number of candidate sites selected, total edge, and edge.

Table 5. 19 - Existing Protected Areas Conservation Scenario - Summary Statistics for both Greedy Heuristic and Simulated Annealing Algorithms which crown lands were included in the selection process

Boundary Length Modifier	Total Area Selected (ha)		Number of Candidate Sites Selected		Mean Size of Candidate Sites (ha)		Total Edge (m)		Edge Density (m/ha)	
	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing
Conservation Target 15%										
0.0	51,776	51,712	122	129	424.39	400.87	998,400	1,012,800	19.28	19.59
0.5	52,544	52,480	130	131	404.18	400.61	1,027,200	1,033,600	19.55	19.70
1.0	52,544	52,480	130	132	404.18	397.58	1,027,200	1,033,600	19.55	19.70
Conservation Target 25%										
0.0	57,920	57,152	149	162	388.72	352.79	1,156,800	1,185,600	19.97	20.74
0.5	57,920	57,600	152	152	381.05	378.95	1,168,000	1,174,400	20.17	20.39
1.0	50,304	57,600	119	148	422.72	389.19	964,800	1,164,800	19.18	20.22
Conservation Target Proportional										
0.0	51,328	50,304	127	119	404.16	422.72	998,400	964,800	19.45	19.18
0.5	51,328	51,328	127	127	404.16	404.16	998,400	998,400	19.45	19.45
1.0	57,344	51,328	143	127	401.01	404.16	1,132,800	998,400	19.75	19.45

density for the 15% and proportional conservation targets. As for the 25% conservation target, the reverse occurred

No Existing Protected Areas

A summary of the top scores for the *no existing protected areas* conservation scenario are displayed in Table 5.21 for both the greedy heuristic algorithm and the simulated annealing algorithm. This table displays the results that were produced for all three sets of conservation targets and BLM in which the selection algorithm had the freedom to select candidate sites from both crown lands and privately owned lands. The simulated annealing algorithm consistently selected a larger amount of area for all three conservation targets. The greedy heuristic algorithm selected a greater number of candidate sites, but on average they were smaller in size compared to the candidate sites selected by the simulated annealing algorithm. On average, the greedy heuristic algorithm also had a larger overall boundary and edge density. For all three conservation targets, as the BLM increased, so did the total area and mean size of the candidate sites selected by the simulated annealing algorithm. There was also a decrease in the actual number of sites selected and the edge density. As for the greedy heuristic algorithm, there was an increase in the total area selected for all three conservation targets as the BLM increased. However, this algorithm reacted differently when it came to the other descriptive parameters. For the 15% ad 25% conservation target, the BLM of 0.5 selected a much

Table 5. 20 - No Existing Protected Areas Conservation Scenario - Summary Statistics for both Greedy Heuristic and Simulated Annealing Algorithms which all lands were included in the selection process

Boundary Length Modifier	Total Area Selected (ha)		Number of Candidate Sites Selected		Mean Size of Candidate Sites (ha)		Total Edge (m)		Edge Density (m/ha)	
	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing
Conservation Target 15%										
0.0	56,320	62,912	388	324	145.15	194.17	1,900,800	1,843,200	33.75	29.30
0.5	62,656	68,160	444	295	141.12	231.05	2,163,200	1,854,400	34.53	27.21
1.0	56,832	72,960	390	284	145.72	256.90	1,921,600	1,883,200	33.81	25.81
Conservation Target 25%										
0.0	89,984	95,552	462	409	194.77	233.62	2,638,400	2,545,600	29.32	26.64
0.5	90,240	104,832	468	383	192.82	273.71	2,630,400	2,569,600	29.15	24.51
1.0	90,176	103,744	463	378	194.76	274.46	2,612,800	2,550,400	28.97	24.58
Conservation Target Proportional										
0.0	42,240	53,120	443	552	95.35	96.23	1,761,600	2,220,000	41.70	24.42
0.5	56,896	79,104	357	328	159.37	241.71	1,838,400	2,179,200	32.31	26.65
1.0	57,216	185,104	360	317	158.93	271.14	1,835,200	2,108,800	32.07	25.35

larger number of candidate sites who's mean size was smaller that the rest. This resulted in a much larger total edge for the 15% conservation target but not for the 25% conservation target.

Table 5.22 displays the top results for the greedy heuristic algorithm and the simulated annealing algorithm for the *no protected areas* conservation scenario. This is summarized for all three conservation targets and BLM where the selection algorithm was confined to select areas on crown lands. On average, the greedy heuristic algorithm selected a larger amount of land, with the exception of the 25% conservation target where both algorithms selected the exact same amount of area. For the15% and 25% conservation targets, the annealing selected a greater number of candidate sites, however, their average size was smaller. In addition they had longer total boundaries and edge densities. This was reversed for the proportional conservation target class. As the BLM increased, the number of sites selected by the annealing algorithm had a tendency to decrease. However, their mean size increased as the BLM increased for both the 15% and 25% conservation targets. The number of candidate sites selected by the greedy heuristic algorithm increased for all three conservation targets. However, their mean size and edge density decreased as the BLM increased.

Table 5. 21 - No Existing Protected Areas Conservation Scenario - Summary Statistics for both Greedy Heuristic and Simulated Annealing Algorithms which crown lands were included in the selection process

Boundary Length Modifier	Total Area Selected (ha)		Number of Candidate Sites Selected		Mean Size of Candidate Sites (ha)		Total Edge (m)		Edge Density (m/ha)	
	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing	Greedy	Annealing
Conservation Target 15%										
0.0	57,472	57,216	145	160	396.36	357.60	1,140,800	1,174,400	19.85	20.53
0.5	58,048	57,728	149	156	389.58	370.05	1,155,200	1,179,200	19.90	20.43
1.0	58,048	57,792	150	155	386.99	372.85	1,156,800	1,185,600	19.93	20.51
Conservation Target 25%										
0.0	69,504	69,504	179	187	388.29	371.68	1,417,600	1,435,200	20.40	20.65
0.5	69,504	69,504	177	179	392.68	388.29	1,409,600	1,411,200	20.28	20.30
1.0	69,504	69,504	178	178	390.47	390.47	1,414,400	1,419,200	20.35	20.42
Conservation Target Proportional										
0.0	57,216	57,600	162	137	353.19	420.44	1,184,000	1,115,200	20.69	19.36
0.5	58,560	58,176	148	143	395.68	406.83	1,155,200	1,137,600	19.73	19.55
1.0	58,560	58,112	148	143	395.68	406.38	1,156,800	1,145,600	19.75	19.71

5.3.2 Representation

A gap analysis was applied to the top results of the two selection algorithms in order to evaluate the extent to which conservation targets were achieved within the designated candidate lands. The results of the gap analysis that was applied to the *existing protected areas* conservation scenario in which both crown lands and private are lands are summarized in Table 5.23, and Figures 5.17, 5.18, 5.19 and 5.20. Table 5.23 lists the hectares of land that were selected. Figure 5.17 graphs the level of representation achieved for each conservation target group, while Figures 5.18, 5.19 and 5.20 map out the levels of representation for each conservation target class. For all three conservation scenarios, deep basin / black chernozem, deep basin / regosols, glaciofluvial deposits / regosol, glacial till derived from palaeozoic rock / regosol / moraine and glacial till derived from mesozoic rock / regosol were classified as not captured. The enduring landscape features beach and nearshore deposits / black chernozem, glaciofluvial deposits / black chernozem and glacial till derived from palaeozoic rock / black chernozem were partially captured for all three conservation targets, along with beach and nearshore deposits / regosols for the 25% conservation target. Only the 15% and 25% conservation targets moderately captured alluvial deposits / black chernozem. Enduring landscape feature beach and nearshore deposits / black chernozem was moderately captured under the 15% conservation target. However, no enduring landscape features were moderately captured under the proportional conservation target. All three conservation target classes adequately captured deltaic deposits / black chernozem. Each conservation target

Table 5.22 – Existing Protected Areas: Assessment of Representation

Enduring Landscape Feature	Existing Protected Areas All Lands Conservation Targets (ha)			Existing Protected Areas Crown Lands Conservation Targets (ha)		
	15%	25%	Proportional	15%	25%	Proportional
AD/C	5,120	5,120	4,096	1,088	1,088	1,088
AD/R	11,328	11,456	10,880	9,856	10,048	9,856
BN/C	2,432	2,432	1,344	0.0	0.0	0.0
BN/R	320	320	320	0.0	0.0	0.0
DB/C	128	128	128	0.0	0.0	0.0
DB/R	0.0	0.0	0.0	0.0	0.0	0.0
DD/C	15,552	26,496	26,496	10,176	10,176	10,176
DD/C/S	2,368	4,608	1,280	2,368	3,520	1,216
DD/R	8,320	11,776	8,896	7,936	11,776	7,936
DD/R/S	18,944	19,200	19,072	17,728	17,920	17,664
GD/C	320	320	320	0.0	0.0	0.0
GD/R	0.0	0.0	0.0	0.0	0.0	0.0
OD/C	1,024	1,216	1,024	320	320	320
OD/R	3,072	3,136	3,072	3,072	3,072	3,072
T1/C	384	384	384	0.0	0.0	0.0
T1/R/M	64	64	64	0.0	0.0	0.0
T2/R	0.0	0.0	0.0	0.0	0.0	0.0

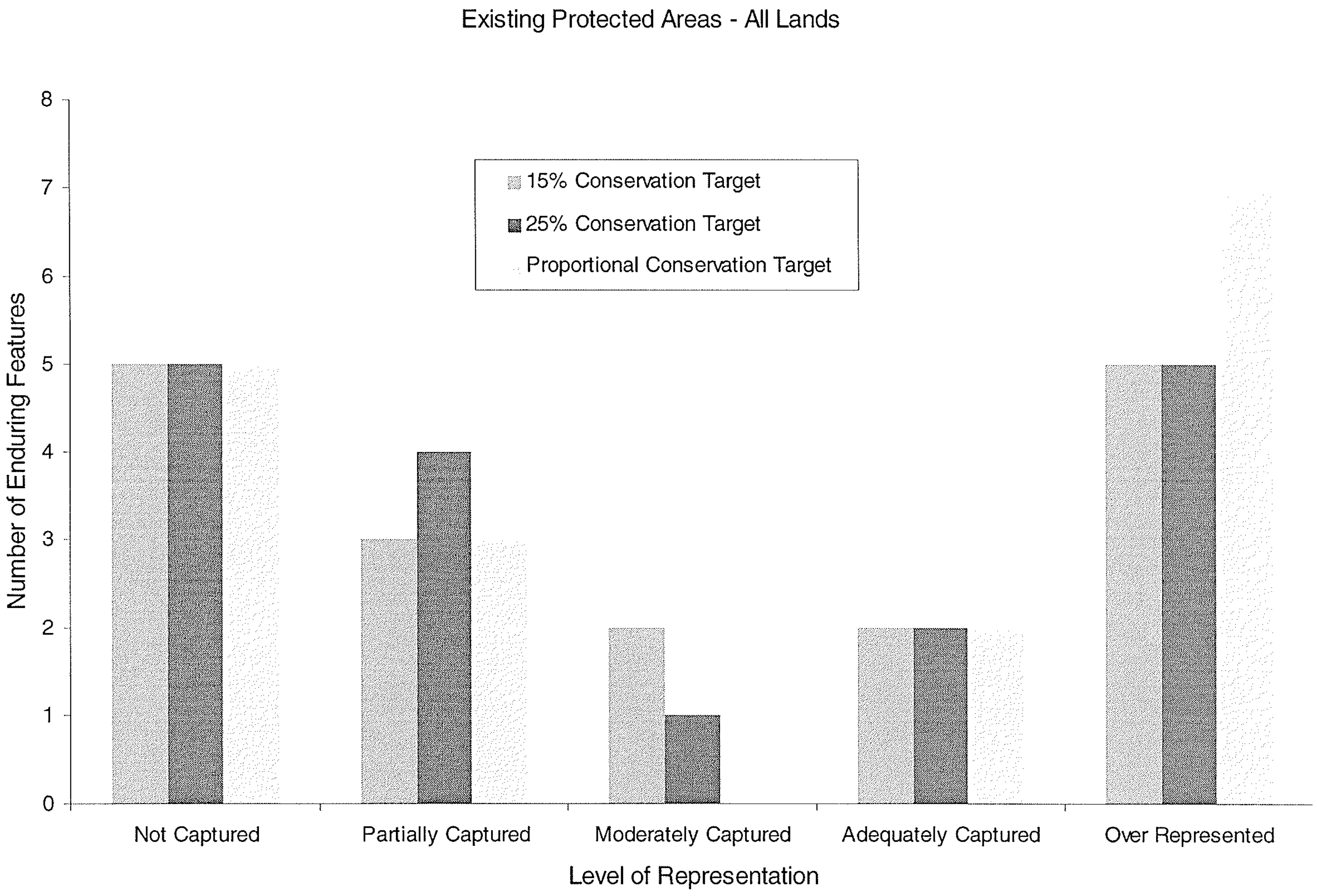


Figure 5.17 Existing Protected Areas - The Level of Representation Achieved for Crown and Private Lands

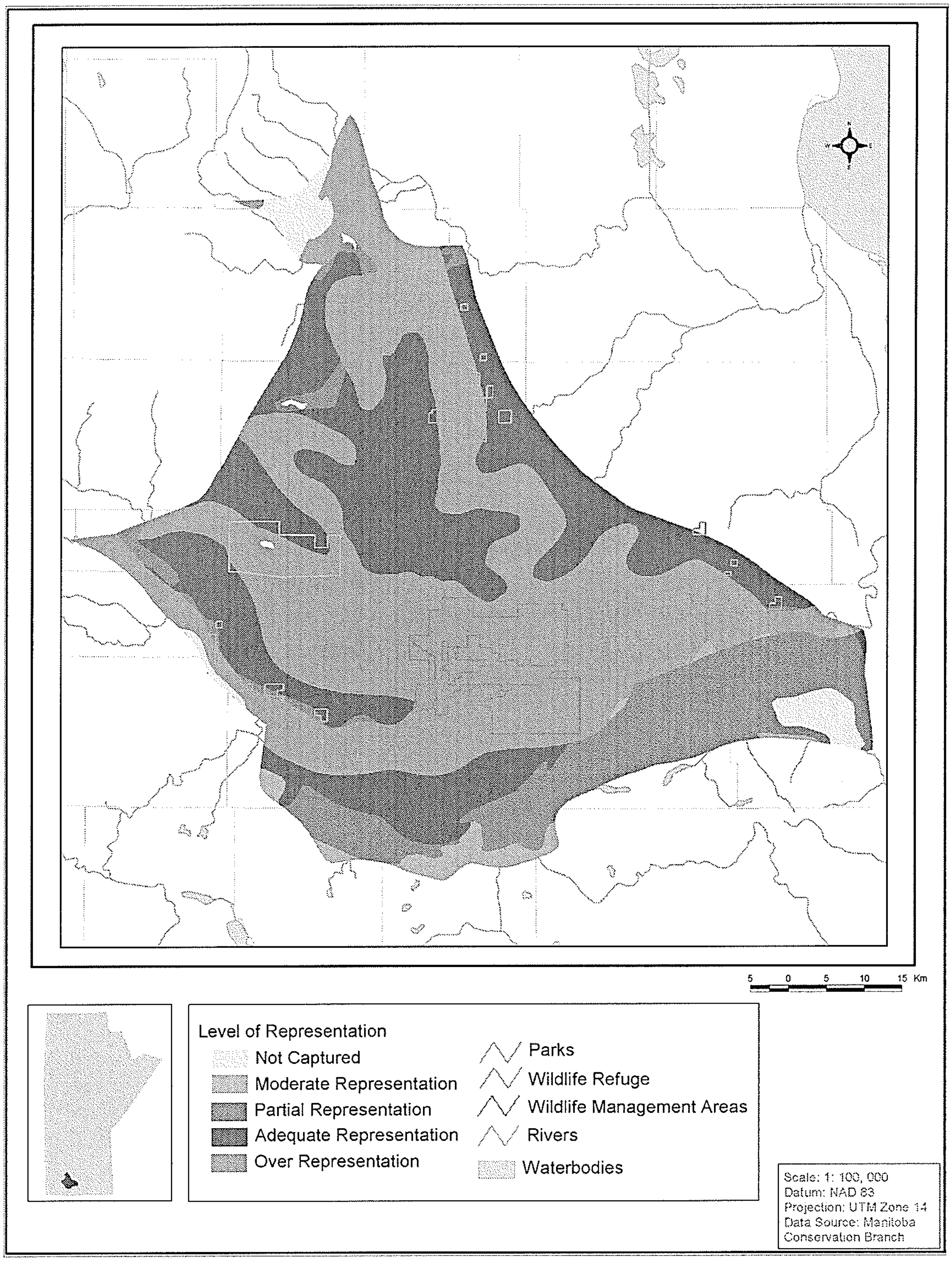


Figure 5.18 Existing Protected Area Conservation Scenario: The Level of Representation achieved for the 15% Conservation Target Class, Crown Lands and Private Lands

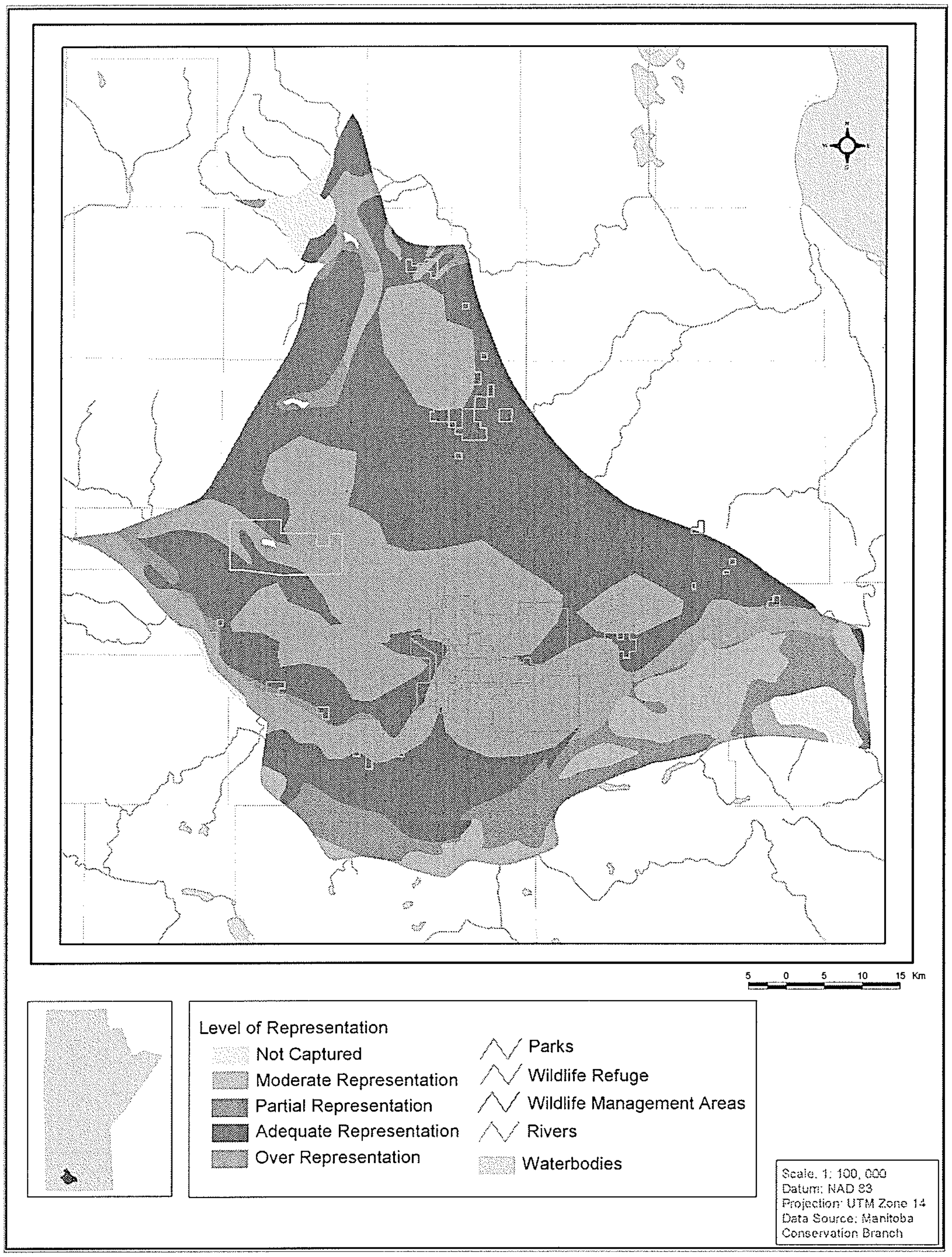


Figure 5.19 Existing Protected Area Conservation Scenario: The Level of Representation achieved for the 25% Conservation Target Class, Crown Lands and Private Lands

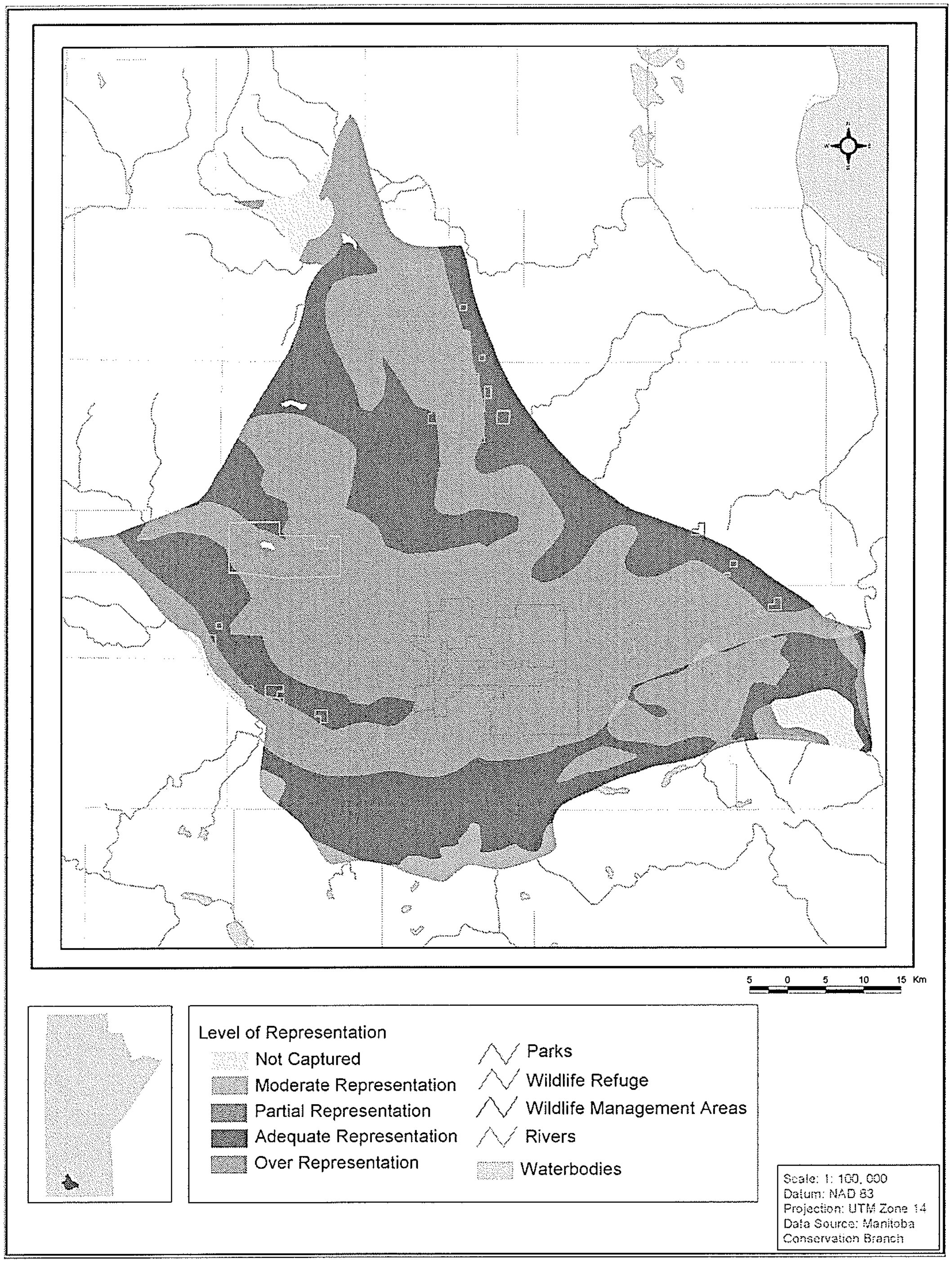


Figure 5.20 Existing Protected Area Conservation Scenario: The Level of Representation achieved for the Proportional Conservation Target Class, Crown Lands and Private Lands

managed to adequately represent two enduring landscape features. Enduring landscape features alluvial deposits / regosols, deltaic deposits / regosol / sand dunes, organic deposits / black chernozem and organic deposits / regosol were over represented in all three conservation target categories. The conservation goal for deltaic deposits / regosol / sand dunes was over represented for the 15% conservation target class, as was deltaic deposits / black chernozem / sand dunes for the 25% conservation class. The proportional conservation target class had the most conservation targets over represented with both deep basin / black chernozem and deltaic deposits / regosol making this a total of seven over represented enduring landscape features.

