Fighting Fire with Fire: Investigating Prescribed Burns for Fuel and Fire Management in Quetico Provincial Park, Ontario

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Uncontrolled wildfires occur in Ontario and across Canada each year, typically during the fire season from April 1 to September 30. Fire suppression in protected areas and property (private, Crown land) coupled with warmer and drier summers are causing increased hazardous conditions that add fuel to the fire and result in more intense and prolonged wildfires.

Park managers realize that fire plays a significant role in maintaining the health of a boreal ecosystem and reducing flammable forest fuels. Prescribed burning is one practice that can regenerate fire-dependent ecosystems, reduce hazardous fuels, reduce wildfire spread, and protect values.

The objective of this research is to develop and test a methodology for modeling the potential of prescribed burns to serve as regional fire breaks. This method will be suitable for parks and protected areas, particularly those with flammable fuels close to their boundaries and ensure that fire does not spread beyond their jurisdiction. Park managers that implement fire as a tool in managing the landscape and permitting prescribed natural fires may find interest in the results of this proposed fire break method. The research study area is Quetico Wilderness Provincial Park, a park that successfully integrated the use of fire in their management strategies. However, it is anticipated that this method can be applied to other locations to regenerate fire-dependant ecosystems, reduce fuel and control wildfires.

Five fire break designs were simulated using Prometheus fire growth modeling software. There was statistically less fire outside the barrier, compared to having no barrier in place. Factors influencing the effectiveness of each break included fire break size, number of years required to create the break, proximity to the park boundary and barrier compactness (fragmentation or continuity). The potential escape in wildfires and area burned varied significantly between fire break designs.

In these simulations, a fire break is effective in reducing flammable fuels, regenerating boreal forest species and reducing the spread of and containing wildfires. It is evident that fire is an important factor in park management for maintaining ecosystem diversity. Regional fire breaks should be incorporated for fire and vegetation fuel management in parks. The use of software modeling should also be included with park operation.

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Glossary: Acronyms and definitions

BUI: The Buildup Index (BUI) is a numeric rating of the total amount of fuel available for combustion. It combines the DMC and the DC (USDA Forest Service, 2006).

BWCA: Boundary Waters Canoe Area Wilderness

CA: cellular automata model

CFFDRS: Canadian Forest Fire Danger Rating System

Crown fire: Fire involving tree canopies or upper branches of trees (USDA Forest Service, 2006).

Danger: exposure or liability to injury, pain, harm, or loss (Hornby, 2005).

DC: The Drought Code (DC) is a numeric rating of the average moisture content of deep, compact organic layers. This code is a useful indicator of seasonal drought effects on forest fuels and the amount of smoldering in deep duff layers and large logs (Taylor *et al*, 1997).

DSR: The Daily Severity Rating (DSR) is a numeric rating of the difficulty of controlling fires. It is based on the Fire Weather Index but more accurately reflects the expected efforts required for fire suppression (Hirsch, 1996).

DMC: The Duff Moisture Code (DMC) is a numeric rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-size woody material (Hirsch, 1996).
Duff: partially decomposed layers on the forest floor (Hirsch, 1996).

Ecological Integrity: characteristic for its natural region, including the composition and abundance of native species and biological communities, rates of change and supporting processes (Woodley, 2002).

FBP: Canadian Fire Behaviour Prediction system

FFMC: The Fine Fuel Moisture Code (FFMC) is a numeric rating of the moisture content of litter and other cured fine fuels. This code is an indicator of the relative ease of ignition and the flammability of fine fuel (Hirsch, 1996).

Fire break, fire barrier, fuel break: something impeding the activity and movement of fire; areas manipulated for the common purpose of reducing fuels to reduce the spread of wild fires.

Fire frequency: The return interval of fire in a given area over a specific time (USDA Forest Service, 2006).

Fire Intensity: A rate of heat energy released per unit time and length of the fire front (Taylor *et al*, 1997).

Fire management: the activities concerned with the protection of people, property, and forest areas from wildfire and the use of prescribed fire for the attainment of forest management and land management goals and objectives, all conducted in a manner that considers environmental, social and economic criteria (Annonymous, 1993).

Fire management plan: statement of operational policy that addresses management objectives and prescribed actions with respect to fire use and response to forest fires in a defined area (Anonymous, 1993).

FRI: Forest Resource Inventory; extensive survey of Ontario’s forest resources; based on air photo interpretation and some ground surveys (OMNR, 2002).

Fire-Return Interval: The number of years between two successive fire events at a specific site or an area of a specified size (USDA Forest Service, 2006).

Fire regime: The type of fire activity or pattern of fires that generally characterize a given area. Some important elements of the characteristic pattern include the fire cycle or fire interval, fire season and the number, type and intensity of fires (Heinselman, 1973).

Fire response: is the observation, assessment, suppression, or other influence of fire behaviour such that costs and/or damage are minimized and benefits from the fire are maximized (USDA Forest Service, 2006).

Fire severity: Degree to which a site has been altered or disrupted by fire or depth of burn; also used to describe the product of fire intensity and residence time (Forestry Canada Fire Danger Group, 1992)

Forest fire: any fire that is burning in forested areas, brush, grass, tundra, or other vegetation.

Fuel: vegetative components including woody debris, forest litter that can contribute to wildfire severity (Forestry Canada Fire Danger Group, 1992)

FWI: The Fire Weather Index (FWI) is a numeric rating of fire intensity. It combines the Initial Spread Index and the Buildup Index. It is suitable as a general index of fire danger throughout the forested areas of Canada (Taylor *et al*, 1997).

Ground fire: Fire that burns in the organic material below the litter layer, mostly by smoldering or combustion. Fires in duff, peat, dead moss and lichens, and punky wood are typically ground fires (USDA Forest Service, 2006).

Head Fire: A fire spreading or set to spread with the wind (Taylor *et al*, 1997).

ISI: The Initial Spread Index (ISI) is a numeric rating of the expected rate of fire spread. It combines the effects of wind and the FFMC on rate of spread without the influence of variable quantities of fuel (Taylor *et al*, 1997).

Ladder fuels: Shrubs and young trees that provide continuous fine material from the forest floor into the Crowns of dominant trees (USDA Forest Service, 2006).

OMNR: Ontario Ministry of Natural Resources, division of Government of Ontario.

Ontario Provincial Parks: areas designated by legislation under the Ontario Provincial Parks Act R.S.O. 1990. Provincial Parks protect significant natural, cultural and recreational environments while providing opportunities for visitors to participate in recreational and educational activities.

Prescribed burn: Also known as prescribed fire or controlled burn; the knowledgeable application of fires to a specific land area to accomplish predetermined forest management and other land use objectives (OMNR, 1998).

Prescribed Natural Fire: A fire that is permitted to burn unimpeded by suppression efforts, if it meets specific prescription criteria (OMNR, 1998).

ROS: the speed at which a fire extends its horizontal dimensions, expressed in terms of distance per unit of time.

Silviculture: various treatments that may be applied to forest stands to maintain and enhance their utility for any purpose (Natural Resources Canada, 1994).

Stand replacement fire: Fire that kills or top-kills aboveground parts of the dominant vegetation, changing aboveground structure substantially.

Succession: the directional change with time of the species composition and vegetation of a single site where the climate remains effectively constant (USDA Forest Service, 2006).

Surface fire: Fire that burns in litter and other live and dead fuels at or near the surface of the ground, mostly by flaming combustion (Heinselman, 1973).

Values: the relative worth, utility, or importance of something (Hornby, 2005).

Wildfire: a fire that is burning uncontrollably

Chapter 1
Introduction

Started by a single lightning strike, fire 141 was not initially a threat to the Bird lake region of south central Quetico Provincial Park. It quickly grew from its August birth, to be “one of the most intense crown fires that you would see in Ontario” (Lynham in Peruniak, 2000) and was called the largest and most significant fire in the Park since the 1930’s. The exceptionally dry and hot summer was keeping the fire crews busy elsewhere so fire 141 was not immediately suppressed. Shifts in the wind spread the fire eastwards beyond the Park boundary and into logging property. Later the wind pushed the fire North. The intense crown fire reached as far as the Wawiag River, situated in a boggy valley. Because of this shift in wind, fire 141 slowed down but it smoldered for a further month. In the end, 25,000 ha of boreal forest were consumed. All that was left was a patchy mosaic of charred vegetation, exposed tree roots, total consumption of the organic soil layer and a burnt landscape.

This description of fire 141 sounds horrific for anyone who can imagine being close to the fire’s path. Perhaps a canoeist in the Park, an outfitter housed on the highway, anyone living in the nearby community, and the fire crews can all relate to the dangers of wildfires. Occurrences such as fire 141 are not unique, particularly in boreal forests where for many years management strategies have successfully implemented fire suppression even though it has been identified as causing significant impact on ecological integrity of Parks (Woodley, 2002). Fire is a natural process that “manages” vegetation for reducing fuel load, regenerating and maintaining biodiversity. Without the periodic occurrence of fire, fire-dependent ecosystems, such as boreal forests will not continue to represent the natural area that they were designed to protect (Davis, Wilkinson, & Heaman, 2003). Wildfires occur in Ontario and across Canada every year, especially during what is known as the fire season (April 1 to September 30), with fires burning in Parks and protected areas. Stemming from climate change, warmer and drier conditions are found in the boreal forest ecosystems, which have resulted in an increase in fire intensity (heat generated), fire severity (depth of burn) and lengthening of the fire season (Stocks, 1990; Weber & Stocks, 1998; Wotton & Flannigan, 1993). Suffling (1991) stated that fire areas increased dramatically in response to some of the warmest and driest summers of this century. A prolonged fire season requires park managers to increase fire staff during the season, secure additional financial resources for equipment and staff, and push back the prescribed burn season further into the fall.

Controlling wildfires is both difficult and expensive (Heinselman, 1996). However, the alternative of allowing fires to burn freely may not be an option where tourism and livelihoods are close by. In addition, safety is a concern when fighting these fires or being in close proximity to them. Strategic planning needs to consider incorporating prescribed burn practices. Policies and management plans need to re-allocate expenses and re-evaluate priorities for protecting valuable land and property. Fire management plans should remains flexible to accommodate social, economic and environmental changes as they relate to the Parks goals and objectives.

Park managers are realizing that fire plays a significant role in maintaining the health of an ecosystem. With this realization, the Ontario Ministry of Natural Resources (OMNR) produced a document with regard to fire management in provincial parks and conservation reserves. It provides an array of information from increasing the awareness of fires' ecological role to guidelines in developing fire management plans.

Fire is integral to disturbance-dependent ecosystems and as a result, Park managers are re-examining fire management strategies. These strategies challenge Park managers because they must find the balance between effective forest fires contributing to the boreal forest ecological function within the Park boundary, but without personal injury, property loss or expansion of fire beyond the protected area boundaries. Conflicts emerge between land tenants surrounding protected areas, and Park staff who are interested in re-introducing a fire regime, while neighbouring land owners do not want to lose their valuable resources as a result of fire. It is inevitable that a fire will ignite, either from a lightning strike or campfire in the Park that could put all values (property, livelihoods, and human life) at risk.

One Park that has thus far successfully integrated the use of fire in management is Quetico Provincial Park, in northwestern Ontario. The Park was one of the first in Ontario to develop a fire management strategy that evolved into a fire management plan, and is now used as a template for subsequent Parks wanting to follow. Within the Park, wildfires are allowed to burn, depending on the fire management zone. For example, a wildfire would be actively suppressed if located along the boundary adjacent to logging property or in close proximity to organized campsites. It is important to re-introduce fire, but also consider neighbouring activities. Surrounding Quetico is active logging on Crown lands, a major highway, a native reserve, outfitters, stores and other personal property. Heinselman (1996) warns that we are "…living dangerously if we fail to move aggressively into more proactive fire management programs that could restore a more natural patch mosaic of forest communities and age classes of Quetico and BWCA". The dilemma is how to let fires burn, without causing risk or compromise to the surrounding economy. Logical possibilities for the control of fire spread outside protected areas include the following:

1) Creating a buffer outside the Park with fire control and an understanding that fire will periodically spread to this buffer zone.
2) Establishing a fire fighting zone in the edge of the protected area, known as the measured fire zone as currently performed in Quetico.
3) Establishing a regional fire break to stop fires effectively at the Park boundary.

The first option is not feasible unless logging companies give up a portion of the Crown land to act as this buffer, which would lead to a subsequent loss of timber yield. The second option is to maintain status quo in keeping fires away from Park boundaries and practice fire suppression in this area. This is not feasible since the lack of fire is leading to hazardous conditions in the Park and adjacent land uses. Shang *et al* (2004) determined that this option of fire suppression with no treatment led to the highest potential of fire risk, with a high probability for catastrophic fires.

This research will explore the third option, to create a regional fire break. By doing so, fuel treatments reduce the intensity and size of wildfires (Shang, He, Crow, & Shifley, 2004; van Wagtendonk, 1996). Prescribed burning is suggested to create this fire barrier within protected areas. Prescribed burning will reduce fuel buildup to remove the hazard (Weber & Taylor, 1992), which in turn will decrease wildfire intensity (Alexander & Thomas, 2006; Shang *et al*., 2004).

Within a protected area context, many concerns need to be addressed related to this proposal of a prescribed burn fire break. The risk of escape is present in order to create this fire break. Since the creation involves planned burning close to the Park boundary, there is the potential for a prescribed burn being larger than expected and escaping. The logistics of conducting prescribed burns to create a fire break are immense. The size of a break should be large enough to stop the spread of and contain wildfires, however, acquiring approval to execute such an extensive fire barrier would be difficult.

The factors of the burn are important to address, such as health and safety, reducing life threatening risks, personnel required, appropriate time of year, accounting for wind direction (southwesterly) and historical fire patterns. Executing prescribed burns efficiently and acknowledging the risk of introducing fire to a fuel build area is also important. The cost is not just economic, but social and ecological as well. Species post-fire regeneration rates, need to be addressed because the fire break may only be a short term solution since fire dependent species, such as jack pine will eventually grow back (Heinselman, 1996) creating another fire hazard from organic debris and litter on the ground. The surrounding communities need to be protected from a potential fire escape. Operating efficiently includes utilizing natural barriers such as rocks and water in creating the fire break. In Quetico, there are very few natural barriers along the eastern Park boundary, which could lead to major fire control problems and increased work loads for suppression crews.

Overall, to address these concerns, evaluating the success of a prescribed burn fire break will occur in a simulated environment, where different fire break designs will be evaluated and tested. In the end this research will develop a recommended fire break from a series of prescribed burns that could be implemented not only in Quetico, but other protected areas where the re-introduction of fire is required.

1.1 Thesis Objectives

The general objective is to develop and test a methodology for modeling the potential of prescribed burns to serve as regional fire breaks. This method will be suitable for parks and protected areas, particularly those with flammable fuels close to their boundaries where it is important to ensure fire does not spread beyond their jurisdiction. Park managers who implement fire as a management tool in the landscape and permit prescribed natural fires may be particularly interested in the results of this proposed fire break method. It is anticipated that this approach can be applied to other locations to regenerate fire-dependant ecosystems, reduce fuel and prevent catastrophic wildfires. The prescribed burn fire break method will be evaluated with Quetico Provincial Park data since it is comprised of the fire-dependant boreal forest. Furthermore, fuels resulting from wind storm debris and trees infested or killed by spruce budworm are building up, and increasing the risk of severe and intense wildfire. Quetico is classed as a Wilderness Park where "...where the forces of nature are permitted to function freely..." (OMNR, 1998). Quetico's fire management strategy outlines the ecological role of fire, and its beneficial effects in resource management (OMNR, 1998). With this direction, the Park's goal is to "mitigate the detrimental effects from fires as well as minimizing the ecological impacts of fire suppression wherever possible" (OMNR, 1998). It is anticipated that a prescribed burn fire break will be effective in reducing flammable fuels, regenerating boreal species and reducing the spread of and contain wildfires. Overall, there are three null hypotheses to test:

1. There is no difference in wildfire activity with a fire break
2. There is no difference in wildfire activity with respect to fire break designs
3. There is no difference in fire activity of fire breaks with different post-fire vegetation regeneration speeds.

1.2 Specific Goals

Before introducing regional fire breaks, several specific goals need to be addressed.

1. *Examine the significance of fire's role in ecosystems*; this first goal includes preliminary research about fire in the context of vegetation and fire-dependant species. The first goal will explore literature on fire ecology. Fire is an important process in vegetation management by reducing fuel that contributes to more intense and sustained wildfires. Fire renews and regenerates vegetation of fire dependent species such as grass and coniferous trees. The effects of fire on boreal forest species found in Quetico will be examined.

2. *Examine existing fire management plans within Parks and protected areas;* Park managers recognize fire as an integral part of boreal forest ecosystem in order for fire management strategies is being created. Public safety, objectives for land management, priorities and activities of fire management need to be considered (Hawkes, Vasbinder, Opio, & DeLong, 1997; OMNR, 2004a). Park managers are challenged to find the balance between effective forest fires contributing to the boreal forest ecological function within the Park boundary, without personal injury, property loss or fire spreading beyond their boundaries.

3. *Build a framework to create, test and implement a regional fire break created by prescribed burning within fire management context*; this involves extensive communication with fire

experts, reviewing existing literature and Park fire plans. Creating a fire break using prescribed burns along a Park boundary is not new (Bogardus-Szymaniak, 2006; Helms, 1979; Weyenberg, 2006). However, the idea of a prescribed burn fire break for fire management in regionally containing fires, in addition to its function of reducing flammable fuels and fire growth potential is new and will be explored.

4. *Research fire behaviour simulation software to model regional fire break designs using Quetico Provincial Park as a case study*; this will involve using modeling software to replicate prescribed burn fire breaks. A variety of fire break designs will be simulated under various conditions to test the effectiveness of the fire break against potential wildfires.

5. *Model wildfire scenarios to test the effectiveness of a fire break as a barrier to wildfire activity*; this concept of using fire modeling software by park managers will be explored.

6. *Examine both the park management and ecological implications of introducing fire breaks in Quetico Provincial Park and applicability to other protected areas;* this objective will also include researching alternatives to this approach of a fire barrier in a Park setting and feasibility of a fire break method for Park managers.

7. *Discuss the significance of using modeling software and usefulness to Park managers*; implementing fire modeling software, its usefulness and feasibility to Park managers will be determined.

1.3 Structure of thesis

The thesis will be structured in several chapters:

- Chapter 1: An introduction, significance and implications of fires in parks, the hypotheses, objectives, and anticipated accomplishments of this research will be addressed.

- Chapter 2: A review of relevant literature to examine the role of fire in ecosystems to achieve the first goal. The second goal will be achieved by examining general literature on park management in North America, and more specifically fire management strategies of Ontario Parks. Vegetative fuel treatment options will be researched and alternatives to burning will be explored. This chapter will conclude with documenting the advantages of fire growth models in resource management.

- Chapter 3 focuses on Quetico Provincial Park as a case study, including physiography of the region, and economic activity within and surrounding the Park. The fire history, current fire management plan, role of fire in the Park, both wildfires and planned burns will be explored.

- Chapter 4 comprises the methods whereby the fourth objective will be addressed. It includes a critique of fire modeling software and rationale for choosing an appropriate software package to model the fire breaks. The design considerations to produce the fire breaks, data pre-processing and processing involved, and weather criteria for modeling the fire break scenarios are also outlined. The fifth goal of modeling these scenarios will be included in this chapter. In addition, post-fire vegetation regeneration was researched and incorporated into the modeling scenarios.

- Chapter 5 contains the results of the simulated wildfires and fire break scenarios illustrated in map format. Statistical output will complement the maps to help to determine the level of success, thereby examining evidence that breaks reduce fire spread, contain wildfires and stop the spread of fires. The chapter will end with an acceptance or rejection of the three null hypotheses.

- Chapter 6 contains the discussion of the results, evaluates the effectiveness of each prescribed burn fire break design and will rank each design according to the reduction in fire spread, containment of wildfires and limited spread of fires beyond the Park boundary.

- Chapter 7 contains the conclusion of the research, outlines limitations of the research and provides recommendations including policies for future research directions. This chapter also addresses the sixth and seventh objectives of the implications of introducing this regional fire break method, its applicability beyond Quetico Provincial Park, and the potential advantages for Park managers in using fire behaviour software in fire management.

Chapter 2
Literature Review

This chapter will review relevant literature that pertains to fire ecology and use of fire in creating fire barriers. It is important to research literature to understand what has already been performed, what challenges were encountered and evaluate recommendations that could influence and improve this research. When planning a fire break using prescribed burning methods, evaluating literature from several areas of study will be covered. Creating fire breaks using prescribed burns is a risky undertaking, hence fire simulation methods will be examined. The objectives of this chapter will cover literature pertaining to the following:

- Fire ecology
- Park management
    - Park master planning
    - Fire management planning
- Vegetation fuel treatment options
    - Fire suppression
    - Mechanical thinning
    - Prescribed burning
- Spatial modeling of fire behaviour

2.1 Fire ecology

Fire is a disturbance process that altered forest landscapes in North America well before human interaction, approximately 12-20 million years ago (Weber and Taylor, 1992). The return interval of fire (see *Glossary*) in a given area over a specific time was short compared to today. For example, Quetico Provincial Park's pre-suppression return interval was 78 years and now is 820 (Woods & Day, 1977). In Yellowstone, a fire interval occurred between 20-50 years and is now over 1,000 years (Romme, Turner, Tinker, & Knight, 2004). Aboriginals viewed fire as important in their daily lives, used for cooking and warmth, and to regenerate the landscape and clear land (Hawkes *et al*., 1997). This dependence on fire was less intrusive than the activity of European colonization. With the arrival of Europeans, there was an increased awareness that fire could potentially damage agricultural lands, towns and cities and fire was suppressed. For this research, the term 'values' encompass human lives, personal and Crown property, gravel, timber and natural resource extraction, and infrastructure including dwellings and businesses. Fire was viewed as a negative force with the progression of land settlement, prospecting and logging, particularly from the 1920's to present day. Consequently, natural and human made fires were actively suppressed (Heinselman, 1996). Fire suppression was implemented for public safety, owned property and protection of resources.

Fire is an ecological process in boreal forests, grasslands, mountain Cordillera, Carolinian and Acadian forests (Woodley, 2002). It can be regarded as a regulator in vegetation management that consumes vegetative fuel which can contribute to more intense and sustained wildfires. Fire renews and regenerates vegetation of fire dependent species such as grass and coniferous trees. For example, many vegetated areas in the Sierra Nevada region require fuel treatment to manage fuel accumulations and understorey canopies that have resulted from decades of fire suppression (van Wagtendonk, 1996). Across the boreal forest ecosystem, fire-dependant species such as *Pinus banksiana* (jack pine) require heat from fire for seed release and germination. Within the Yellowstone ecosystem, most of the forested area such as *Pinus Contorta* (lodgepole pine) and *Picea sp*. (spruce) relies on fire disturbance as part of its natural fire regime. The grasslands are also dependant on fire to seed and sprout (Romme *et al*., 2004). Fire is an environmental factor that controls species composition, age structure of forests, and produces a landscape pattern that some animals depend upon for foraging and habitat. For example, moose visit recently fire-disturbed land to forage upon young *Populus sp*. (aspen) and *Betula sp.* (birch). White-tailed deer visit recently burned areas as well, for young plant shoots (Alverson, 1994; Heinselman, 1996). In addition, fire maintains biodiversity by releasing nutrients back into the soil, balances chemical composition in soil, activates seed release and germination by heat and eliminates accumulated debris (Alexander & Thomas, 2006; McRae & Lynham, 2000).

Although fire influences many ecosystems around the world, the role of fire in the boreal forest will be emphasized. In this research, the boreal region has been historically shaped by fire which is important for re-growth and renewal. The boreal region is the largest forest region in Ontario, comprising 59 % of the provinces' total forest cover (Ray, n/a). It stretches from the Quebec border, North of the French River and Lake Superior in the West, to the Manitoba border, covering most of northwestern Ontario (Figure 2-1).

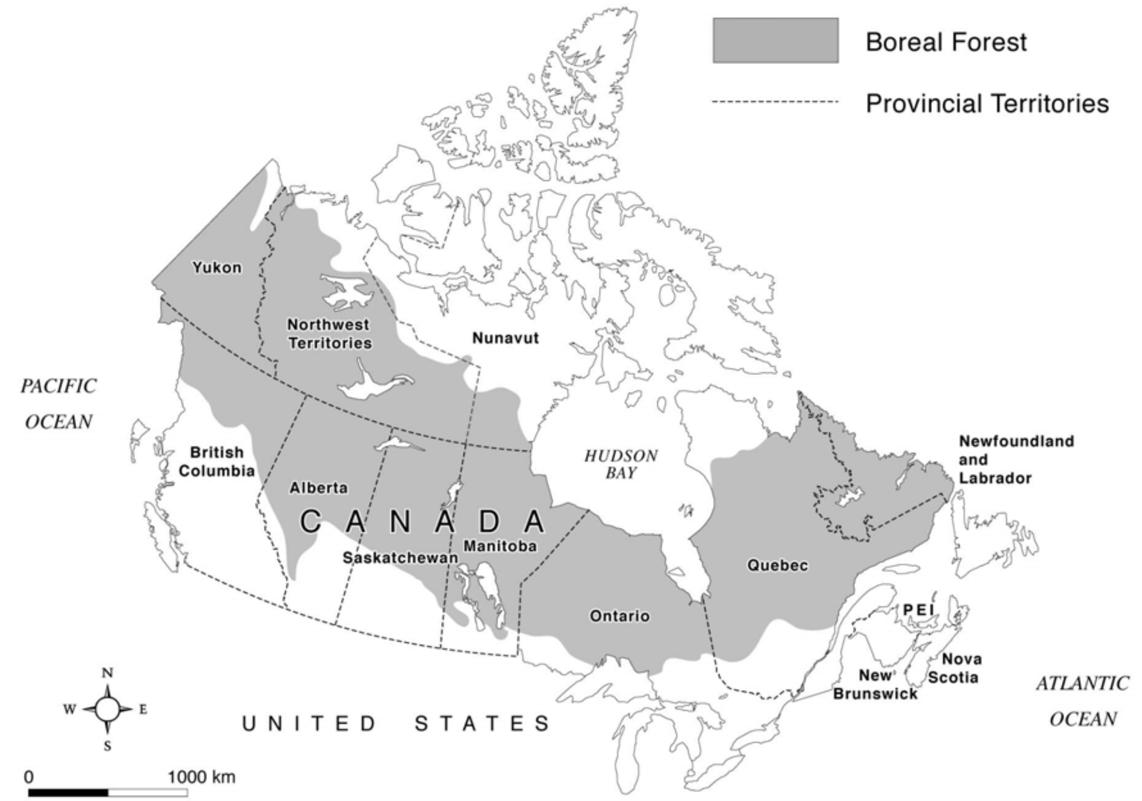


Figure 2-1: Map of Boreal Region in Canada

Source: (Natural Resources Canada, 2004)

According to Canada's forested land statistics, the boreal forest sustains the largest amount of burned area, which is partially attributed to the remoteness of Canada's boreal forests whereas other forest regions account only for a small fraction of burned area (Weber & Stocks, 1998). Van Wagner (1988) estimated an average annual area burned at 1.3 million hectares (ha) per year from 315 million ha that the boreal biome occupies. Since the 1980's with population growth and more extreme weather, there have been more instances of wildfires (Weber & Stocks, 1998). The boreal forest is composed primarily of coniferous species and includes the following species listed in Table 2-1. In addition, the Forest Resource Inventory (FRI) short names are included for future reference.

Table 2-1: Some Common Boreal Tree species in Canada

FRI code	Common Species Name	Latin Name	Author
Bf	balsam fir	*Abies balsamea*	Robert, M. Frank
Bw	white birch	*Betula papyrifera*	John C. Bjorkbom
Pw	jack pine	*Pinus banksiana*	P.R. Laidly
Pw	black spruce	*Picea mariana*	William F. Johnston
Pr	red pine	*Pinus resinosa*	Paul O. Rudolf
Pw	eastern white pine	*Pinus strobus*	G.W. Wendel
Pot	trembling aspen	*Populus tremuloides*	D.A. Perala

Source: Burns & Honkala, 1990

With the absence of fire in boreal forests, regeneration does not occur in fire-dependant species such as jack pine and black spruce, which need fire for seed dispersal and colonization (McRae & Lynham, 2000). Without fire, successional species dominate; balsam fir and white pine are example of this. These species are shade tolerant and thrive in undisturbed forests creating an abundance of fuel and an increase risk of wildfires. Some wildlife depends on food source and habitats. Without fire, there is an increase in biomass, insect infestations, and overall degradation of ecological diversity and health. Dead wood is more abundant after trees are 100-300 years old because they deteriorate and die, are susceptible to wind breakage, disease such heart-rotting fungi and parasites such as black spruce dwarf mistletoe as well. The lack of fire disturbance can result in non-representative boreal ecosystems (Franklin, 2001; Heinselman, 1970; Miller, Landres, & Alaback, 1999; OMNR, 2004a; Woods & Day, 1977).

The ecological costs are increasingly evident, particularly in parks. For example, in Voyageurs National Park, in northern Minnesota, forest fires have historically altered vegetation with approximately two-thirds of the park either burned or logged. There is a dramatic shift in forest composition as a result of fire suppression from predominantly pine or spruce forests to present day's predominantly aspen forests (Alexander & Dube, 1983).

The economic costs of fire suppression include costs in fighting wildfires, social, transportation, tourism, and resource extraction disruptions (Goodman, 1985). In the early 1900's, most North American wildland fire agencies were established for fire control and protection. When fires started, these organizations attempted to extinguish the fires as quickly as possible. Now the view has shifted to wildfire as a natural component. This shift comes with the recognition that fire suppression is causing significant impact to ecological integrity in parks. Re-introducing fire has a range of social, economic and ecological impacts that need to be considered. Despite this recognition, fire has been re-introduced in only a few areas, primarily parks and wilderness areas for restoring natural ecosystems (Johnson & Miyanishi, 2001). The challenge still lies in minimizing uncertainty and lowering risk which can be overcome through the development of strategic fire planning (Martell, 2001).

2.2 Park Management Plans

Protected areas were designated as such because of particular ecosystems characteristics. Examples of these include natural, cultural and historical features. Natural features include biodiversity and geology. Cultural features include pictographs in Grand Canyon National Park in Arizona, and historical relevance such as Yoho National Park in British Columbia. Further, park staff promotes ecotourism in Algonquin Provincial Park in Ontario. In general, all Park management plans serve a purpose of maintaining a landscape that is valuable for recreation, education and research.

However, there is a realization that parks are not self-regulating natural ecosystems (Woodley, 2002). Without active management, park ecosystems will no longer be representative of their original goal for supporting viable ecosystems and diversity (Anonymous, 2006; USDOI National Park Service, 2002). In Ontario, the *Forest Fire Management Strategy for Ontario* document outlines the direction for wildfire management should be to balance protected values and forests with ecological resource management. The strategy was developed for Crown and private properties, and also parks and protected areas. It is recognized that many ecosystems require fire for disturbance and renewal and without it, fire-dependant ecosystems change (OMNR, 2004a). The strategic directions outlined in this document include:

- *Maintaining public safety* –Prevent personal loss or injury and considering communities when managing fire.
- *Protecting wood supply and forest productivity* –The fire management activities need to consider forest industries and value of resources.

- *Promote fire's role in the ecosystem* –Fire management needs to incorporate fire's ecological benefits safely and effectively by prescribed burning. In addition, practicing "light on the land" techniques in sensitive areas (environmentally or culturally significant areas) (Davis *et al*, 2003).
- *Enhance partnerships and agreements* –This involves working with various levels of government, first nations, resource-based tourism operations, private land and forest industry to ensure there are minor or no interruptions from fire activity.
- *Promote public education and prevention* –Promoting awareness of fire in ecosystems and the public's responsibility of reducing human-caused fires.
- *Manage business of fire management* –The cost in preparing fire management programs from infrastructure to fire response.
- *Manage forest fire response* –This strategy includes how personnel will respond to fire that ranges from complete fire suppression if threatening human values, to monitoring fires that will renew forests without threat.

These fundamental strategies guide effective fire management. The *Fire Management Policy for Provincial Parks and Conservation Reserves* emerged from the need for policy and planning in protected areas. To allow wildfires to burn freely is not possible in many parks. One must consider visitor safety and neighbouring land practices, so implementation of fire planning is designed to provide safe and effective use of fire (Davis *et al*., 2003). The fire management policy's goal is to promote fire management in parks and protected areas to restore and maintain ecological integrity without compromising personal injury, value loss and social disruption resulting from fire (OMNR, 2004b). The policy also establishes responsibilities for approving fire management plans (Van Sleeuwen, 2006). Fire management direction from this document recommends preparing fire management plans, where appropriate, from the *Ontario Provincial Parks Planning and Management Policies* for parks and conservation reserves.

2.2.1 Fire Management in Parks and Protected Areas

A fire management plan provides direction for fire response and fire use within a defined area and time frame. The fire response includes decisions regarding detection, suppression or monitoring of wildfires. Fire use includes ecological renewal and prescribed burning (Davis *et al*., 2003). Fire management can be defined as the activities concerned with the protection of people, property, and forest areas from wildfire and the use of prescribed fire to attain forest and land management goals and objectives, as well as being conducted in a manner that considers environmental, social and economic criteria (OMNR, 2004b). The path of fire activity does not know jurisdictional, park, property or international boundaries. Fire management plans are complex because weather events need to be considered. Precipitation, temperature and wind contribute to the complexity of fire management plans. In addition, park managers need to determine the historical natural fire regime, its vegetation conditions and the response of species to fire needs (Davis *et al*., 2003). Fire management plans are incorporated into existing management strategies needing effective fire management.

i. Ecological imperative not to suppress all fires and recognizing the need for fire disturbance and renewal of forest resources;
ii. Social imperative to inform and educate the public of fire programs;
iii. Economic imperative that it may be more expensive to combat wildfire than allow controlled and monitored fires;
iv. Technical consideration of satellite imagery, equipment and software for fire prediction and response;
v. Incorporate programs into fire and resource management planning (Goodman, 1985).

A park is usually divided into fire zones and classified based on concentration of visitors, facilities, valuable sites, terrain and proximity to park boundaries. Fire activity in these zones is monitored or suppressed according to theses fire zones. In addition, a fire management plan provides objectives for the area, and for understanding the role of fire, its impacts and opportunities of fire occurrence and fire suppression, fire management and response (*ibid*). Knowing when and where a fire is likely to occur and how it may behave are essential to sound fire management decision-making.

Miron Heinselman researched the origin of fire activity in Minnesota, and expressed the need of fire management planning in parks. His work in the Boundary Waters Canoe Area (BWCA) within the Superior National Forest in Minnesota was instrumental in forest fire management. Over the years (1970's-1990's), Heinselman compiled and documented information related to forest succession within the BWCA, and the historical role of fire in the structure of the BWCA. He developed a method to map past fires using written records, fire scars and stand origins (Johnson & Van Wagner, 1985). In addition, Heinselman produced an extensive fire chronology in the BWCA and concluded that fire plays a major role in the composition and structure of the vegetation within the BWCA. Groundbreaking evidence from maps, fire scars and other historical data revealed a fire return interval of 100 years on average. His study confirmed the importance of re-introducing fire in this forest ecosystem and promoting monitored lightning fires or prescribed burns. For example, forests infested with spruce budworm, barkbeetle or dwarf mistletoe would benefit from a controlled or prescribed burn because the fire would largely eliminate the problem species in these sites (Heinselman, 1973).

Heinselman's study of fire relationship to the boreal forest triggered other Parks to evaluate the impact of fire suppression. In Ontario, several Parks have approved fire management plans, and others are examining their success. Quetico, Pinery and Rondeau Provincial Parks have burn programs to thin, restore and maintain the landscape (OMNR, 1995). These fire management plans are important because particular protected fire-dependent ecosystems require fire disturbance. Without this disturbance, ecosystems are not representative of why the park was protected in the first place. The ecosystems deemed worthwhile of preservation at the time of park designation, have changed over the decades due to lack of disturbance. Fire management plans for parks should be created on an individual basis based on each area's unique situation.

Components of fire management planning are based on fire history, fire risk to valuable resources such as property and land use, and the role of fire in the ecosystem (Alexander & Dube, 1983; Suffling & Perera, 2004; Woodley, 2002). Fire management is needed in parks because fires that burn out of control, or wildfires (refer to *Glossary*), cannot be entirely prevented. Hence, fire management is predicted on three rationales:

1. Protection of ecological and economic values and cost-effective operations;
2. Fires can spread beyond individual land parcels and jurisdiction;
3. Fire is needed in the context of ecosystem renewal.

In Ontario, fire management plans are prepared for each wilderness class park since the "occurrence of natural fire in certain wilderness environments is recognized as a process integral to evolving natural succession" (Anonymous, 1993). Fire management can be described as constantly evolving from protection, preservation, management and adaptive management.

Typically, parks are divided into fire management zones and are classified based on proximity to resources, fuel type, terrain, and human safety. The management of these zones can be characterized as suppression, containment, or observation in response to fire and associated risks. For this research, risk encompassed by the following definitions:

> "A situation that could be dangerous or have a bad result" (Hornby, 2005)
>
> "The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions". (UN International Strategy for Disaster Reduction, 2003)

Two beliefs stand out when considering a risky proposal: first, incurring risk is acceptable only if there are offsetting benefits and second, one should reduce the risk where possible (Lind, 1988). In addition, there is the degree of risk in an event, for example, determining the level of risk in living close to something that is dangerous, such as a nuclear power plant (Martin & Lafond, 1988). The risk of re-introducing fire needs to be considered. Although the re-introduction of fire into protected areas can be written into an effective fire management policy, there are many factors to consider in implementing a successful fire management program that is well integrated with resource management. For example climate fluctuations are influencing forest ecology that could impact fire severity and frequency (Kronberg, Watt, & Polischuk, 1998). Types of fire ignition need to be specified and negotiated in the fire plan. Thus, a human induced fire from a cigarette or camp fire may be treated differently than a naturally caused lightning fire that strikes in the middle of a park. Fire management programs typically include fire prevention methods to reduce human-caused fires. Detection systems are also used to find all types of fires. Modifying or reducing the fuel load, such as through prescribed burning to fulfill both safety and ecological objectives is also implemented. Prescribed burning can be defined as the supervised burning of forest fuels in a specific area, under predetermined conditions, so that the fire is confined to the intended area to fulfill silvicultural, wildlife management, sanitary or hazard reduction requirements (OMNR, 1998).

For successful and responsible management of a park, various fire related scenarios need to be considered and solutions conceived jointly by park and fire managers. In addition, these managers will assist in the approval of fire management by communicating and educating people on the role of fires in fire-dependent ecosystems. Perhaps the most difficult partner to convince is the forest industry because they have the most to potentially lose in fire re-introduction. As a fire management plan is implemented, communication should ensue to inform the industry of hazard reduction opportunities, response priorities and the possibility of controlled fires (OMNR, 2004a). This next section will address prescribed burning methods as part of park management.

2.3 Vegetation Fuel Treatment Options

Fire management strategies for boreal forests need to encompass both operational and ecological benefits and implications. Two alternative fuel treatment options to using fire are mechanical fuel treatment and active fire suppression. Mechanical fuel treatment can involve bulldozing accumulated fuels or removing the hazardous fuels by other means to lower fire spread rates and intensities (Finney, 1994; Fule *et al*., 2002). Mechanical treatment, such as thinning dense forests is expensive, only feasible on gently rolling terrain (Agee *et al*., 2000) and contributes to ecological problems. For example thinning the sub-canopy and exposing shaded vegetation to sunlight may cause vegetation stress (Romme *et al*., 2004). Fire suppression is feasible and a simple alternative because fire crews are dispatched on demand. However, a fire management plan should be in place for prompt response to wildfires. Although active suppression is straightforward, it does not minimize the risk of wildfires and can increase the hazard of more intensive ones. The fire seasons are increasingly severe due to drier and hotter summers (O'Connor, 2006; Romme *et al*., 2004). With this severity, it is increasingly difficult to control fires. Suppressing fires is not ideal for fire-dependent ecosystems and species that depend on this disturbance. A proposed strategy involves using prescribed burning methods and creating a defensible space for protecting property and ecologically regenerating the landscape (Romme *et al*., 2004).

2.3.1 Prescribed Burning in Parks and Protected Areas

Prescribed burning is the application of fire to a specific land area to accomplish pre-determined forest management or other land management objectives (see *Glossary*). Prescribed burn techniques may also include a fire that is started by lightning and is managed to accomplish specific, ecosystem-based, management objectives (Government of Ontario, 2002). Prescribed fires have multiple uses both within protected areas and beyond their boundaries. These controlled burns can reduce hazardous wildfire activity and prevent severe wildfires. Prescribed burns can reduce wildfire intensity, reduce damage potential, reduce suppression efforts and labour needed to contain wildfires, and even enhance the use of natural barriers in junction with water and rock to prevent wildfire spread. Prescribed burns are commonly used in harvested areas, to reduce the logging debris. In silviculture (Weber & Taylor, 1992) burns were used for site preparation and rehabilitation to create a suitable seedbed, however, this practice does not occur regularly now because of cost and labour requirements. Burning to improve livestock forage is a technique practiced for many years to maintain the land and plant communities (Weber & Taylor, 1992). Finally, prescribed burning is performed in parks to maintain ecological integrity and diversity.

One area where prescribed burns have been recently applied is in British Columbia, where the forest problems linked to mountain pine beetle were treated by prescribed burn methods for stand rehabilitation and host elimination (Weber & Taylor, 1992). In Ontario, a canker infestation on red pine was eliminated by burning a small area of red pine (*ibid*). In the BWCA in Superior National Forest in Northern Minnesota and in Quetico Provincial Park, prescribed burns were conducted to reduce hazardous forest fuels resulting from a blowdown or wind-damaged stands (Bogardus-Szymaniak, 2006). The Canadian Parks Service increased fire frequency by conducting prescribed burns with the purpose to restore the natural fire regime. Prescribed fire is currently used in 17 national Parks in Canada (Woodley, 2002). Prescribed burning occurs annually in Banff to reverse biodiversity effects of fire suppression and fuel accumulation (Roulet, 2005). Yellowstone National Park conducts prescribed burning for vegetation regeneration (Anonymous, 1993; Romme *et al.*, 2004).

2.3.2 Factors to Consider when Planning Burns

Several factors should be considered when planning prescribed burns. These factors are relevant in proper fire management, particularly within protected areas that need to find a balance between ecological restoration and social and economic costs. These factors are summarized in Table 2-2.

Table 2-2: Factors to consider in planning prescribed burns

Factor	Description/Relevance	Example	Sources
ECONOMIC			
Values	• Livelihood and potential job loss • Human safety concern or loss of life • High liability if property is damaged	• Nearby infrastructure including stores, outfitters, homes, Park structures, commercial resources	(van Wagtendonk, 1996; Weber & Taylor, 1992; OMNR, 2004a)
Cost	• Budget constraints in fighting wildfires • Less expensive to plan prescribed burns and maintenance of fuel load, than fire suppression or mechanical thinning	• Prescribed burn costs $100/ha vs. $500/ha to fight wildfires and $450/ha for mechanical treatments • Other economic costs include loss of tourism and Park visitation	(Curran, 2000; Wilkinson, 2006; van Wagtendonk, 1996; Alexander & Thomas, 2006)
SOCIAL			
Risk	• Safety concern to communities and visitors • Damage to infrastructure and thus experienced personnel executing burns • Proper training to reduce this risk but conversely prescribed burning will reduce fuel buildup	• Prescribed burn escapes and becomes wildfire	(Alexander & Thomas, 2006)
Air quality	• Disrupts land, air travel • Reduces air quality • Irritates respiratory systems causing health problems	• Smoke pollution from burning • Need appropriate notice of prescribed burning for visitors and community	(Heinselman, 1996; OMNR, 1998)
Public perception	• Need to inform and educate public • Encourage participation so they understand the positive effects of fire, especially prescribed burning • Minimize social disruption	• Successful Smokey the bear campaign perceiving fire as negative, destructive, risk to economic activity • Need approval from citizens so fire personnel are not viewed negatively	(Murphy, 1995; Weber & Stocks, 1998)
POLITICAL	• Governments need to be supportive of fire management practices but	• Politicians may not want to be associated with risky fire activity	(Alexander & Thomas, 2006; Kutas *et al*., 2002)

	also recognize risk. Without their support, prescribed burning and funding for execution cannot be fulfilled.	• Case of Geralton PB-3/79 whereby 7 employees were killed on a prescribed fire • Consideration of First Nations needs • Quetico Provincial Park managers incorporate First Nations rights and values into Park management policies and boundary zone issues, which is done through an *Agreement of Co-existence*	
ECOLOGICAL	• Specific objective of burn so can assess post burn conditions • Significant for disturbance dependant systems	• Voyageurs Park setting up burn mosaic to regenerate jack, red and white pine • Appropriate weather conditions for burning • Objective of burn may include fuel maintenance, species regeneration, or provide barrier	(Heinselman, 1996; O'Connor, 2006; Weyenberg, 2006)

Overall, economic, social, political and ecological factors are significant in planning prescribed burns.

2.4 Fire Barriers for Containing Wildfires

There are many approaches to re-introduce fire that range from allowing wildfires to burn, to prescribed burn implementation. Within parks and protected areas, barriers can be used to protect if there is a risk of fire threatening valuable resources. A fuel break is defined as areas manipulated for the common purpose of reducing fuels and to reduce the spread of wildfires (Agee *et al*., 2000). In this research, “fuel break”, “fire break” and “fire barrier” will be used interchangeably. A fire break can be defined as something impeding the activity and movement of fire. Fuel breaks consist of areas where the structure of the natural vegetation have been modified (Dupuy & Morvan, 2005) and where the amount of shrubby and sub-canopy vegetation, commonly referred to as ladder fuels, have been reduced or removed. The design of fuel breaks vary according to width, amount of fuel reduction needed and maintenance standards according to the experienced personnel (*ibid*). For example, forest managers often maintain fuel breaks to minimize risk associated with fuel buildup. This is particularly the case when ladder fuels intensify fire status and become crown fires, the most dangerous and difficult to control of fire types.

Although fuel breaks are not expected to stop a wildfire, they can assist firefighters to control the spread and provide safer conditions (Dupuy & Morvan, 2005). This was experienced in BWCA in summer of 2006 when a wildfire rapidly spread across the park. The fire reached an area that has been burned two years prior to remove blowdown. As a result, the rate of spread was reduced and fire crews were able to control the wildfire (Oakes, 2006). It is important that fire personnel skillful in choosing ideal burn areas to create a fire break. They recommend choosing natural fire breaks such as water and rock to keep the costs low. These natural breaks include the location, size, shape, and alignment of swamps, bogs, lakes, standing timber, and deciduous growth, as well as height of bedrock, troughs, valleys, soil textures and rockiness (Heinselman, 1996; Isherwood & MacQuarrie, 1985; Weber & Stocks, 1998). Creation of fuel breaks in easily accessible areas is less expensive compared to more remote areas.

Effective fuel breaks should balance creation and maintenance costs against reduction in wild fire suppression expenditures and lost values. The latter can include habitats, homes, recreation sites, and timber resources (Agee *et al*., 2000; Bevers, Omi, & Hof, 2004). A well designed fuel break should include management of ignited fires, prescribed burn anchor points which are the locations of fire crews and equipment, so prescribed burns and fuel breaks will complement each other (Bevers *et al*., 2004; Franklin, 2001).

Fire breaks can be created mechanically or with prescribed fires. In creating a break mechanically, machinery such as a bulldozer or pruner are used to thin the under story vegetation and remove fuel buildup on the forest floor. Mechanical treatment is effective to work around buildings and infrastructure, however, it is neither economic nor ecologically sound and may cause further destruction to the area of interest. This method is intrusive to ecosystems and should be implemented with caution. To create a fire break manually is time consuming and costly (Agee *et al*., 2000; USDOI National Park Service, 2002). Using prescribed burning methods to create a fire break is an economically and an ecologically attractive alternative to other methods of site preparation and will be discussed in the following section.

The size and shape of a fire break are important because this will determine the construction costs, the labour and equipment needs (Bevers *et al*., 2004; Finney, 2001). Fire breaks are typically linear treatments because they are cost and time effective to construct, although they can deviate in shape depending upon the topography and natural barriers within the area of interest.

Depending upon the management objective, a break should be wide enough to account for wildfire spotting (Curran, 2006b; Dupuy & Morvan, 2005). Spotting is when smaller flames precede the fire front. Fuel break studies by Agee *et al* (2000) have determined that wider breaks are more successful at stopping fire spotting than narrow breaks and hence have a higher probability of suppressing fires. Breaks with any reduction in hazardous fuel contribute to the success in containing wildfires. For example, fuel breaks with a moderate density of fuel are still more economically efficient than fire suppression methods. Thus, fire break planners must factor in ignition potential and values surrounding the break, particularly since secondary breaks are less successful (Bevers *et al*., 2004). Secondary breaks are established if the same area was burned a second time or manual thinning occurred. A fire break should be large enough to justify costs of fire staff and planning (O'Connor, 2006) and achieving the goal of reducing wildfire spread and potentially containing wildfires.

2.4.1 Creating Fire Breaks by Prescribed Burning

The oldest applications of prescribed burning date back thousands of years. More recently, prescribed burns are used in reducing hazardous conditions within the forested landscape. In the 1900's, Ontario and British Columbia (and in subsequent years the rest of Canada), used prescribed fire to reduce logging debris and later legislated as a method to eliminate hazardous slash from logging (Weber & Taylor, 1992). The role of fire breaks is to minimize flammable fuels. Prescribed burning is less expensive in this context than mechanical and manual methods, and the fire disturbance restores fire-dependent species, while reducing the risk associated with fuel loads resulting from fire exclusion, insect and disease. One example of effective containment through prescribed burning occurred in the southern US, whereby the "Blountsville" wildfire burned uncontrollably until it reached an area recently prescribed burned. The reduction in fuel load on the prescribed burn land reduced the intensity of the subsequent wildfire so that fire crews were able to contain and suppress the fire. In the "Woodpecker" fire, a prescribed burn conducted a year prior to a wildfire reduced the damage potential from spotting and spread, since the wildfire could not spread over the previously burned area and it was eventually extinguished (Helms, 1979). Similarly, in Canyon National Park in the USA, control of a wildfire was attributed to prescribed burns that had greatly reduced the fuel load of an area (Vasiliauskas & Chen, 2002).

An effective and economical prescribed burn size-range is 100-1,000 ha (Weyenberg, 2006). If a fire was smaller, then it might not be worth the preparation and planning. Conversely, if a burn is larger, there is increased risk that it could become an uncontrolled wildfire. Fire direction and intensity are influenced by topographic features that include slope and aspect. Fuel breaks should be created along ridges, roads or valley bottoms because they form a barrier to fire activity. In addition, breaks that are created on upper South and West slopes will reduce the vegetation growth. Natural barriers such as rock, water and less flammable fuel types should be incorporated with the prescribed burns to reduce the chance of fire escape and provide a continuous fire break (Hunter, 1993; O'Connor, 2006). Fuel characteristics within a prescribed burn and surrounding the break are also important. There should be sufficient conifer content to carry fire, and the rate of spread will depend more on the quantity and arrangement of fine fuel than on the accumulation of downed logs or deep organic matter (Van Wagner, 1983; Johnson *et al* 1998). Most important, proximity of valuable property will influence decisions about conducting a prescribed burn (Maynard, 2006).

2.5 Modeling Fire Behaviour

When evaluating the role of fire in influencing the forested landscape, prominent fire experts are routinely cited for their research in defining fire patterns, frequency and fire cycles.
Van Wagner (1978) developed a theory that uses forest stand age and a negative exponential distribution to estimate the fire cycle. The model demonstrates that under certain conditions, the forest age distribution can exhibit an exponential shape and that the instantaneous fire hazard rate is constant for all stand ages (Boychuk & Perera, 1997; Johnson & Van Wagner, 1985). In another forest fire frequency model developed by Johnson (1979), these distributions reveal that for a population of sites at risk of burning, there is a characteristic distribution of fire intervals (Isherwood & MacQuarrie, 1985). The research conducted by Suffling, Smith, & Dal Molin, (1982) and Suffling (1983) used the age-class distribution approach to examine patterns of disturbance. Overall, these researchers use empirical observations of past conditions to construct generalized statistical

distributions for the prediction of future events. These statistical models are fundamental in modeling landscape scale fire behaviour and expanding upon the traditional approaches and technological advances, while fire simulations provide a suitable testing environment. However, problems with these models are the assumptions that forest stand age is equal, the vegetation re-growth occurs simultaneously and the year of each burn occurs during a particular year. In reality, vegetation regeneration is influenced by other factors including severity of fire, insect infestation and seasonal climate conditions. The number of burns can also vary each year depending on climate, lightning strikes and human-caused ignitions.

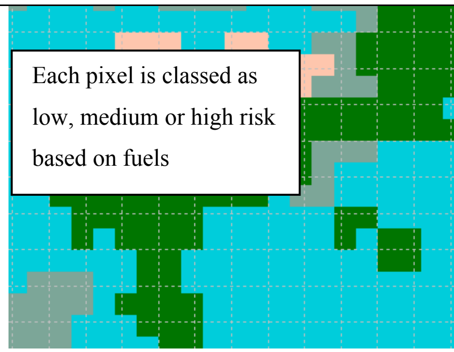
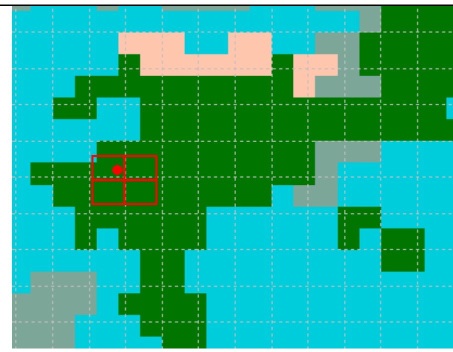
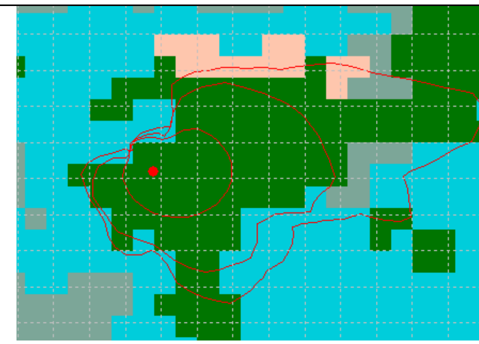
It has not been feasible to conduct experimental burning where wildfires could be ignited against fire breaks to determine effectiveness of fire breaks. Instead of conducting prescribed burns on the ground, simulating different scenarios using burn algorithms within software is ideal since there is no risk. Recent developments in fire simulation technology provide opportunities to evaluate fuel treatments through a variety of re-constructions, from fuel mosaics to varying suppression levels (Agee *et al*., 2000). Forest fire modeling is a useful method in mapping fire disturbance patterns and dynamics. Creating fire growth models can be useful to Park managers because they can assess the risk of fire and plan accordingly for fire suppression or evacuation techniques. This technology can be used in park planning by communicating between software modelers and land managers. Input from the managers is critical in building realistic models, so customizing the software to the fire experts' needs would be ideal (Miller *et al*., 1999). The software should have an easy-to-use graphical interface for these practitioners. Understanding the behaviour, propagation, and effects of wildfire is also essential to achieving sustainable forest management.