The results of the gap analysis that was conducted for the *existing protected areas* conservation scenario in which the algorithms were restricted in the site selection to crown lands is summarized in Table 5.23 which identifies the amount of land that was selected for each conservation feature and Figures 5.21, 5.22, 5.23 and 5.24 display the level of representation achieved for each conservation feature. A total of ten enduring landscape features for the 15% and 25% conservation target classes were not captured. Not only did the proportional conservation target class fail to both moderately and adequately represent any enduring landscape features, alluvial deposits / black chernozem, deltaic deposits / black chernozem and organic deposits / black chernozem were classified as partially represented and it had the largest number of over represented features. As for the 15% and 25% conservation target classes, ten conservation features were not captured, and only one was moderately captured and adequately captured. For

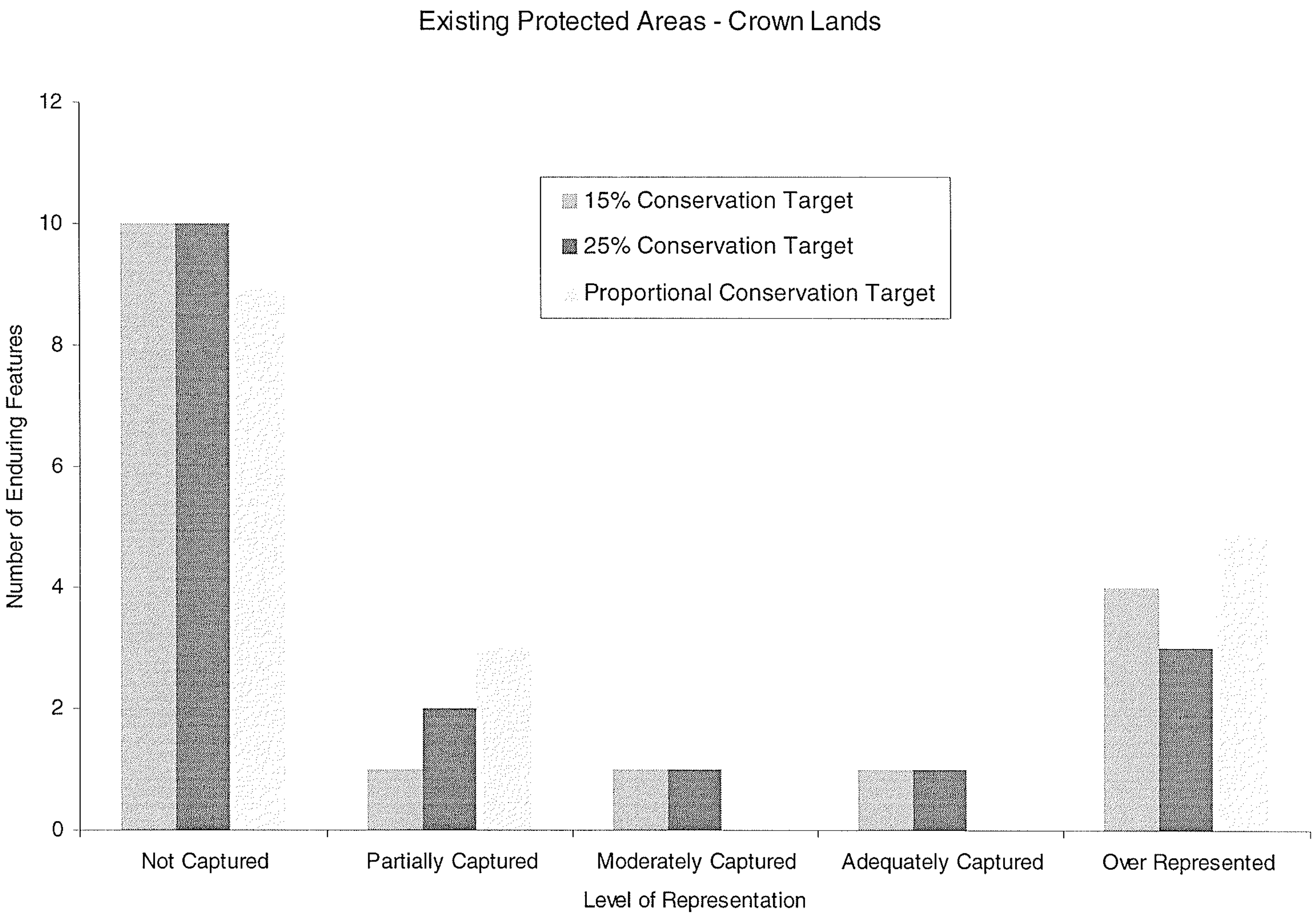


Figure 5.21 Existing Protected Areas - The Level of Representation Achieved for Crown

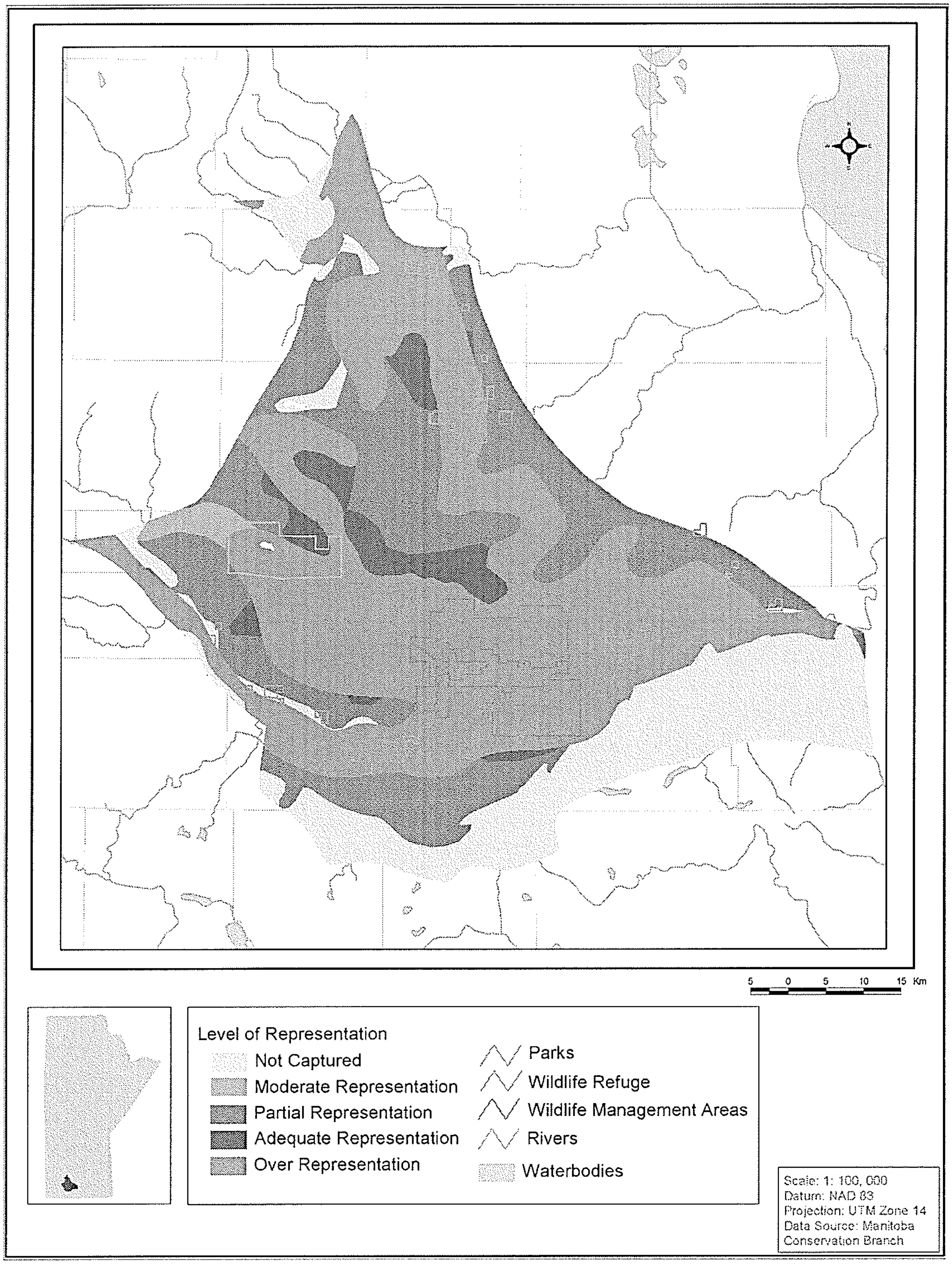


Figure 5.22 Existing Protected Area Conservation Scenario: The Level of Representation achieved for the 15% Conservation Target Class, Crown Lands

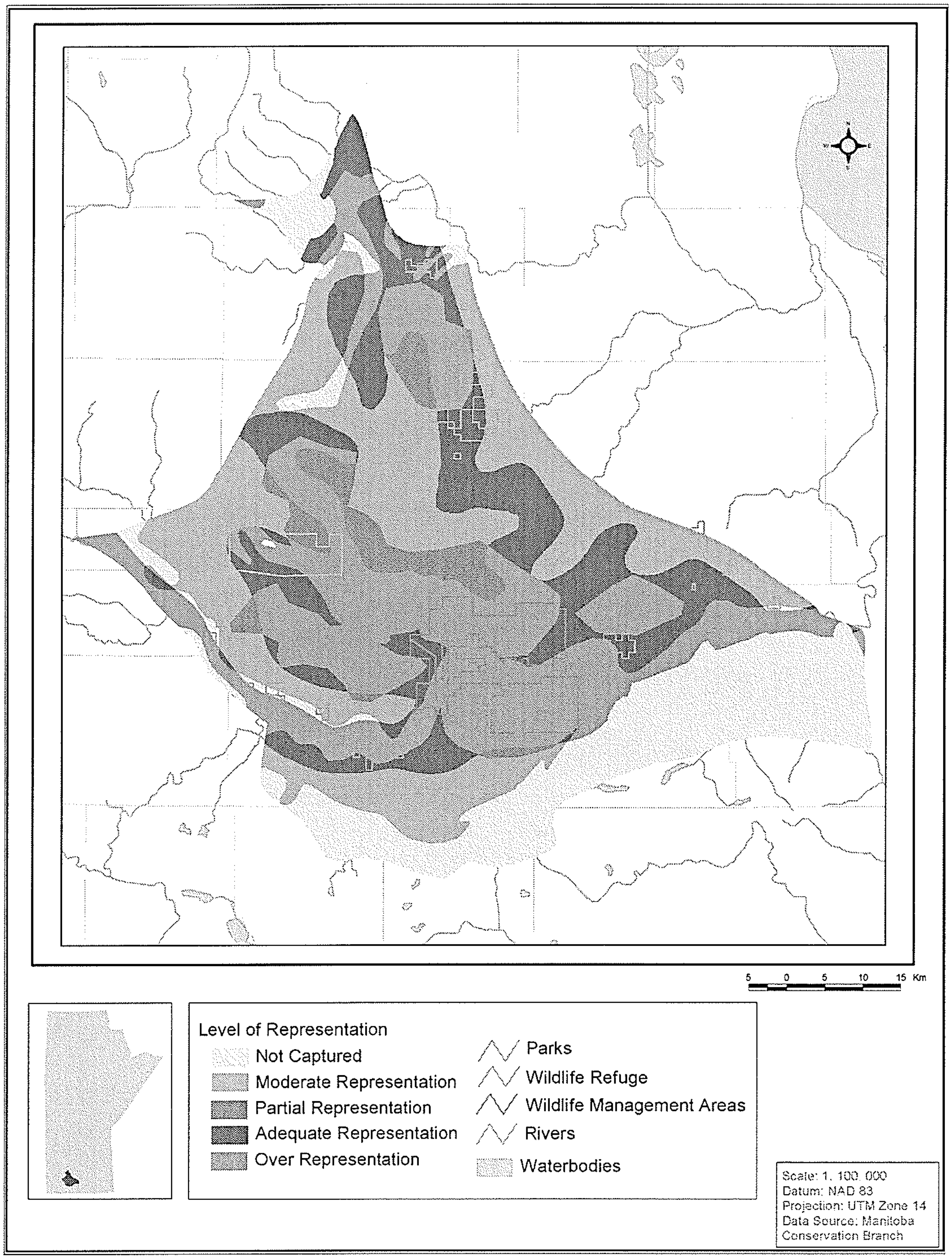


Figure 5.23 Existing Protected Area Conservation Scenario: The Level of Representation achieved for the 25% Conservation Target Class, Crown Lands

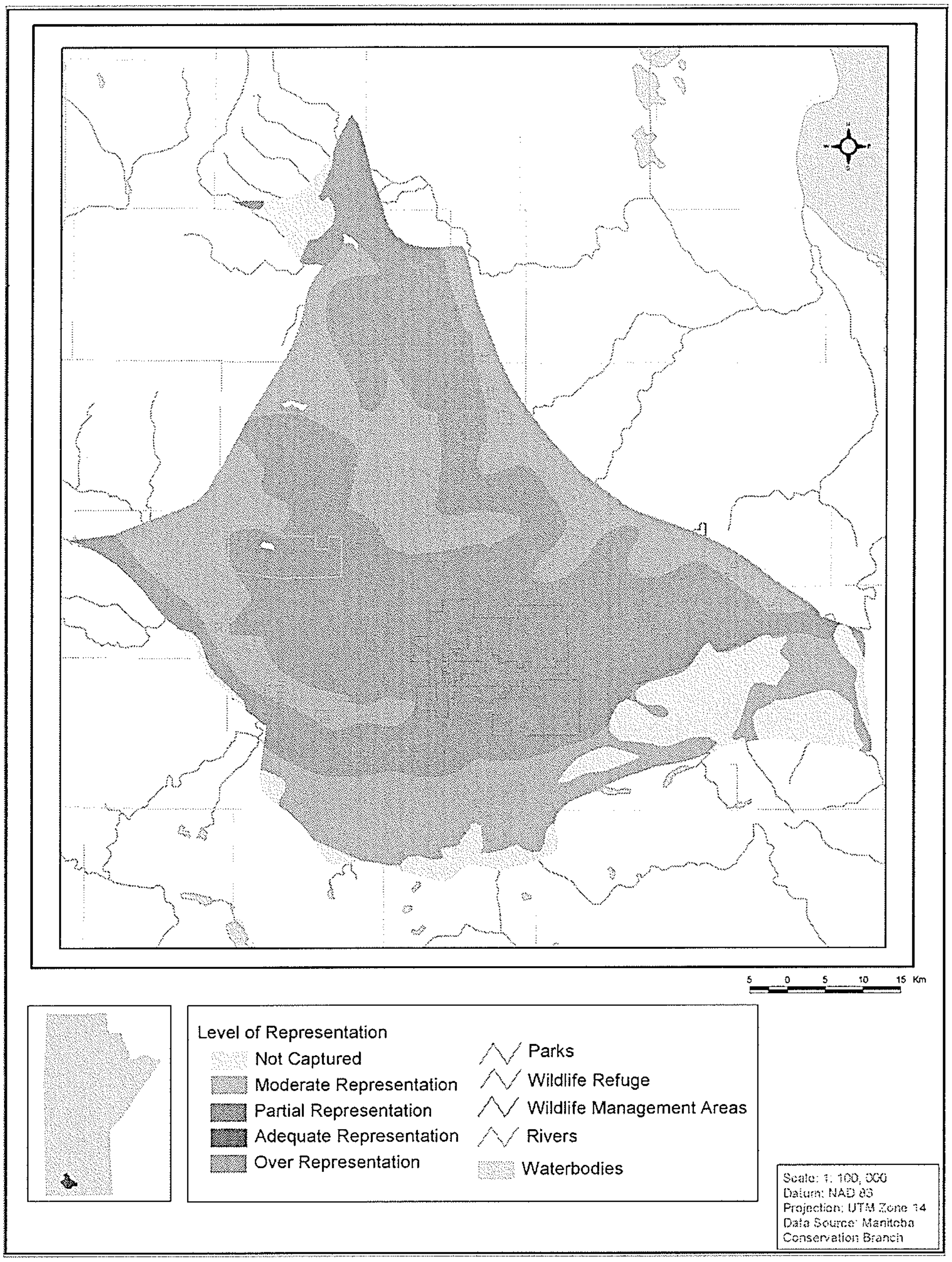


Figure 5.24 Existing Protected Area Conservation Scenario: The Level of Representation achieved for the Proportional Conservation Target Class, Crown Lands

the 15% conservation target, deltaic deposits / black chernozem was moderately captured and deltaic deposits / black chernozem / sand dunes was adequately represented. Deltaic deposits / black chernozem / sand dunes was moderately captured and deltaic deposits / regosol was adequately captured for the 25% conservation target.

Table 5.24 and Figure 5.25 summarize the gap analysis results for the *no existing protected areas* conservation scenario in which the algorithms selected sites from both crown and private lands. For all three conservation target classes, the level of representation is displayed in Figures 5.26, 5.27, and 5.28. Enduring landscape features deep basin / black chernozem, deep basin / regosols, glaciofluvial deposits / regosol, glacial till derived from palaeozoic rock / regosol / moraine and glacial till derived from mesozoic rock / regosol were classified as not captured for all three conservation target classes. The enduring landscape features consisting of beach and nearshore deposits / black chernozem, glaciofluvial deposits / black chernozem and glacial till derived from palaeozoic rock / black chernozem were partially captured for all three conservation targets, along with beach and nearshore deposits / regosols for the 25% conservation target. The 15% conservation target class moderately captured two enduring landscape features alluvial deposits / black chernozem and beach and nearshore deposits / black chernozem, where as the 25% and proportional classes only captured one each, alluvial deposits / black chernozem and deltaic deposits / black chernozem respectively. Only one enduring landscape feature, deltaic deposits / black chernozem was adequately captured by the 25% conservation target class. The 15% and the proportional target

Table 5.23 – No Existing Protected Areas Assessment of Representation

Enduring Landscape Feature	No Existing Protected Areas All Lands Conservation Targets (ha)			No Existing Protected Areas Crown Lands Conservation Targets (ha)		
	15%	25%	Proportional	15%	25%	Proportional
AD/C	5,120	5,120	4,352	1,088	1,088	1,088
AD/R	10,752	12,800	11,840	10,048	12,160	10,112
BN/C	2,432	2,432	1,344	0.0	0.0	0.0
BN/R	320	320	320	0.0	0.0	0.0
DB/C	128	128	128	0.0	0.0	0.0
DB/R	0.0	0.0	0.0	0.0	0.0	0.0
DD/C	17,728	26,496	26,496	10,176	10,176	10,176
DD/C/S	3,328	5,568	2,624	3,328	3,520	1,408
DD/R	12,096	25,664	14,528	12,096	19,584	14,464
DD/R/S	12,736	41,984	13,696	17,920	19,584	17,920
GD/C	320	320	320	0.0	0.0	0.0
GD/R	0.0	0.0	0.0	0.0	0.0	0.0
OD/C	1,216	1,792	1,792	320	320	320
OD/R	1,536	6,208	1,280	3,072	3,072	3,072
T1/C	384	384	384	0.0	0.0	0.0
T1/R/M	64	0.0	0.0	0.0	0.0	0.0
T2/R	0.0	0.0	0.0	0.0	0.0	0.0

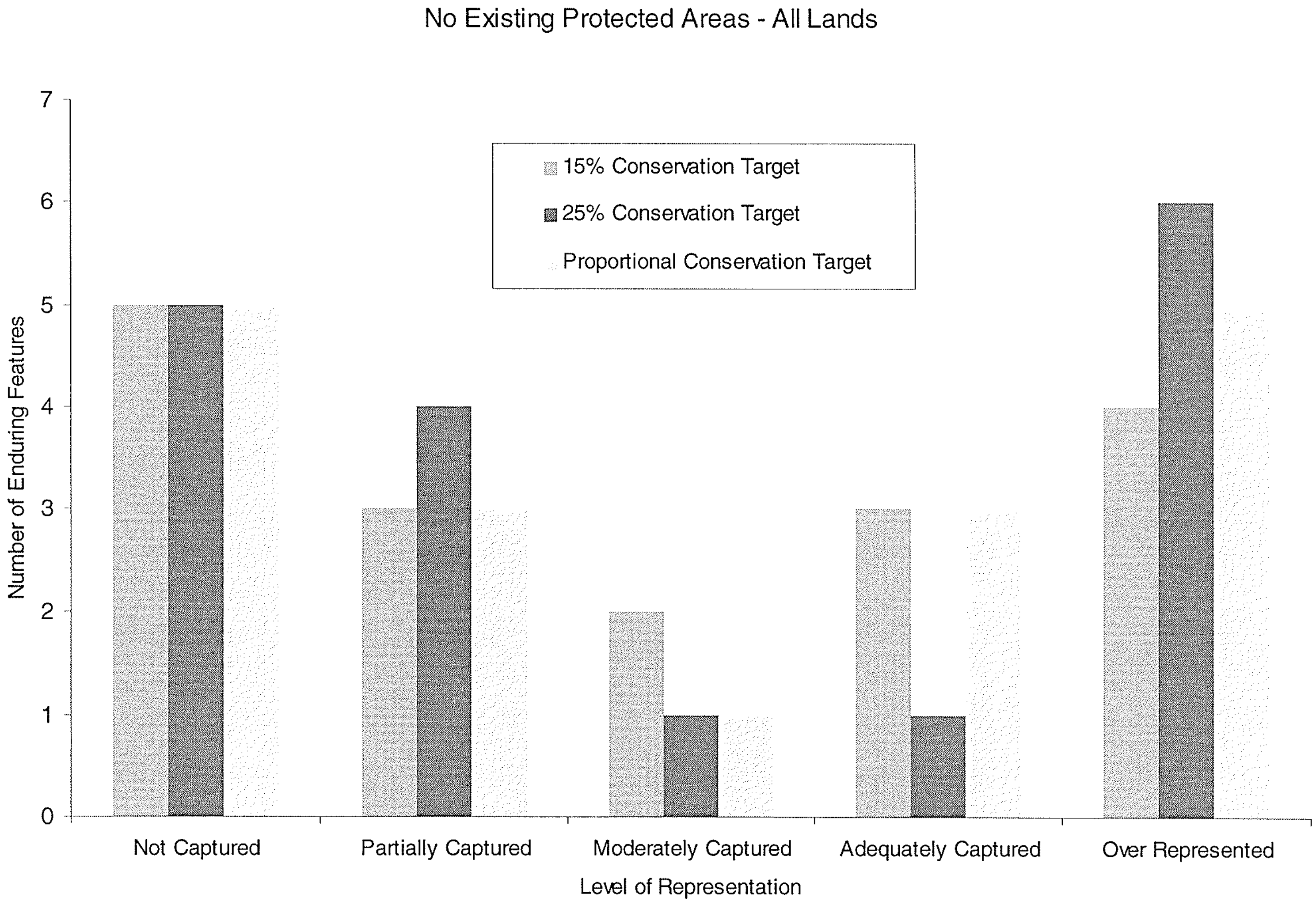


Figure 5.25 No Existing Protected Areas - The Level of Representation Achieved for Crown and Private Lands