Generally, in the 1970's, disturbance models were empirically based on fire spread to understand fire behaviour and determine suppression action. As models evolved in the 1980's, forest management models were developed to include ecological processes, such as succession and landscape patterns. With satellite imagery and Geographic Information Systems (GIS), spatial analysis became more feasible in ecological mapping. Around this time, another path of development originating from mathematical theories emerged. Fire analysis has evolved from fire frequency models and static mapping to mathematical modeling that can incorporate multi-scale, multi-process spatial modeling. Further information on these fire growth models is outlined in Table 2-3. Static mapping of risk is a simple and efficient method because of the output with a GIS. The mathematical model cellular automata (CA) are either deterministic or probabilistic models, whereas wave propagation models are deterministic models (Doran, 2004; Mladenoff & Baker, 1999). Each one of the models mentioned can map fire growth, depending on the output required. Table 4-1 outlines this evolving list of software vendors and their capabilities to model fire behaviour.

It is important to incorporate spatial modeling into resource management. Managers can model scenarios at various spatial and temporal levels to assist with management decisions. In addition, modeling is a safe alternative to assess fire's influence on the landscape (Mladenoff & Baker, 1999). Further evaluation of fire modeling software will be discussed in Chapter four.

Table 2-3: Fire Growth Models

Method	Static Mapping of risk	Cellular Automata (CA)	Wave Propagation
Definition	• Static fire risk mapping is a common, simple and efficient method because essentially all mapping is done with a GIS and outputted as a map.	• CA uses decision rules to simulate fire spread theories, and is made up of grid cell based models that rely on neighbourhood rules to change the cell's value (Mladenoff & Baker, 1999). • Each cell can contain conditions for ignition and point to point fire spread occurs from centre of cell to the next. • This type of model is theoretical, which allows the researcher to explore landscape scale effects.	• Simulates fire growth as a spreading elliptical wave. The concept of applying Huygens principle to model fire growth involves using the fire environment at each perimeter point to dimension and orient an elliptical wave around each point on a fire front at each time step (Finney, 2005). • The reliance on an assumed fire shape, in this case an ellipse, is necessary because the spread rate of only the heading portion of a fire is predicted by the present fire spread model (Rothermel, 1972).
Advantages	• Fire risk maps help managers visualize a variety of variables that contribute to the fire pattern and the application of Fire Weather Index (FWI) and Canadian Forest Behaviour Prediction (FBP) systems. • This static map is useful to some organizations such as the Spatial Forest Management System (sFMS) that provides daily fire risk maps for up to date information on their web site (Doran, 2004).	• In terms of forest ecology, theoretical models can be generated to reveal forest fire spread patterns. • Probabilistic fire spread models rely on user-defined probabilities, which will define the criteria for fire spreading from cell to cell.	• Fire spread in all other directions is inferred from this forward spread rate using the mathematical properties of the ellipse. An elliptical shape would not have to be assumed if the spread rate in all directions could be computed independently from the fuels, weather, and topography. • The wave propagation theory provides realistic results for heterogeneous landscapes it overcomes the pixel adjacency issues that are common in CA

			models.
Disadvantages	• The fire risk map only provides a snapshot of the potential fire risk for that particular point in time. (Keane, Burgan, & Wagtendonk, 2001).	• Pixel adjacency issue where it will resample neighbouring pixels.	• May over-sample the data by incorporating entire pixels into the ellipse, particularly dependent upon resolution.
Illustration			

Chapter 3
Quetico Provincial Park

It is anticipated that the prescribed burn fire break method can be applied to any terrestrial forested protected area, and potentially outside of parks and protected areas. The detailed case study will focus on Quetico Wilderness Provincial Park. This chapter discusses the following:

- Overview of Quetico Provincial Park
  - Climate and land features
  - Economic activity
- Fire activity in the Park
  - Quetico's fire management plan
  - Quetico's fire zones
  - Prescribed burning in Quetico

3.1 Quetico Provincial Park Study Area

Pristine forests, habitat for wildlife and home for numerous outdoor pursuits make Quetico Provincial Park a destination for many. Its lakes and forest are home to moose, wolves, black bear, approximately 250 bird species and 50 fish populations (Crossman, 1976; Elder, 1994). It truly provides a wilderness experience.

Quetico is located in northwestern Ontario, approximately 160 Km southwest of Thunder Bay, approximate co-ordinates 48dºN and 90dºW (Figure 3-1). Originally set aside as a Forest Reserve following the establishment of Superior National Forest in neighbouring Minnesota in 1909 (Stradiotto, 1984), the Forest Reserve was established as a Park in 1913. Today it is the third largest wilderness Park in Ontario at 476,000 ha. With over 1,400 Km of water routes and 612 portages, Quetico is known as the canoeing capital of Canada.

Figure 3-1: Location of Quetico Provincial Park

The topography of Quetico is gently rolling to moderately rugged, with 550 lakes dotting the landscape. The combination of rivers, bogs, and rock outcrops form a broken, discontinuous landscape. There is a rich history of fur trade and western settlement with evidence of pottery and tools found throughout the Park. Pictographs found throughout the Park illustrate the importance of the area.

The 434,000 ha BWCA area which is situated in Superior National Forest, borders Quetico and is the most heavily used backcountry area in North America. The BWCA combined with Quetico provides a vast region of 130 Km of waterways. Voyageurs National Park is also located nearby on the Ontario-Minnesota border. This 89,034 ha park is smaller than Quetico and BWCA. The combined attraction of Quetico, Voyageurs and BWCA has earned the waterways their reputation as North America's premiere, near-urban, wilderness canoe routes.

This research focuses on the 202,500 ha (45 Km^2) northeast portion of Quetico Provincial Park (Figure 3-1). The study area includes an 8 Km buffer adjacent to the Park on the North and East boundaries. This buffer is included in order to illustrate the importance of creating a break to contain escaping wildfires. The decision to focus on the eastern boundary was a result of several factors that include balsam fir killed by insects and wind storm damage, leftover timber from harvesting, lack of water features, few tourist destinations and highly valued timber on Crown lands North and East. These fuel types are vulnerable to rapid fire spread. The lack of extensive natural fire barriers along the eastern Park boundary result in high risk of fire escaping the Park. This is an area of active fire suppression and hence, a greater buildup of hazardous fuels compared to elsewhere in the Park may result in a catastrophic wildfire. The western portion of the Park is not considered because there are less insect and wind damage areas, less flammable vegetation types (mixedwoods), and higher volume of campers.

3.1.1 Climate and Land Features

Quetico's climate is influenced by the continental polar air mass, and the continental dry air mass from the foothills of the Rockies. These air masses cause a decrease in humidity and create a warmer and drier climate than is found throughout most of Ontario. The prevailing winds are predominantly from the southwest in the spring and summer and from the northwest in the winter (OMNR, 1995).The July mean daily temperature in Quetico is 17.5°C (Elder, 1994). The mean total annual precipitation of Quetico is 69 cm compared to 86 cm in Toronto. Overall Quetico experiences long cold winters, short, warm summers, moderate precipitation, and large seasonal changes.

Quetico lies within the Precambrian Shield, also known as the Canadian Shield that contains some of the oldest rocks on earth. Thin layers of acidic and nutrient-poor soils cover most of the area (Stradiotto, 1984). A proportion of Quetico's irregular landscape contains thin and coarsely textured soil deposits. The eastern area of Quetico contains bedrock covered by clays and sand. The central and western portions have discontinuous patches of lacustrine and beach deposits with water-washed till (*ibid*). Quetico waters drain to the West, through Rainy Lake to Lake of the Woods, Lake Winnipeg and finally Hudson Bay. With the retreat of glaciers across North America, ice lobes retreated to create Glacial Lake Agassiz that covered much of Voyageurs National Park and Quetico.

Quetico's climate greatly influences the flora and fauna of the Park. Quetico occupies a zone of transition between the Boreal forests to the North, the Mixed forests to the South and southeast, and the Great Plains forests to the West and southwest. After the last ice age, the Great Lakes-St. Lawrence forest expanded North to Lake Superior, where the soil conditions and climate became ideal for pine communities (Rowe, 1972). In addition, the changes in topography and geology caused variation in moisture, nutrient and light availability which influenced the boreal ecosystem (Kronberg *et al*., 1998). Of the four major vegetation regions found in Ontario (Deciduous; Great Lakes-St. Lawrence; Boreal; and Tundra), Quetico contains both boreal and a transition between the Mixed forests to the South and southeast and the Great Plains forests to the West and southwest (Table 3-1).

Table 3-1: Some of Quetico's Forest Species

Common Species Name	Latin Name	Author
red maple	*Acer rubrum*	Russell S. Walters
silver maple	*Acer saccharinum*	William J. Gabriel
sugar maple	*Acer saccharum*	Richard M. Godman
yellow birch	*Betula alleghaniensis*	G. G. Erdmann
white birch	*Betula papyrifera*	John C. Bjorkbom
green ash	*Fraxinus pennsylvanica*	Harvey E., Jr. Kennedy
bur oak	*Quercus macrocarpa*	Paul S. Johnson
red oak	*Quercus rubra*	Ivan L. Sander
jack pine	*Pinus banksiana*	P.R. Laidly
black spruce	*Picea mariana*	William F. Johnston
red pine	*Pinus resinosa*	Paul O. Rudolf
eastern white pine	*Pinus strobus*	G.W. Wendel
poplar sp.	*Populus sp*	Maurice E., Jr. Demeritt
trembling aspen	*Populus tremuloides*	D.A. Perala
American basswood	*Tilia americana*	T.R. Crow
northern white cedar	*Thuja occidentalis L.*	William F. Johnston
American elm	*Ulmus Americana*	Calvin F. Bey

Source: Burns & Honkala, 1990, Annonymous, 1993

Boreal forest species are predominant, occupying about 90 % of the Park's total area. Of this, jack pine and black spruce alone dominate approximately 55 % of Quetico, followed by poplar (25 %) and white birch (10 %). red pine and white pine are found on the shorelines of lakes and rivers and comprise 8 % of Quetico's forest cover. In the southern end of the Park, is Great Lakes-St. Lawrence forest vegetation such as northern white cedar, red oak, and sugar maple.

These temperate species are found sporadically throughout the Park, restricted to sites of hotter-than normal microclimates on South-facing slopes, rocky ridge tops, lakeshores and islands, especially where richer, less acidic soils are present. Other mixed forest tree species include yellow birch, American elm, red maple, silver maple and green ash. Western influence on the local flora is provided by the Great Plains forests, namely basswood, red oak and bur oak (Anonymous, 1993).

3.1.2 Economy of Quetico and Surrounding Area

With a population of 3,000, the town of Atikokan is close to Quetico and the Lac La Croix First Nations reserve with population of 250 is situated on Quetico's western park boundary. The town relies on forestry and tourism as their economic base. More than two-thirds of northwestern Ontario communities are primarily dependent on the forest and forest industries. The forest industry provides 40 %, of direct and indirect, regional employment (Natural Resources Canada, 2006). Logging historically influenced the forests of Quetico Park. Clear-cutting of jack pine and black spruce took place in the northeast area of the Park between 1961 and 1971. Remnants of logging activity are evident with logging roads and stumps throughout the northeastern portion of the Park. Quetico is surrounded by valuable timber resources, governed by forest management agreements (FMA's), dedicated to forestry companies including Atikokan and Abitibi forest products. On the northern, eastern and western boundary of the Park, timber harvesting is evident, therefore fires that start near the Park boundary are actively suppressed to prevent wildfires from consuming valuable timber. There are mills at Atikokan and Sapawe. Five hundred individuals are directly employed in the forestry industry, while 200 are indirectly employed. Atikokan's power generating stations is another major employer with approximately 90 employees (Atikokan Economic Development Corporation, 2007).

Tourism is also a large source of economic activity for Atikokan and surrounding area. Quetico generates $3 million in economic activity in the Atikokan district with 80 direct and 30 indirect jobs. A recent study calculated that 1 job lost in Atikokan, is proportional to 1,347 jobs lost in Toronto (McKinnon, 2007). This study emphasizes the relative importance of every single job in smaller communities like Atikokan.

The local community of Atikokan relies on tourism for income and economic development. Canoeing within Quetico has become popular. Individuals want the wilderness experience and tend to congregate in the North, West and southern portions of the Park. Figure 3-2. With 2,146 interior campsites in the Park, visitation levels currently run at about 130,000 camper nights annually. Peak visitor periods correspond with high fire hazard periods during the summer. Park managers need to find the proper balance with fire management that includes maintaining visitor safety and enjoyment while upholding the Park's ecological objectives. In addition, Quetico has

28 pictograph sites (Heinselman, 1996), as well as historic sites, cabins and sensitive habitats that need to be protected from fire activity.

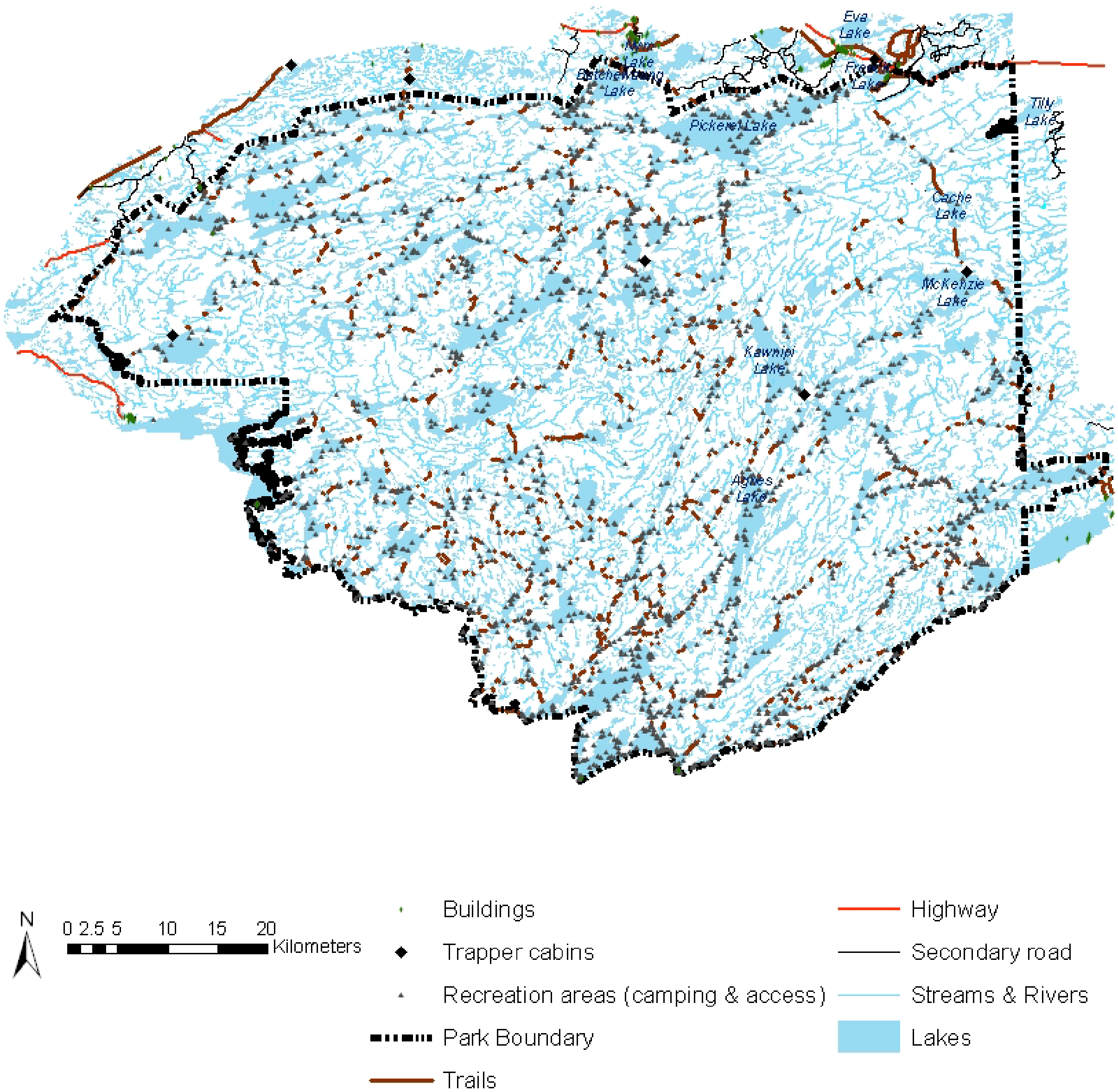


Figure 3-2: Recreational use and other features in Quetico Provincial Park

Source: (Legacy Forest, 2004)

3.2 Fire Activity in Quetico

Fire has influenced the forest composition in Quetico. The natural force of fire in Quetico has been responsible for the renewal and continuance of major virgin forests for thousands of years (Woods & Day, 1977). Approximately 90% of Quetico's plant communities are comprised of pioneer species and can be defined as fire originated communities, such as jack pine stands. Without fire, many of Quetico's forest communities would probably not exist (Woods & Day, 1977). Understanding historical fire regimes helps researchers and managers to appreciate ecological processes and the natural conditions of Quetico. Since the 1930's, a total fire suppression policy was applied in Quetico and the boreal forest changed. With reduced fire frequency, the vegetation mosaic of even-aged boreal species will be replaced by uneven-aged forests including hardwood and late successional shrub and tree species, which will result in non-representative boreal forest ecosystem. Fire-dependant black spruce and jack pine will actually disappear as a natural component of the boreal forest landscape in the absence of fire. To illustrate the fire dependency, the serotinous cones from black spruce and jack pine need heat from fire to open the bound cones. The fire not only heats the cones and releases seed, it also creates a seed bed providing nutrient rich soil so germination will take place (Weber & Stocks, 1998). Without fire, vegetation protection issues are raised because the area was set aside to protect pioneer species and the boreal ecosystem. With the absence of fire in the boreal ecosystem, maintaining and enhancing Quetico's ecological integrity is compromised.

3.3 Quetico Fire Management Plan

Lightning caused fires play a more significant role in the boreal forests than in any other type of forest (Li, Ter-Mikaelain, & Perera, 1996) because the boreal forests are dependent upon fire for regeneration and survival. With suppression efforts, there is still a fire potential. Although suppression has been effective at minimizing fire size, human caused fires and weather conditions may result in uncontrollable fires and wildfires (Anonymous, 1993). Within the Park, lightning accounts for 62.5% and recreational activities 36.5% of the total number of fire occurrences (OMNR, 2006).

Today's managers must address the re-introduction of fire as a natural component of the boreal forest ecology (Kutas *et al*., 2002). The motivation typically occurs after a major event. In Quetico, Park managers, along with fire experts, developed a fire management plan as a result of a catastrophic 1995 wildfire. A lightning strike ignited an area that was highly susceptible to fire.

Rainy River district fire 141, referred to in Chapter One, was the worst fire in the 20th century in this region, burning over 25,000 ha, or 5 % of the Park's area (Peruniak, 2000). As a result, a fire plan was drafted and approved in 1998. Remarkably, Quetico was the first Park in Ontario to institute a fire management plan.

Fire management strategies challenge Park managers because they must balance the need for effective forest fires contributing to the boreal forest's ecological function against the risk of personal injury, property loss or expansion of fire beyond the Park boundaries. Although fire suppression crews have been effective at minimizing fire's effects on the landscape, fire prevention programs have also reduced human caused fires. In addition to fire suppression and prevention, fuels are building up in Quetico as a result of periodic blowdown occurrences, as well as spruce budworm forest mortality. In addition, there is a gradual accumulation of organic matter on the forest floor as forests mature. This fuel composition combined with fire suppression practices result in high quantities of highly flammable fuels.

A flammability map (Figure 3-3) was derived from components in the Field Guide to the Canadian Forest Fire Behaviour Prediction (FBP) System (Taylor, Pike, & Alexander, 1997). The FBP system quantitatively assesses fire behaviour, particularly within Canadian fuel types and topographic variabilities (Hirsch, 1996) (refer to Chapter Four, section 4.1.3). Criteria to determine fuel flammability were set based on the fire intensity class of the fire (Table 3-2). Fire intensity class ranges from 1-5 categorizing the type of fire and fire suppression difficulty.

Table 3-2: FBP Fire Intensity Class

Fire Intensity Class	**Type of fire and fire suppression difficulty**
1	Ignition occurs but cannot be sustained; smouldering may occur
2	Creeping or gentle surface fire; fight this type of fire with hand tools and water
3	Low to moderate vigorous surface fire; heavy equipment (helicopter with bucket, retardant material)
4	Extremely intense surface fire
5	Crown fire to active crown fire possible; very difficult to control; indirect attack by aerial ignition

Source: (Taylor, Pike, & Alexander, 1997)

The potential intensity of the fire in terms of its initial spread index (ISI) was also a criterion for determining level of flammability. The ISI is the numerical rating of the expected rate of fire spread. This value results from wind, slope and fine fuel moisture affecting fire spread (*ibid*). The data was derived from the FBP fuels map acquired from the OMNR. There are 16 benchmark vegetation types, which were classified according to the fire's propensity to spread (7 coniferous, 1 deciduous, 4 mixedwood, 3 slash and 2 grass). The FBP system for determining fuel flammability considers the rate of spread (ROS) or the speed at which a fire travels along the ground, the fire intensity (rate of heat release, fuel consumed and linear rate of spread), and type of fire (ground, surface or in the forest canopy) to determine the fire potential of a particular fuel type (Taylor, Pike, & Alexander, 1997). Within the study area, Table 3-2 summarizes the flammability classes according to low, medium, and high.

Table 3-3: Flammability Values of Fuel Types

Flammability	**ISI**	**Intensity class**
Low	31 >	1,2
Medium	13-30	3,4
High	<12	5, 6

According to the re-classed map layers (Figure 3-3), the majority of the study area is highly flammable. There is greater flammability inside the Park, particularly in the southeast portion of the Park. This is important because a wildfire could spread eastwards and become more intense as it reaches the eastern park boundary.

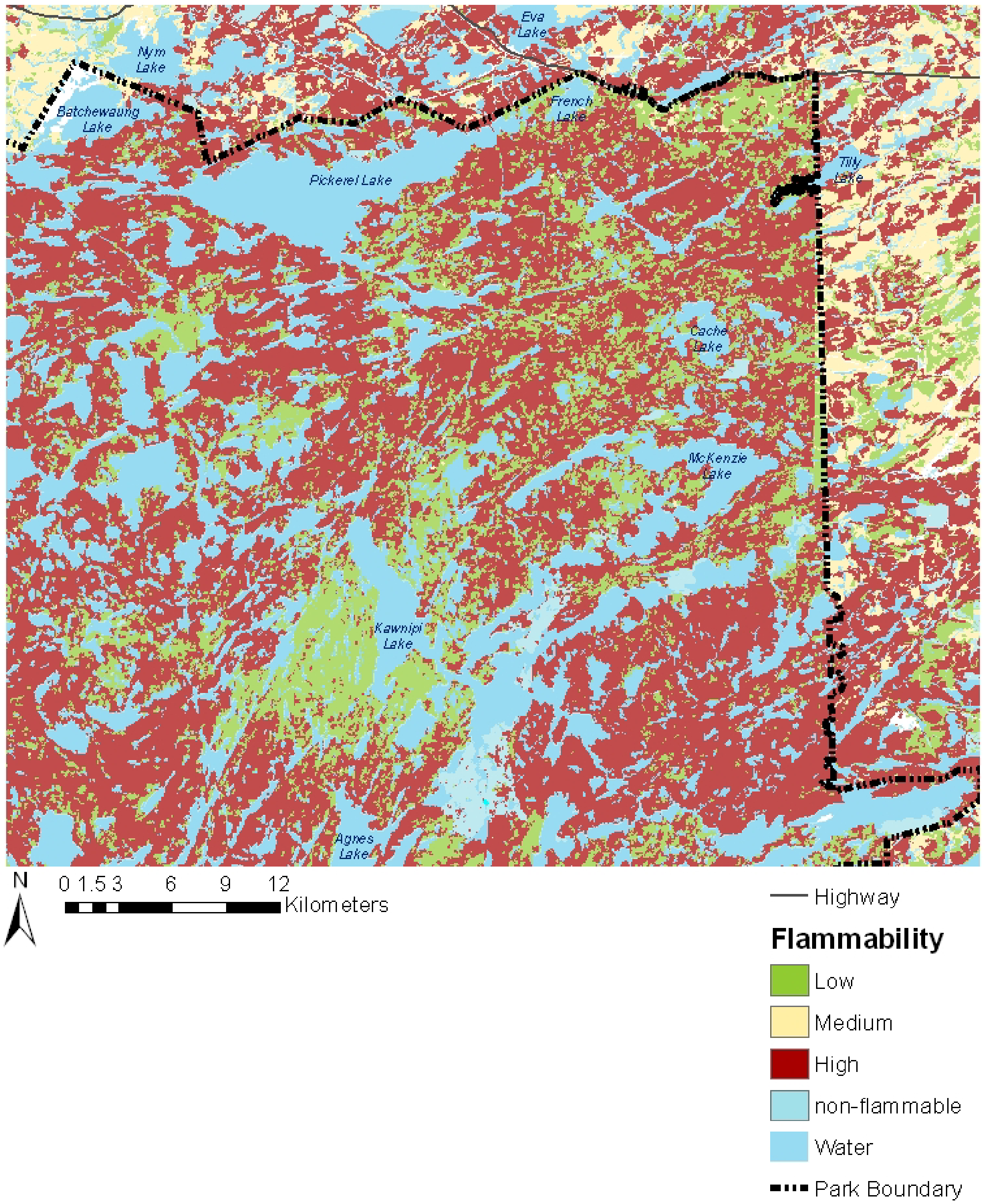


Figure 3-3: Map of flammability levels in and around Quetico Provincial Park

The *Ontario Provincial Parks Planning and Management* policies recommend each wilderness class park prepares a fire management plan. The policy states, "Natural fires in wilderness…will normally be allowed to burn undisturbed unless they threaten human life, access zones or land outside the Park" (OMNR, 1998). Not only is understanding that effective fire management fundamental to achieving Quetico's goals and objectives, but fire is a major management tool that can be used to achieve natural forest and wildlife habitat conditions (OMNR, 1998). With this understanding, Quetico's fire management goal is "to approximate the natural role of fire in perpetuation of Quetico's ecological processes, within the constraints of personal injury, value loss, economic and social disruption" (OMNR, 1998, p5). Quetico's fire management plan is intended to remain flexible, so there can be future changes. The plan accommodates social, economic or environmental changes as they relate to the Park's goals and objectives. However, the plan has a clear protocol to make decisions (Appendix A) about fire management based on location of each fire (Figure 3-4) and fire weather. For example, a fire is assessed using the fire plan criteria in combination with the location within the management zones.