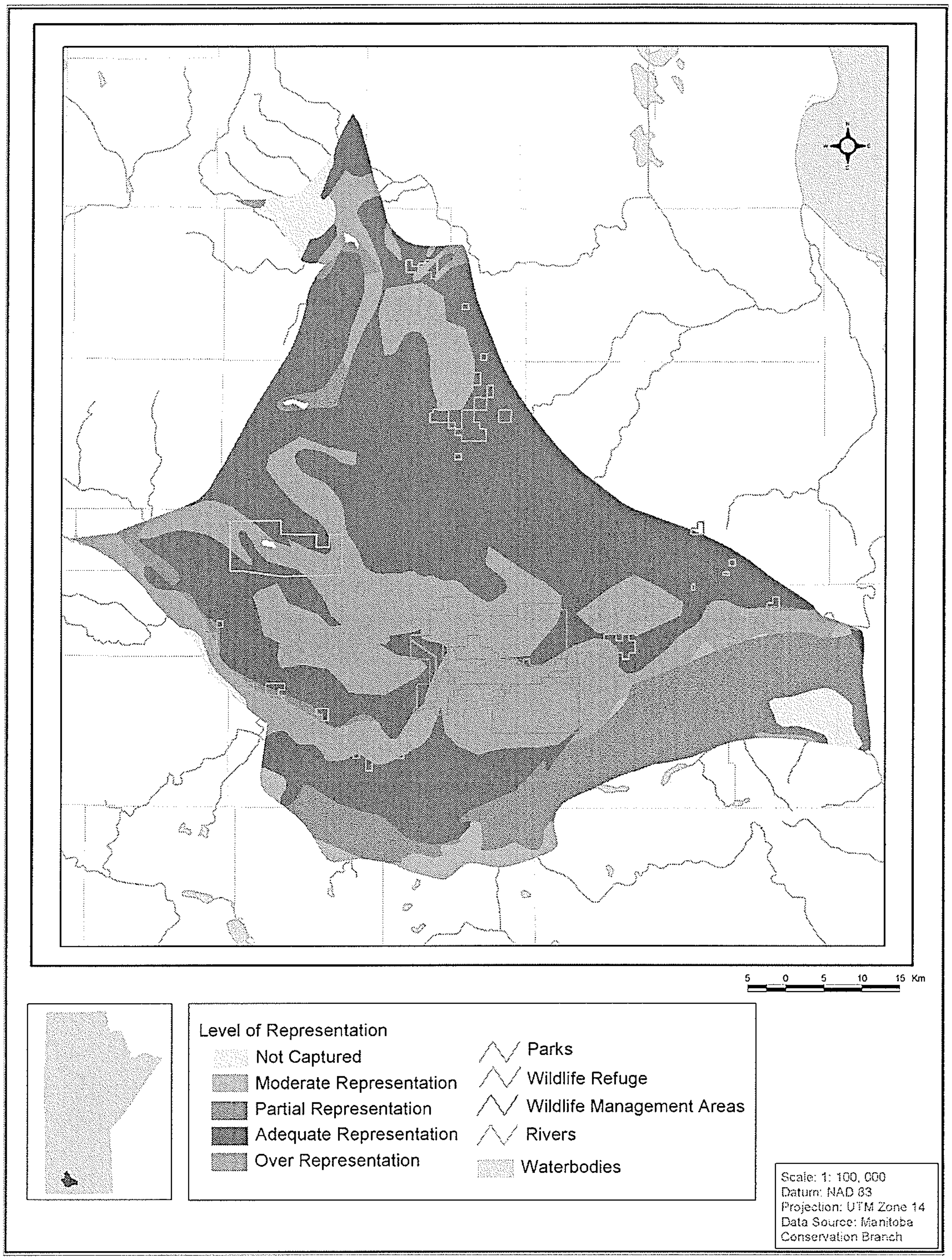


Figure 5.26 No Existing Protected Area Conservation Scenario: The Level of Representation achieved for the 15% Conservation Target Class, Crown Lands and Private Lands

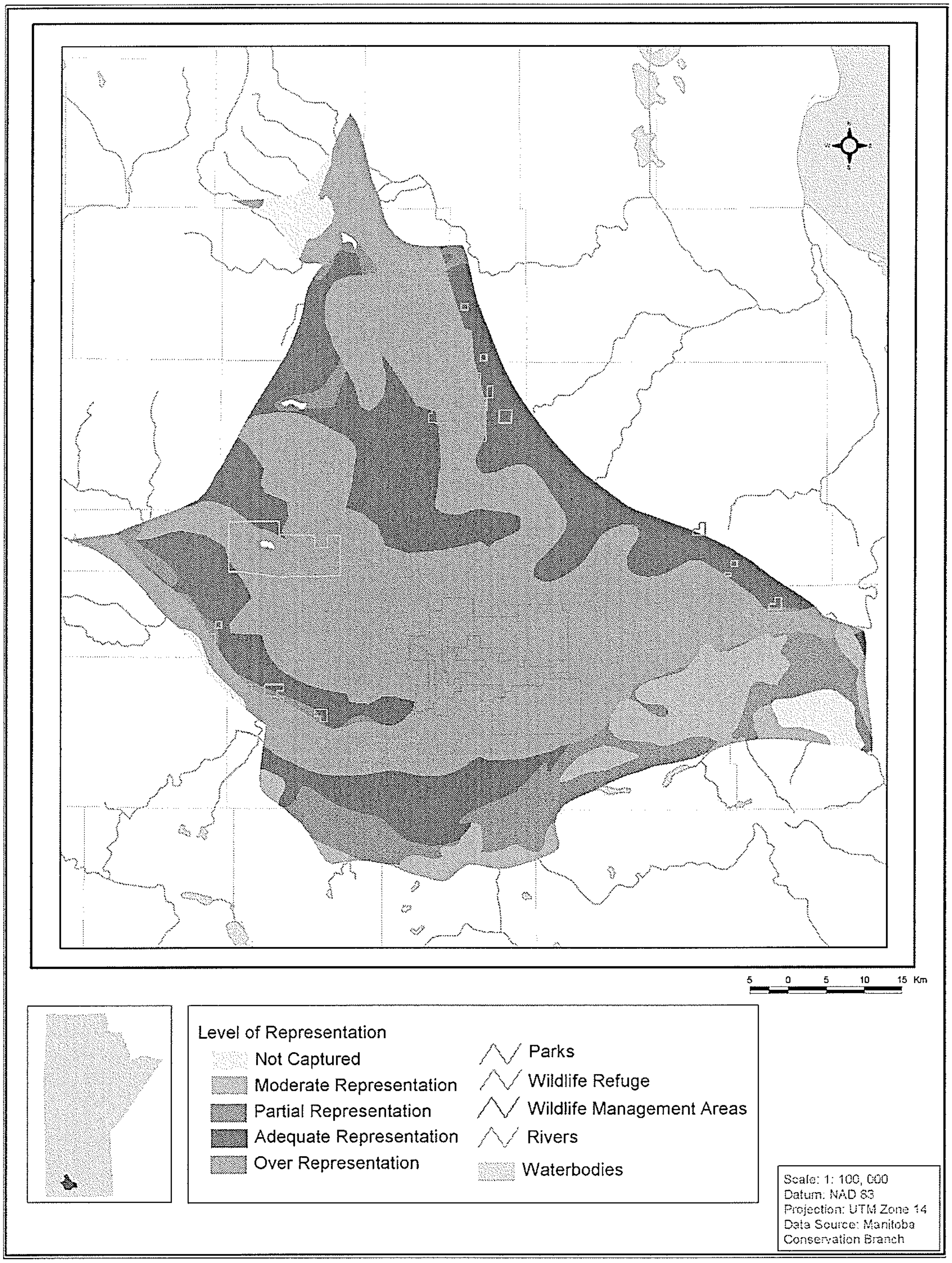


Figure 5.27 No Existing Protected Area Conservation Scenario: The Level of Representation achieved for the 25% Conservation Target Class, Crown Lands and Private Lands

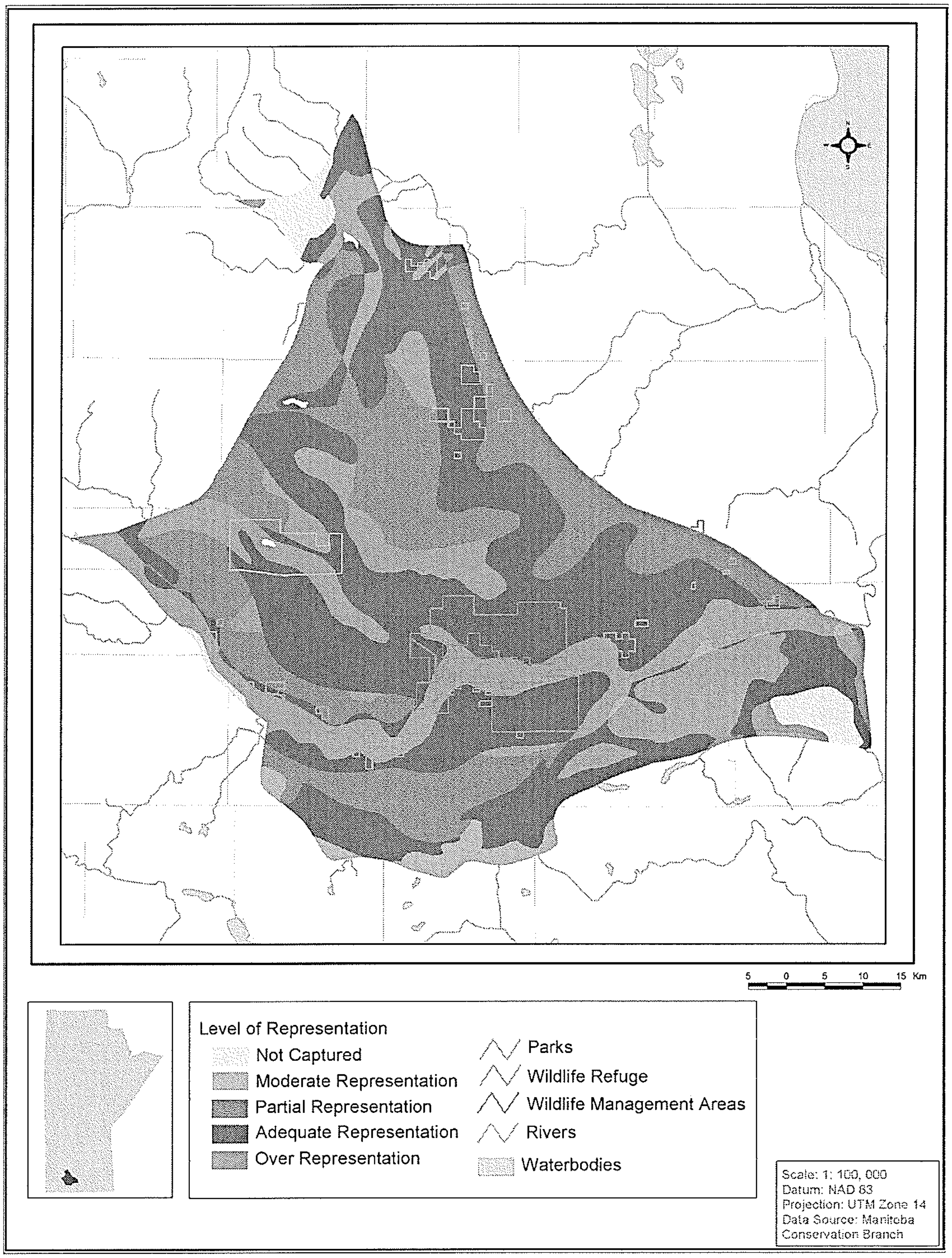


Figure 5.28 No Existing Protected Area Conservation Scenario: The Level of Representation achieved for the Proportional Conservation Target Class, Crown Lands and Private Lands

classes both adequately represented three enduring landscape features, deltaic deposits / black chernozem, deltaic deposits / black chernozem / sand dunes and deltaic deposits / regosol. Enduring landscape features alluvial deposits / black chernozem, deltaic deposits / regosol and deltaic deposits / regosol / sand dunes were adequately captured by the proportional target class. Enduring landscape features alluvial deposits / regosolss, deltaic deposits / regosol / sand dunes, organic deposits / black chernozem and organic deposits / regosol were over represented in all three conservation target categories. Deltaic deposits / regosol / sand dunes was over represented for both the proportional and 25% conservation target class. Deltaic deposits / regosol was also over represented by the 25% conservation target class.

The results in which the selection algorithms had to confine their search to crown lands within a conservation scenario where there are *no existing protected areas* are summarized in Table 5.24 and Figures 5.29, 5.30, 5.31 and 5.32. A total of ten enduring landscape features for the 15% and 25% conservation target classes were not captured. A total of nine enduring landscape features were not captured by the proportional target class. For the 15% conservation target class, only one enduring feature, organic deposits / black chernozem was partially captured. The 25% conservation class partially captured deltaic deposits / black chernozem and organic deposits / black chernozem. Three enduring features were partially captured by the proportional class, they include alluvial deposits / black chernozem, deltaic deposits / black chernozem, and organic deposits / black chernozem. Both 15% and 25% conservation target classes moderately captured

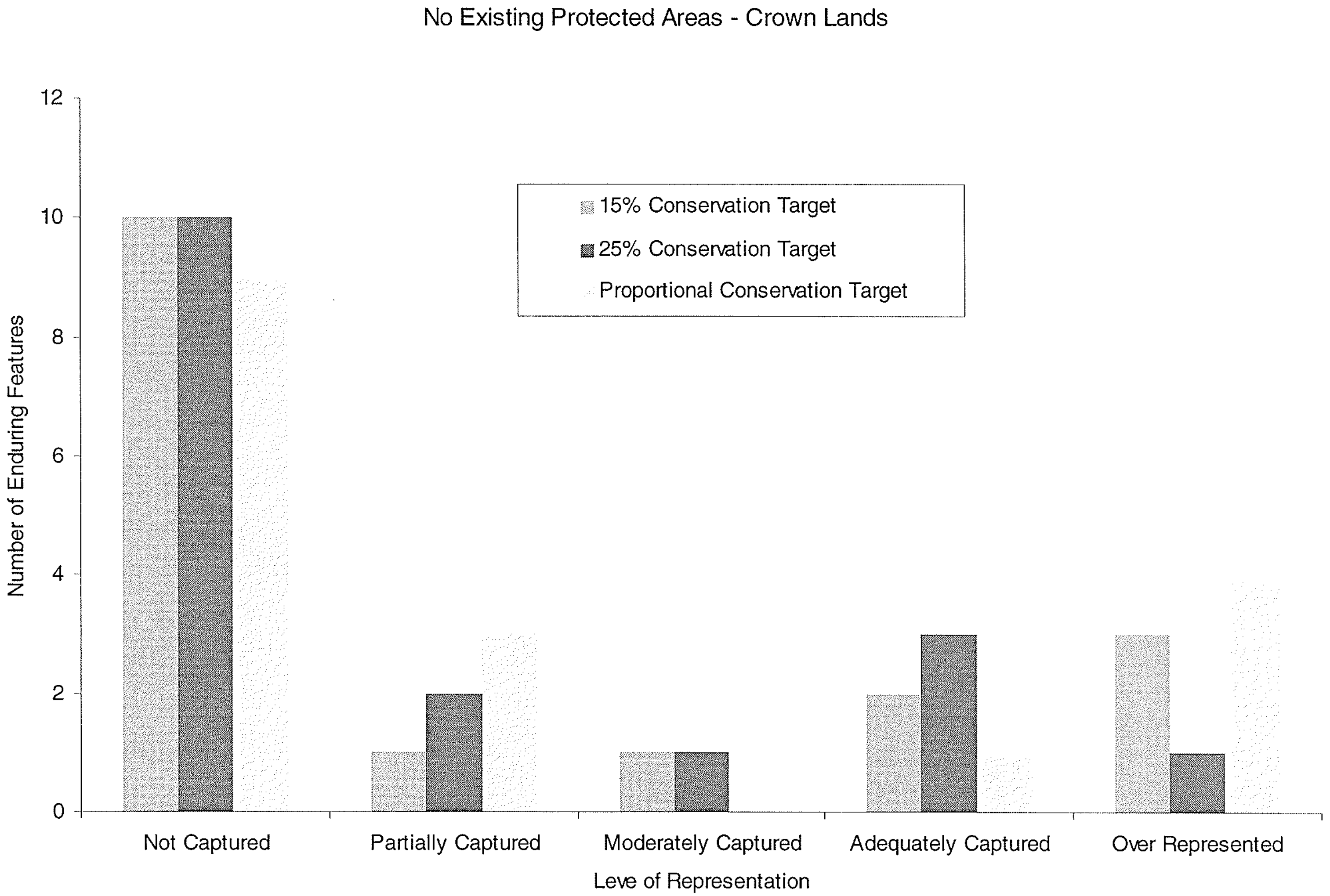


Figure 5.29 No Existing Protected Areas - The Level of Representation Achieved for Crown Lands

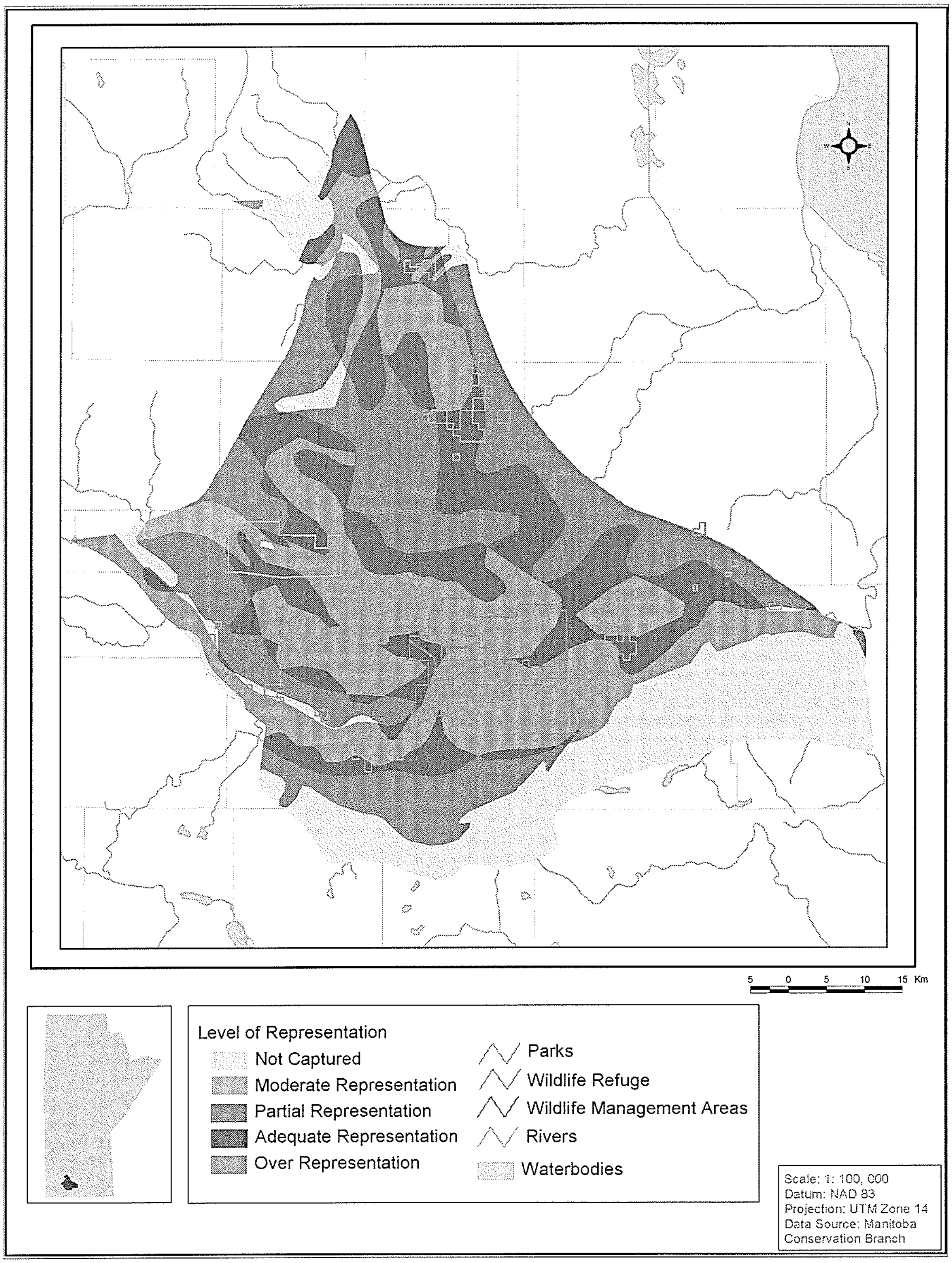


Figure 5.30 No Existing Protected Area Conservation Scenario: The Level of Representation achieved for the 15% Conservation Target Class, Crown Lands

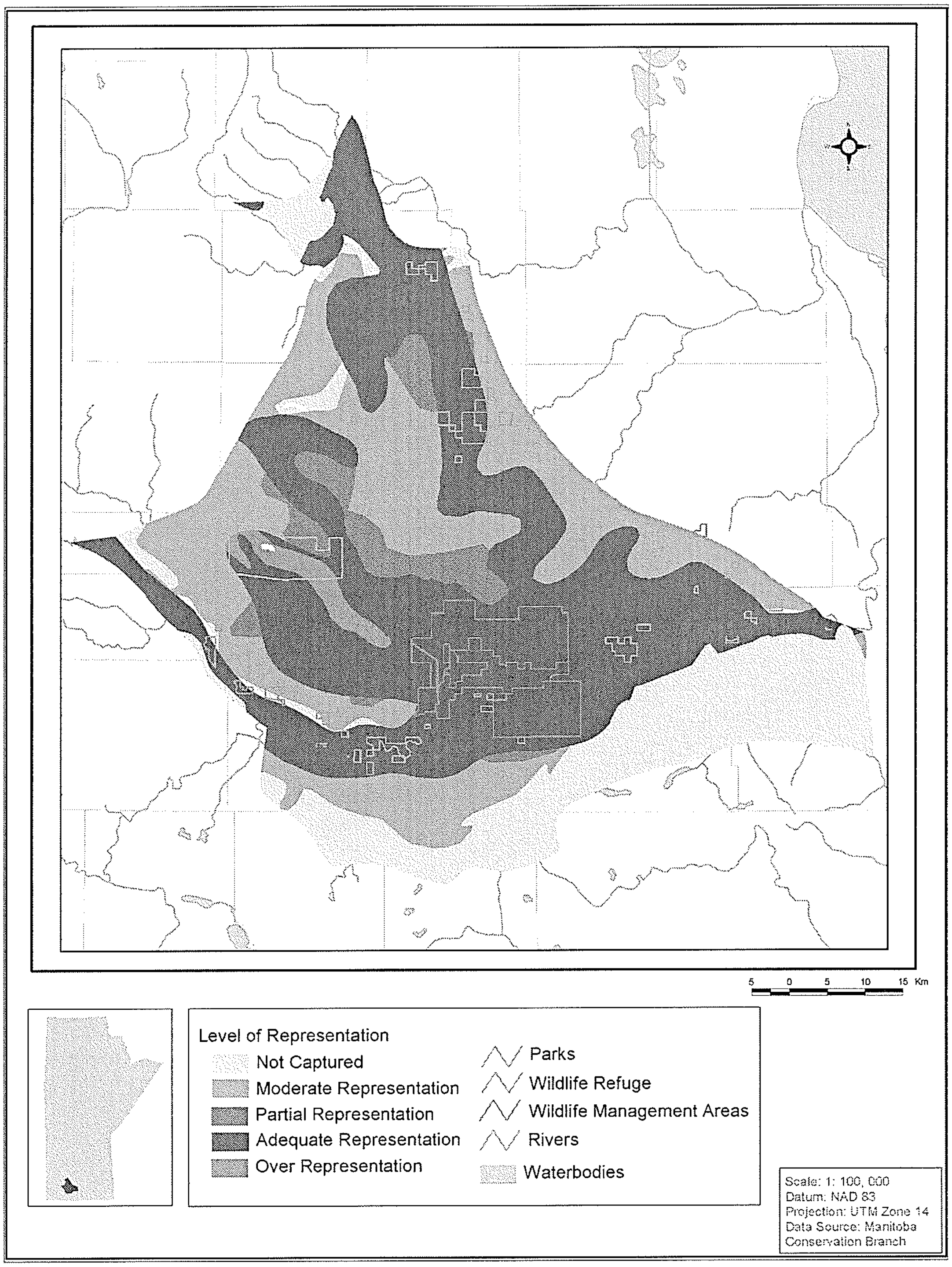


Figure 5.31 No Existing Protected Area Conservation Scenario: The Level of Representation achieved for the 25% Conservation Target Class, Crown Lands

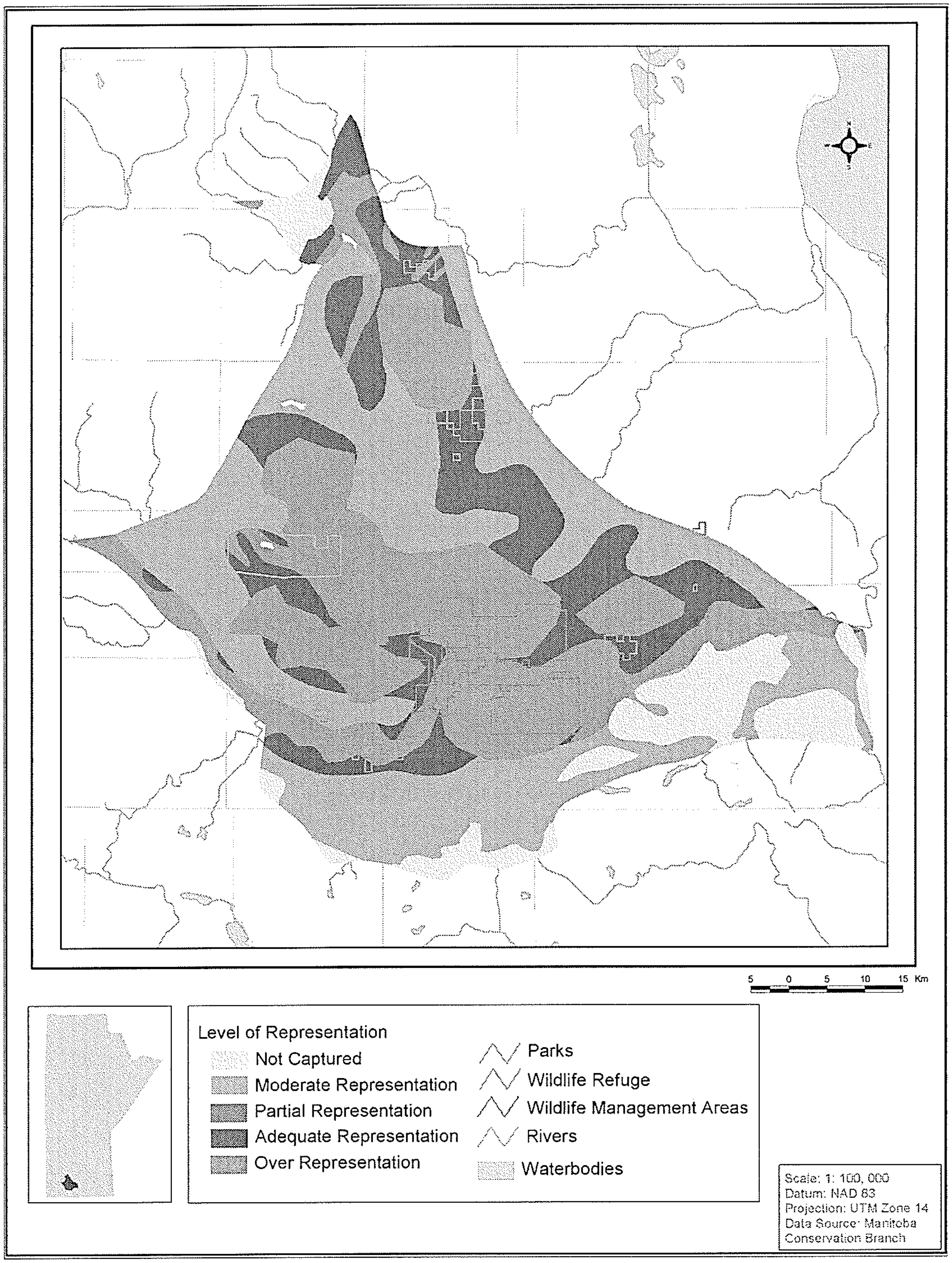


Figure 5.32 No Existing Protected Area Conservation Scenario: The Level of Representation achieved for the Proportional Conservation Target Class, Crown Lands

deltaic deposits / black chernozem and deltaic deposits / black chernozem / sand dunes respectively. The 25% conservation class had the largest number of enduring landscape features adequately represented; including alluvial deposits / regosols, deltaic deposits / regosol and deltaic deposits / regosol / sand dunes. The 15% conservation class adequately represented deltaic deposits / black chernozem / sand dunes and deltaic deposits / regosol. The proportional conservation target class only adequately captured one enduring feature, deltaic deposits / regosol, and over represented four, including alluvial deposits / regosols, deltaic deposits / black chernozem / sand dunes, deltaic deposits / regosol / sand dunes and organic deposits / regosol. The 15% conservation class had three over represented conservation features, alluvial deposits / regosols, deltaic deposits / regosol / sand dunes and organic deposits / regosol, while the 25% conservation class only had one enduring landscape feature that was over represented, organic deposits / regosol.

5.3.3 Efficiency

The greedy heuristic algorithm and simulated annealing algorithm attempt to be as efficient as possible when selecting sites to meet established conservation targets. Table 5.25 and Figures 5.33 and 5.34 summarize and graph the efficiency scores that were calculated for both conservation scenarios. Both algorithms were free to select sites that were located within both crown lands and relatively undisturbed private lands. For all three sets of conservation targets, the simulated annealing algorithm produced the most efficient results. When the annealing algorithm was run for the *no existing protected areas* conservation scenario, the most efficient solutions generated were generated when the BLM was set to 0.5. There appeared to be a tendency for the simulated annealing algorithm to select too many sites when the boundary modifier was set at 1.0. However when the simulated annealing algorithm selected sites when the existing protected areas were locked into the analysis, the simulated annealing algorithm was most efficient at selecting sites when the BLM was set to 1.0, with the exception of the proportional target where the simulated annealing algorithm was most efficient when the BLM was set to 0.5.

Table 5.24 - Efficiency Calculations for Crown Land and Privately Owned Lands

		Existing Protected Areas		No Existing Protected Areas	
		Greedy	Annealing	Greedy	Annealing
Conservation Target 15%					
Boundary Length Modifier	0.0	0.0789	0.0798	0.2176	0.1260
	0.5	0.0789	0.0291	0.1296	0.0531
	1.0	0.0336	0.0309	0.2105	-0.0135
Conservation Target 25%					
Boundary Length Modifier	0.0	0.2717	0.2728	0.2195	0.1712
	0.5	0.2484	0.2506	0.2173	0.0908
	1.0	0.2484	0.2501	0.2179	0.1002
Conservation Target Proportional					
Boundary Length Modifier	0.0	0.0877	0.0877	0.4769	0.3421
	0.5	0.0425	0.0417	0.2954	0.0203
	1.0	0.0433	0.0441	0.2914	-0.0645

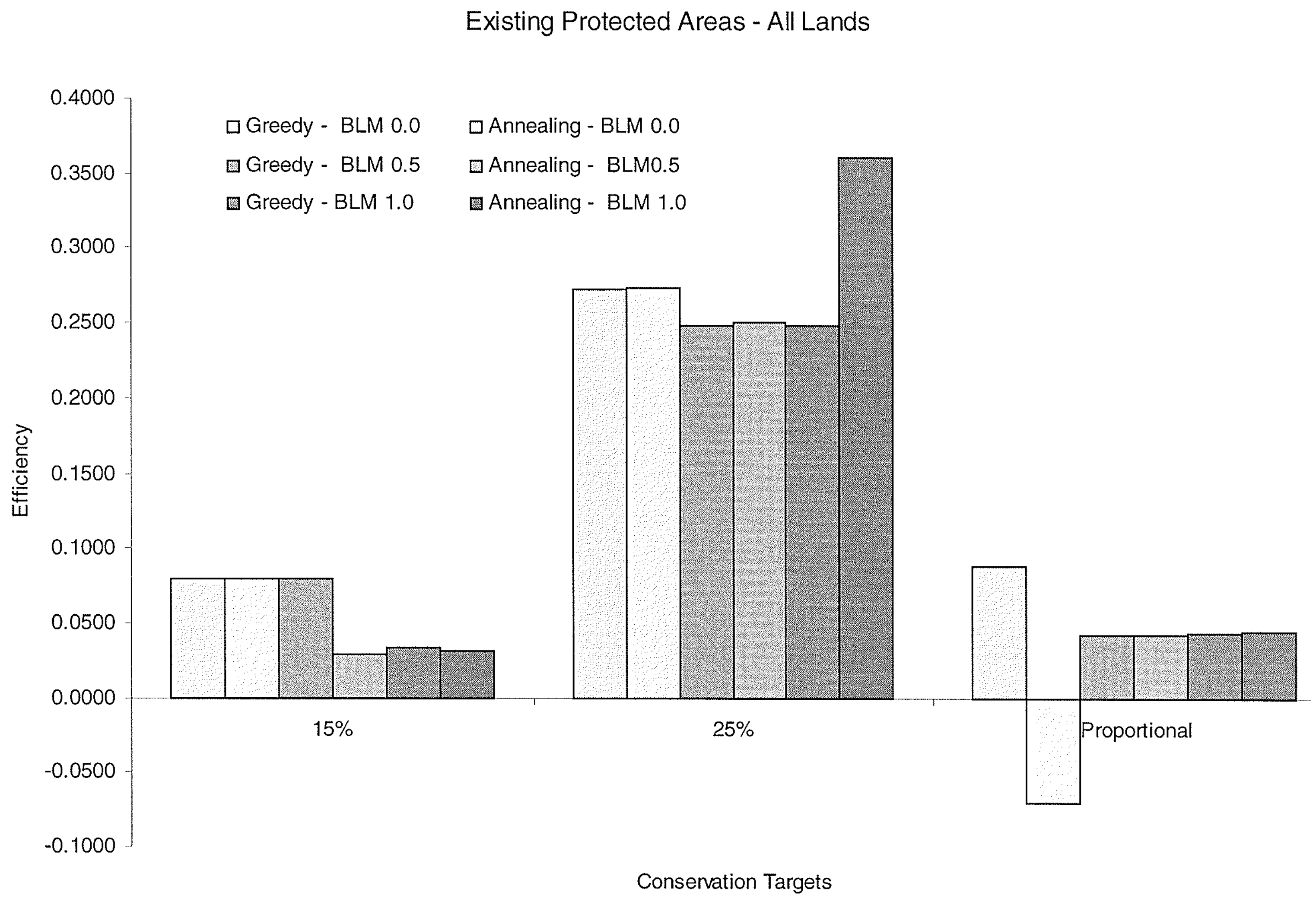


Figure 5.33 Efficiency Calculations for the Existing Protected Areas Conservation Scenario – Crown Lands and Private Lands

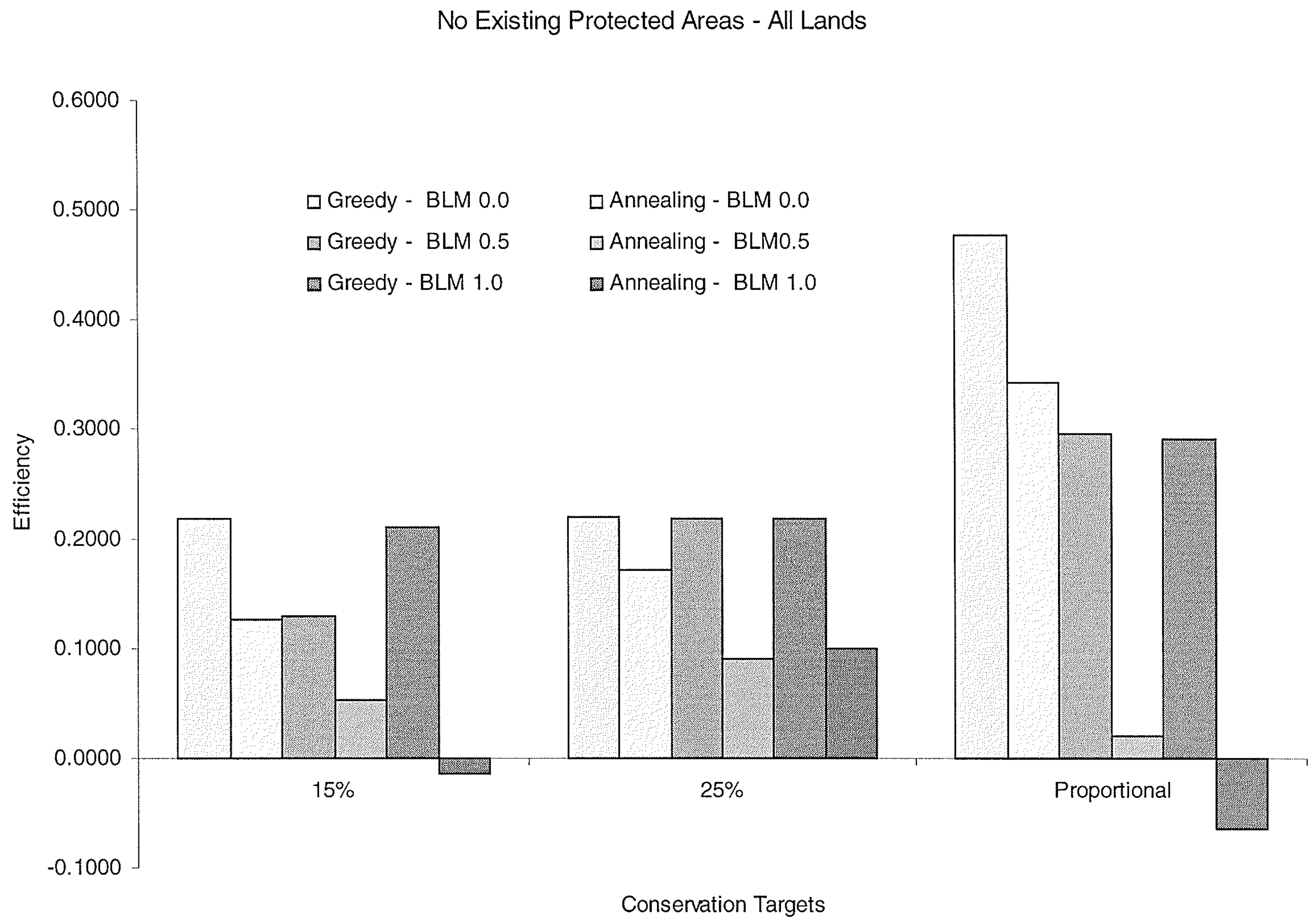


Figure 5.34 Efficiency Calculations for the No Existing Protected Areas Conservation Scenario – Crown Lands and Private Lands

Table 5.26 and Figures 5.35 and 5.36 summarize and graph the efficiency scores that were calculated for both the *existing protected areas* and *no existing protected areas* conservation scenario. For conservation situations where the algorithms had limited their search to crown lands, the measure of efficiency was difficult to evaluate. For the *existing protected areas* conservation scenario, the greedy heuristic algorithm produced results for the 15% and proportional conservation scenario that were more efficient. The simulated annealing algorithm generated the most efficient set of results for the 25% conservation target. The efficiency results were identical for the BLM of 0.5 and the 1.0 for both the 15% and 25% conservation targets. The results were also identical between the two selection algorithms for the proportional targets. For the *no existing protected areas* conservation scenario the greedy heuristic algorithm was more efficient for the 15% and the proportional conservation targets. For the 25% conservation target, the efficiency results are all identical as well.

5.3.4 Objective Three Summary

The summary statistics were very indicative of how the two algorithms operated under the two conservation scenarios. As expected, the amount of land selected by the two algorithms did vary according to the conservation targets. However, how the two algorithms responded to variations in the planning units was unexpected. When the selection of sites was limited to crown lands, the simulated annealing algorithm consistently selected a large amount of land area for all three conservation targets. This

Table 5.25- Efficiency Calculations – Crown Lands

		Existing Protected Areas		No Existing Protected Areas	
		Greedy	Annealing	Greedy	Annealing
Conservation Target 15%					
Boundary Length Modifier	0.0	0.2807	0.2816	0.2016	0.2052
	0.5	0.2701	0.2710	0.1936	0.1981
	1.0	0.2701	0.2710	0.1936	0.1972
Conservation Target 25%					
Boundary Length Modifier	0.0	0.5026	0.5043	0.3972	0.3972
	0.5	0.4976	0.5004	0.3972	0.3972
	1.0	0.4976	0.5004	0.3972	0.3972
Conservation Target Proportional					
Boundary Length Modifier	0.0	0.3770	0.3770	0.2914	0.2867
	0.5	0.3643	0.3643	0.2748	0.2795
	1.0	0.3643	0.3643	0.2748	0.2803

was consistent for both the *existing protected areas* and the *no existing protected areas* conservation scenario. When the algorithms were free to select sites from both crown and private lands, the greedy heuristic selected a greater number of sites, which was also consistent for the two conservation scenarios.