3.3.1 Quetico Fire Management Zones

Quetico is divided into Intensive, Measured and Prescribed Natural Fire zones (Figure 3-4) and based on the fire risk in a particular fuel type and terrain, weather patterns, sources of ignition and presence of people and facilities (OMNR, 1998). The area beyond the boundary of the Park is zoned Intensive, whereby a fire will be immediately suppressed. Fires in the Intensive zone may threaten timber harvesting practices, human life and properties. Prescribed burns may occur in the Measured zone to reduce fuel buildup or for ecosystem renewal. The Prescribed Natural Fire zone comprises approximately 63 % of the Park and fires are allowed to burn given a set of criteria and monitoring. With the establishment of fire zones, Park staff can evaluate and monitor fires, determine risk and decide on appropriate management steps to ensure safety, but also manage ecosystems.

Figure 3-4: Map of Quetico's Fire Management Zones

Source: (OMNR, 1995; Woods & Day, 1977)

Beyond the northern Park boundary is the town of Atikokan (20 Km away), highway 11, homes, cabins hotels/resorts, and gas stations. The land North and East of the Park is Crown land. With such valued properties surrounding the Park, it is important to effectively manage and contain fires within the Park's boundary.

Quetico's southern boundary borders BWCA, part of the Superior National Forest in Minnesota. Their fire plans are similar to Quetico's in that they recognize the importance of fires to restore and maintain a natural ecosystem in wilderness areas. As in Quetico, some fires caused by lightning are allowed to burn under specific conditions and objectives in BWCA. Just West of Quetico, Voyageurs National Park in Minnesota has a similar management plan. Lightning-caused fires are allowed to burn in designated areas, however, all unplanned human-caused fires are suppressed. Currently there is a *memorandum of understanding between Ontario and the State of Minnesota* concerning detection and suppression of fires within 3 Km of the international boundary (OMNR, 1998).

3.1.1 Prescribed Burning in Quetico Provincial Park

Quetico Provincial Park recognizes the importance of fire, so their fire management plan permits some natural fires to burn. In addition to the approved Park and fire management plan used by Park managers, a *Prescribed Burn Planning Manual* is utilized. Depending on the zone (Figure 3-4) and what needs to be accomplished, prescribed burns may be used as a management tool to reduce hazards and manage ecosystems.

Quetico promotes minimum impact or "Light on the Land" techniques to reduce human impact during fire response in Parks and protected areas (OMNR, 2004a). This array of techniques also reduces the costs involved in mechanical fire suppression. The planning of prescribed burns requires sound decision-making, detailed documentation and interaction with all people affected by the burn. The personnel need to communicate their plan to the timber companies surrounding the Park, members of the community and Park visitors. The planned prescribed burns are subject to environmental assessments. Planned fires are published in the Parks annual trip planning guide so Park visitors are notified and can adjust their routes if required.

Quetico regularly conducts prescribed burns for ecological purposes. For example, two successful prescribed burn operations reduced the hazards associated with large areas of blowdown in Quetico. In 1999, a massive windstorm, the "Independence Day Blowdown", threw down or damaged trees over approximately 291,000 ha of forest along the Ontario/Minnesota border. The goal of the 1,790 ha Emerald Lake prescribed burn was to remove as much fuel as possible, to serve as a fuel break and reduce the potential for a wildfire (Figure 3-5).

Figure 3-5: Emerald Lake Prescribed Burn in Quetico
Source: (Curran, 2000)

In summary, Quetico Provincial Park is known for its pristine wilderness experience, and is promoted by Atikokan as the canoeing capital of Canada. Active logging areas and other commercial establishments surround the Park, and communities depend upon these for their livelihoods. Park activity accounts for $3 million in revenue locally and hence, protecting this valuable tourism resource is important. Primarily populated with boreal forest species, Quetico is fire-dependent. Without fire within the Park, the ecological integrity of the area will diminish and mixedwoods and late successional species will replace conifers. In contrast, fire that is integrated into the Park's management plan and landscape will perpetuate and renew biodiversity and ecosystem health.

Productive fire management needs to balance the detrimental effects of fire activity with regards to human values, infrastructure and resources, but also balance fire's natural role in rejuvenating ecosystem health of fire-dependent species. The Park personnel acknowledge this relationship between fire and boreal forests, and have successfully implemented prescribed burns for hazard reduction and ecological purposes as well as prescribed natural fires. In addition, the Park's master plan is in the process of being revised and updated with the anticipation of further implementing the Park's goals to allow natural forces such as fire to function freely. In support of this, there is the potential to incorporate the proposed regional fire breaks into the revised master

Park plan. The research outlined here, if incorporated with park plans, may assist Park personnel with deciding on which wildfire to control, which wildfire to monitor and where an ideal fire barrier could be constructed to optimally reduce the wildfire hazard.

Although personnel in Quetico allow some wildfires to burn and be monitored and plan prescribed burns in certain locations, it is imperative to execute these fires safely. There are opportunities in this research to map prescribed burn activity in the context of creating a fire barrier and examine a variety of planning scenarios in a safe environment. This mapping can be simulated through fire modeling software and achieve the fifth research goal of *modeling wildfire scenarios to test the effectiveness of a fire break as a barrier to wildfire activity*. The criteria for selecting appropriate software and steps involved running fire break scenarios are described in the following methods chapter.

Chapter 4
Methods

This chapter describes the methodology for modeling and testing the prescribed burn fire breaks (Figure 4-1). First, fire growth modeling software is examined for compatibility with this project, based on a set of criteria. Next, ease of data retrieval and processing is researched and a model selected. The chapter ends with a discussion of the methodology in testing the success of fire breaks.

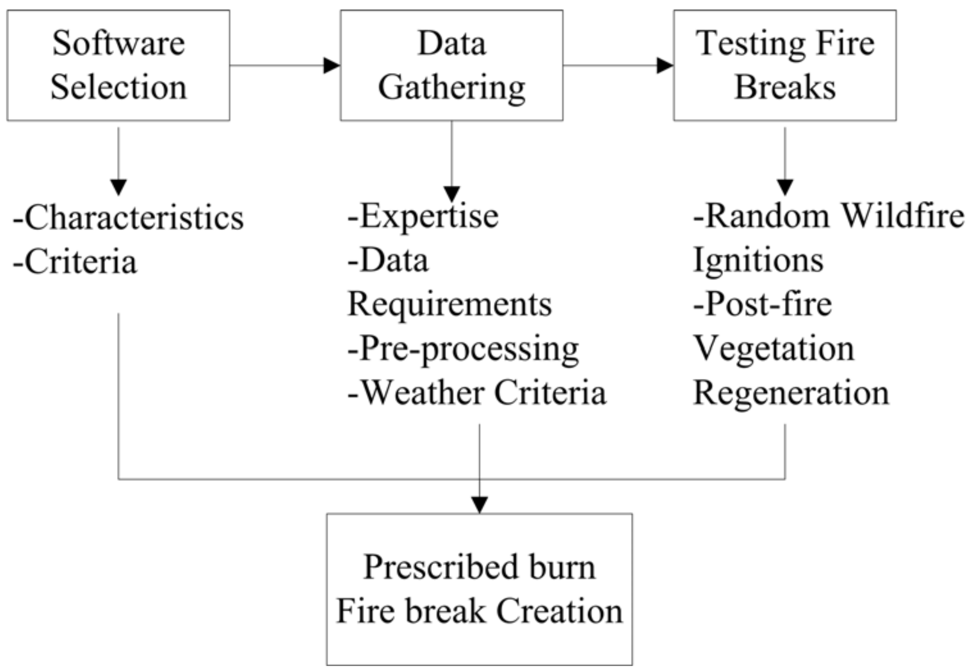
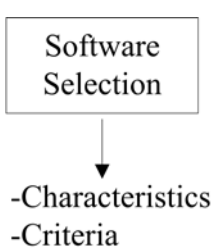


Figure 4-1: Flowchart of Methodology

4.1 Fire Modeling Software Selection



As noted in Chapter 2, spatial modeling is a beneficial approach in resource management. Modeling can assist personnel with management decisions, visualizing "what if" scenarios, evaluating burn probabilities across a landscape, and tracing how fire spreads across the landscape. In addition, management working within budgetary constraints can strategically predict wildfire behaviour and assess situations in a simulated environment.

Modeling software can encompass many components. For example, the Fire-BGC model simulates carbon, nitrogen and water flow across ecosystem variables (Keane *et al*., 2001). Gap models such as FIRE-SUM and JABOWA determine successional forest dynamics (Keane *et al*, 2001). LANDIS, a forest landscape model that simulates landscape processes (seed dispersal, succession, wind, fire, harvesting) (He & Mladenoff, 1999). General circulation models predict air temperatures over a region and potential impact on ecosystems (Wotton, Logan, & McAlpine, 2005). The previous chapters addressed the first three objectives, and to achieve the fourth goal, *research fire behaviour simulation software to model regional fire break designs using Quetico Provincial Park as a case study*, several fire related software programs are examined. BFOLDS, FARSITE, LANDIS and Prometheus were evaluated based on suitability for simulating fire breaks in Quetico. There are many fire models available for use, however, a selected sample of available software was examined to determine appropriate software for modeling fire breaks. The capabilities of each program are outlined in Table 4-1 along with descriptions, such as type of fire growth model, its application to boreal forest vegetation and the cost, if any in obtaining the software in addition to other parameters. Using the features of each software program, criteria are defined to find an appropriate program.

The fire modeling software was selected based on the following criteria:

- Applicability to the research and case study (both study area extent and vegetation type)
- Ease of use, including stand alone workstation download and supported documentation available
- Appropriate spatial and temporal resolution
- Achieving realistic burning results for both prescribed burning techniques and wildfires
- Use of wave propagation principle
- Allowed for validation and realistic simulations and calculations based on Canadian Forest Fire Danger Rating system (CFFDRS), Canada's national system for rating danger.

The fire behaviour modeling software based on these criteria is summarized in Table 4-2. This table illustrates the software's' capabilities as they relate to simulating boreal forest conditions and contributing to designing a prescribed burn fire break.

Table 4-1: Spatial modeling software characteristics

Characteristics	Software Examined			
	BFOLDS	**LANDIS**	**FARSITE**	**Prometheus**
Contact Information	information.ofri@mnr.gov.on.ca	http://www.missouri.edu/~umcsnrlandis/	http://www.farsite.org	http://www.firegrowthmodel.com
Type of model	Cellular Automata	Cellular Automata	Wave propagation	Wave propagation
Software developer	Perera	Mladenoff, He and Boeder	Finney	CWFGM Project Team and Province of Alberta
Applicable to boreal forest	Yes	Yes	Yes	Yes
Minimum spatial resolution	1 hectare (ha)	10 metres (m)	1 m	25 m
Minimum temporal resolution	100 years	100 years	1 minute	30 minutes
Minimum study area required	100, 000 ha	1,000 ha	n/a	300 cells
Computationally intensive and ease of use?	BFOLDS runs on powerful workstations at the Ontario Forest Research Institute (OFRI); requires staff to model for researchers/users	LANDIS runs on personal workstation and researcher can work from training or manual	FARSITE runs on personal workstation; proper training is recommended since software is complex	Prometheus runs on personal workstation; researcher can work through tutorials and learn from training or manual
Ease of accessibility	No, must visit OFRI	Yes, free download	Yes, free download	Yes, free download
Simulate natural, prescribed fire or both	Natural	Natural	Natural and Prescribed	Natural and Prescribed
Widely used relative to provincial research centres	No	Yes	No	Yes

Output map generation and output compatible with other software	Yes	Yes	Yes	Yes
Example of software used in research	(Perera *et al*., 2003)	(He, Mladenoff, & Boeder, 1999)	(van Wagtendonk, 1996)	(Doran, 2004)

Table 4-2: Criteria for selecting fire growth software

	Criteria									
Software	Boreal forest vegetation input feasible	Minimal hardware requirements (stand alone workstation)	Supported documentation and small learning curve	Spatial resolution between 30-60m	Temporal resolution (minimum 30 minutes)	Study area minimum of 500 raster cells	Wave propagation model	Validated	CFFDRS incorporation	Simulates prescribed fires?
BFOLDS	X									
FARSITE	X	X		X	X	X	X			X
LANDIS	X	X	X	X		X				
Prometheus	X	X	X	X	X	X	X	X	X	X

Prometheus was selected for this research because it is based on the Canadian Wildland Fire Growth Model CWFGM and because it has been validated extensively in boreal forest environments. This stand-alone software validates the calculation of Fire Weather Index (FWI) values and Fire Behaviour Prediction system (FBP) calculator and insures that outputs are consistent with the Canadian Forest Fire Danger Rating system (CFFDRS) FBP codes provided by the Canadian Forest Service. (The CFFDRS will be explained in section 4.1.1). In addition, software developers compared simulated burns with actual fire occurrences of 486 unique files of data prior to releasing Prometheus. This validation is important for confidence in the results of the present simulation experiment.

Prometheus incorporates wave propagation fire algorithms developed at Brandon University (Canadian Interagency Forest Fire Centre (CIFFC), 2006). Wave propagation modeling is preferable to static mapping or cellular automata because it provides realistic results with a fire being able to spread in all directions in the form of an ellipse. In addition, the program uses vegetation fuel types similar to those in Quetico Provincial Park. The free software is available for download from its web site, (http://www.firegrowthmodel.ca) and can be installed easily on computers with relatively modest processing capabilities. Prometheus is relatively straightforward to use, with a tutorial and sample data included, unlike the other programs that require formal training (FARSITE) or a computing assistant (BFOLDS). The temporal and spatial resolutions are also satisfactory since Prometheus allows at least 30-minute fire growth intervals and 60 m resolution of input data layers. With these resolutions, the researcher can view daily fire activity with accuracy compared to viewing an entire century of fire activity and its effects on the landscape. This short time interval is an important requisite to model prescribed burns that typically burn for only one day, or a wildfire that burns for several days. Although Table 4-2 indicates that both FARISTE and Prometheus met the criteria for simulating wildfires and prescribed burns, Prometheus was designed to use a combination of fire growth models and features from FARSITE and other models (Canadian Interagency Forest Fire Centre (CIFFC), 2006). Depending on the end use of the software, there are strengths in all of the software evaluated however, Prometheus was most suitable for this modeling approach. With the software chosen, the next step is to map potential fire break locations that will provide a barrier to wildfires from escaping the Park.

4.1.1 Canadian Forest Fire Danger Rating system (CFFDRS)

Prometheus is based on the CFFDRS, Canada's national system for rating fire danger. This is important because it considers the measurements of many different fire components including fire occurrence and prediction of fire behavior. As a result, fire managers can prepare for fire prevention, planning, conducting prescribed burns and assist with fire behaviour training (Natural Resources Canada, 2004). Two significant sub-components, the Fuel Behaviour Prediction (FBP) and Fire Weather Index (FWI) system are required for Prometheus to accurately simulate fire scenarios. Fire occurrence prediction system (FOP) is currently under development. The following chart depicts the components comprising the CFFDRS system and the parameters used in Prometheus.

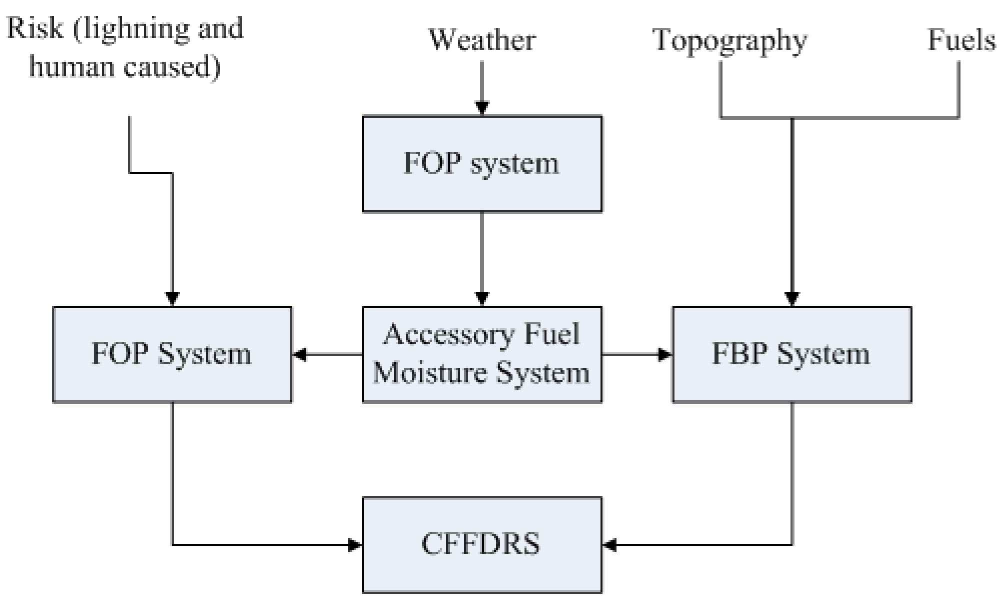


Figure 4-2: CFFDRS flowchart

Source: (Hirsch, 1996)

4.1.2 Canadian Forest Fire Weather Index (FWI)

FWI, a sub-component of the CFFDRS, is comprised of relative fire potential on standard fuel types on level terrain (Hirsch, 1996). The fire weather observations include temperature, relative humidity, wind speed and precipitation (Figure 4-3). These inputs are used to calculate rates of spread for fire vertices along the fire perimeter, using a fire intensity equation.

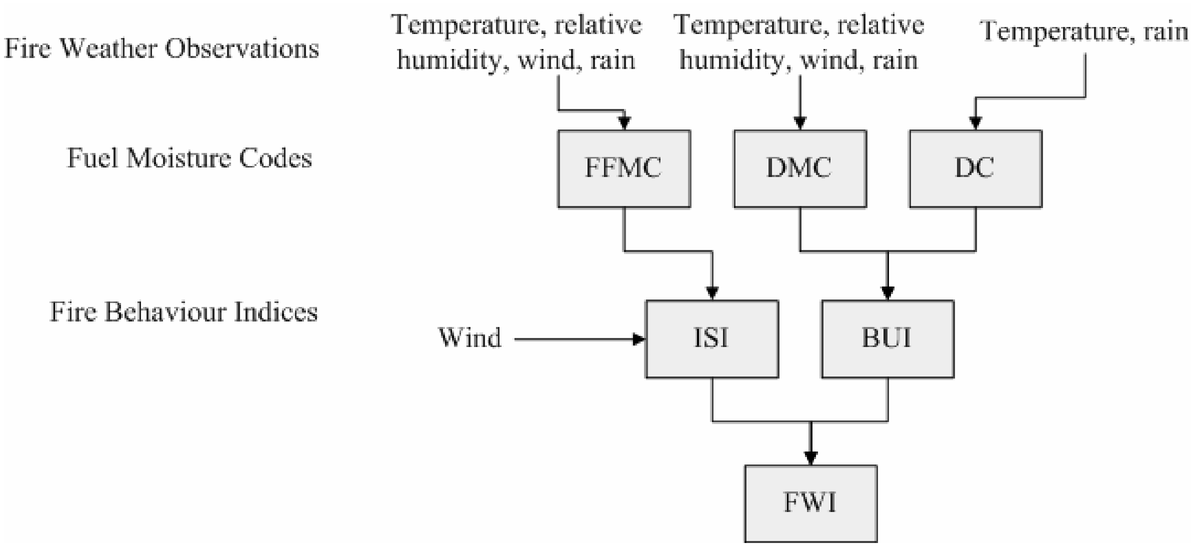


Figure 4-3: Structure of FWI system

Source: (Forestry Canada Fire Danger Group, 1992)

There are three moisture codes: Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC) and Drought Code (DC), which are numerical ratings of the moisture content on the ground of leaf litter, and loosely compacted organic layers at moderate and deep depths respectively. The moisture codes indicate the relative ease of ignition and the flammability of fuel (Canadian Forest Service, 2006; Hirsch, 1996). The fire behaviour indices are Initial Spread Index (ISI), which combines the wind and FFMC and their effect on the rate of spread in a fire. The Buildup Index (BUI) combines DMC and DC to numerically determine the amount of fuel and flammability. The ISI and BUI output the FWI, which is the fire intensity and assigns a general index of fire danger throughout the forested areas of Canada (Canadian Forest Service, 2006). Table 4-3 breaks down each class of fire weather, from low to extreme. These components are incorporated into decisions regarding campfire activity and proper time to conduct prescribed burning. The FWI values differ for each province. FWI gives a general indication of the fire danger, whereas the FBP system calculates fire behaviour in a specific fuel type.

Table 4-3: Ontario Fire Weather Index (FWI) Chart

FWI Class	FWI Components					
	FFMC	**DMC**	**DC**	**ISI**	**BUI**	**FWI**
Low	0-80	0-15	0-140	0-2.2	0-20	0-3
Moderate	81-86	16-30	141-240	2.3-5	21-36	4-10
High	87-90	31-50	241-340	5.1-10	37-60	11-22
Extreme	91+	51+	341+	10+	61+	23+

Source: (Antozsek, 2005b)

4.1.3 Canadian Forest Fire Behaviour Prediction (FBP) System

The FBP is based on the FWI and hourly weather (Hirsch, 1996). The FBP systematically quantitatively assesses fire behaviour, particularly within Canadian fuel types and topographic variabilities (Hirsch, 1996). The FBP calculations are based on over 400 experimental fire behaviour observations that include fire spread, fuel consumption. An overview of FBP's main components is displayed in Figure 4-4. Although there are 14 inputs of the FBP structure, they can be grouped into 5 categories: fuels, weather, topography, foliar moisture content and type and duration of prediction.

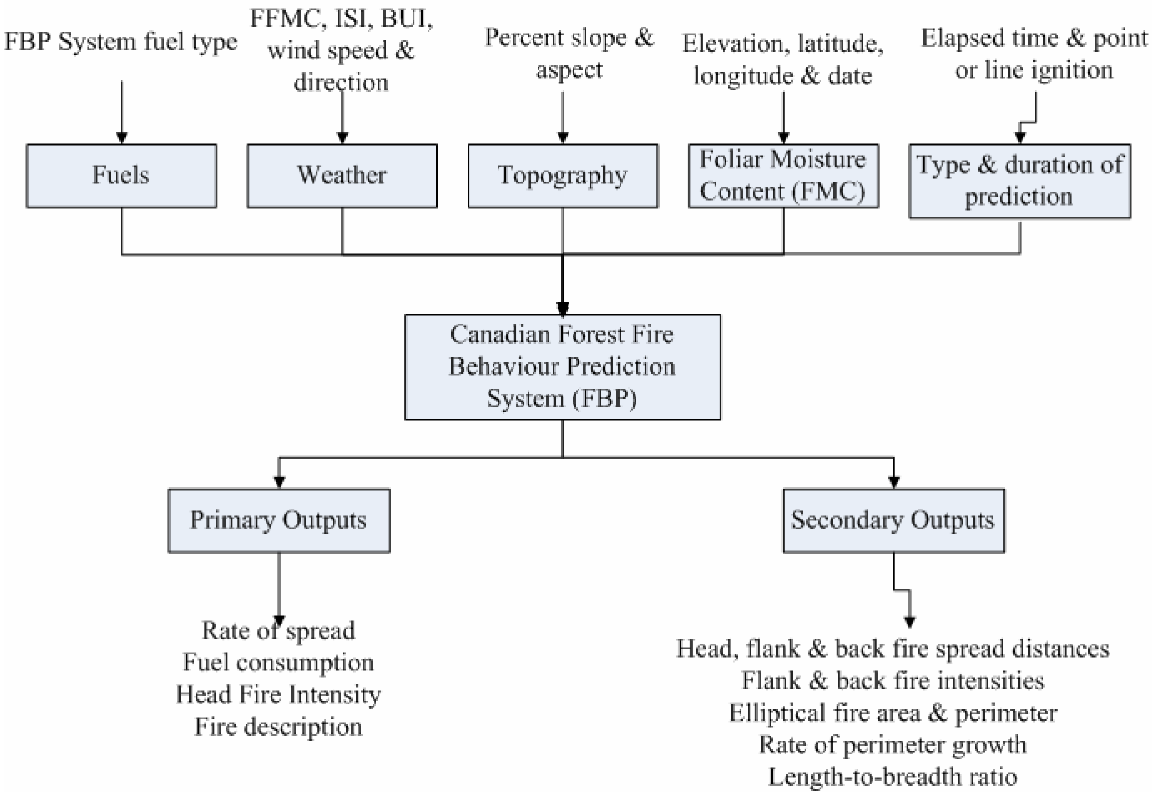


Figure 4-4: Chart of FBP Structure

(Hirsch, 1996)

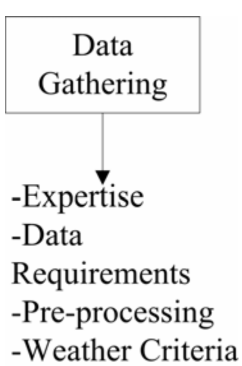
The FBP system has 16 fuel types (Figure 4-4) that are defined as "an identifiable association of fuel elements of distinctive species, form, size, arrangement and continuity that will exhibit characteristic fire behaviour under defined burning conditions" (Merrill & Alexander, 1987). These characteristics of fuel type include forest floor cover, organic layer, surface and ladder fuels, stand structure and composition (Forestry Canada Fire Danger Group, 1992). These fuel types represent many of the major fuel types found in Canada.

Table 4-4: Individual FBP fuel types in Canada

FBP Code	Common species name
C-1	Spruce–Lichen Woodland
C-2	Boreal-Spruce
C-3	Mature jack or lodgepole pine
C-4	Immature jack or lodgepole pine
C-5	Red and White Pine
C-6	Conifer Plantation
C-7	Ponderosa Pine and Douglas Fir
D-1	Leafless Aspen
S-1	Jack or lodgepole slash
S-2	White spruce and balsam slash
S-3	Coastal Cedar, hemlock and Douglas-fir slash
O-1	Grass
M-1	Boreal Mixedwood –leafless
M-2	Boreal Mixedwood –green
M-3	Dead Balsam Fir Mixedwood –leafless
M-4	Dead Balsam Fir Mixedwood –green

Source: (Taylor, Pike & Alexander, 1997)

4.2 Data Gathering



4.2.1 Expertise to create prescribed burn fire break

For the prescribed burn fire break creation and design, maps containing topography, FBP fuels, recreation points and trails were sent as paper copies to various fire experts and knowledgeable personnel within the province and internationally. These fire experts were discovered from a combination of researching related literature, and networking during a visit to Quetico and the towns of Atikokan and Dryden in May 2005. These people were asked (Appendix B) to consider the information delivered and to sketch potential prescribed burn sites in close proximity to Quetico's eastern Park boundary that would serve as an effective fire break to reduce fire spread and contain wildfires. In addition, they were informed that the fire break design should help to fulfill fire's ecological role in the boreal landscape and uphold the objectives of the Park. The prescribed burn fire break was to be mapped within the park boundary because active timber harvesting occurs surrounding the park and it is economically more valuable than forested land within the park. The written questions allowed for suggested approaches independent of bureaucratic, economic and other limitations that might influence fire break design. For example, the first question stated, "if there was no risk of prescribed fires escaping, or political and budgetary limitations influencing decisions, how would a break be designed?" The purpose in the wording of questions was to receive uninhibited suggestions on fire break designs and considerations. The questions were open ended, so individuals could choose where to establish the fire break, for example on the Park boundary or several kilometres within the Park. Further, questions were posed related to their prescribed burn strategy, for example few large burns or several smaller burns. Participants were also requested to provide rationale for the designs so that some insight into their expertise and experience could be discovered. Considerations in creating the fire breaks included examining historical fire occurrence data, values at risk within and outside the Park, fuel characteristics, and weather.

The input received in these fire break designs varied by level of expertise and involvement with fire management. For example, one design was created by a fire expert specializing in prescribed burn techniques and fire sciences for the province, with many years experience in this field. A fire expert from the US who regularly conducts prescribed burns in a national Park to build up a fire barrier created another design. Fire experts who regularly research fire behaviour and the impacts upon the landscape created two other designs. For those individuals with expertise in fire management who did not sketch potential burn locations on paper or electronically, the researcher sketched the recommendations based on conversations and a combination of input. In total, 10 people were contacted and five prescribed burn designs were outlined over the topography and fuel maps. Five designs sufficiently address different scenario designs. The five designs will give a general overview of the capabilities of a fire break.

Using the five resultant sketches and appended comments, the prescribed burn locations were digitized to create the fire break areas. In Prometheus, ignition lines were digitized on-screen to best portray the input. The digital layout of each prescribed burn assumed an ignition line, similar to a fire torch line laid out by fire crews on the ground or a heli-torch of fire released from a helicopter.

4.3 Spatial Data

This section describes parameters needed to model fires and the steps taken pre-process to prepare the data for modeling in Prometheus. In Prometheus, fire scenarios are based on the following data layers to determine potential fire spread: FBP fuels; topography; weather; fire ignitions; fire breaks or fuel breaks. The CFFDRS is used in Prometheus and considers the FBP and FWI components. Prometheus incorporates GIS data, FBP system calculations, and weather calculations such as the daily FWI indices to estimate patterns of fire for the study area (Canadian Interagency Forest Fire Centre (CIFFC, 2006). These calculations are combined with CFFDRS and modeled as elliptical fire perimeters.

Weather is another component in the CFFDRS that includes wind speed and direction and also FFMC, ISI and BUI from the FWI system (Figure 4-4). Topography is important because it influences the fire behaviour. The Foliar Moisture Content (FMC) accounts for the crown fire rate of spread given the latitude, longitude and elevation. The type and duration of prediction refers to the fire behaviour reaching equilibrium rate of spread, or when a fire is burning steadily. The primary and secondary outputs (Figure 4-4) are measurements of fire intensity, consumption, and type of fire, spread distance and area. These outputs follow the assumption that the fire shape is elliptical (Hirsch, 1996).

Each component was pre-processed in geomatics software (ArcGIS and PCI Geomatica), as outlined later in this chapter. The required and optional parameters, data file types and rationale for using specific parameters is listed below (Table 4-5).

Table 4-5: Input parameters for Prometheus modeling

Required Data		
Parameter	**File Type required**	**Rationale for use**
FBP Fuel Type Grid ASCII	Grid ASCII	Vegetative fuel to burn and model fire spread
Projection Data	ASCII text	For standard projection of data
FBP Fuel lookup table	ASCII text	Description of fuel type and colour-coded for map display
Weather Data	ASCII text	Will influence fire behaviour
Fire Ignition Data	Generate ASCII, Shapefile	To model fires at specific locations
Optional Data		
Parameter	**File Type required**	**Rationale for use**
Elevation	Grid ASCII	Influences moisture levels on ground
Aspect	Grid ASCII	Influences fire behaviour, depending on exposure
Slope	Grid ASCII	Influences rate of fire spread, depending on degree of slope
Wind Speed	Grid ASCII	Affects rate of fire spread
Wind Direction	Grid ASCII	Affects rate and direction of fire spread
Fire Lines/Fuel Breaks	Generate ASCII, Shapefile	Used to test effectiveness of barrier
Vector and Attribute Data	Generate ASCII, Shapefile ASCII text, dbf	Additional description for weather, ignitions, fire line data

4.3.1 Raster and Vector Pre-processing

4.3.1.1 Spatial resolution

Spatial resolution is a measure of the smallest angular or linear separation between two objects (Jensen, 2007). The spatial resolution of all the raster data layers was considered. A raster grid is composed of many pixels, or cells that represent an area on the ground. Raster cells are typically square and the resolution of a grid is expressed in terms of a cell's width or length, for example, 10x10 metres (m), or 30x30 m. Grids are easier to process but they provide a more generalized representation of the landscape. A grid with a small spatial resolution is composed of a comparatively large number of cells. Smaller cell size allows linear and smaller features to be represented but is computationally demanding such as fire breaks, trails, and roads.

Conversely, a coarser spatial resolution could merge and generalize distinct features into one pixel and thus, distort the image (Doran, 2004). The suggested resolution of input data layers for Prometheus is between 25 and 200m (Canadian Interagency Forest Fire Centre (CIFFC), 2006). After experimentation using the Quetico data, the higher resolutions caused the workstation to "crash". After consultation, (Wotton, 2006; Feick, 2006) a 60m resolution was used. Although a higher resolution may provide greater detail, natural fire breaks such as rock outcrops, rivers and lakes remain evident in the data layer with 60m pixel resolution.

Some data layers were vector based and converted to a raster grid. A vector image is made up of points and lines, whereas raster images are grids of pixels that contain colour information (Figure 4-5). The grid ASCII raster format is required for fuels and topographic files in Prometheus because it is a standard format that can be transferred between various applications and is efficient to work with when examining individual cells. Shapefiles can be used in Prometheus for vector data, such as fire line breaks, ignition points and lines since shapefiles store spatial and attribute data of the feature (Canadian Interagency Forest Fire Centre (CIFFC), 2006). When converting from vector to raster or the reverse, there are potential inaccuracies. For example, fuel vector polygons converted to raster resulted in a line feature such as the road or stream, spreading across many pixels and appearing wider than in reality. Conversely, line features when transformed to raster format can become smaller or discontinuous.

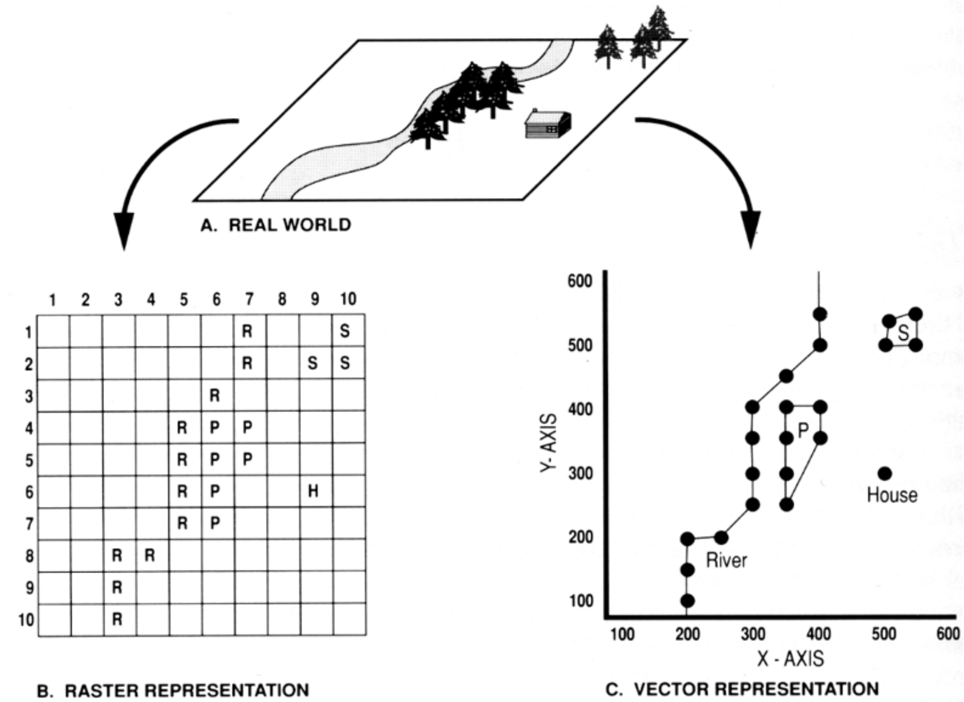


Figure 4-5: Raster and vector image representation

(Aronoff, 1995)

4.3.2 Data Layers

The first data layer is the FBP fuel type, which was acquired from the OMNR. The combination of a classified Landsat satellite image and Forest Resource Inventory (FRI) data produced the FBP fuel map. FRI is an extensive survey of Ontario's forest resources. The FRI is based on air photo interpretation and some ground surveys (OMNR, 2002). Assessing the accuracy of these FBP fuel classes by field validation would increase the reliability of these data. During the field trip in 2005, FBP classes were validated in the North portion of Quetico Provincial Park including: the entire northern Park boundary, French Lake, northeast Pickerel Lake, Nym Lake, and the trails and shorelines associated with these lakes (Figure 3-1). Of the total study area in Quetico, 1.3% of the data were missing and classified as "not-available" in the map. Projection information associated with the image is also required so that Prometheus can convert the FBP fuels and topographic layers into a standard projection. In addition to the FBP fuel raster layer, a lookup table (LUT) that contains a description of the FBP fuel and associated colour for map output is required (Table 4-6).

Table 4-6: Example of LUT for Prometheus modeling

Grid Value	Export grid value	Agency FBP fuel type	FBP fuel type	Red	Green	Blue	Hue	Saturation	Luminance
1	1	C-1	C-1	0	205	219	120	255	255
4	4	C-4	C-4	190	0	80	90	255	180

For the fire growth pattern to be realistic, topographic information relating to elevation, slope and aspect are considered in the FBP system. Slope can affect fire behaviour since ridges can slow down or block fire spread, whereas steeper slopes cause fires to travel faster if heading uphill. Aspect will influence the fire behaviour as well because South facing slopes tend to be drier and have more abundant or even different vegetation growth. Elevation will also influence the moisture level on the land and is dependent on the geographic location. The digital elevation model (DEM), a grid with elevation values depicted in each cell, was retrieved from the Legacy Forest Map services web site (http://www.legacyforest.ca). The DEM was reprojected to the appropriate datum and resolution and converted to a grid ASCII for input into Prometheus. Slope and aspect were derived from the DEM in Geomatica Focus using the *SLP* and *ASP* algorithms respectively (Figure 4-6).

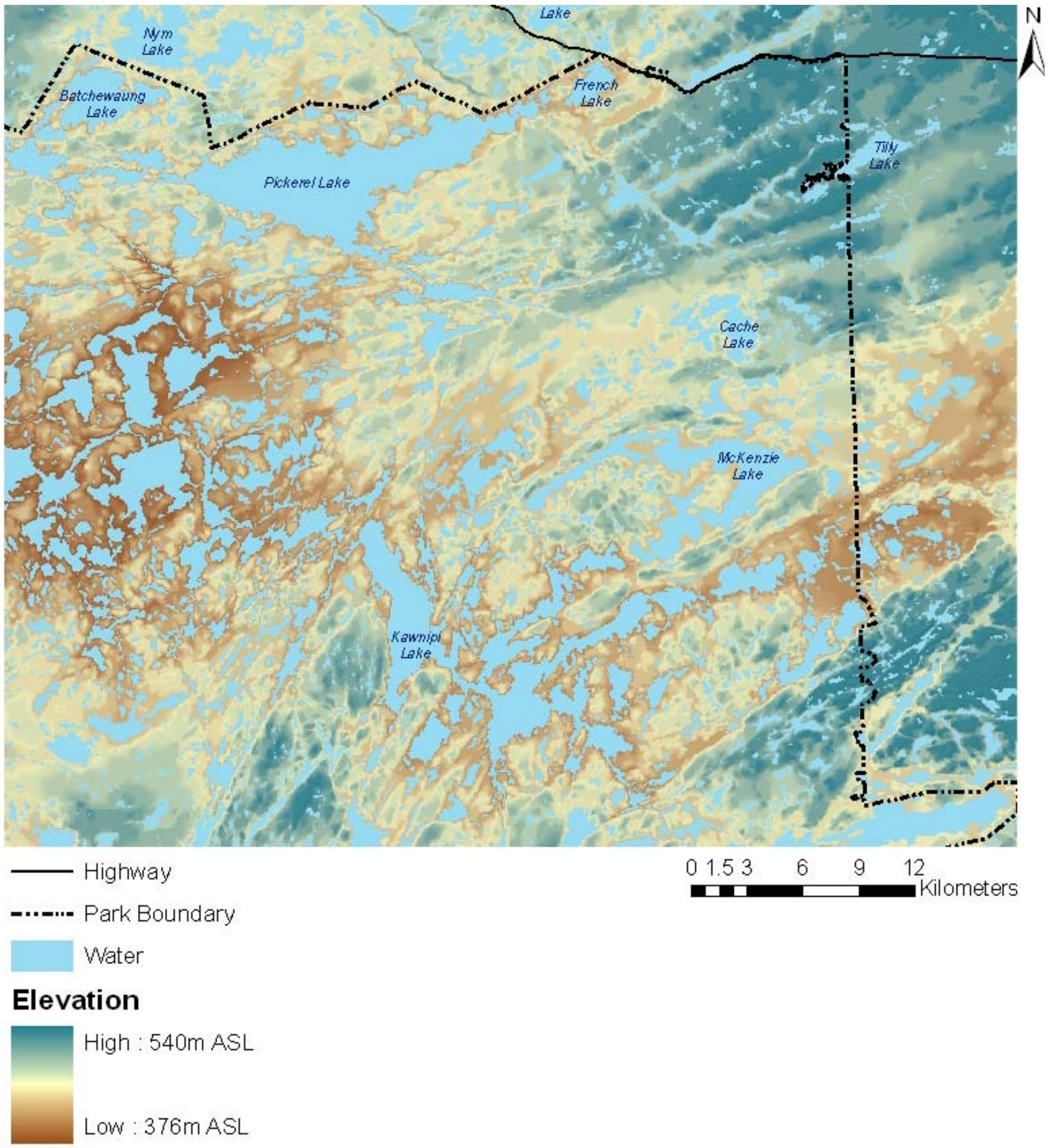


Figure 4-6: Elevation of Quetico study area

With the addition of a FBP fuels and topographic layers, Prometheus will output physical characteristics of a fire such as rate of spread (ROS), fuel consumption and head fire intensity (HFI) in a forest stand (Figure 4-7). Incorporated into Prometheus, the FBP system provides the underlying fire spread models to simulate fire propagation over the landscape and how the perimeter of a fire changes over time (Canadian Interagency Forest Fire Centre (CIFFC), 2006). The model propagates a new fire perimeter that is a product of a specified time step and the respective rates of spread for the fire vertices (Canadian Interagency Forest Fire Centre (CIFFC), 2006)

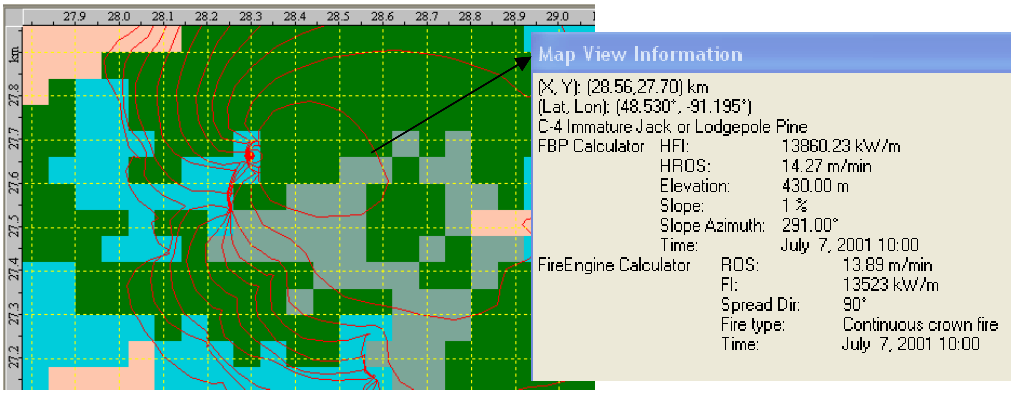


Figure 4-7: Fire ellipses used to calculate fire spread and type

4.3.3 Weather Data Measurements

Weather is a significant parameter in realistic and simulated fire modeling. Relative humidity and precipitation affect the FBP fuel moisture calculations, while wind speed and direction also influence fire spread. Weather stream data based on the FWI required for modeling fire scenarios in Prometheus can be imported or created in several delimited ASCII file formats. Prometheus offers the option to import daily or hourly weather streams, so extrapolations from daily weather is not required. The elevation and geographical location of the weather station are manually entered into the weather station menu. These streams can define current or forecasted weather data.

Weather data were acquired from Environment Canada (Mills, 2005) and the OMNR (Caputo, 2005). To produce accurate and realistic results, fire modeling requires weather stations to be close to the study site (Simard, 1972). Unfortunately, many weather stations across the province have been closed due to funding cuts and those that are currently operational periodically experience equipment malfunctions with consequent missing information.

In order to have complete weather stream of data for the fire simulations, weather measurements were stitched together from several weather monitoring stations. For example, the closest weather station to the Park was at the Park headquarters in Atikokan, approximately 20 Km away. This weather station closed in 1995, so data from other nearby stations, Kahshahpiwi and Sapawe were used to fill in missing values. Data from the latter two stations are also used for current operational procedures in Quetico. As a result, weather data from 1994-2004 were used in simulating prescribed burn and wildfires.

The measurements required for Prometheus are temperature (temp), relative humidity (RH), precipitation (PRECIP), wind speed (WS) and wind direction (WD). A sample weather stream is outlined below in Table 4-7.

Table 4-7: Example of weather stream for Prometheus

Hourly	**Hour**	**Temp (ºC)**	**RH (%)**	**WS (Km)**	**WD**	**PRECIP (mm)**
7/7/2001	9	13	30	5	225	0
7/7/2001	10	14	30	4	270	0
7/7/2001	11	14	27	4	315	0

The precipitation measurements were converted from daily to hourly values and were based on the relative humidity, as advised from a fire expert for realistic simulations. With regards to the other weather measurements, hourly data were available from the weather stations and hence, applied to the weather stream. The elevation (389 m) and geographical co-ordinates (48.29°W lat, -91.59°N long) of the weather station were created based on the Atikokan weather station. Elevation of all the other weather stations differed by approximately 10m. With these requirements, Prometheus calculated the FBP and FWI indices. These values are combined with CFFDRS to determine the rate of spread, and then accumulated into hourly elliptical fire perimeters. The next step after compiling the weather information was to choose appropriate days to simulate prescribed burns and to simulate wildfires.

4.3.3.1 Weather Criteria for Simulating Prescribed Burns

To determine ideal prescribed burn weather conditions, several sources were examined. The first was the existing prescribed burn plans used in Quetico that consider actual prescribed burn dates such as the Emerald Lake and The Pines prescribed burn plans (Curran, 2000; Ontario Ministry of Natural Resources, 2000). The second source was the FWI chart (Table 4-3), which categorizes the risk of fires based on FWI components. Finally, advice was obtained from fire experts from the OMNR on the ideal time of year to burn, and associated weather criteria pertaining to the Quetico area (Antozsek, 2005a; Curran, 2006a; O'Connor, 2006).

Based on the documentation and discussions, prescribed burns should be planned after the peak fire season, preferable from mid-September to the end of November. The moderate FWI indices were selected for the prescribed burn scenarios because if the FWI components are too low, a fire will have difficulty igniting and sustaining. Conversely, if the FWI components are in the high or extreme classes, there is potential for the controlled burn to escape and become a wildfire. In determining ideal simulated weather scenarios, the following parameters were considered:

- Prescribed burn dates ranging from September 15th – November 30th only
- ISI value in moderate range for the day of prescribed burn
- No precipitation two days before anticipated prescribed burn date
- DC in moderate range
- Wind not greater than 15 Km per hour on prescribed burn date.

In addition to the FWI values, the prescribed burns were set to only burn for one day, with ignition starting in the morning at 9:00 am and extinguishing at the end of the day at 6:00 pm, as typically performed in the field. Precipitation occurring the following day to further extinguish the burn would be ideal but was not a criterion.

4.3.3.2 Weather Criteria for Simulating Wildfires

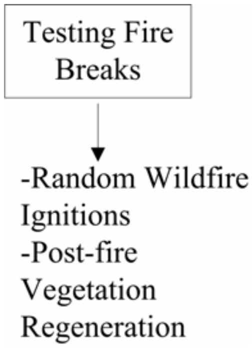
To determine ideal weather conditions for intense wildfires, a variety of sources were examined. Van Wagtendonk (1996) recommends specifying the 95th percentile of the extreme FWI index for severe fire seasons. Although there is no document to rate “worst fire year”, fire activity by wildfire occurrence in the Park in the years corresponding to the weather data available was evaluated and the year with the amount of area burned was deemed the worst. In 1995 for example, the summer conditions were described as hot and dry (Suffling, 1995) and 39 fires burned a total of 25,369 ha (unpublished information). 1995 may be the worst recent year for the number of fires and area burned, but other variables were examined to determine if it was also the worst fire weather year. To determine the worst fire weather, the extreme class of FWI components were viewed. The wildfire should be simulated during Ontario's burn season, from the beginning of April to the end of September. In determining realistic wildfire weather scenarios, the following variables were considered:

- Wildfire dates in accordance with burn season of April 1st-September 30th
- ISI of 10 or greater for two days prior to ignition and on ignition day
- 0 mm of precipitation on ignition date
- Moderate wind speed, 7-15 Km per hour to sustain fire.

The FWI index was also examined when selecting weather streams, but was not a criterion. One limitation in Prometheus is that if there is neither a barrier nor a time to stop the fire, then it will run to the extent of the data layer. In reality the wildfire would spread until all the fuel was consumed, hit a non-fuel area, be controlled by fire suppression or put out by moisture or cold temperatures. In this study, the wildfires burned for only five days to simulate a hazardous fire situation and to display the extent of a wildfire burning for a short period of time.

By examining the warmest decade on record, from 1994-2004, weather streams were selected based on the criteria for both prescribed burns and wildfires. There are 44 potential prescribed burn dates and 14 severe wildfire weather dates to select for the fire scenario input. The prescribed burn dates were narrowed down to 3 dates by considering the precipitation post burn and from there, 1 date was randomly selected, September 18, 2002. The highest rated weather week to incorporate into the wildfire scenario was narrowed down by considering the FWI index values and is July 7, 2001.

4.4 Testing Fire Breaks Against Wildfires



The prescribed burns to create the fire breaks simulated in Prometheus were based on ideal weather streams for fall burning. To test the effectiveness of the fire breaks, in the reduction and spread of and containing wildfires, 100 randomly located wildfire ignition points were generated for each fire break scenario. Historical lightning strike ignition points across the Park were evaluated. However, a decision was made to use 100 randomly placed ignition points created in PCI Geomatica image processing software (Figure 4-8) because there is no pattern or dependency on events with this approach. A mask was applied to prevent the ignitions being mapped on non-flammable fuel including “non-fuel”, “data not available”, and “water” classes and beyond the Park boundary. The “non-fuel” class is not a true representation as this is a processing error with the FBP classification. The “non-fuel” class is composed of rock, sparse vegetation, and data missed in classification or not available at time of processing. Unfortunately, the “non-fuel” class located in the South of the study area was not field validated and left as “non-fuel” for the simulations, but this accounted for only 58 ha.

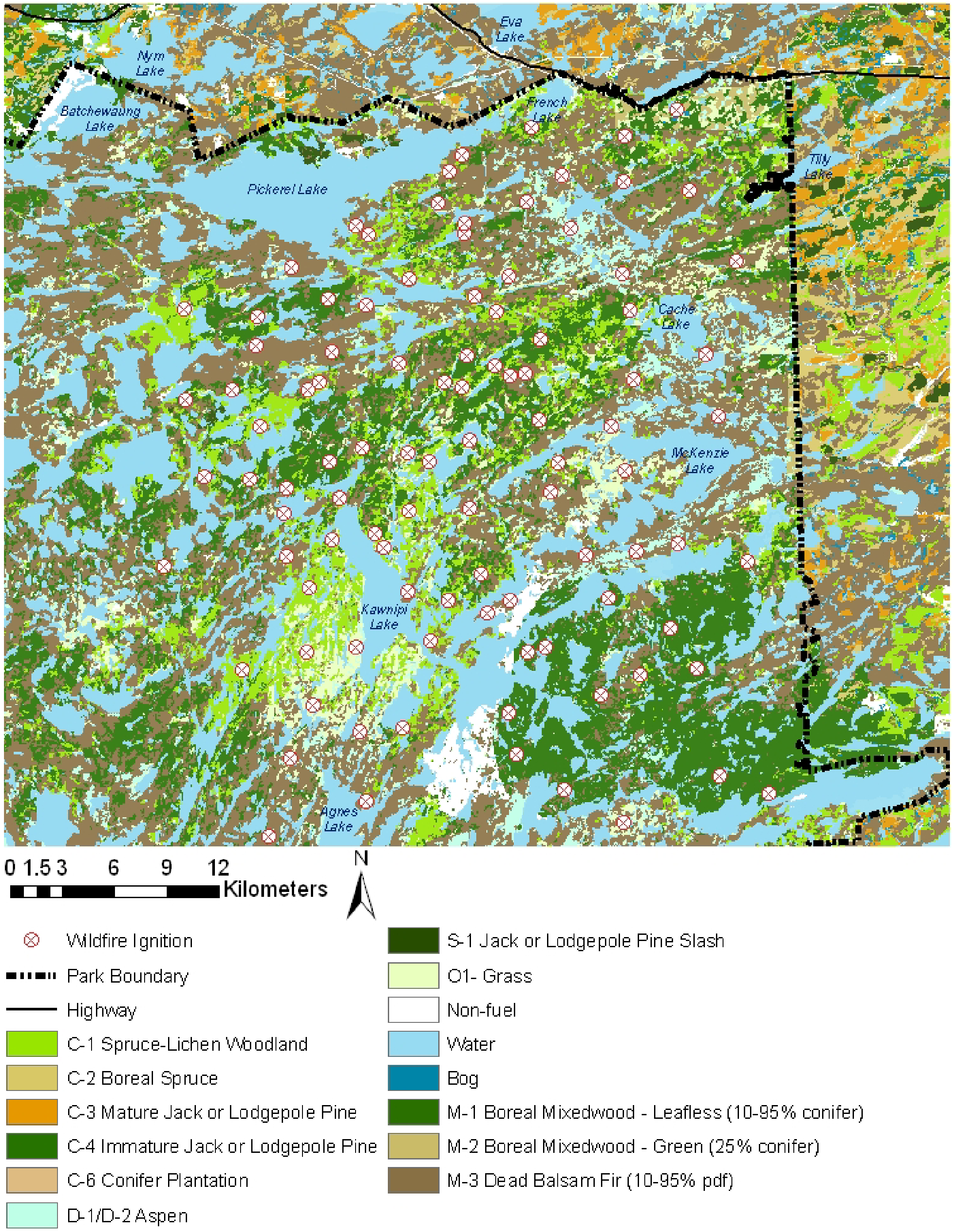


Figure 4-8: Random wildfire ignition points and fuel types in the Quetico study area

4.5 Post-fire Vegetation Regeneration

The FBP fuel vegetation data layer was reclassified according to the prescribed burn fire break input for all five fire break designs. The post-fire vegetation regeneration was researched for years subsequent to burning. The vegetation was reclassified based on the vegetation pre-fire and the time period since the prescribed burn to determine re-growth of each species. It is important to consider the vegetation regeneration in modeling these prescribed burns because it will realistically model post-fire conditions. In addition, the vegetation regeneration rates account for sensitivity of re-growth. The simulated post-fire vegetation re-growth used to create the three scenarios is based on literature researched and summarized according to the FRI vegetation abbreviations in Table 4-8 (refer to Table 2-1 for complete forest species names). This table illustrates the regeneration of each fuel type found in the study area that has the potential to burn. Many comprehensive studies exist on vegetation succession and factors attributing to re-growth. Thus, specific considerations were not incorporated. These include insect infestation, wind damage, human activity, seed dispersal by wind, birds, and animals, soil conditions, extreme weather events (drought, wet seasons), the changing climate, or other unplanned fire activity. However, as the objective of this research is to test the effectiveness of prescribed burns serving as a regional fire break, the various factors influencing the rate of succession were not included in the regeneration decisions. Table 4-9 shows the conversion of vegetation types to FBP fuel types needed for Prometheus to model the regeneration following burning. Each fuel type in the study area was reclassified and imported into Prometheus.