The level of representation that was achieved varied according to the conservation scenario and to changes in the planning units. For the *existing protected areas* conservation scenario where the two algorithms had the freedom to select sites from both crown and private lands, the 15% conservation target class was most successful at achieving representation, while the proportional target class was the least successful at

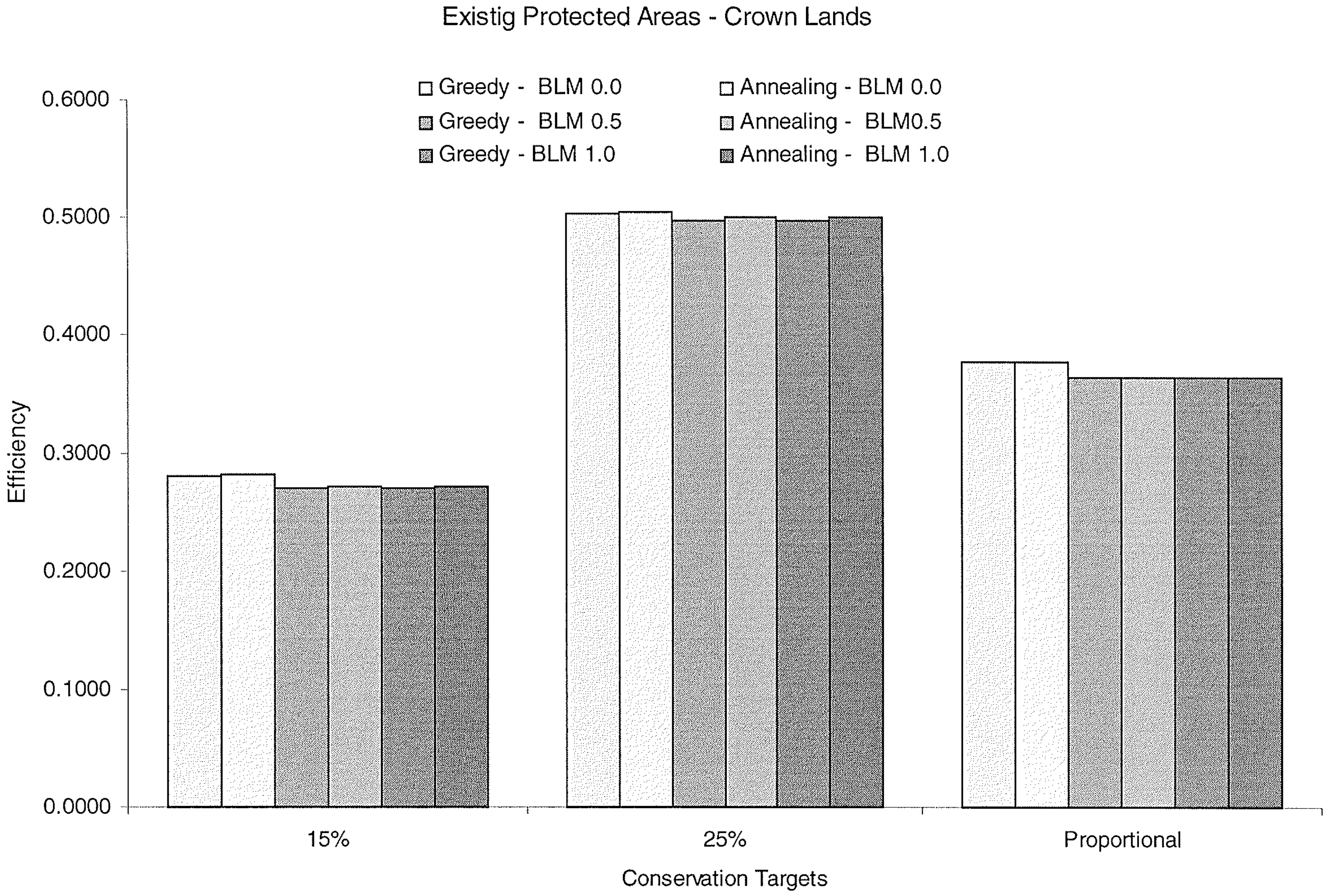


Figure 5.35 Efficiency Calculations for the Existing Protected Areas Conservation Scenario – Crown Lands

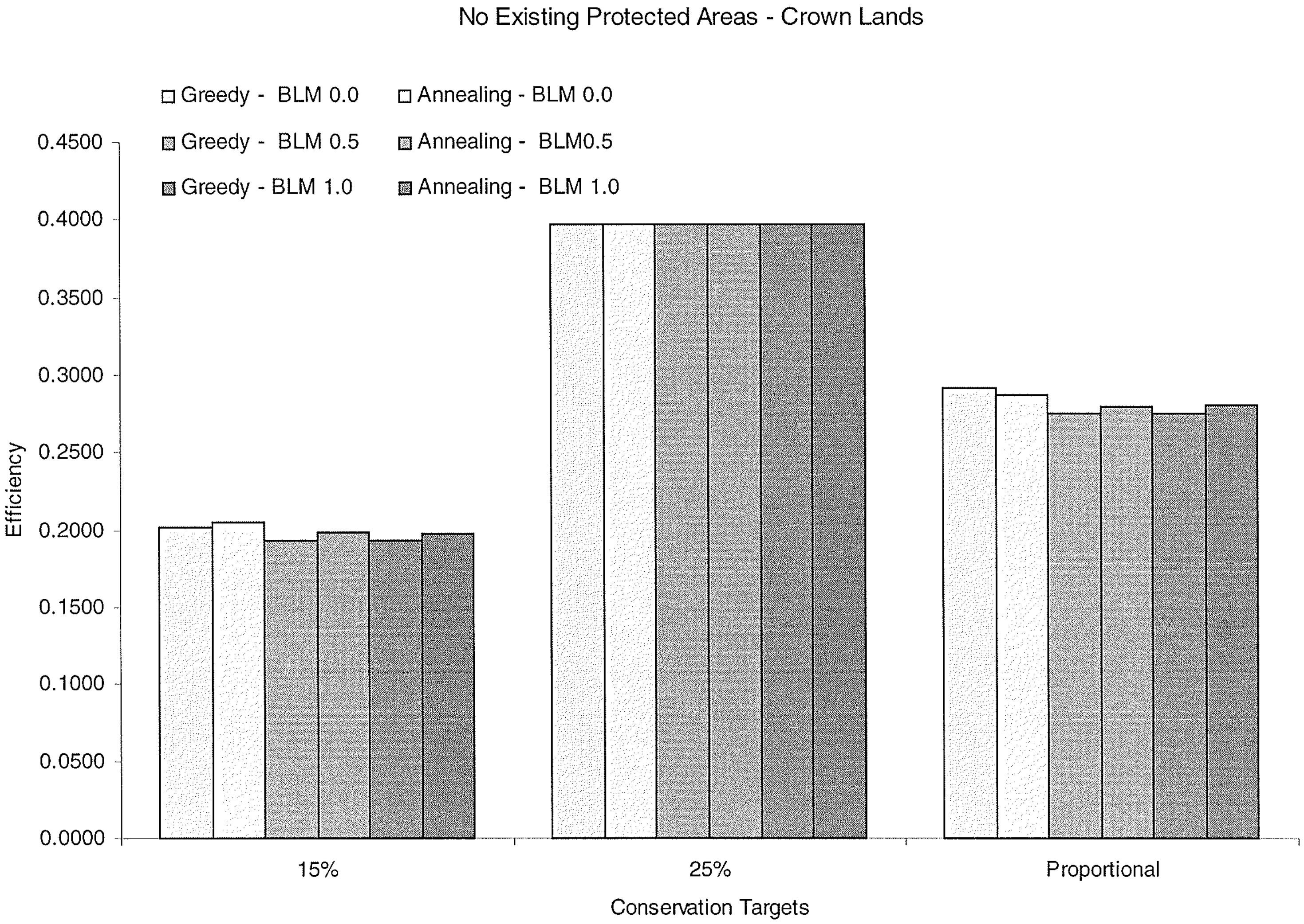


Figure 5.36 Efficiency Calculations for the No Existing Protected Areas Conservation Scenario – Crown Land

achieving overall representation. Within this conservation scenario, the proportional conservation target class did not manage to capture any enduring landscape features, as well, this target class had the most over-represented conservation features. For the existing protected areas conservation scenario where the algorithms selection of planning units was limited to crown lands, the 25% conservation target class was the most successful at achieving overall representation while the proportional conservation target class was least. Within this scenario, the proportional target class failed to moderately and adequately represented any enduring landscape features. As well, this target class had the largest number of over-represented enduring landscape features. For the *no existing protected areas* conservation scenario where the selection algorithms had the freedom to select planning units from both crown and private lands the 15% conservation target class was the most successful at achieving overall representation. The 25% conservation target class was the least successful at achieving overall representation. Not only did this conservation target have the largest amount of over-represented conservation features, the 25% conservation target class also had the fewest adequately represented conservation features. For the *no existing protected areas* conservation scenario where the algorithm's search radius is limited to crown lands, the 25% conservation target class was the most successful with regards to achieving representation while the proportional conservation target class was the least successful. The proportional target class did not manage to moderately capture any enduring landscape features and had the largest number of over-represented conservation features.

There were distinct differences in the level of efficiency between the two algorithms when changes were made to the planning units. When the two algorithms had the freedom to select sites from both crown lands and private lands for the no existing protected areas conservation scenario the simulated annealing algorithm produced the most efficient results for al three sets of conservation targets. When there was an increase emphasis placed on the spatial aggregation of the sites, the most efficient solutions were generated when the boundary length modifier was set to 0.5. However for the existing protected areas conservation scenario, the simulated annealing algorithm was most efficient at selecting sites when the boundary length modifier was sites to 1.0. This may be attributed to the fact that the current network of protected areas is already quite spatially compact. When the two algorithms had the freedom to select sites from crown lands for the existing protected areas conservation scenario the greedy heuristic algorithm generated the most efficient results for al three sets of conservation targets. When an increased emphasis was placed on the spatial aggregation, there appeared to be minimal variation between the efficiency levels generated when the boundary length modifier was set to 0.5 and 1.0 for the 15% and proportional conservation target class. Where as for the 25% conservation target class, the level of efficiency was the same for all three boundary length modifiers.

5.4 Objective Four

The fourth objective was to identify a spatial framework within which the different conservation scenarios for the Assiniboine Delta Region could be presented. As there are a number of protected area configurations that can be generated for the Assiniboine Delta region, it was useful to know something about the relative importance of individual planning units for conservation planning. The selection frequency count, otherwise referred to as 'summed irreplaceability' was utilized to provide a measure of the contribution of any one planning unit to the reservation goals (Ball and Possingham, 2001; Pressey *et al.,* 1994). In order to fulfill this objective, the frequency with in which the various planning units were selected was examined for crown lands and the combination of crown and private lands.

Crown Lands

The identification of irreplaceability sites within the study area provided some very useful information in that it presented a way to bring together valuable information about particular areas such as which areas consistently contribute to meeting the conservation goals. The selection frequencies for the top three conservation targets were examined for each conservation scenario. Figures 5.37, 5.38, and 5.39 display the results in which the selection algorithm is forced to select areas for conservation within crown lands for the existing protected areas conservation scenario. Due to the fact that the majority of the planning units for this scenario were already locked into the analysis, this did not leave many options open for the algorithms to fulfill their conservation targets, thus most planning units were required for each of the 100 runs. The results in which the

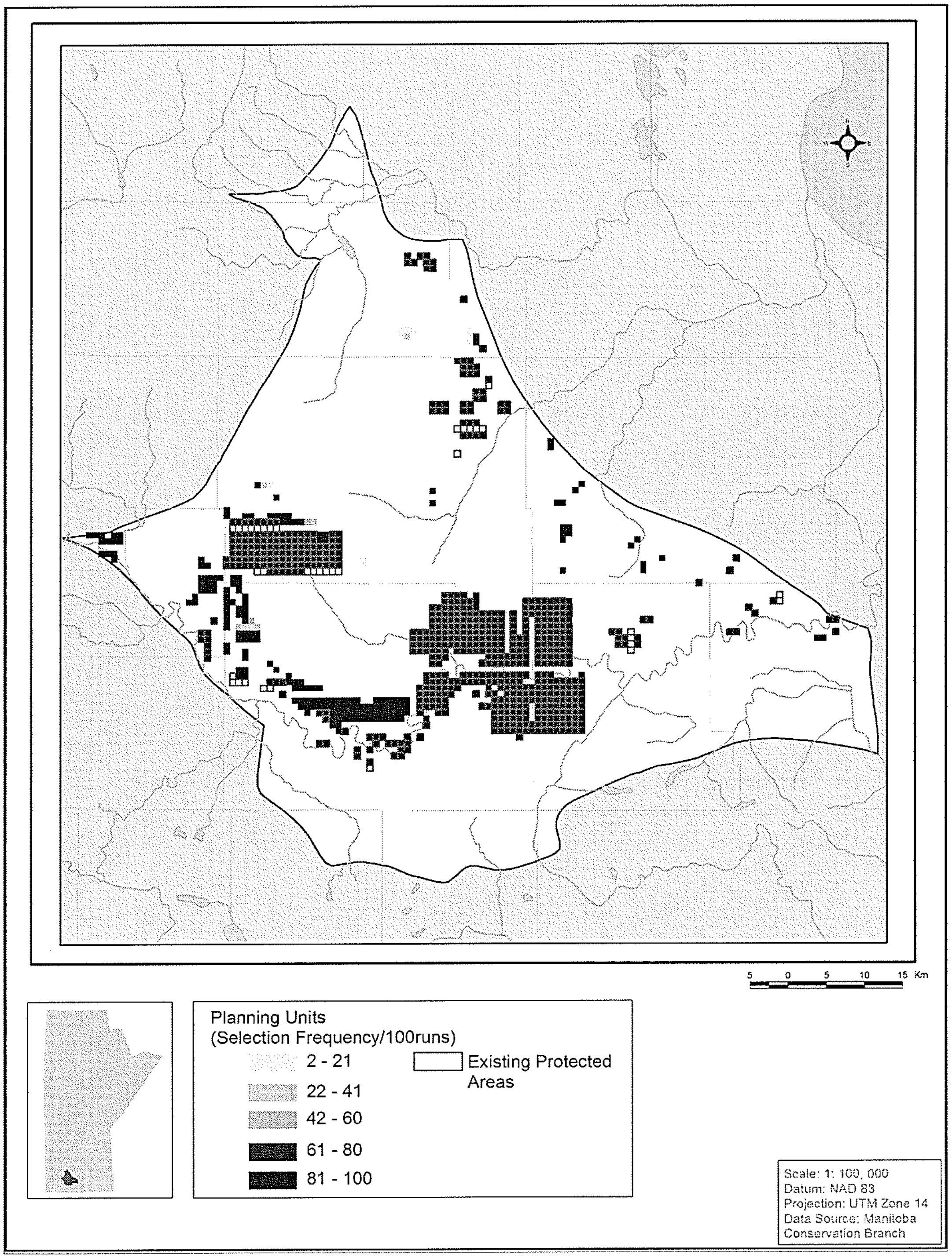


Figure 5.37 Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown Lands - 15% Conservation Target

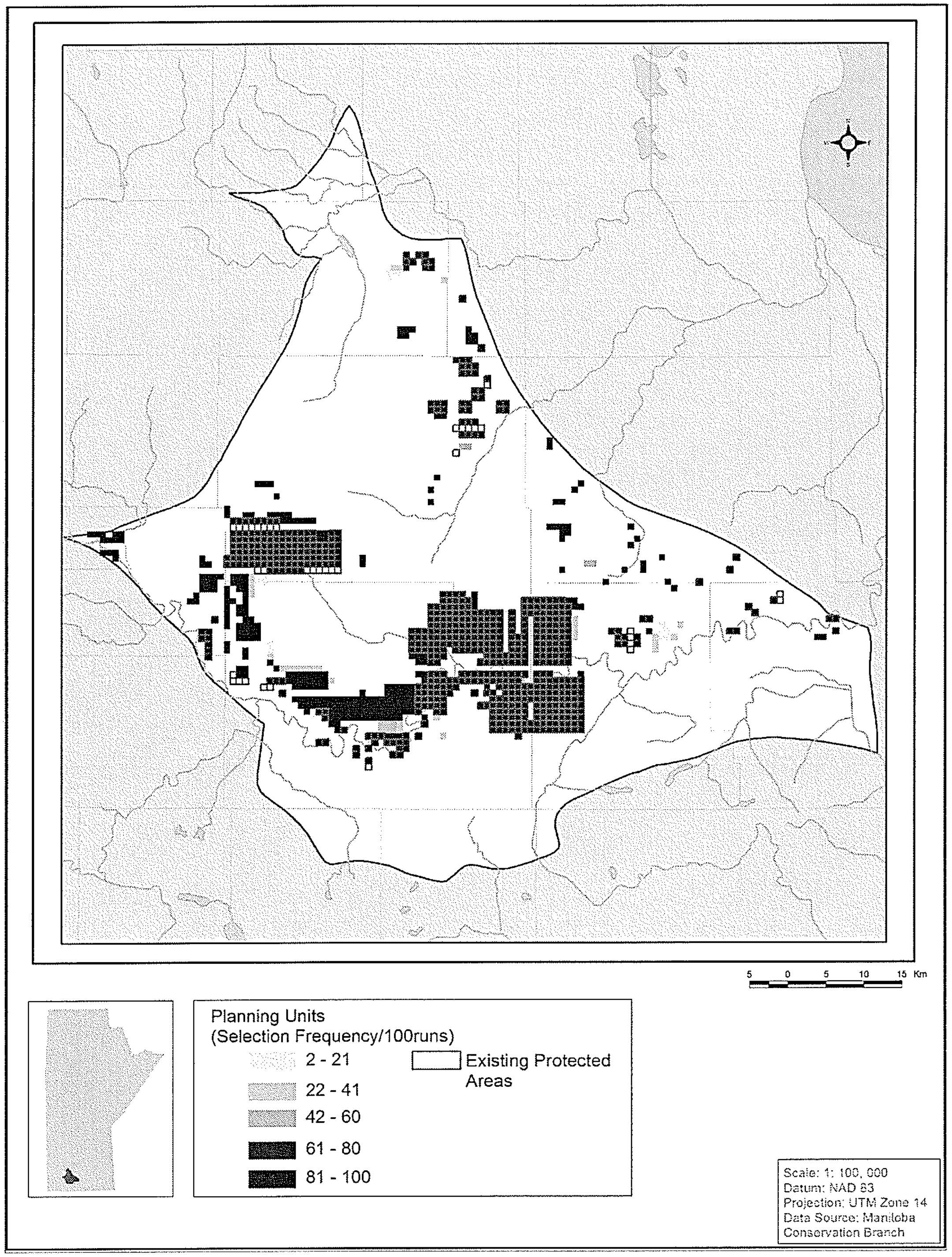


Figure 5.38 Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown Lands - 25% Conservation Target

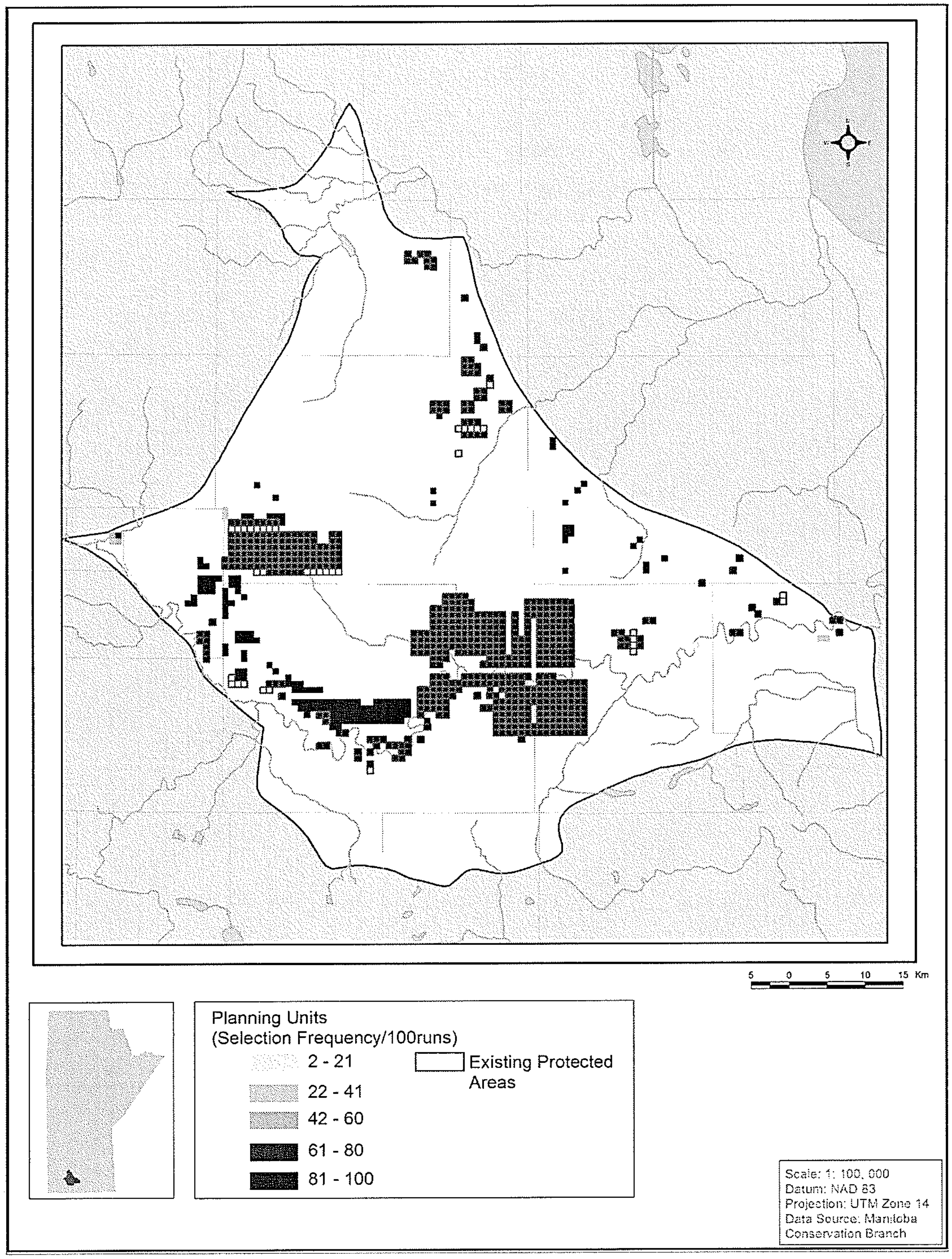


Figure 5.39 Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown Lands - Proportional Conservation Target

selection algorithms confined to select areas for conservation within crown lands for the *no existing protected areas* conservation scenario are presented in Figures 5.40, 5.41,and 5.42. Since there are restricted options for site selection because of the limited number of crown land planning units, the algorithms were not left with very many choices when selecting candidate sites to include within a network of protected areas. As a result, the majority of available planning units were used for each of the 100 runs.

Crown and Private Lands

Figures 5.44, 5.45, and 5.46 illustrate the best solutions for the algorithms in which they were free to select candidate sites from both crown lands and privately owned lands which are relatively undisturbed. This is summarized for the *existing protected areas conservation* scenario. Because the algorithms had the option of selecting sites from both crown lands and private lands, the algorithms could generate a number of different conservation scenarios. However, the algorithms were still forced to incorporate the existing protected areas within their selection analysis, thus, this did place constraints on the selection process. The results of the analysis where the selection algorithm had the option to select areas from both the crown and private lands for the no *existing protected areas* conservation scenario is summarized in Figures 5.46, 5.47, and 5.48. In this particular scenario, the algorithms had the greatest amount of planning units and no constraints placed on which sites they selected to meet the required conservation targets.

For this particular situation, only a small proportion of existing protected areas were selected in all 100 runs.

5.4.1 Objective Four Summary

When examining the results generated from the evaluation of summed irreplaceability, it became evident that the planning units and the spatial distribution of the planning units influenced the frequency in which the algorithms selected sites. When the selection algorithms selection was limited to crown lands with no existing protected areas locked into the analysis, because of the limited selection quite a number of the available planning units were selected for each 100 trials. When the selection algorithms selection was limited to crown lands and existing protected areas were locked into the selection set, there was even less variation in site selection options, thus the majority of planning units were utilized for each of the 100 trials. However, when the algorithms had the freedom to select sites from both crown and private lands, because there were a greater of planning units there a greater number of site selection options. When the two algorithms were free to select any planning unit, only a small number of planning units which fell within existing protected areas were selected.