Table 4-8: Post-fire regeneration of FBP fuel types

Year after burn	**FBP fuel type in Quetico study area**							
	C-1 spruce-lichen	**C-2 boreal spruce**	**C-3 mature Pj**	**C-4 immature Pj**	**D-1 Pot**	**O1 grass**	**M1 & M2 mixedwood**	**M3 & M4 dead balsam mixed**
1	non-fuel[1,2]	non-fuel[1,2]	Pj seedlings [4,5]	non-fuel[7]	Pot [3]	grass [4]	Pot [1]	Pot [1]
2	non-fuel [1,2]	non-fuel1[,2]	seedlings [4,5]	non-fuel [7]	Pot [3]	grass [4]	Pot [1]	Pot [1]
3	Sb seedlings [3,4]	non-fuel [3,4]	seedlings[4,5]	sparse seedlings [3,7]	Pot [3]	grass [4]	Fb, Pot, Bw, Sb, Pj [4,9]	Fb, Pot,Bw, Sb, Pj [4,9]
4	Sb seedlings [3,4]	Sw, Sb seedlings [1]	seedlings [4,5]	sparse seedlings [3,7]	Pot [3]	grass [4]	Fb, Pot, Bw, Sb, Pj [4,9]	Fb, Pot, Bw, Sb, Pj [4,9]
5	Sb saplings [3]	Sw, Sb seedlings [1]	dense seedlings [1,6]	immature saplings [1,3]	Pj, Sb, Pot regen [3]	grass [4]	Fb, Pot, Bw, Sb, Pj [4,9]	Fb, Pot, Bw, Sb, Pj [4,9]
6	Sb saplings [3]	Sw, Sb seedlings [1]	dense seedlings [1,6]	immature saplings [1,3]	Pj, Sb, Pot regen [3]	grass [4]	Fb, Pot, Bw, Sb, Pj [4]	Fb, Pot, Bw, Sb, Pj mix [4]
7	Sb saplings [3]	Sw, Sb seedlings [1]	dense seedlings [1,6]	immature saplings [1,3]	Pj, Sb, Pot regen [3]	grass [4]	Fb, Pot, Bw, Sb, Pj [4]	Fb, Pot, Bw, Sb, Pj [4]
8	Sb saplings [3]	Sw, Sb seedlings [1]	dense seedlings [1,6]	immature saplings [1,3]	Pj, Sb, Pot regen [3]	grass [4]	Fb, Pot, Bw, Sb, Pj [4]	Fb, Pot, Bw, Sb, Pj [4]
9	Sb saplings [3]	Sw, Sb saplings [3]	dense seedlings [1,6]	immature saplings [1,3]	Pj, Sb, Pot regen [3]	grass [4]	immature Pj [3]	immature Pj [3]
10	Sb saplings [3]	pre-fire DBH	dense seedlings [1,6]	immature saplings [1,3]	Pj, Sb, Pot regen [3]	grass [4]	immature Pj [3]	immature Pj [3]
11	Sb saplings [3]	pre-fire DBH	dense seedlings [1,6]	immature saplings [1,3]	Pj, Sb,	grass [4]	immature Pj [3]	immature Pj [3]

					Pot regen [3]			
12	Sb saplings [3]	pre-fire DBH	dense seedlings [1,6]	immature saplings [1,3]	Pj, Sb, Pot regen [3]	grass [4]	immature Pj [3]	immature Pj [3]
13	Sb saplings [2]	pre-fire DBH	dense seedlings [1,6]	immature saplings [1,3]	Pj, Sb, Pot regen [3]	grass [4]	immature Pj [3]	immature Pj [3]

[1](Frelich, 2002); [2](Wagner & Colombo, 2001); [3] (Heinselman, 1996); [4] (U.S. Department of Agriculture, Forest Service); [5] (Burns & Honkala, 1990); [6] (Lavoie & Sirois, 1998); [7] (Lynham & Curran, 1996); [8] (Vasiliauskas & Chen, 2002); [9] (Suffling, 2004).

Table 4-9: FBP fuel type conversion from post-fire regeneration

Year after burn	**FBP fuel type in Quetico study area**							
	C-1	**C-2**	**C-3**	**C-4**	**D-1**	**O1**	**M1 & M2**	**M3 & M4**
1	non-fuel	non-fuel	non-fuel	non-fuel	D-1	O1a	D-1 or non-fuel	D-1 or non-fuel
2	non-fuel	non-fuel	non-fuel	non-fuel	D-1	O1a	D-1 or non-fuel	D-1 or non-fuel
3	non-fuel	non-fuel	non-fuel	C-4 low a value	D-1	O1a	D-1 or non-fuel	D-1 or non-fuel
4	non-fuel	non-fuel	C-4 low a value	C-4 low a value	D-1	O1a	M-2 5% conifer	M-2 5% conifer
5	non-fuel	non-fuel	C-4 moderate a value	C-4 low a value	D-1	O1a	M-2 10% conifer	M-2 10% conifer
6	non-fuel	non-fuel	C-4 moderate a value	C-4 low a value	M-2 5% conifer	O1a	M-2 15% conifer	M-2 15% conifer
7	non-fuel	non-fuel	C-4 moderate a value	C-4 low a value	M-2 10% conifer	O1a	M-2 20% conifer	M-2 20% conifer
8	C-1	C-2	C-4 moderate a value	C-4 low a value	M-2 15% conifer	O1a	M-2 25% conifer	M-2 25% conifer
9	C-1	C-2	C-3	C-4	M-2 20% conifer	O1a	M-2 30% conifer	M-2 30% conifer
10	C-1	C-2	C-3	C-4	M-2 25% conifer	O1a	C-4	C-4
11	C-1	C-2	C-3	C-4	M-2 30% conifer	O1a	C-4	C-4
12	C-1	C-2	C-3	C-4	M-2 35% conifer	O1a	C-4	C-4
13	C-1	C-2	C-3	C-4	M-2 40% conifer	O1a	C-4	C-4

Three regeneration scenarios were created. The first scenario assumed a regular regeneration rate. The second scenario involved an accelerated approach whereby the vegetation growth was accelerated by five years. This acceleration accounts for sensitivity in the vegetation re-growth and the degree to which it influences the effectiveness of the fire break. The third scenario is a decelerated approach whereby the vegetation re-growth was set back five years. These provide potential worst-case and best-case scenarios to account for uncertainty in the regeneration decisions. A total of 1500 wildfires (100 ignitions per scenario, multiplied by three regeneration rates) were run to test the effectiveness of a fire barrier built by prescribed burning. Prometheus has a batch tool, Pandora, but was not used for these simulations because at the time the software was incompatible with each other.

In summary, the prescribed fires were simulated in Prometheus fire modeling software to map different fire break designs along Quetico's eastern Park boundary. The designs varied according to input received and the vegetation species burned to create the barrier were reclassified according to the year that the burning took place and the length in years to create the break. With a reclassified fire break, they were tested against wildfires to determine how effective each design was in containing wildfires within the Park.

Chapter 5
Results

This chapter outlines the results of all the simulated fire activity. The five prescribed burn fire break designs and rationale are evaluated, as well as their effectiveness in containing wildfires and reducing the risk of wildfires escaping the Park boundary. Results of post-fire vegetation regeneration scenarios will be examined and the five fire break designs will be ranked to determine the most effective break. An overview of the sections covered includes the following:

- Fire break designs
    - Factors considered
    - Results of each break including number of prescribed burns, time period, total area burned, proximity to boundary, compactness
- Fire break effectiveness
    - Number of wildfires escaped/contained
    - Area burned past fire break; area burned past Park boundary; area burned in total
    - Influence of vegetation regeneration rates

5.1 Prescribed burn fire break designs

As outlined in the methods (Chapter 4), five prescribed burn fire breaks were developed. All participants considered the following factors when designing their fire breaks:

- Need for public safety
- How close the fire break is to valuable resources such as infrastructure and timber
- Cost in creating the break
- Prescribed burns are elliptical in shape
- Proximity to water as a natural fire barrier
- Need to reduce flammable fuel type
- Need to account for southwest winds
- Need for linearly shaped breaks
- Need for firebreak width at least 1.5 – 2.0 Km to account for spotting

Human safety and infrastructure are priorities. The fire break needs to be impermeable to wildfires escaping and burning beyond the Park boundary. This concern ties directly to the second factor listed of how close the break will be to valuable resources. Economic resources are particularly important for smaller communities such as Atikokan and surrounding area with limited prosperity. To create a fire break created close to communities and logging facilities involves careful planning because if a fire was to spot or escape, there is little room for error. In comparison, breaks situated a safer distance away from values provide greater time for fire fighting response. Cost is important since park budgets allot limited resources for prescribed burning. Hence, each break design spreads the number of prescribed burns over several years (these economic considerations were reviewed in Chapter 2 in Table 2-2). Situating the fire break near water and other non flammable areas provides efficient natural barriers and can assist the fire break effectiveness. Another efficiency recommended by the personnel is to plan prescribed burns so that they are elliptical. This allows a fire to burn efficiently and fire crews can operate optimally.

Another factor considered by all personnel is the ecological justification for having a break. Prescribed burning will reduce the fuel load in vegetation types and hence reduce the flammability. In the context of creating a fire barrier, it is important to burn specific flammable vegetation fuels to reduce the potential rate of spread if a wildfire started. For example, dead balsam fir should be managed by fire to reduce the fuel content that can contribute to fire spread. Wind patterns in Quetico are another factor because the wind direction influences the wildfire path. In Quetico, winds are generally from the southwest in the summer months which is why the fire breaks are proposed for the far eastern Park boundary to contain wildfire that may spread from the interior eastwards. The fire break is recommended to be linear in shape for a “catch all” along the boundary (refer to Chapter 2, section 2.7). Using natural breaks have both short and long term benefits in that it is cost-effective and the safest to protect against hazardous fire spread. A final point is the width of the break should be at least 1.5-2.0 Km in width to account for potential wildfire spotting (Curran, 2006).

The five fire break designs vary in number of burn years, number of prescribed burns, area, length and width of the fire break and proximity to Park boundary (Figure 5-1-Figure 5-5). These maps depict the results from testing the fire breaks against 100 simulated wildfire ignitions under three regeneration conditions. The results will assist in accepting or rejecting the three null hypotheses, as first presented in the introduction (Chapter One):

1. There is no difference in wildfire activity with a fire break.
2. There is no difference in wildfire activity with respect to fire break designs
3. There is no difference in fire activity of fire breaks with different post-fire vegetation regeneration speeds.

The results of the five prescribed burn fire breaks are mapped in Figure 5-1 to Figure 5-5 and statistics summarized in Table 5-1. The significance of these results is further explored in subsequent sections.

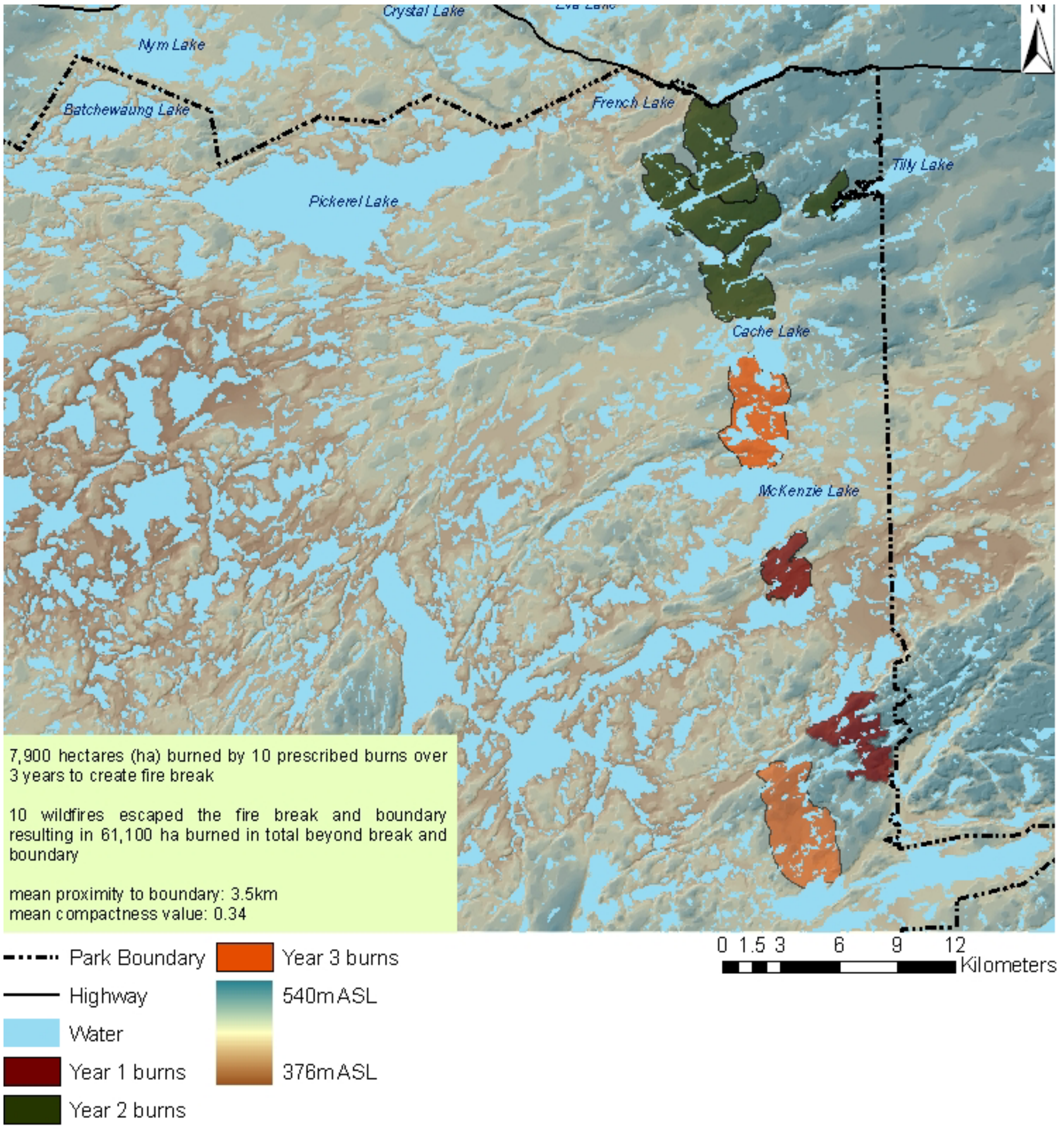


Figure 5-1: Fire Break design A output

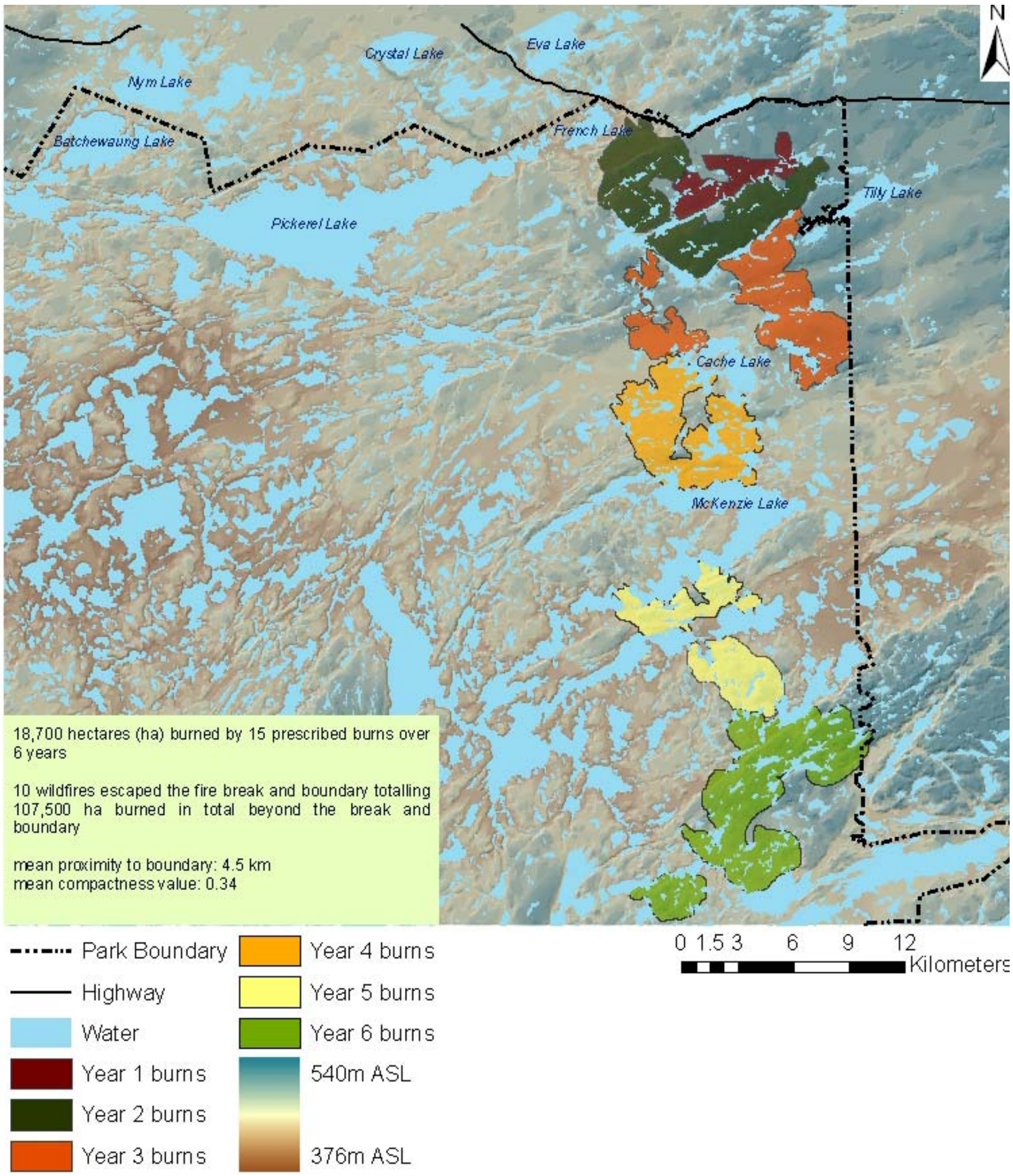


Figure 5-2: Fire Break design B output

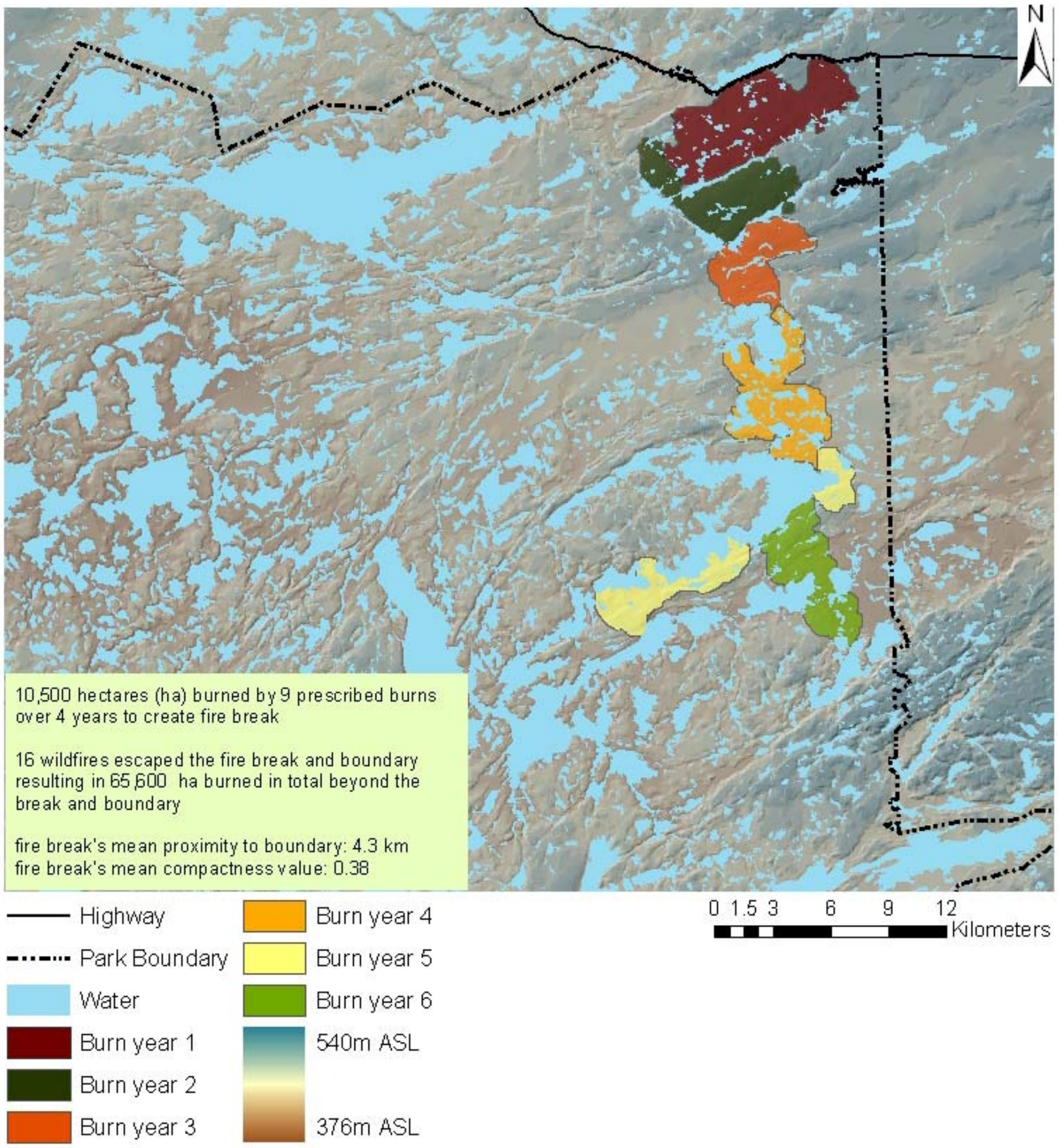


Figure 5-3: Fire Break design C output

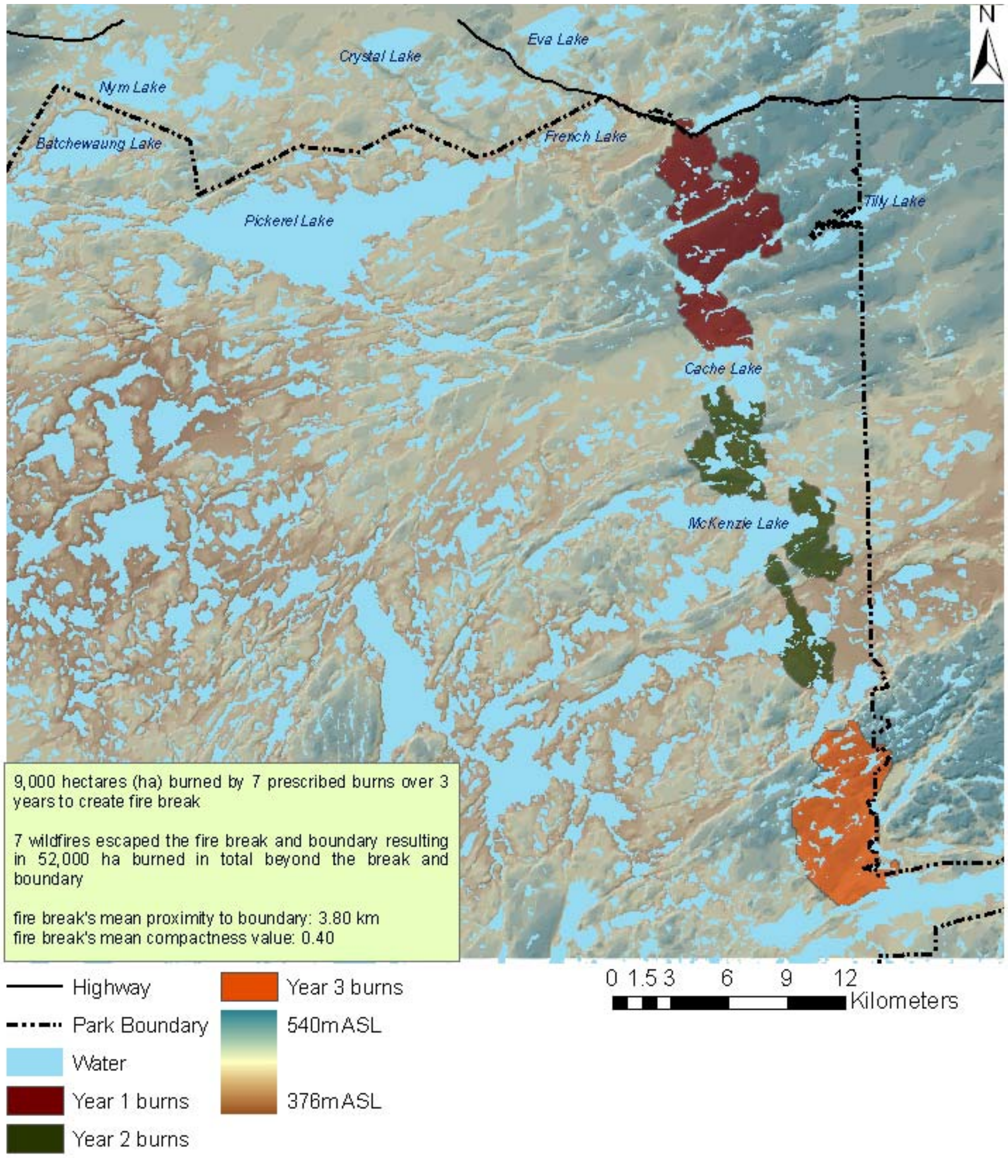


Figure 5-4: Fire Break design D output

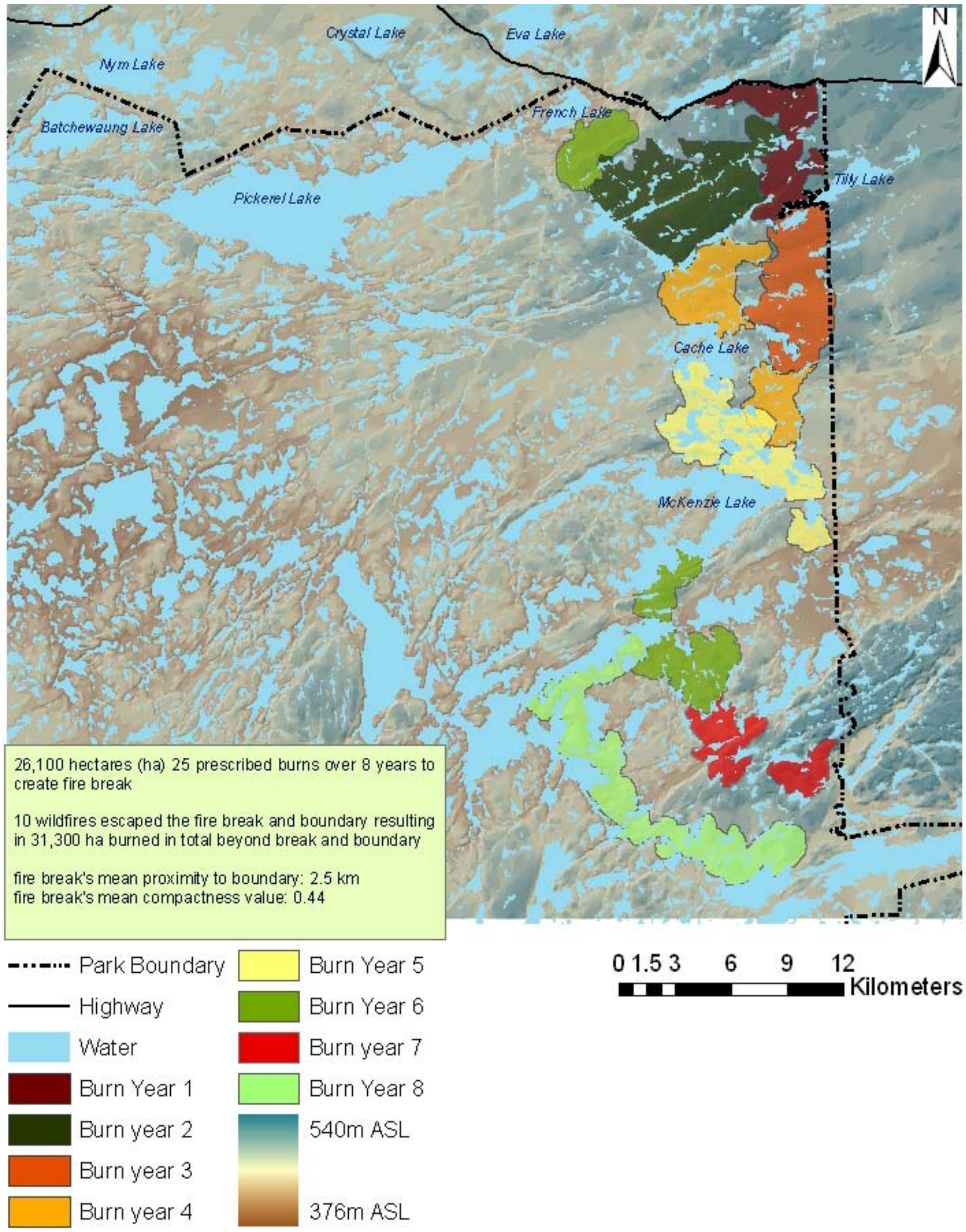


Figure 5-5: Fire Break design E output

Table 5-1: Results of prescribed burn fire break designs

Fire break design	Number of prescribed burns	Time period (years)	Total hectares burned	Mean distance to boundary (Km)	Compactness to measure length and width
A	10	3	7,900	3.5	0.35
B	15	6	18,800	4.5	0.34
C	9	4	10,500	4.3	0.38
D	7	3	9,000	3.8	0.40
E	25	8	26,100	2.6	0.44