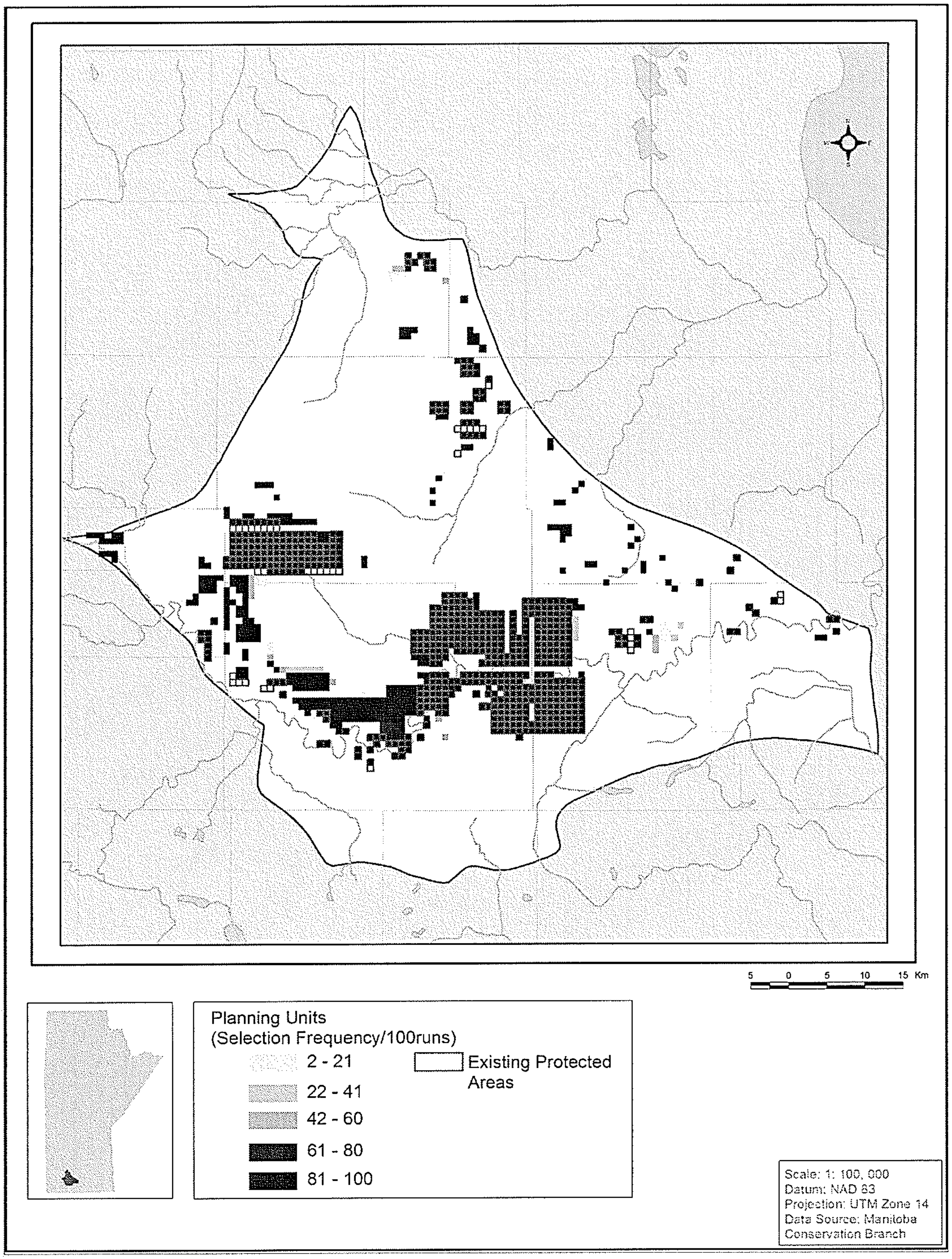


Figure 5.40 No Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown Lands - 15% Conservation Target

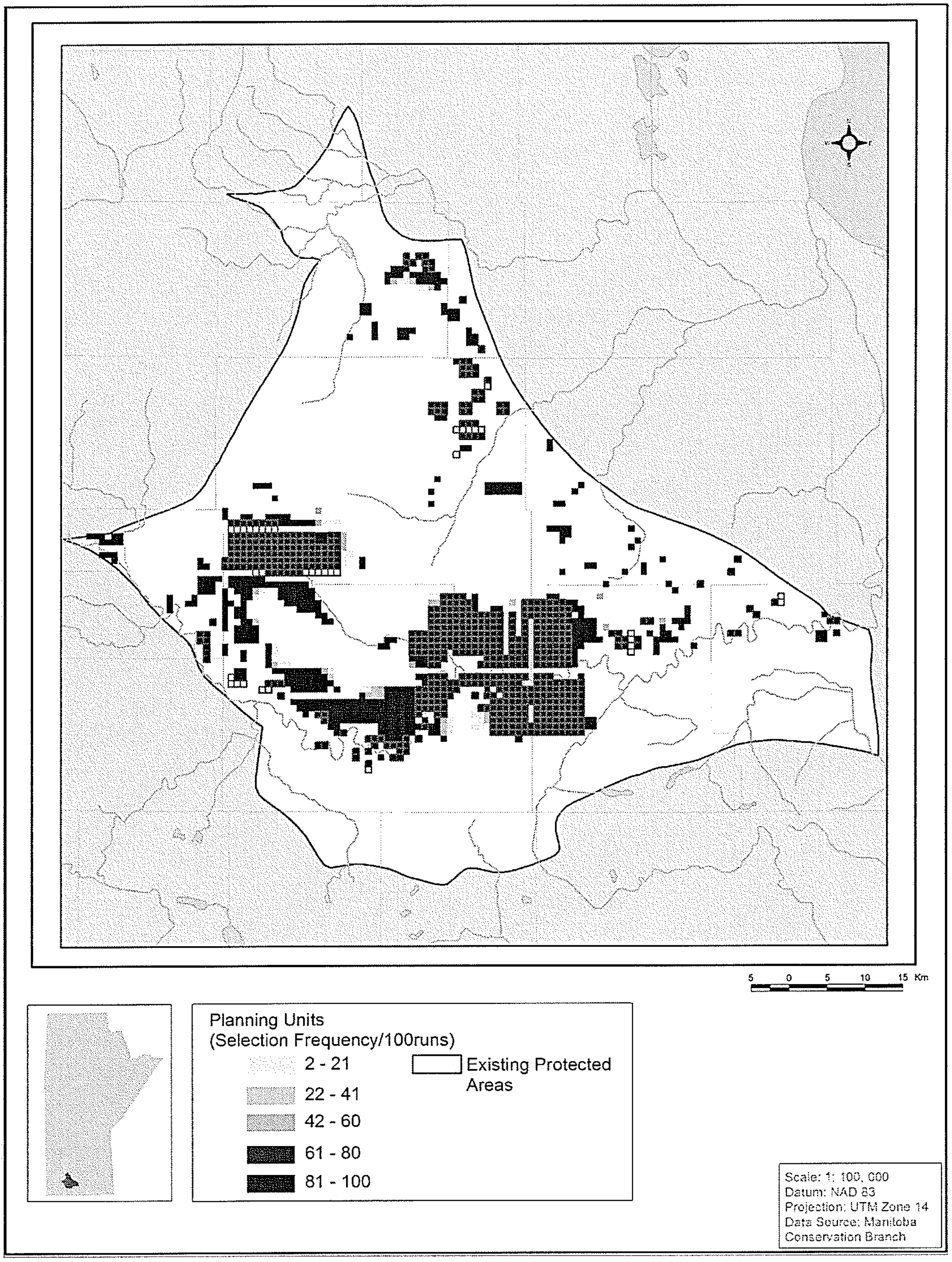


Figure 5.41 No Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown Lands - 25% Conservation Target

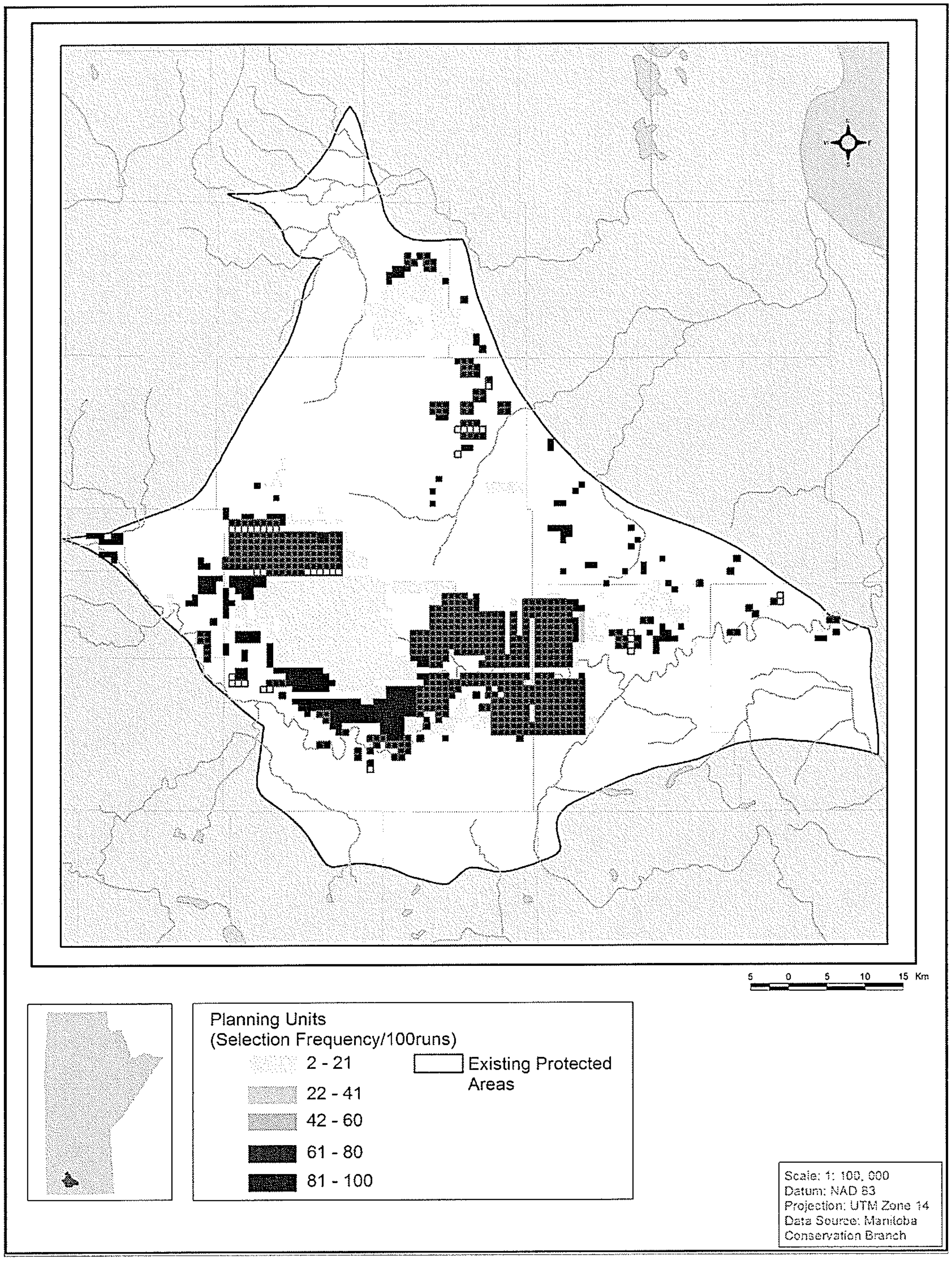


Figure 5.42 No Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown Lands - Proportional Conservation Target

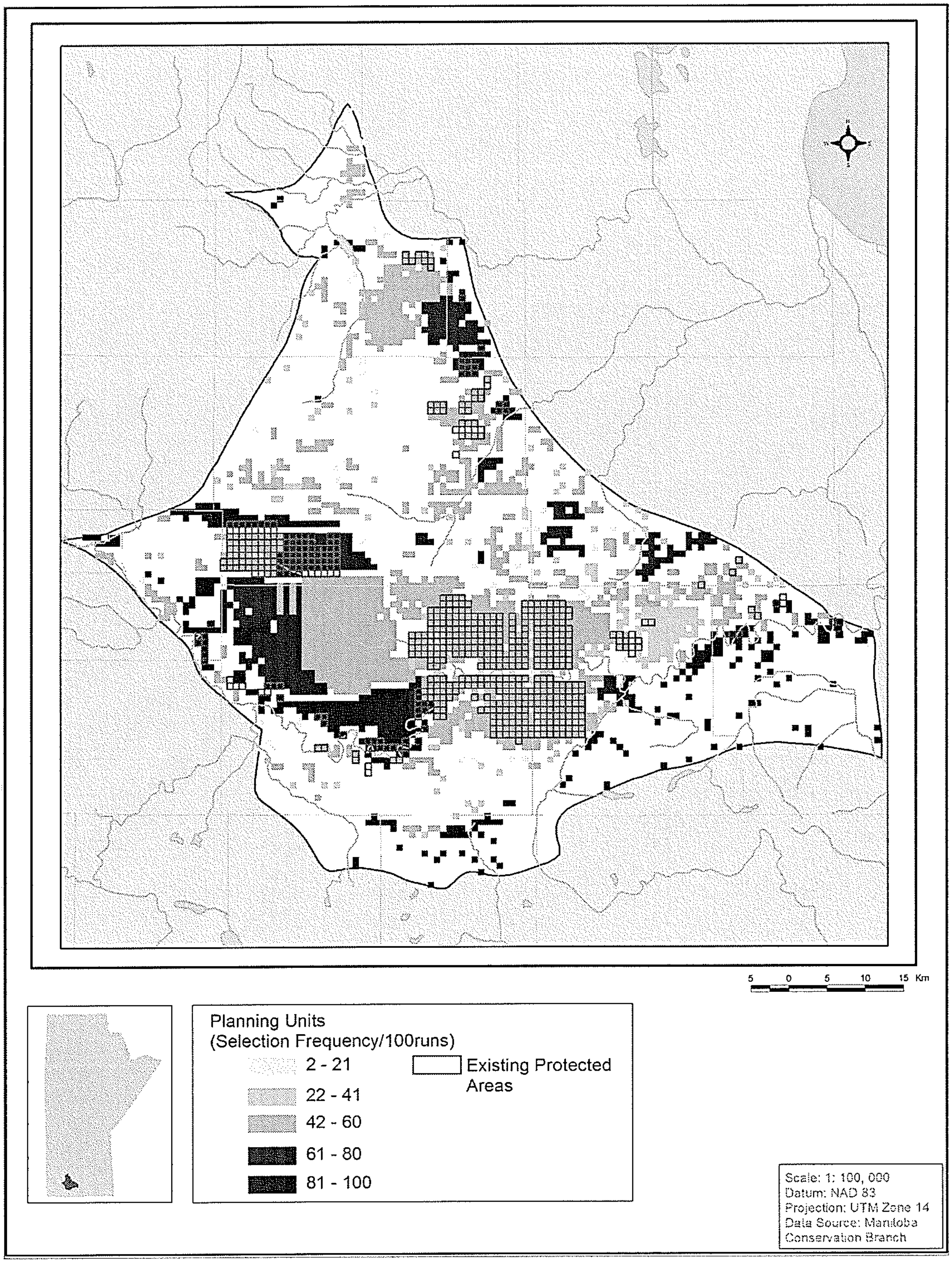


Figure 5.43 No Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown and Private Lands - 15% Conservation Target

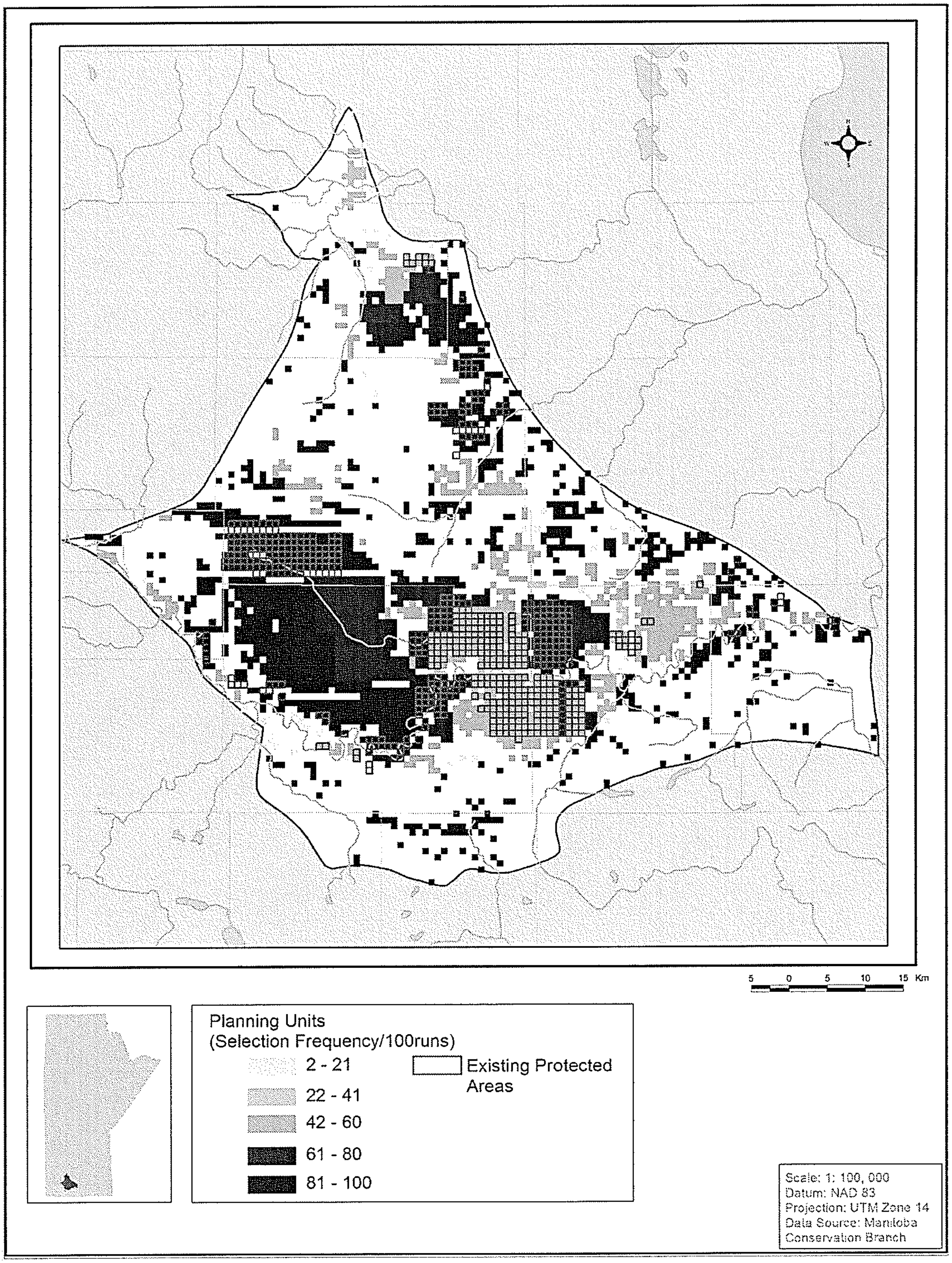


Figure 5.44 No Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown and Private Lands - 25% Conservation Target

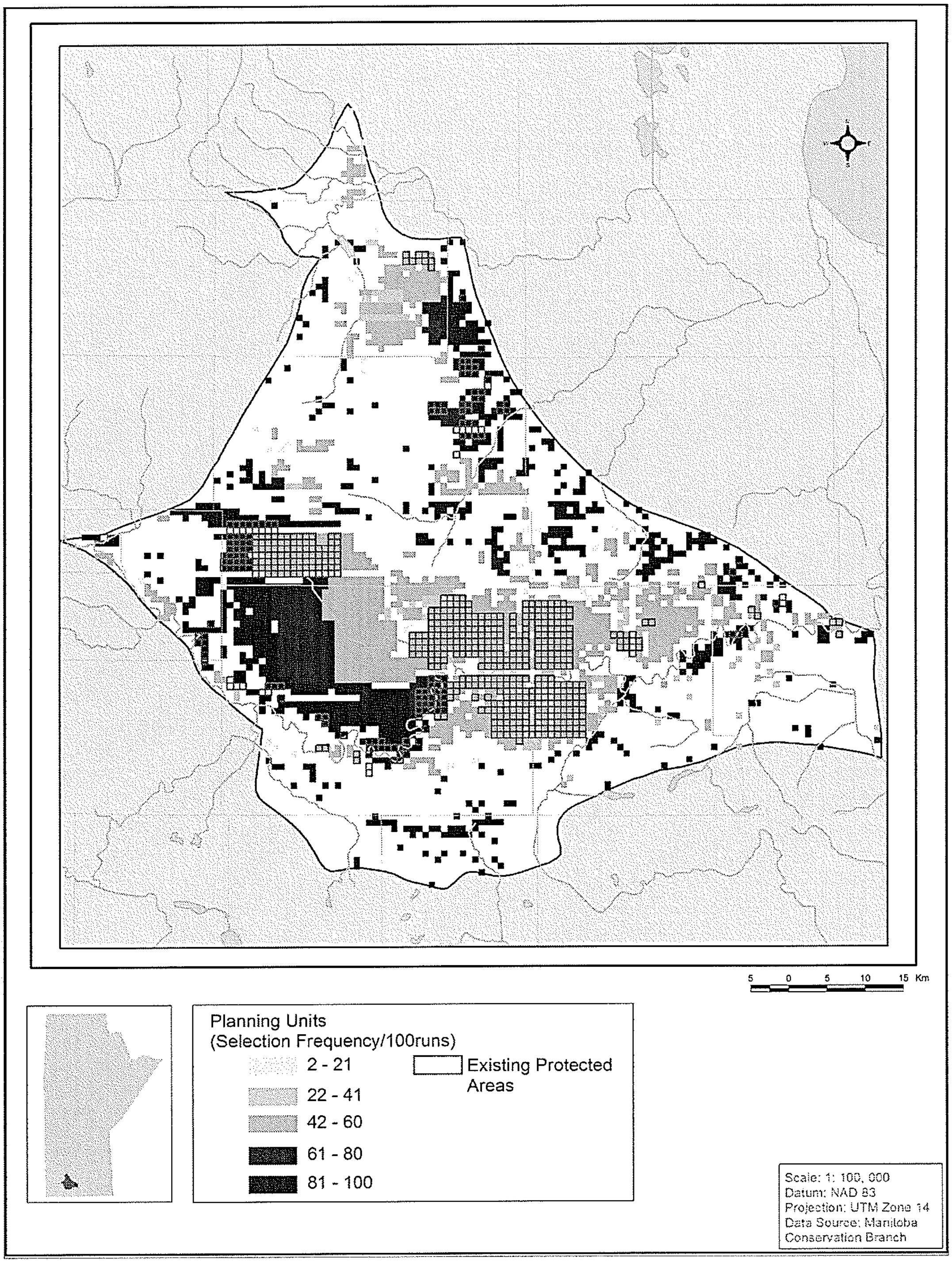


Figure 5.45 No Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown and Private Lands - Proportional Conservation Target

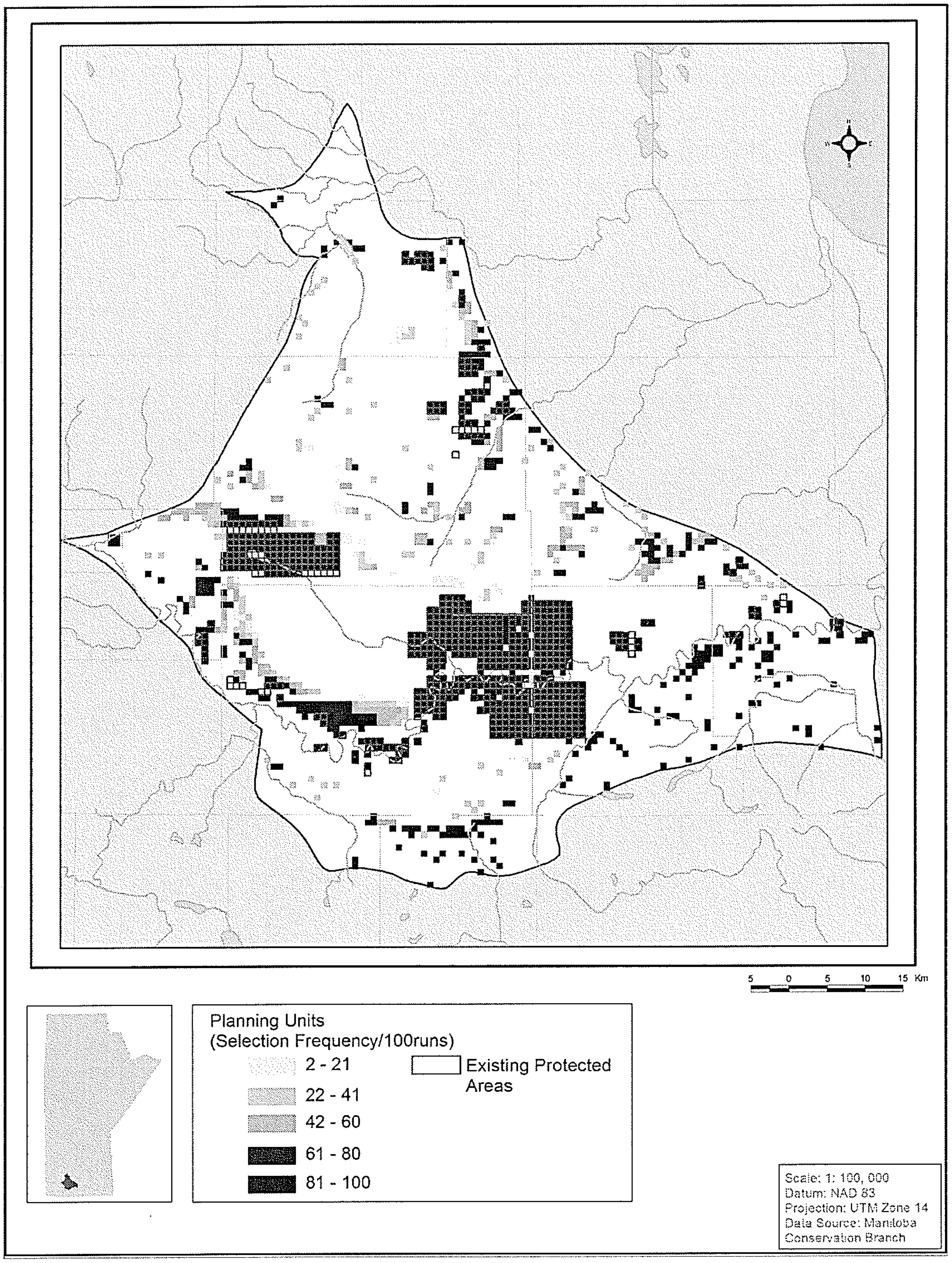


Figure 5.46 Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown and Private Lands - 15% Conservation Target

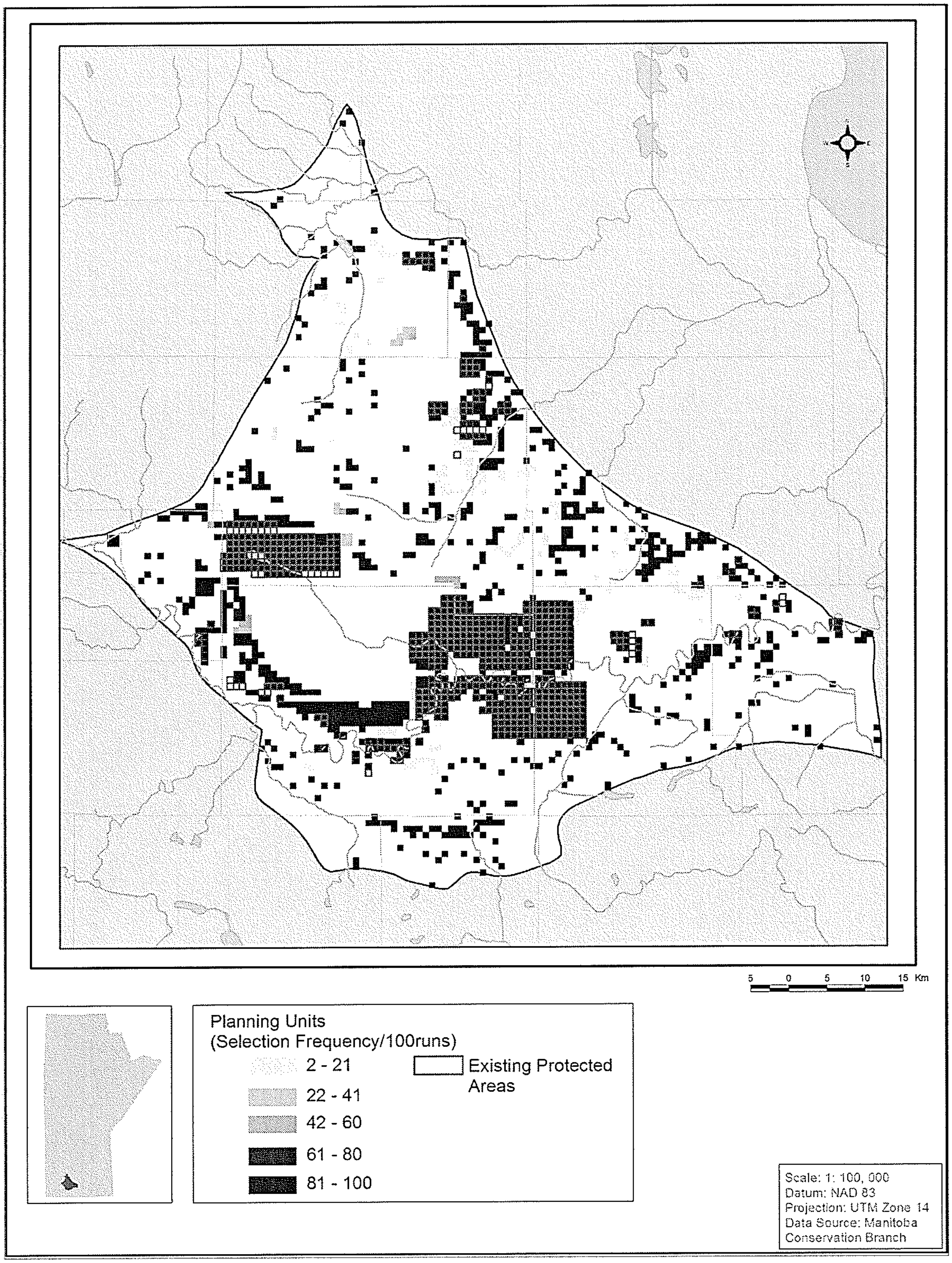


Figure 5.47 Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown and Private Lands - 25% Conservation Target

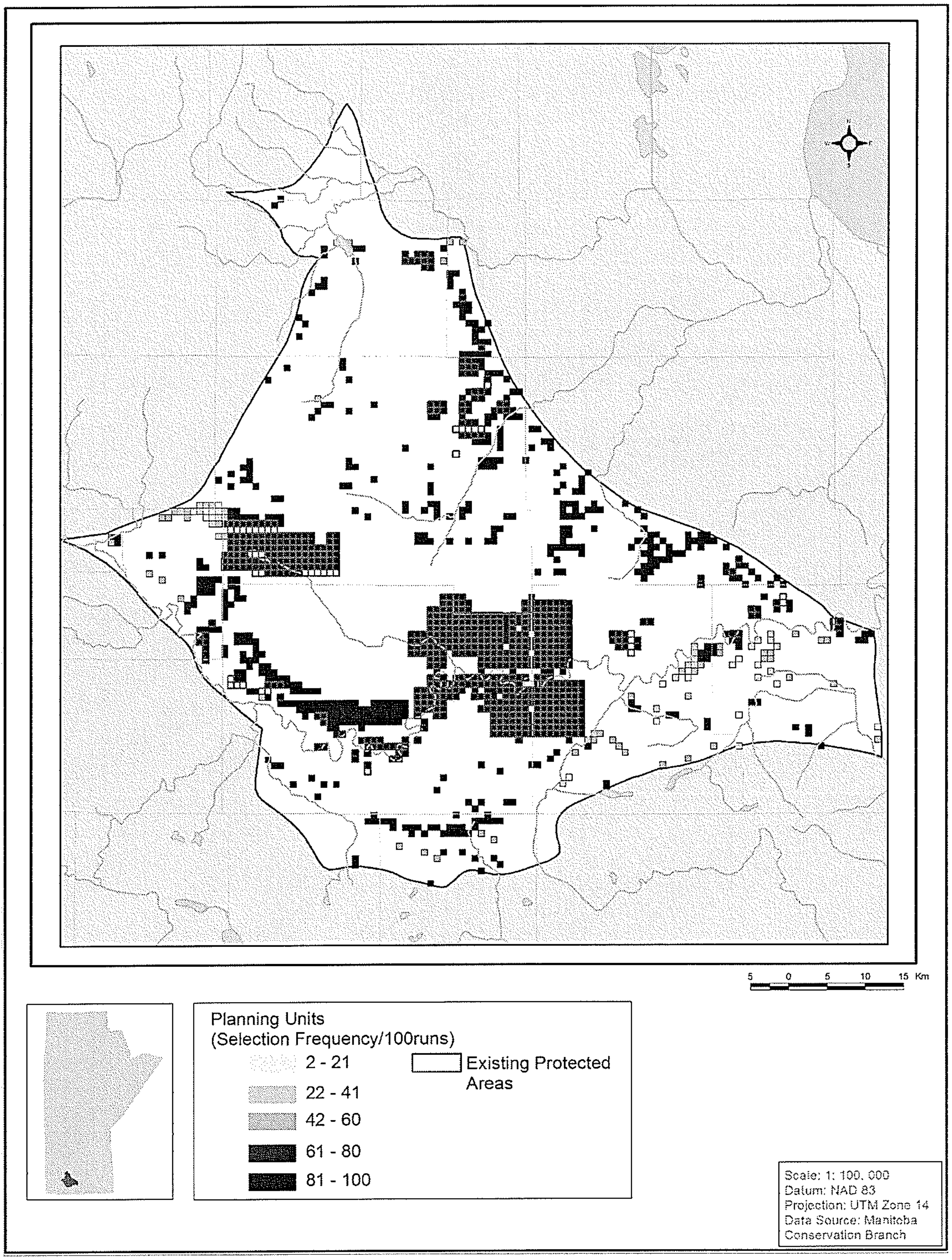


Figure 5.48 Existing Protected Area Conservation Scenario: Planning Units Selection Frequencies on Crown and Private Lands - Proportional Conservation Target

Chapter 6: Discussion and Conclusion

6.1 Introduction

Systematic site selection methods contain the potential to be successfully utilized as tools for conservation planning. These methods incorporate spatially explicit data and conservation principles in order to identify comprehensive networks of protected areas. This thesis focused on the application of two systematic site selection methods, a greedy heuristic algorithm and a simulated annealing algorithm in order to identify areas that could potentially contribute towards the representation of biodiversity within the Assiniboine Delta region. As part of this analysis, several parameters were varied in order to explore how they influenced the different conservation scenarios that were under investigation.

6.2 Objective 1 – Discussion and Conclusion

The first objective of this thesis was to examine the extent to which previously established protected areas contributed towards the conservation of the biodiversity within the Assiniboine Delta region, and to establish conservation goals for this region based on the results of this assessment. In order to fulfill this objective, conservation goals were calculated for each enduring landscape feature for the three conservation target classes (15%, 25% and proportional). Next, a gap analysis was performed. The importance of running a conservation gap analysis was that it provided a sense of direction with regards to where conservation efforts were required. The information generated from the gap analysis was used to assess the extent to which ecosystem representation had been previously achieved.

The current network of protected areas within the Assiniboine Delta region conserved a total of seven enduring landscape features, which amounted to 42,176 hectares of land. The extent to which the seven enduring landscape features were represented is listed in Tables 5.5, 5.6 and 5.7. The influence of the existing conservation network varied significantly between the three conservation target classes. For the 15% conservation target class, none of the enduring landscape features were adequately represented. However, for the 25% and proportional conservation target classes, deltaic deposits / regosol / sand dunes was adequately captured within the existing conservation network. The extent to which enduring landscape features were over represented revealed some interesting information. The over representation of enduring landscape features translated into an additional 10, 249 hectares of land for the 15% conservation target class, 2,096 hectares of land for the 25% conservation target class and 10,347 hectares of land for the proportional conservation target class. As noted by Pressey (1994), the presence of existing protected areas can make the goal of representing regional biodiversity more expensive. This may lead to difficulties with regard to protecting the full range of conservation features within a region, in that it reduces the overall efficiency in which a fully representative conservation network can be established. In addition, because of competing interests within the landscape, the over representation of certain enduring landscape features may take away the opportunity of other enduring landscape features being protected, especially if a ceiling has been placed on the amount of land base that has been allocated to conservation efforts.

Based on the results of the gap analysis, existing protected areas may influence the manner in which candidate areas were selected for conservation, thus representation goals were generated for two conservation scenarios. The first conservation scenario took into account the current network of protected areas and the other treated the Assiniboine Delta study region as if no protected areas had been previously established. These conservation goals are listed in Table 5.10. For the *no existing protected areas* conservation scenario, the representation goals for each of the enduring landscape features were left unchanged. As for the *existing protected areas* scenario, the representation goals that were generated for the three conservation target classes were adjusted accordingly so that additional sites would be selected in a manner that would complement the existing network of protected areas.

6.3 Objective Two – Discussion and Conclusion

Conserving biodiversity through the establishment of protected area networks forms the foundation for most conservation strategies (Willis *et al.,* 1996). To be successful, protected area networks must contain samples of the natural diversity found within the region, and so need to be selected with great care. Different approaches have been developed over the past couple of decades to facilitate conservation planning. The second objective of this thesis was to review and evaluate the different site selection methods that have been developed, and to apply them in the selection of candidate protected areas for the Assiniboine Delta region.

The first methods that were adopted by conservation planners were combinatorial scoring methods. In response to a number of inherent limitations with these approaches, the scientific community developed a variety of new conservation methodologies. GAP analysis, enduring feature analysis approach and systematic selection methods have been proposed as new techniques to conservation planning. Of the three approaches, systematic selection methods have been the most widely adopted (Nantel et al 1998). Systematic selection methods are a powerful decision support tool in conservation planning. In particular, what distinguishes systematic approaches is their ability to efficiently select areas for conservation in a manner that is most complementary, thus producing a selection of candidate areas that are representative of the diversity found within a region (Williams, 2000). The information that is generated can be used to set priorities for the conservation activities, such as designing future reserves, ecosystem restoration and planning land acquisition. Due to their inherent flexibility, efficiency and explicitness, systematic methods allow planners to appraise a wide range of alternative conservation options in order to achieve various goals and to minimize conflicts with other land uses.

A major component of this thesis was to demonstrate how alternative reservation systems could be generated under different conservation scenarios. Systematic approaches were capable of producing different sets of results, which allowed for changes to be made to the data sets, algorithms, and conservation goals. The two algorithms that were used in this analysis were a greedy heuristic algorithm and a simulated annealing algorithm. These two algorithms have been designed to select the minimum number of sites required to meet representation goals as efficiently as possible. Three sets of conservation targets were assessed (15%, 25% and proportional), along with three measures of clustering (BLM's 0.0, 0.5 and 1.0).

For both conservation scenarios, the greedy heuristic algorithm selected the smallest number of sites when the BLM was set to 0.0. However, the greedy heuristic algorithm also generated the longest boundary lengths for that class. This occurred for ten of the twelve scenarios. Therefore for the BLM of 0.0, the greedy heuristic algorithm effectively selected sites despite the fact that their spatial configuration was not compact. When the greedy heuristic algorithm had the option of selecting planning units from both crown and private lands for the 15% and 25% conservation target classes, the largest number of planning units was selected and the longest boundary length was generated when the BLM was set to 0.5. This indicated that the greedy heuristic algorithm was not overly effective at selecting sites when the BLM was set to 0.5.

The simulated annealing algorithm produced a different set of results when the BLM was varied for the different conservation scenarios. When the algorithm's selection radius was limited to selecting sites on crown lands, the smallest number of planning units and the largest boundary lengths were generated for the BLM of 0.0 for all three conservation target classes. As such, the simulated annealing algorithm was effective at selecting sites, although they were not spatially compact. This was also the case when the simulated annealing algorithm had the option of selecting sites from both crown lands and private lands for the *existing protected areas* scenario, as well as for the proportional target class in the *no existing protected areas* scenario. The simulated annealing algorithm generated both the most compact and effective selection for the 15% conservation target when the BLM was set to 0.0, and for the 25% conservation target when the BLM was set to 0.5.

When comparing the results for all twelve conservation situations, the simulated annealing algorithm generated the most compact and effective selections. These were generated for the *no existing protected areas* conservation scenario for the 15% conservation target when the BLM was set to 0.0, and for the 25% conservation target when the BLM was set to 0.5. It was interesting to note that the two algorithms had the identical objective function scores for the same conservation scenarios when they selected sites from crown lands and the combination of crown and private lands. However, based within the scope of this thesis, it was not possible to determine if this was a function of the algorithms themselves or a function of the data sets and planning unit constraints. The overall success of the simulated annealing algorithm may be attributed to the fact that as the algorithm generated solutions, the new solution was compared with the previous solution, and the best one was accepted. The advantage of this approach was that it potentially avoids getting trapped in local minimum (Possinghan *et al.,* 2000). That is greedy heuristic algorithms quickly converged to just a few selection sets because there were few points where two or more neighbouring solutions provided the same decrease in the cost, and hence random selection of neighbouring solutions were rarely made.

6.4 Objective Three – Discussion and Conclusion

6.4.1 Summary Statistics

This component focused on how greedy heuristic algorithm and simulated annealing algorithms could be used to identify protected areas that comprehensively represent all habitat types in a sensible spatial arrangement. The best results that were generated for each conservation scenario were imported into a GIS where summary statistics were generated for each conservation scenario. These summary statistics were indicative of how the two algorithms operated under the two conservation scenarios.

When there was an increase in the BLM, the algorithm gave preference to the inclusion of sites which minimized the overall perimeter, thereby clustering the sites and generating a well-connected reserve system. When the algorithms were free to select candidate sites from both crown and private lands, as the BLM increased both algorithms selected a greater number of sites, as to be expected. For the simulated annealing algorithm, as the BLM increased, so did overall compactness of the selected sites. Whereas the greedy heuristic algorithm experienced an increase in the total amount of area selected, the number of sites that were selected and the total boundary edge compared to the simulated annealing algorithm. These results indicated that the sites selected by the simulated annealing algorithm have a tighter spatial aggregation, whereas the sites selected by the greedy heuristic algorithm were much more scattered throughout the study area. The variation in the way the two selection algorithms preformed with regards to clustering of sites might be attributed to the different way in which the algorithms select sites. Simulated annealing algorithms were capable of selecting and dropping planning units as they move through the selection process, where as this was not incorporated into the greedy heuristic algorithm selection design.

When the algorithms were confined to select candidate sites on crown lands, some interesting trends occurred. The greedy heuristic algorithm selected a larger total area for both conservation scenarios. The simulated annealing algorithm had a more difficult time with developing clusters of sites when the selection of candidate areas to was limited crown lands. For both the 15% and 25% conservation target classes, the simulated annealing algorithm selected a greater number of actual sites and had a longer boundary length. This may indicate that when the algorithm search radius was confined to a smaller amount of planning units, the options with regards to selecting sites to form clustered areas was limited. However, it was difficult to determine if this trend was a result of an artifact of the data, or a real trend in the analysis.

6.4.2 Representation

The idea that a system of protected areas should represent the range of biological diversity of the surrounding has been advocated widely as the underlying principle that the selection process aims to satisfy (Mondor, 1990). Thus the measure or the degree to which a network of protected areas portrays the biological diversity of a region is very important. Within the scope of this work, the goal of representation was to fully capture specific amounts of all the enduring landscape features within designated candidate lands, that is, crown lands and private lands that were still in their natural state. This research revealed that the extent to which the two algorithms were able to successfully fulfill their conservation objectives was strongly influenced by the availability of enduring landscape features for selection.

Neither algorithm achieved full representation for all conservation scenarios that were under investigation. The reason being was that enduring landscape features deep basin / black chernozem, glaciofluvial deposits / regosol and glacial till derived from mesozoic rock / regosol were not present within any crown lands or suitable private lands, thus were not included within any of the planning units used for the selection analysis. Therefore a stronger emphasis was placed on how effectively the algorithms represented each enduring landscape feature in order to identify which of these features had a tendency of being over represented when different conservation target classes were applied.

Enduring feature representation within crown lands was fairly low compared to that of crown and private lands. Within crown lands, a total of nine enduring landscape features were not available within the existing set of planning units. As for the other eight enduring landscape features, alluvial deposits / regosols, deltaic deposits / regosol / sand dunes and organic deposits / regosol were over-represented. The reason for this was that these enduring landscape features were previously over represented within the existing network of protected areas. These findings were consistent for both the *existing protected areas* and *no existing protected areas* conservation scenario.

The algorithms came closer to reaching their conservation targets when they had the option of selecting enduring landscape features from both crown and private lands. Within crown and private lands, a total of three enduring landscape features deep basin / black chernozem, glaciofluvial deposits / regosol and glacial till derived from mesozoic rock / regosol were not available within the existing set of planning units. For all three conservation target classes, more enduring features were adequately represented which was to be expected, since there was a larger group of planning units to select from. As a result the overall representation of enduring landscape features was more successful when the algorithms had the option to select sites from both crown and private land parcels.

6.4.3 Efficiency

Efficiency refers to the degree to which reserve selection minimizes unnecessary duplication of features in a reserve system by identifying sites that are highly complementary in terms of the features they contain (Pressey and Nicholls, 1989). In most regions, only a small proportion of land area will ever be dedicated to nature conservation so efficiency can be determine the likelihood of achieving a reservation goal in the face of limited resources and competition with alternative land uses. Efficiency was important to consider when examining the extent that representation targets were achieved under the different sets of constraints. In addition, it was useful for comparisons between the different conservation scenarios. It was important to recognize that efficiency can be influenced by the number of surrogate classes and the target percentage of each feature to be represented. As previously noted, the representation of the maximum diversity of the relevant features at the minimum cost was important because reserves will commonly be in direct competition with other forms of land use.

Given that an increase in the BLM influenced the emphasis that the selection algorithms placed on selecting sites that were clustered, it was interesting to see if this increase had any effect on the efficiency in which the algorithms selected sites. The efficiency of which the algorithms selected candidate sites from crown land was not overly affected by an increase in the BLM. The algorithms proved to be the least efficient when the BLM was set to 0.0, but there appeared to be minimal difference between a BLM that was set to 0.5 or 1.0. However, there was a noticeable difference when the algorithms were free to select candidate sites from both crown and private lands. In this particular instance, the most efficient solutions were generated when the BLM was set to 0.5. For the conservation scenario in which the algorithms had the option of selecting sites from both crown and private lands the simulated annealing algorithm produced the most efficient results overall. The opposite was illustrated when the selection algorithms search radius was limited to crown lands. In this instance, the greedy heuristic algorithm was more efficient.

As for examining how efficient the two algorithms were at achieving their conservation goal for the three sets of conservation targets when restricted to selecting sites on crown lands, the 25% conservation target class was the least efficient. This was not unexpected since the area requirements for this class were much larger. In instances where the algorithms search radius was limited to crown land parcels, conservation goals for the individual enduring landscape features were not satisfied. Following this, the 15% conservation target class was the most efficient at satisfying the required conservation targets. As for the conservation scenario in which the two algorithms had the freedom to select areas from both crown lands and private lands, the trends varied somewhat. For the 15% and the proportional conservation target classes, the algorithms were more efficient at generating solutions for the *existing protected area* conservation scenario. As for the *no existing protected areas* conservation scenario, both the 15% and 25% were closely matched.

6.5 Objective Four – Discussion and Conclusion

The fourth objective was to identify a spatial framework within which the different conservation scenarios for the Assiniboine Delta Region could be presented. As there were many possible reserve systems, it was useful to know something about the relative importance of individual planning units for conservation planning. Selection frequency counts, otherwise referred to as 'summed irrpelaceilibility' were used to provide a measure of the contribution of any one planning unit to the reservation goals (Ball and Possingham, 2001). An indication of a planning unit's utility was generated by examining how many times a particular planning unit was selected by the selection algorithms (Ardon, 2002). The information generated from summed irreplaceilibility can facilitate the exploration of different conservation scenarios such as the extent to which the option of achieving the set of targets are reduced if the area is unavailable for conservation. In addition, the visualization of those areas that were consistently selected in the analysis can be a useful tool.