5.1.1 Quantity of Prescribed Burns and Time Period to Create Fire Breaks

Each recommended fire break has a different configuration. In fire break A (Figure 5-1), 10 prescribed burns over 3 years are recommended. The controlled burns start in the middle of the study area, progress towards the southern boundary, then up to the northern boundary and burn southwards. In contrast, fire break B, (Figure 5-2), recommends 15 prescribed burns over 6 years, starting in the North and moving southwards along the eastern Park boundary. Fire break C, (Figure 5-3) has 9 prescribed burns over 4 years, burning from North to South. Fire break D, (Figure 5-4), recommends 7 prescribed burns over 3 years, starting in the North and burning southwards. Finally, fire break E (Figure 5-5) is the most extensive, with 25 burns suggested over 8 years, starting North and burning southwards in close proximity to and contiguous with the eastern park boundary. Ideally, the fire break should be created in the shortest time feasible. Otherwise, if a break was created over several years, the probability of vegetation growth and fuel load increases with each passing year in the previously burned areas and there may need to be maintenance to keep the flammability low.

5.1.2 Total Area Burned for Fire Break Creation

The five prescribed burn fire breaks varied in total area burned to create the break (Table 5-1). Scenario A has the least amount of burning (7,900 ha) to create a fire break, whereas Scenario E suggests a much more extensive fire break with 26,100 ha. Theoretically, the more fuel that is burned, the less likelihood there is of wildfires penetrating through the fire break. The next step will be to examine how effective each break is and make comparisons to determine which design is ideal in containing simulated wildfires.

5.1.3 Proximity of Fire Break to Park Boundary

The prescribed burns were calculated to determine their proximity to the eastern Park boundary. This is important because if the fire break is situated right on the Park boundary there is no room for error, and if a controlled burn escapes it will burn immediately onto adjacent Crown land. In contrast, if the fire break is not close to the boundary, a wildfire may ignite between the break and Park boundary, defeating the purpose of a fire break to contain wildfires.

Using ArcMap ArcGIS software, each prescribed burn was converted from polygons to points. The distance of each prescribed burn to the Park boundary was calculated by splitting each prescribed burn perimeter according to the approximate head fire rate of spread moving toward the eastern Park boundary. The head fire intensity information was derived in Prometheus. The average distance of the head fire spread to the Park boundary was derived for all of the prescribed burns. The nearest points varied for each burn depending on the size and shape. The mean distance to the Park boundary was calculated for each fire break scenario (Table 5-1). Scenario E is the closest to the Park boundary, with a mean distance of 2.5 Km and the furthest from the Park is Scenario B with a distance of 4.5 Km.

The average distance from the boundary for these scenarios ranges from 2.5 to 4.5 Km and ANOVA reveals that the breaks differ significantly (Table 5-2). ANOVA is a repeated measure that isolates the sources of variability in a set of measurements. ANOVA is used to test the hypothesis that several means are equal (Berenson, Levine, & Rindskopf, 1988). Since the fire breaks differ at a statistically significant level, a post hoc Least Significant Difference (LSD) comparison reveals further details of each scenario such as which fire break scenarios are significantly different from one another, as marked by an asterisks. Scenario E is significantly different from all other scenarios (Table 5-3). Other scenarios differ from one another except for A and D, B and C and C and D, which are similar in the burn years to create the fire break, number of prescribed burns and area burned to create the fire barrier.

Table 5-2: ANOVA analysis of fire break proximity to Park boundary

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	688517500.784	4	172129375.196	30.158	.000
Scenario	688517500.784	4	172129375.196	30.158	.000
Total	19899303673.936	1001			
Corrected Total	6373341159.333	1000			

Table 5-3: Post hoc LSD comparison of fire break proximity to Park boundary

* indicates significant difference at <0.05 probability level

A					
B	*				
C					
D	*	*			
E	*	*	*	*	
	A	**B**	**C**	**D**	**E**

A box plot of the fire break reveals the significant differences represented above in Table 5-3 of how close or distant each individual fire is to the Park boundary, rather than relying on an average calculation (Figure 5-6). A box plot, or box and whisker diagram shows interval values based on interquartile range (Mendenhall & Sincich, 1995). The box plot includes a measure of central location (the median), two measures of dispersion (the range), the skewness (from the orientation of the median relative to the quartiles) and potential outliers (Everitt & Dunn, 1983; Freund & Simon, 1992).Values show that Scenarios A, B and D have many prescribed burns close to the boundary. However, there are just as many distant prescribed burns and hence, a high median value (4.2, 4.3 and 3.2 Km respectively). Scenario C has many burns far away from the boundary, with a median distance of 4.1 Km, and scenario E has the lowest median distance of 1.6 Km and is closest to the boundary. Scenario E consistently results in being closest to the Park boundary and therefore, stands out from all the other scenarios.

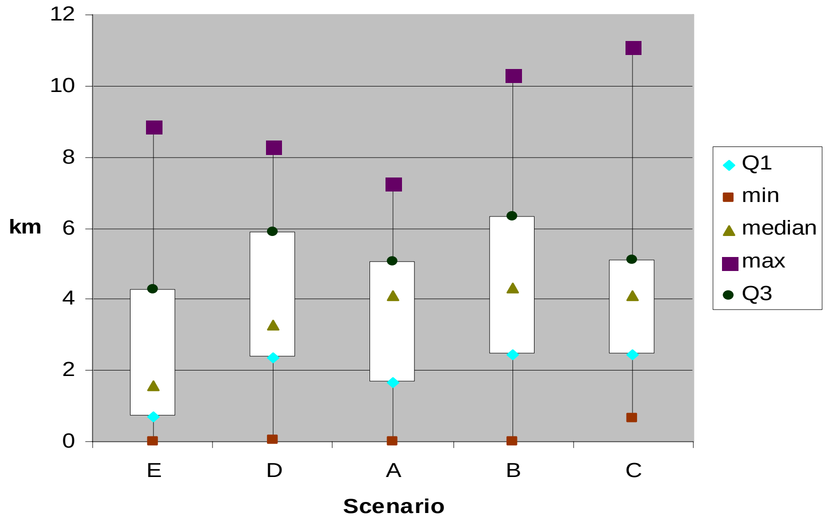
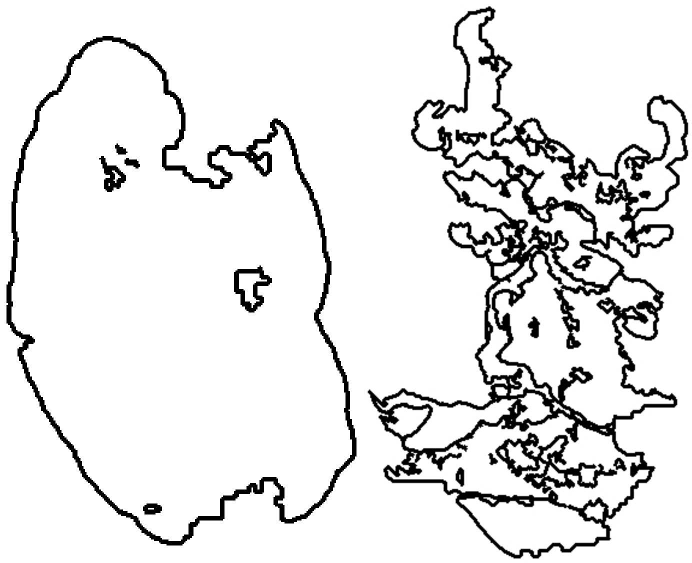


Figure 5-6: Box plot depicting fire break proximity to Park boundary

5.1.4 Compactness of Fire Break Designs

Just as the area burned and quantity of controlled burns varied amongst the five fire breaks designs, the length and width of the fire break also varied. Geographic shapes are difficult to express and measure (Frolor, 1995). They are not generally rectangular, straight or circular and cannot be represented by a calculation. Since each break has multiple burns scattered along the eastern Park boundary, following natural and topographic features, and hence a discontinuous linear shape, these are difficult geographic shapes to characterize quantitatively. Spatial compactness is one of many measures used for assessing geographic shape characteristics. This compactness measure is typically used by geographers to better define and calculate the perimeter of a very large irregular boundary such as a country or a river basin (Swan & Ridgeway, unknown). The compactness measurement was used to determine how fragmented or continuous the fire breaks are. The compactness ratio is calculated by $A/(\pi * r^2)$, where *A* is the area, in this case a prescribed burn; and *r* is the radius of the smallest circle that surrounds the shape and the results are scaled on a theoretical range from 0-1. A perfect compact shape should have a measure of 1, resembling Figure 5-7 (compactness ratio of 0.83), while a long, thin, shape should have should resemble Figure 5-7 (compactness ratio of 0.15). Theoretically, a highly compact shape will better serve as a fire barrier than a larger, irregular shape (Stocks, Williams, & Cleaves, 1996; Irme & Bogaert, 2004). If burns are fragmented or deviate from an elliptical shape, then the break may not be as effective.



Compactness ratio of 0.83 Compactness ratio of 0.15

Figure 5-7: More compact and less compact prescribed burns

Each prescribed burn within the fire break was calculated for its compactness (Table 5-1). Further, the mean was derived to summarize the fire break as a whole, rather than to examine each prescribed burn. The compactness was derived from the mean because the fire break as a whole is being critiqued for effectiveness in containing wildfires. The results for the compactness measure range from a low 0.38 in Scenario B to a high 0.44, which do not vary significantly.

The area burned by the prescribed burn may have burned around lakes affecting the compactness. A box plot was used to further summarize the compact measurement for each fire break. This is important for the compactness measure because examining the mean alone does not show variations within the breaks. For example, the scenario means ranged from 0.38 to 0.44. The boxplot in Figure 5-8 depicts scenario B, which has many poorly compacted fires comprising the firebreak; whereas scenario E depicts many highly compact burn perimeters composing the firebreak. Non-flammable components within a prescribed burn were not calculated into the area, but will contribute to a break’s effectiveness.

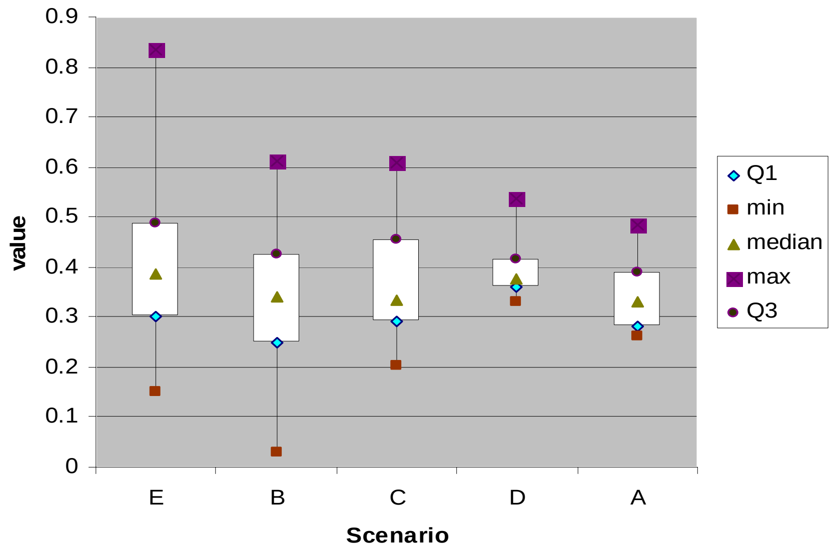


Figure 5-8: Box plot depicting compactness for each fire break

To explore this measurement further, an ANOVA was run on the compactness values for each prescribed burn to test for significant differences between the five scenarios. There is no significant difference between the scenarios in terms of compactness (Table 5-4). However, scenario E is the most compact, and having a more compact shape in the context of containing wildfires is important because the break will be more robust in the reduction of fire spread and containing wildfires.

Table 5-4: ANOVA for compactness

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.137(a)	4	0.034	0.710	0.588
Total	13.347	67			
Corrected Total	3.136	66			

An overlay of all the prescribed burns from each of the fire breaks, (Figure 5-9), illustrates that many designs emphasize burning in the northeast corner of the Park and as a result, few wildfires escaped beyond this portion along the boundary. The South portions of each break provide minimal coverage against wildfire activity. This map overlay corresponds with the escaped burns in Figure 5-10 to Figure 5-14 that more wildfires escaped the southern portion of the fire breaks rather than the northern portion. Further, wildfires escaped the middle fire break South of McKenzie Lake where there are few prescribed burns as well.

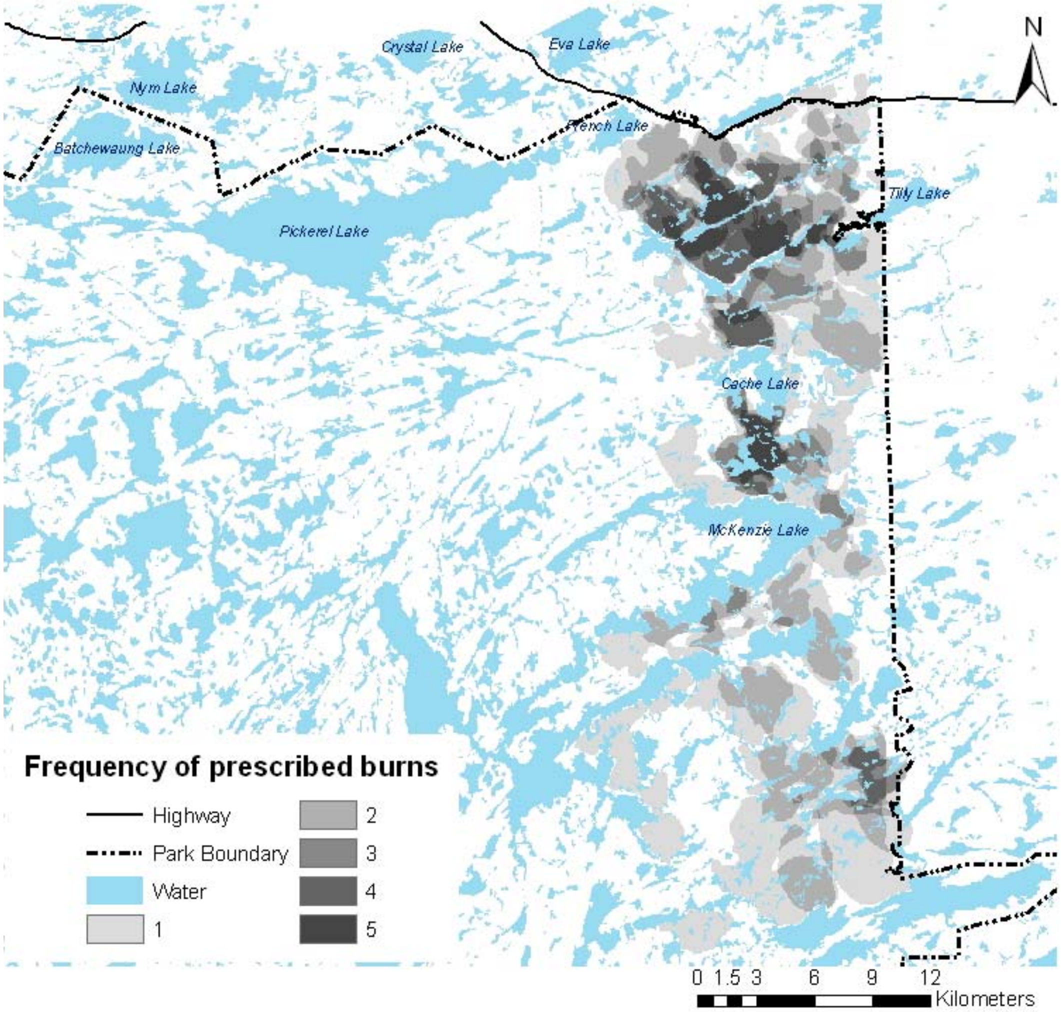


Figure 5-9: Map of Prescribed Burns frequency for all fire break designs

5.2 Effectiveness of Fire Breaks with Wildfire Activity

Prometheus was used to simulate 100 randomly placed wildfire ignitions. Each of these fires burned for five days. Without any fire breaks in place, 69 % of fires escaped the eastern and northern Park boundary. Not all of the 100 fires escaped because the ignition point was either a considerable distance away from the boundary so the fire never reached the boundary in five days, or fires fell on less flammable fuel or fire were not sustained. A total of 4,663,700 ha were burned from the wildfires including 483,800 ha beyond the Park boundary. These totals of acreage burned are extremely high because Prometheus over-estimates fire potential by assuming all portions of the fire front are active, whereas, in reality, portions of the fire front spread behave differently (Prometheus Course Notes, 2006). Also, an entire pixel burns and cannot be split. These computing limitations combined with the FWI extreme hot summer weather stream create severe wildfire simulations. However, any amount of area burned as a result of wildfire activity beyond the boundary is not ideal for responsible Park management.

Thus, 100 wildfire ignitions were run on the Quetico study area with no barriers in place. The next step was to run the same 100 ignitions against each of the five fire breaks. The total number of escaped fires dropped significantly when any one of the five fire break designs was in place. The results are summarized in Table 5-5 for the regular regeneration conditions. This chart can be compared to the fire break designs in Table 5-1. For example, fire break D has the least number of wildfires escape, however, a large area burned beyond the park boundary. The other variables, such as the fire break's proximity to boundary or how large the break is will be further explored.

Table 5-5: Summary of results of fire break statistics

Fire Break	Number wildfires escaped break and/or Park	Area burned beyond Park (ha)	Area burned in between break and Park boundary (ha)	Total area burned from fire break eastwards (ha)
A	10	29,900	31,200	61,100
B	9	35,400	69,400	107,500
C	16	32,700	32,800	65,600
D	7	15,400	36,600	52,000
E	10	31,300	4,600	35,900

Figure 5-10 to 5-17 illustrate that under regular regeneration conditions, the number of wildfires that escaped the breaks and where they escaped, revealing patterns and vulnerabilities in each break. These wildfires are overlaid to show the spatial risk for a wildfire to escape.

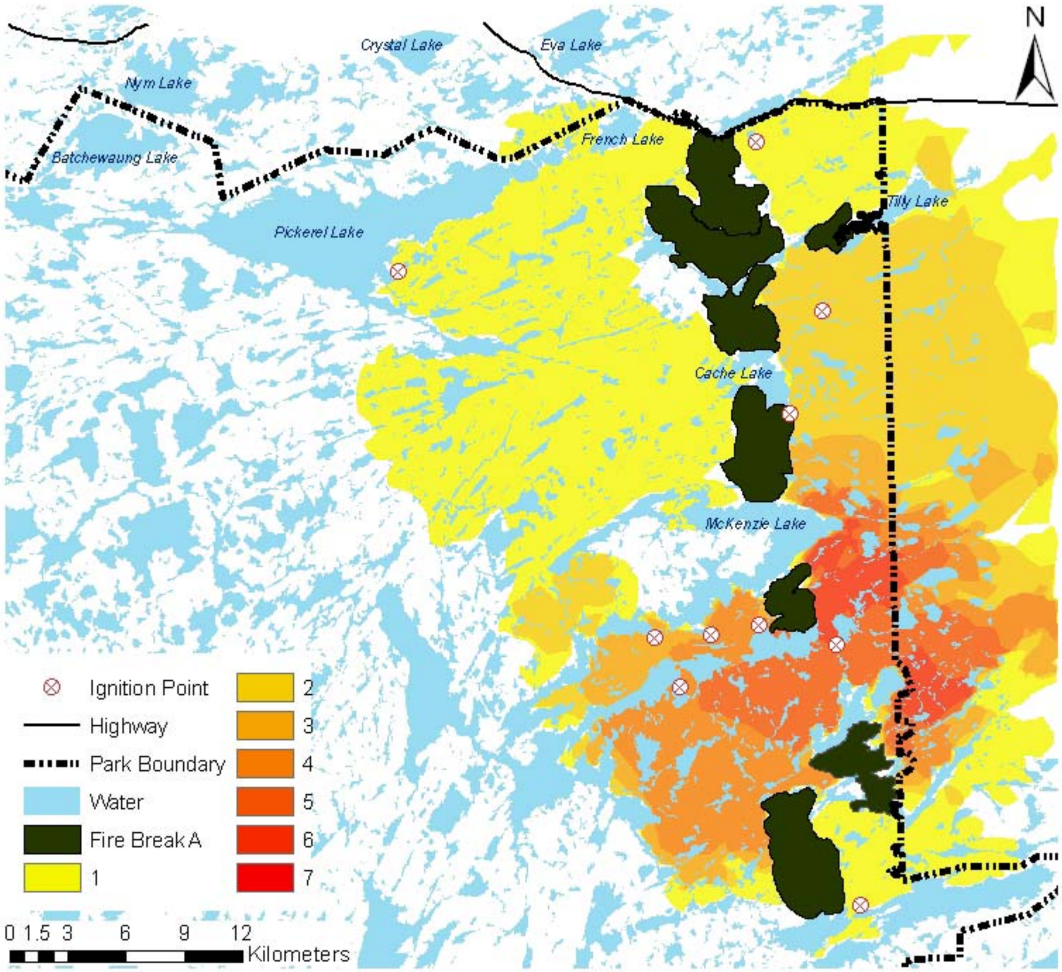


Figure 5-10: Frequency of wildfires that escaped the break and boundary in Fire break design A

The fire break design A (Figure 5-10) was created using 10 prescribed burns for a total 7,900 ha. A total of 10 wildfires escaped either the break or boundary. The South portion of the Park experienced the highest number of wildfires escaping, with 7 breaking through, as illustrated in orange and red. The northeast Park area is adequately protected compared with the vulnerabilities in the South. With these fires escaping, 29,900 ha burned beyond the Park boundary. The fire break is 3.5 Km West of the Park boundary which influences the area burned in between the break and boundary (31,200). An additional prescribed burn in the South could substantially reduce the area burned outside of the Park and situating the break closer to the boundary would minimize the opportunity of a wildfire starting in this location.