When the algorithm's selection radius was confined to crown land, similar patterns emerged for both the *existing protected areas* and the *no existing protected areas* scenario. When examining the frequency of which of the two sets of planning units were selected by the algorithms, it became evident that the algorithms had a tendency to select the same sites. This can be attributed to the fact that there was limited number of combinations that the algorithms could choose from. However, when the selection algorithms had the choice to select areas from crown and private lands, there was a lot more flexibility with regards to the frequency in which particular sites were selected. As a result of the two algorithms selecting relatively the same combination of sites, it was difficult to evaluate and compare the two conservation scenarios i.e. *existing protected areas* and the *no existing protected areas.*

The most insight was gained from evaluating the *no existing protected areas* conservation scenario when the algorithms had the freedom to select sites from all lands. When there were no constraints placed on the algorithms, few planning units that contained existing protected areas were used in all 100 runs. For the 15% conservation target class, a total of 832 hectares of land were selected included current protected areas. For the 25% conservation target class, 1994 hectares of land were selected from existing protected areas. For the proportional target class, 1984 hectares of land were selected included the existing network of protected areas.

While the areas that were continuously selected for each of the 100 runs by themselves would not make up an adequate conservation network, it was likely that if the majority of them were not included, such a network would be difficult or impossible to achieve. The reason was that certain areas were consistently selected by the algorithms because those planning units represented the only available options for conservation of those enduring landscape features, thus they were selected because with out them, ecosystem representation would not be possible.

6.6 Conclusion

The intent of this thesis was to explore how site selection algorithms can facilitate the identification and selection of networks of protected areas that comprehensively represent all habitat types in a sensible spatial arrangement. This was accomplished by examining variations in the amount of spatial clustering, conservation targets and conservation scenarios for a greedy heuristic algorithm and a simulated annealing algorithm.

It was noted by Roberts et al (2003), that by design, systems with lower perimeter values tend to be better connected; a quality that may be preferable for both biological and sociopolitical reasons. However, there were trade offs between emphasizing spatial compactness and the total area of the network of protected areas.

Even though an increase in the BLM resulted in a more clustered set of reserves, this also resulted in a corresponding increase of the total area selected. When the emphasis was placed on generating a selection set that was spatially compact, the simulated annealing algorithm outperformed the greedy heuristic algorithm. With regards to achieving conservation targets, the simulated annealing algorithm was much closer at meeting the conservation goals in the most efficient manner. Overall, the strength of the simulated annealing algorithm was that it offered a variety of scenarios that met the incorporated goals. This was important in that with more options, stakeholders have a greater chance of creating an ecological and socially sustainable system of protected areas.

When examining the extent to which a comprehensive network of protected areas could be established within the study area, the question was posed; what would a network of protected areas within the Assiniboine Delta region look like, and is it possible to establish one that is representative of the surrounding ecosystem? In order to examine the full depth of this question in a manner that would not only define achievable conservation goals, yet based on the general suitability and availability of land, two conservation scenarios were examined, along with two sets of potential candidate areas for protection, and three sets of conservation targets. In the first scenario, existing protected areas were locked into the analysis, thus the algorithms were forced to include existing protected areas as part of their site selection. The second scenario represented the reverse set of conditions leaving the algorithms free to either ignore or incorporate existing protected areas into the site selection process.

The main findings that emerged from the first conservation scenario, where the selection algorithms concentrated their search efforts on crown land parcels, was that efficient ecosystem representation could not be achieved. The main reasons for this are as follows. First, in order to achieve full ecosystem representation, a much larger land base would be required than what was available. Second, the manner in which the crown land parcels were spatially distributed across the landscape did not adequately sample all of the enduring landscape features. Third, the manner in which previously established protected areas have been selected resulted in the over representation of three enduring landscape features. This was consistent for all three sets of conservation targets. Therefore the presence of existing sites may significantly reduce the efficiency of a network at representing overall biodiversity, so that more reserves will be needed in total. Even though past conservation decisions have a strong influence on the future development of a comprehensive network that is representative of a region of biological diversity, it is important to recognize that part of the existing reserve system does make an efficient contribution to achieving biodiversity conservation targets.

As for the second conservation scenario in which the algorithms were free to either ignore or incorporate existing protected areas into the site selection process, the main findings are as follows. Even when relatively undisturbed privately owned lands were incorporated into the selection pool, it was still not possible to achieve full ecosystem representation. The reason being was that enduring landscape features deep basin / black chernozem, glaciofluvial deposits / regosol and glacial till derived from mesozoic rock / regosol were still not available for selection within this more extensive set of planning units. If full ecosystem representation based on enduring landscape features was going to be accomplished, not only would conservation planners have to look outside crown land to include privately owned land, but they would also have to examine the options of restoration and rehabilitation.

Some interesting management implications emerged from this work. In particular, it became evident that it would not be possible to establish a network of protected areas within government-managed lands within the Assiniboine Delta region. This is due to the fact that there is simply not enough land available. Even when relatively undistributed privately managed lands were included in the analysis, not only was there not enough available land but the locations of available land did not always coincide with conservation requirements. Another important management implication that emerged from this research was that because ecosystem representation cannot be achieved within crown lands and undisturbed private lands as previously mentioned, landscape restoration and rehabilitation would have to examine.

With the intent of exploring how site selection algorithms could facilitate the identification and selection of networks of protected areas that comprehensively represent all habitat types in an efficient spatial arrangement some interesting issues emerged from this work. Even though both the greedy heuristic algorithm and the simulated annealing algorithm managed to successfully selected sets of candidate areas, it became quite evident that the availability of planning units did influence the overall selection of sites. When the two algorithms were confined to selecting sites within crown lands, the two algorithms had a more difficult time generating selection sets compared to when they had the freedom to select sites from both crown and private lands. The size of the planning units also influenced the overall selection in that each planning unit contained one conservation feature. If the planning units had been much larger they would have contained various amounts of the different conservation features the results generated by the two algorithms may have been quite different. Overall the data sets that were utilized for this analysis were quite adequate for this level of analysis. However, it is important to note that the choice of surrogate data sets has a very strong influence on the outcome of the analysis. If for instance, a different set of surrogate data was utilized such as a vegetation classification, chances are that the selection sets generated by the algorithms would be quite different. Thus a lot of care and consideration must be placed on the choice of conservation features selected to represent the biodiversity of a particular region under study.

6.8 Future Work

The results generated by this research suggest that systematic selection methods provide a set of promising and powerful tools for the selection of conservation areas. As such, there exist many future avenues for research that can be explored by modifying various aspects of the selection process. One important component of conservation is the extent to which both natural and social sciences can be incorporated together. Systematic methods offer a practical way of incorporating the two sciences when selecting sites for conservation.

Systematic selection algorithms are programmed to be as efficient as possible when selecting candidate areas to include in the networks of protected areas by minimizing the cost of the network. One of the main reasons for this is that the use of an area for conservation purposes generally translates into the unavailability of that area for commercial use. With this in mind, another valuable area of future research would involved the examination of the reverse situation, that is the incorporation of the economic cost of land use such as the costs associated with management, or even the loss of agricultural or timber potential.

Another powerful component of systematic site selection methods is their ability to explore a number of variations with regards to conservation goals, spatial configuration and surrogate databases. In this thesis habitat representation was used to formulate goals, however, there are many other types of goals that could be explored such as specific requirements for the algorithms to include such factors as a certain number of occurrences of conservation features, the inclusion of particular sites or combination of sites, specific size requirements, or even sites that are a specific distance from each other. Another area of future research could center on the spatial dimensions of systematic site selection, for example, specific requirements for size, connectivity, replication and ailment of boundaries could be evaluated. Additional variations that can be adopted could focus on the application of different surrogate ecosystems, as well as the incorporation of local and traditional knowledge or social perceptions towards the conservation of ecosystem conservation thus allowing for the examination of how these characteristics influence the selection process.

Another area of future research centers on the notion that landscapes are considered to by dynamic in that they continue to change with regards to economic and social conditions. Typically even though a conservation network design may have been identified, there are usually insufficient resources to implement the entire conservation network. In some cases it may take decades of negotiation and land acquisition to establish a network of protected areas on the ground. However, over time key sites may be lost before they become available for conservation action, and if these key sites are integral to the overall reserve networks goals, then the final system may be quite poor when measured against the initial goals. Due to the fact that unforeseen changes could potentially result in the loss of candidate areas before implementation is complete, it would be interesting to model 'potential changes' in the cultural landscape to see if and how these changes affect the overall network of protected areas. Solutions to these problems, even approximate solutions will improve the design of effective reserve networks and ultimately will contribute to better protection for biodiversity.

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Appendix 1: Base Layer Data Sets

Data Layer	Data Source	Year	Projection Information	Scale	General Description
Protected Area Boundaries in Manitoba	Manitoba Conservation - Parks and Natural Areas	2001	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:500,000	The Manitoba Protected Area digital boundary layer was updated June 6, 2001. The boundaries of this layer were delineated using best available base maps. The file was refined using the Director of Survey Plans. This boundary file was made to show all the protected areas in Manitoba, regardless of land designation.
Areas of Special Interests	Manitoba Conservation - Parks and Natural Areas	2001	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	NA	This boundary file was made to show all the areas in the. Province that are flagged for the Protected Areas, and are currently under review.
Provincial Forest Boundaries	Manitoba Conservation - Forest Resources Management	NA	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:50,000	These forests have been zoned for different use including creating provincial parks, wildlife management areas and ecological reserves within their boundaries. Land that is classified as Provincial Forest. Purpose to give a general geographic representation of Manitoba's Provincial Forests.

Appendix 1: Base Layer Data Sets cont.

Ecological Reserves	Manitoba Conservation - Parks and Natural Areas	1998	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:500,000	Areas that contain rare or sensitive habitats can be set aside as ecological reserves with greater restrictions on uses and activities. The Ecological Reserve theme shows the boundary of the Ecological Reserves in Manitoba.
Wildlife Management Areas	Manitoba Conservation - Wildlife Branch	2000	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:60,000	File is the boundary file for Manitoba's Wildlife Management Areas. It contains WMA Names, Unit names and year of creation. File is designed to give quick, accurate location information on Wildlife Management Areas
Cadastral - Provincial Boundaries	Manitoba Conservation - Geomatics Services	1994	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:500,000	To provide end users with a digital map of Manitoba's boundaries. It is suitable for most medium and small scale digital map applications as well as GIS georeferencing in general.

Appendix 1: Base Layer Data Sets cont.

Manitoba Natural Regions	Manitoba Department of Conservation Branch - Parks and Natural Areas	NA	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:1,000,000	To provide users with a digital map of Manitoba's Natural Regions which are broad areas that share similarities in geography, climate and vegetation.
Enduring Landscape Features	Manitoba Conservation Branch	1996	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:1,000,000	To provide users with a spatial description of the enduring landscape features found in Natural Region 12. Each natural region has been sub-divided into smaller ecological units based on geology, soils and landforms, which are used to represent the biological diversity of a natural region.
Municipalities and LGD Boundaries	Manitoba Department of Conservation-Land Information Division	2000	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:50,000	The Administrative Boundaries data sets contain vector representation and names of various administrative regions and index grids for the Province of Manitoba. To provide the public with the official governing boundary attributes of various administrative regions in the Province of Manitoba.

Appendix 1: Base Layer Data Sets cont.

Township Grid	Manitoba Department of Conservation-Land Information Division	2000	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:50,000	The Administrative Boundaries data sets contain vector representation and names of various administrative regions and index grids for the Province of Manitoba. To provide the public with the official governing boundary attributes of various administrative regions in the Province of Manitoba.
Roads	Manitoba Transportation-Planning and Design	1996	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:60,000	The Linear Referencing System is the digital representation of the Highway Network in Manitoba. The features indicate region number, highway number and control section.
Rivers	Manitoba Conservation,L and Information Division	1996	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:1,000,000	The 1 to 1,000,000 scale Topographic Base Map is a digital map dataset that shows rivers, To provide the public with a general topographic base map coverage of Manitoba.

Appendix 1: Base Layer Data Sets cont.

Lakes	Manitoba Conservation,L and Information Division	1996	North American North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:1,000,000	Topographic Base Map is a digital map dataset that shows lakes. This data layer is used to provide the public with general topographic base map coverage of Manitoba.
Urban Centers	NTS Sheets 62G & 62J Third Edition	1989	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:250,000	Topographic Base Map is a digital map dataset that shows city limits and towns. This data layer is used to provide the public with general topographic base map coverage of Manitoba.
Rail Network	NTS Sheets 62G & 62J Third Edition	1989	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:250,000	Topographic Base Map is a digital map dataset that shows the rail network. This data layer is used to provide the public with general topographic base map coverage of Manitoba.

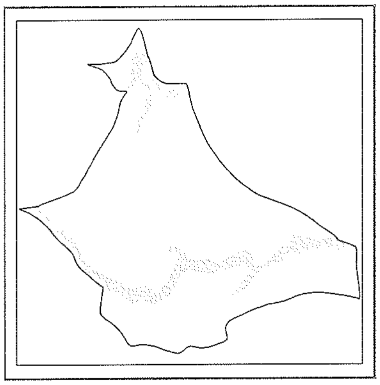
Appendix 1: Base Layer Data Sets cont.

Power Network	NTS Sheets 62G & 62J Third Edition	1989	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	1:250,000	Topographic Base Map is a digital map dataset that shows the power network. This data layer is used to provide the public with general topographic base map coverage of Manitoba.
Manitoba Land Use Classification	Manitoba Center for Remote Sensing	1993-1994	North American Datum of 1983, Ellipsoid GRS 80, Universal Transverse Mercator Zone 14	30 meter resolution	This dataset contains coverage of various size, depicting land use / land cover features, which were compiled based on Landsat Thematic Mapper (TM) imagery. The pixel resolution of this data is 30 meters. Upon classification, sixteen land classes are mapped, these being agricultural crop land, forage crops, grassland, open deciduous, deciduous, coniferous, mixed wood forests, treed rock, bogs, marshes and fens, bare rock, burnt areas, forest cutovers, open water, cultural features, roads and trails. Purpose: To display land use / land cover features used by earth resources management agencies and for environmental monitoring.

Appendix 2: Summary Information for Individual Enduring Landscape Features

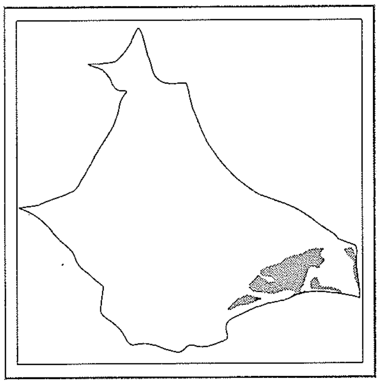
AD/R: Alluvial Deposits / Regosols

Number of ELF	8
Total Area (Ha)	49,276
Mean Area (Ha)	6,160
Total Boundary Length (m)	41,2826



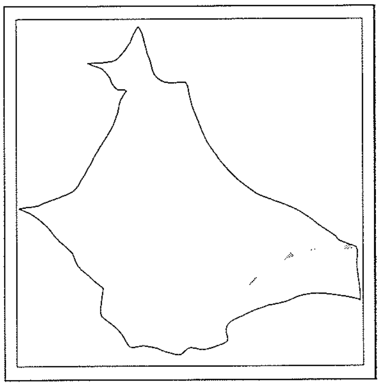
BN/C : Beach and Nearshore Deposits / Black Chernozem

Number of ELF	4
Total Area (Ha)	2,305
Mean Area (Ha)	5,976
Total Boundary Length (m)	162,555



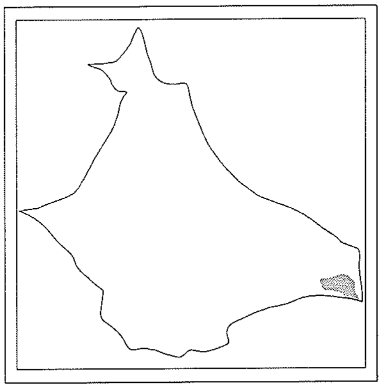
BN/R : Beach and Nearshore Deposits / Regosols

Number of ELF	4
Total Area (Ha)	923
Mean Area (Ha)	231
Total Boundary Length (m)	29,677



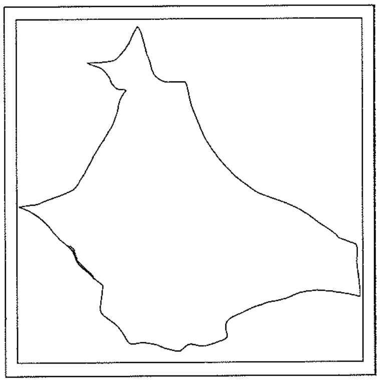
DB/C : Deep Basin / Black Chernozem

Number of ELF	2
Total Area (Ha)	5,611
Mean Area (Ha)	2,805
Total Boundary Length (m)	34,544



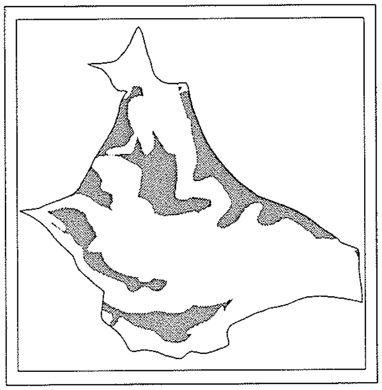
DB/R : Deep Basin / Regosols

Number of ELF	1
Total Area (Ha)	987
Mean Area (Ha)	987
Total Boundary Length (m)	28,772



DD/C : Deltaic Deposits / Black Chernozem

Number of ELF	8
Total Area (Ha)	118,319
Mean Area (Ha)	14,790
Total Boundary Length (m)	624,801

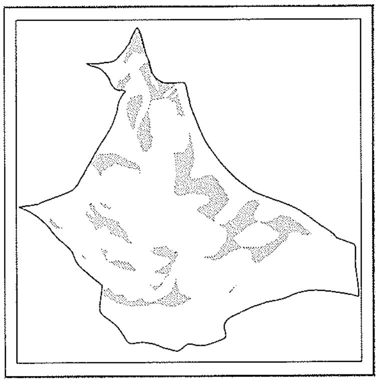


DD/C/S : Deltaic Deposits / Black Chernozem / Sand Dunes

Number of ELF	9
Total Area (Ha)	22,145
Mean Area (Ha)	2,461
Total Boundary Length (m)	201,174

DD/R : Deltaic Deposits / Regosol

Number of ELF	18
Total Area (Ha)	81,007
Mean Area (Ha)	4,500
Total Boundary Length (m)	696,152

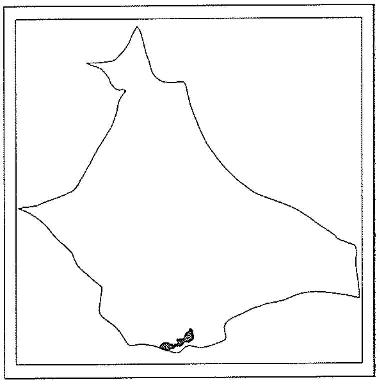


DD/R/S : Deltaic Deposits / Regosol / Sand Dunes

Number of ELF	5
Total Area (Ha)	78,005
Mean Area (Ha)	1,5601
Total Boundary Length (m)	354,597

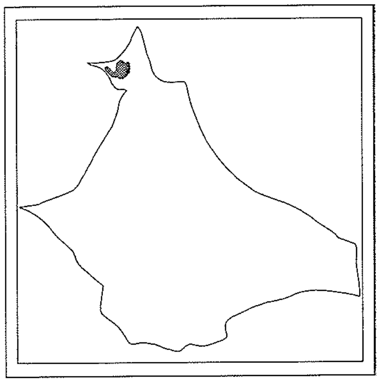
GD/C : Glaciofluvial Deposits / Black Chernozem

Number of ELF	1
Total Area (Ha)	2,652
Mean Area (Ha)	2,652
Total Boundary Length (m)	30,340



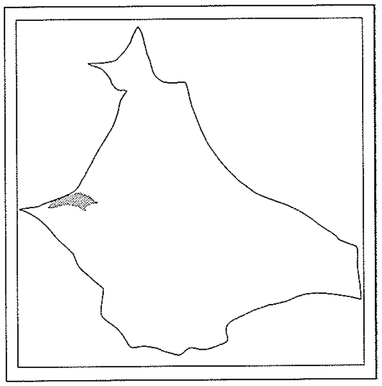
GD/R : Glaciofluvial Deposits / Regosol

Number of ELF	1
Total Area (Ha)	2,876
Mean Area (Ha)	2,876
Total Boundary Length (m)	25,320



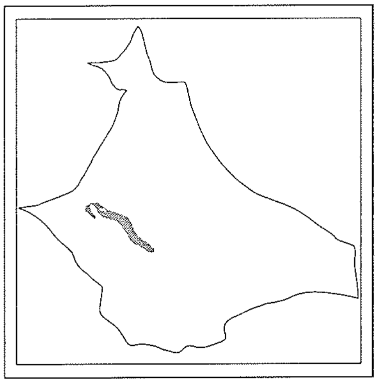
OD/C : Organic Deposits / Black Chernozem

Number of ELF	1
Total Area (Ha)	4,640
Mean Area (Ha)	4,640
Total Boundary Length (m)	37,017



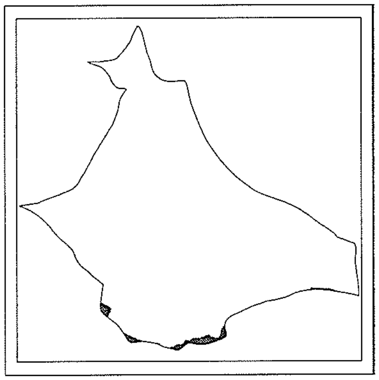
OD/R : Organic Deposits / Regosol

Number of ELF	1
Total Area (Ha)	6,617
Mean Area (Ha)	6,617
Total Boundary Length (m)	69,986



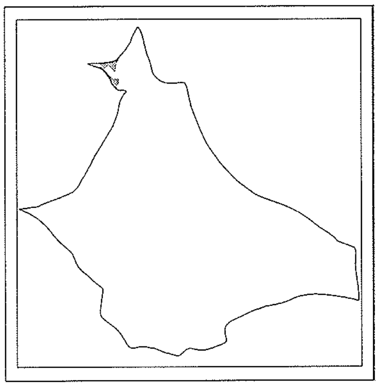
T1/C : Glacial Till Derived from Palaeozoic Rock / Black Chernozem

Number of ELF	5
Total Area (Ha)	5,353
Mean Area (Ha)	1,071
Total Boundary Length (m)	93,072



T1/R/M : Glacial Till Derived from Palaeozoic Rock / Regosol / Moraine

Number of ELF	1
Total Area (Ha)	1,856
Mean Area (Ha)	1,856
Total Boundary Length (m)	33,373



Appendix 2: Summary Information for Individual Enduring Landscape Features cont.

T2/R : Glacial Till Derived from Mesozoic Rock / Regosol

Number of ELF	3
Total Area (Ha)	753
Mean Area (Ha)	251
Total Boundary Length (m)	20,727