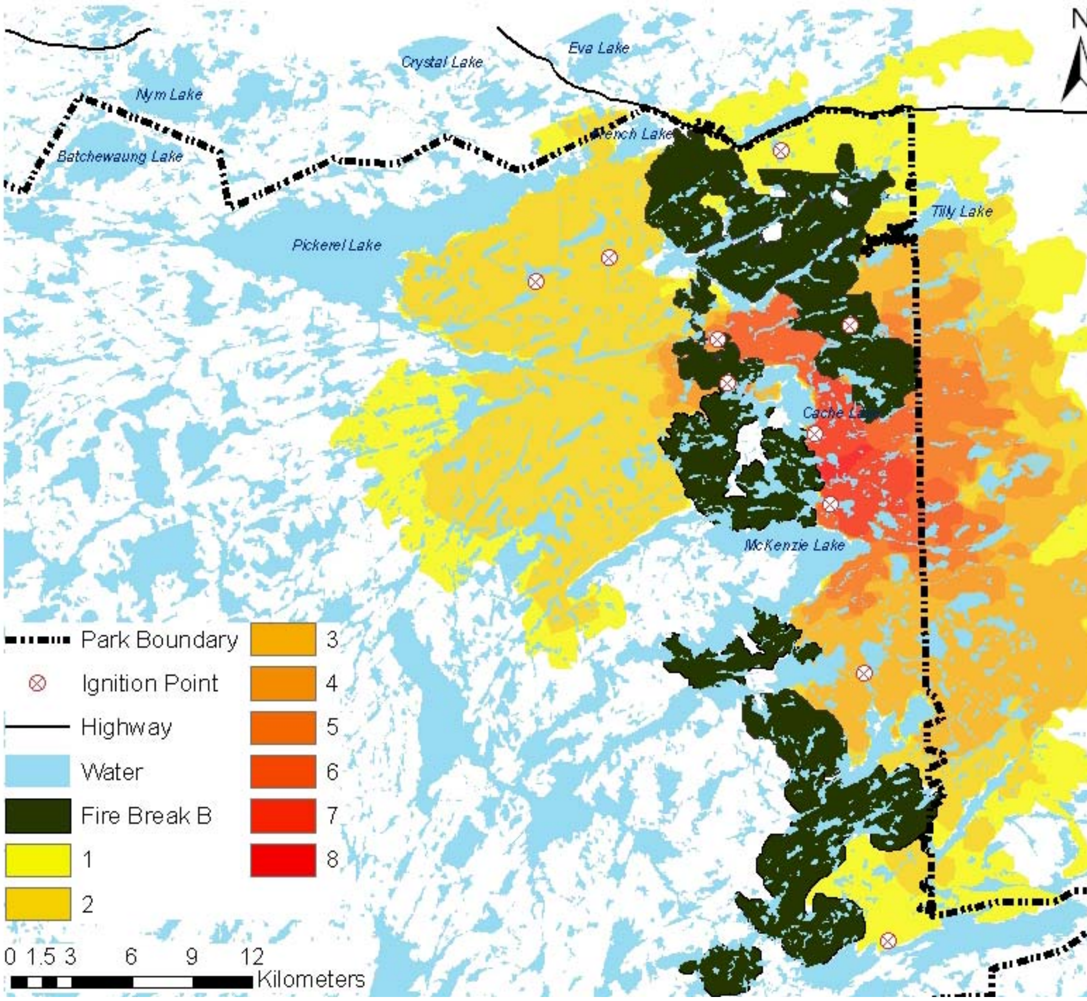


Figure 5-11: Frequency of wildfires that escaped the break and boundary in Fire break design B

Fire break B (Figure 5-11) was created with 15 burns for a total of 18,700 ha burned. Nine fires escaped the Park and burned 35,400 ha. The fire break is situated close to the boundary in the North and South, but the middle portion of this break is less effective with 8 wildfires escaping the break, and this weakness contributed to 69,300 ha burning between the break and boundary. Since a fire started on the East side of the break, placing prescribed burns close to the break will help with reducing fuel that feeds the wildfire and ultimately reduce the risk of wildfire escape.

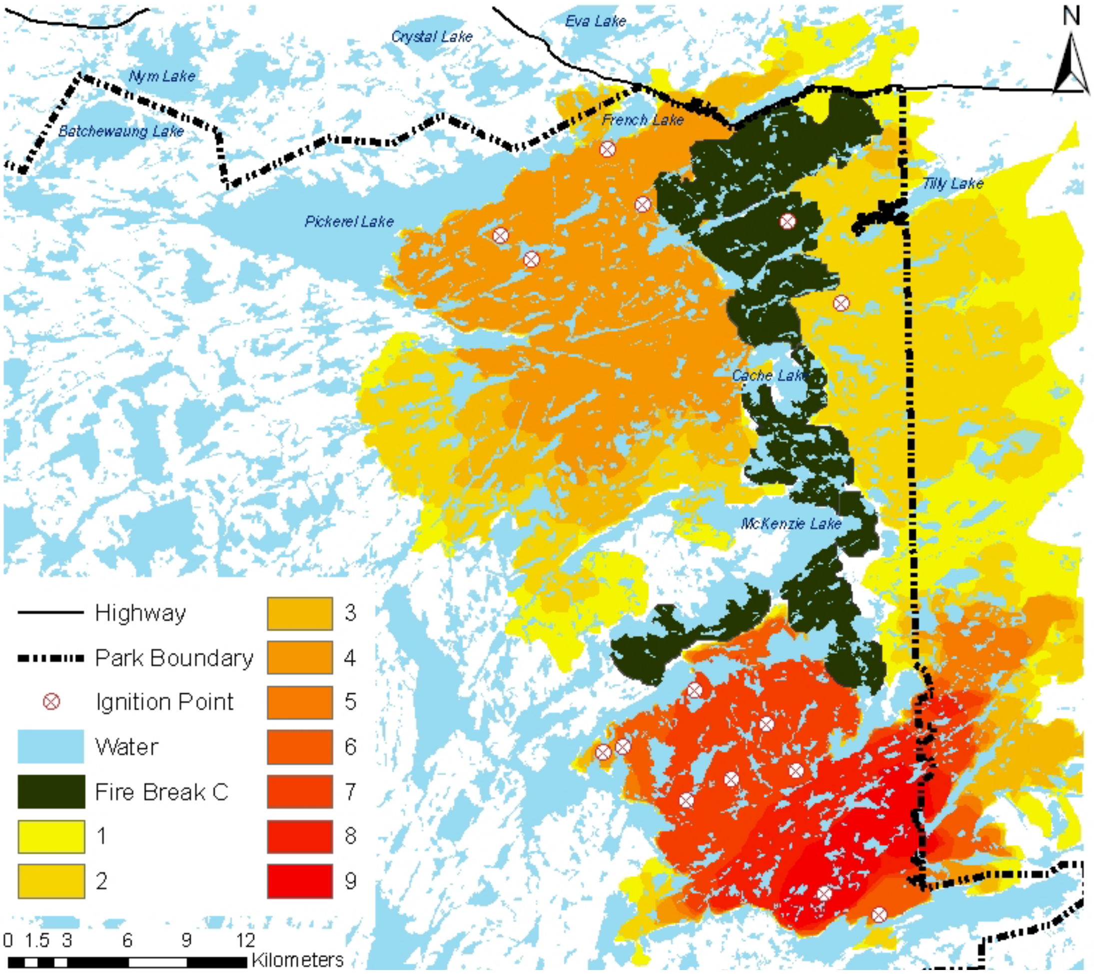


Figure 5-12: Frequency of wildfires that escaped the break and boundary in Fire break design C

Fire break design C (Figure 5-12) offers an ideal barrier to protect the northeast portion of the Park and beyond the boundary. This break was created with 9 prescribed burns totaling 10,500 ha. Unfortunately this break did not extend in the South and almost all of the 16 wildfires escaped the Park in this area since there was no barrier. 32,700 ha burned outside of the Park.

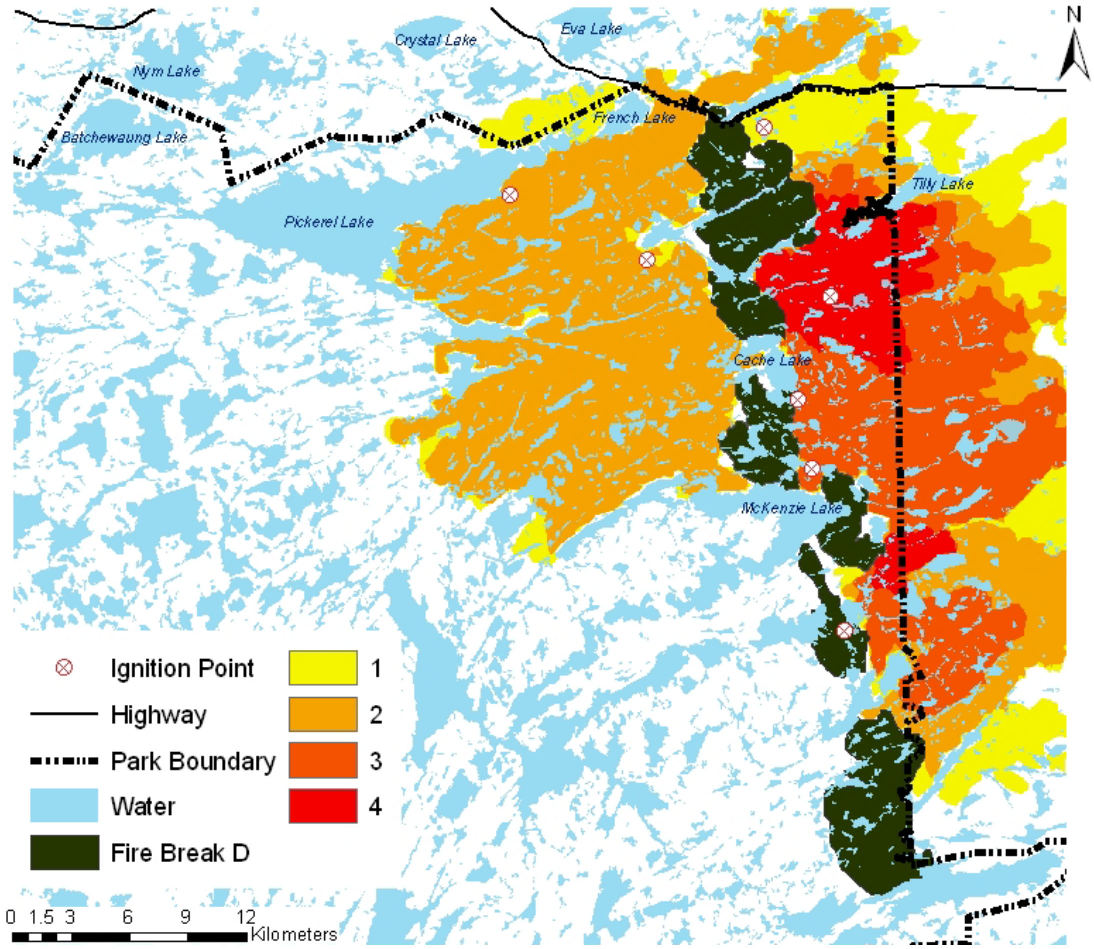


Figure 5-13: Frequency of wildfires that escaped the break and boundary in Fire break design D

Fire break design D (Figure 5-13) was created with 7 prescribed burns totaling 9,000 ha. The break is extensive, with the entire length of the study area covered. Seven wildfires escaped the Park and burned 15,460 ha, 36,600 ha for a total of 52,000 ha burned. Fires escaped all along the break, with particular weaknesses in the northern and southern portion. Since the break was 3.8 Km away from the Park boundary, two wildfires burned in between the break and boundary that could have been mitigated if the fire break was closer to the boundary.

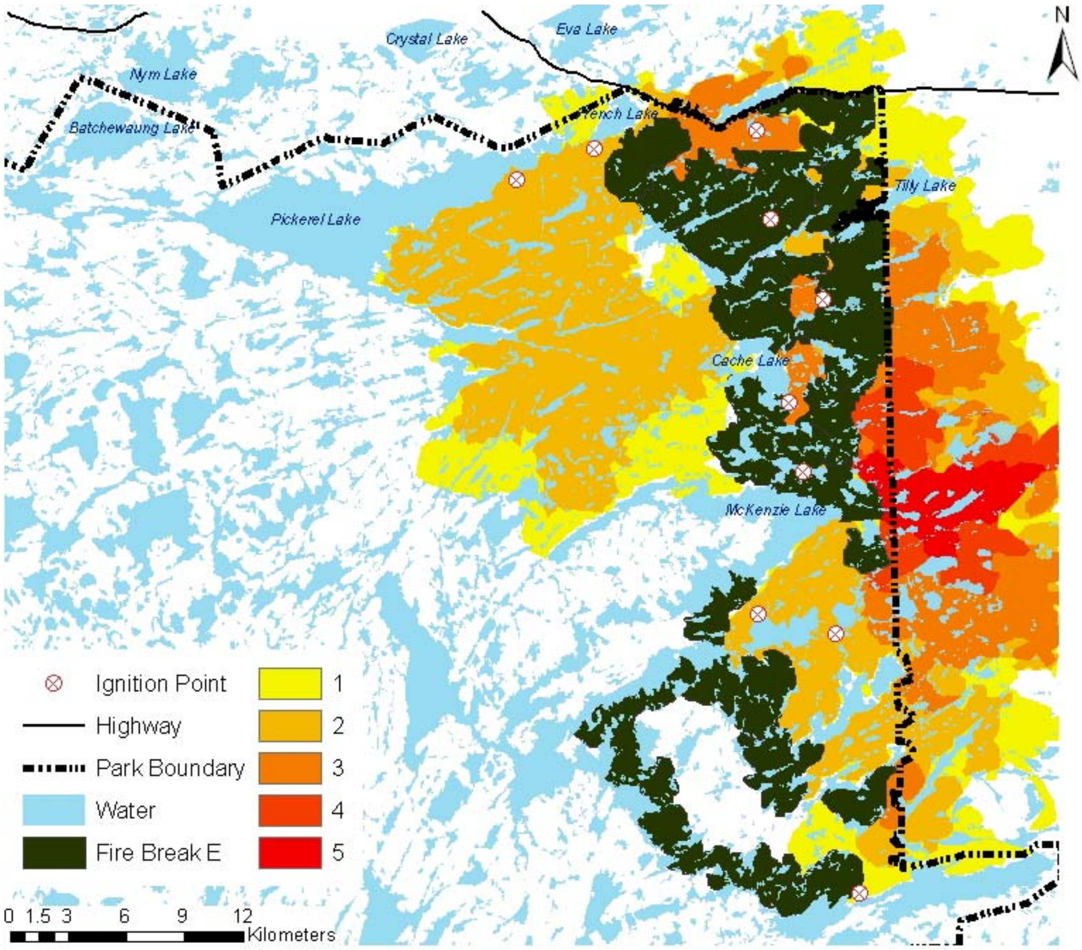
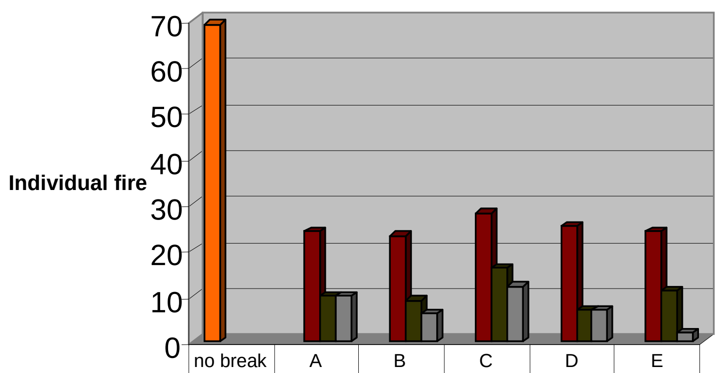


Figure 5-14: Frequency of wildfires that escaped the break and boundary in Fire break design E

Fire break design E (Figure 5-14) was created with 25 burns and 26,100 ha. The break extends from the North to South study area and is the closest to the Park boundary with a mean distance of 2.5 Km. It is evident however, that many of the prescribed burns are placed right on the Park boundary and further South the burns are farther away. As a result, only 4,600 ha are burned in between the break and boundary. The vulnerability is in the middle of this break as 5 fires escaped the Park. Fires escaped the entire length of this break resulting in 31,300 ha burned outside the Park. All of the fire breaks will be analyzed in greater detail to determine which is potentially the most successful and why.

5.2.1 Number of wildfires that escaped the Park boundary

All five fire break scenarios were tested to reveal how effective each design is under three different post-fire vegetation re-growth conditions: regular regeneration based on literature (Table 4-9), accelerated by five years and decelerated by five years. Figure 5-15 depicts that even under accelerated conditions, up to 66 % of wildfires are contained compared to no break.



	no break	A	B	C	D	E
	69					
accelerated		24	23	28	25	24
regular		10	9	16	7	10
decelerated		10	6	12	7	2

Figure 5-15: Number of individual wildfires that escaped Park boundary

The Chi-Square test was applied (Table 5-6) to these results to illustrate any significant differences between the three vegetation re-growth conditions and their impact upon individual wildfires spreading beyond the boundary. Chi-square test of significance is the most popular goodness of fit statistic that reveals the fit between what is observed and what would be expected (Champion, 1981). In addition, a null hypothesis is proposed to ensure that the proportions of these values are the same (Berenson *et al*., 1988). The chi-square is also sensitive for a small sample size, which is applicable to the five fire break designs.

Under accelerated vegetation re-growth conditions, there is a significant difference between having a fire break and not having one with regards to the number of wildfires that escaped the boundary. Without a fire break, 69 of the wildfires escaped the Park boundary and with fire breaks, the number of wildfires escaped was greatly reduced by 60-66% (Figure 5-15). Examining the effectiveness of all the fire breaks, wildfires that escaped the Park boundary were reduced by 64% on average. A chi-square test further revealed that providing a fire break along the Park boundary is significant for the number of fires.

Table 5-6: Chi square distribution for wildfires escaping under Accelerated vegetation re-growth conditions

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	75.291	5	0.000
Likelihood Ratio	70.578	5	0.000

Under simulated regular regeneration, the number of wildfires that escaped the Park boundary ranged from 7 (scenario D) to 16 (scenario C) and a 77 to 90% reduction of wildfires escaping the break. Although there are still fires passing through the barrier and beyond the boundary, these values are greatly reduced by an average of 85% as compared to not having a barrier in place at all. A chi-square test (Table 5-7) reveals that under regular regeneration conditions, these values are statistically significant.

Table 5-7: Chi-square distribution for wildfires escaping under Regular vegetation re-growth conditions

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	178.243	5	0.000
Likelihood Ratio	148.677	5	0.000

Decelerated vegetation re-growth demonstrated the greatest success in reducing the number of wildfires from escaping ranging from 83 to 97 %. The overall reduction was 89% on average, with a range between 2 (scenario E) to 10 (scenario A) individual wildfires escaping. The Chi-square values are statistically significant (Table 5-8).

Table 5-8: Chi-square distribution for wildfires escaping under Decelerated vegetation re-growth conditions

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	221.465	5	0.000
Likelihood Ratio	181.611	5	0.000

Overall, the chi-square distribution revealed that the fire breaks were statistically significant for containing fires compared with not having any barrier. To explore the differences of each fire break in greater detail, the breaks were tested to determine significant differences amongst each fire break design. A chi-square showed that there were no significant differences between the five fire break scenarios for containing individual wildfires as calculated in Table 5-9.

Table 5-9: Chi-square test for significance between fire break scenarios and wildfires that escaped Park boundary

Pearson Chi-Square	Value	df	Asymp. Sig. (2-sided)
Accelerated	0.794	4	0.939
Regular	4.770	4	0.312
Decelerated	8.639	4	0.71

5.3 Area Burned by Wildfire Extending Beyond the Fire Break only

In order to assess how effective the fire breaks are in reducing the area burned, the overall areas burned from the eastern edge of the fire break, and beyond the Park boundary were examined. There were differences between the breaks in terms of effectively reducing the impact of wildfire spread (Figure 5-16). Fire break E appears to provide the greatest protection compared to the other fire breaks for reducing the area burned and creating an effective barrier.

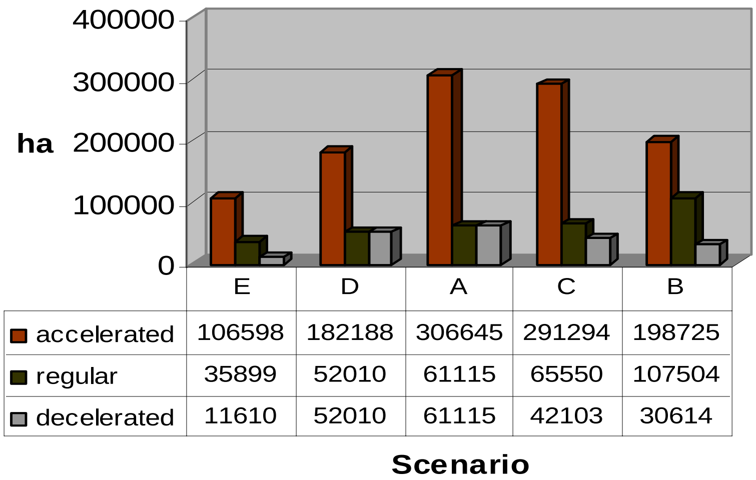


Figure 5-16: Area burned by wildfire beyond the fire breaks and Park boundary

There are significant differences between each fire break design and how the regeneration rate influences the effectiveness, as analyzed with ANOVA with probability of 0.05 (Table 5-10). Fire breaks A and E differed at a significant level (Table 5-11), and post-hoc comparison reveals all vegetation re-growth rates were significantly different as marked by an asterisks in Table 5-12.

Table 5-10: ANOVA of area burned beyond fire break

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	108509363729.600	6	18084893954.934	9.137	0.003
Scenario (A-E)	15890998288.667	4	3972749572.167	2.007	0.186
Regeneration speed	92618365440.934	2	46309182720.467	23.396	0.000

Table 5-11: Statistically significant differences between fire break scenarios

* indicates significant difference at <0.05 probability level

A					
B					
C					
D	*				
E					
	A	**B**	**C**	**D**	**E**

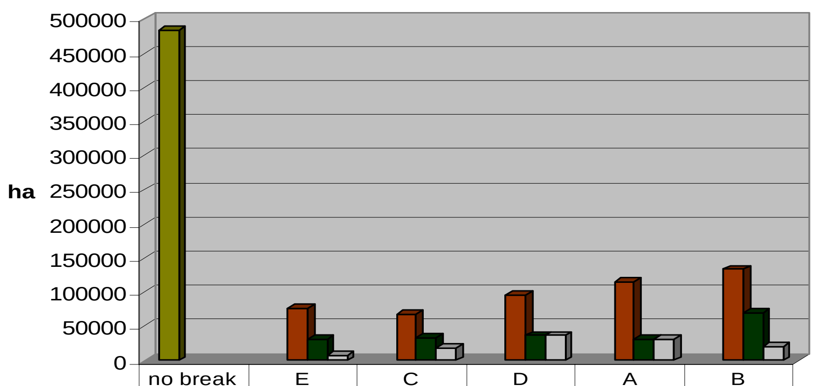
Table 5-12: Post Hoc comparison of regeneration rates and wildfire activity beyond the fire break

* indicates significant difference at <0.05 probability level

Accelerated			
Regular	*		
Decelerated	*	*	
	Accelerated	**Regular**	**Decelerated**

5.4 Area Burned by Wildfire Extending Beyond the Park Boundary

There is a reduction in area burned beyond the Park boundary by having fire breaks in place (Figure 5-17). With regular vegetation regeneration rates, on average the area burned beyond the boundary decreased by 92 %. Under decelerated conditions, or a best-case scenario, the area burned was reduced by 95 %. Under accelerated re-growth conditions, there was a 79 % decrease in the area burned. When examining each fire break individually, scenario E offers the most successful barrier to contain wildfires, within the Park boundary, with an 84%, 94% and 99% reduction in area burned beyond the boundary under accelerated, regular and decelerated conditions respectively.



	no break	E	C	D	A	B
	483851					
accelerated		76638	67973	95066	115948	133534
regular		31331	32809	36550	31228	69371
decelerated		7042	18848	36550	31228	20540

Scenario

Figure 5-17: Total area burned by wildfire extending beyond Park boundary

ANOVA was calculated to determine statistically significant differences between the fire breaks in terms of acreage burned beyond the Park boundary (Table 5-13). Overall, when evaluating the break designs individually, there are significant differences as marked in

Table 5-14. These levels of significance correspond well to their proximity to the Park boundary and the results of individual number of wildfires that escaped the boundary.

Table 5-13: ANOVA of area burned beyond boundary

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	18096056041.067	6	3016009340.178	12.937	0.001
Scenarios a-e	2693356716.934	4	673339179.233	2.888	0.094
Regeneration speed	15402699324.134	2	7701349662.067	33.035	0.000

Table 5-14: Total acreage burned beyond Park boundary by wildfires

* indicates significant difference at <0.05 probability level

A					
B					
C		*			
D					
E		*			
	A	B	C	D	E

Since these values are significant, a Post-Hoc test was conducted to further view significant differences amongst the data. In this case, the vegetation regeneration rates were evaluated and all revealed significant differences between one another (Table 5-15).

Table 5-15: Post Hoc comparison of regeneration rates and area burned beyond the boundary by wildfire

Accelerated			
Regular	*		
Decelerated	*		
	Accelerated	**Regular**	**Decelerated**

The area burned beyond the Park boundary can be compared with the amount burned to create each fire break. A highly correlated relationship between these two variables will reveal a strong linear relationship and regression value close to 1. However, when the two variables were plotted, the linear regression analysis revealed there is no significant relationship between these two variables, with an output value of only 0.06. A possible explanation may be fire break B as the outlier and influencing the correlation. There is no general trend to indicate that the more prescribed area burned equates to less area burned beyond the Park boundary. However, other parameters such as the location of the prescribed burns, as illustrated in Figure 5-9, influences the effectiveness of fire breaks.

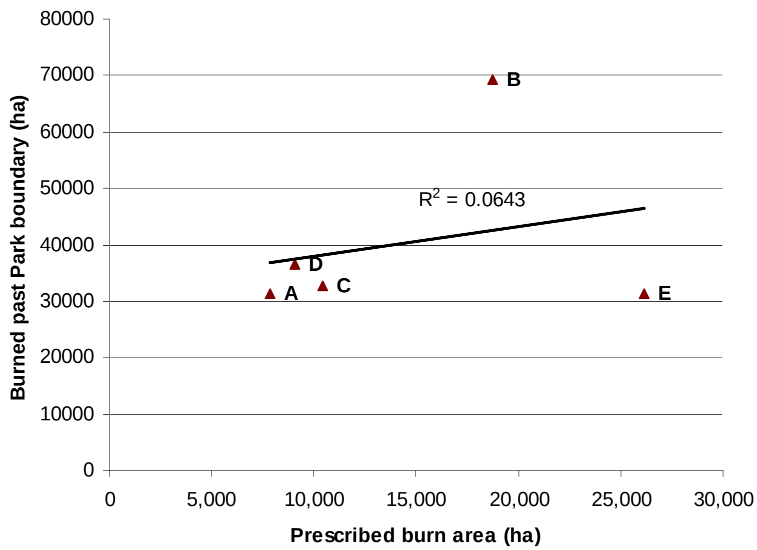


Figure 5-18: Comparison of area burned past the fire break with the prescribed burn amount

Under the different regeneration rates, there is no significant correlation with the prescribed burn area burned.

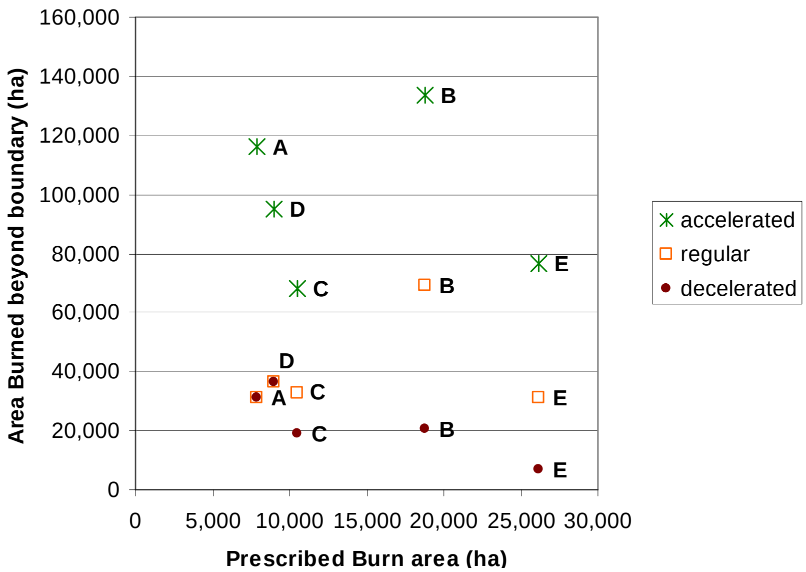
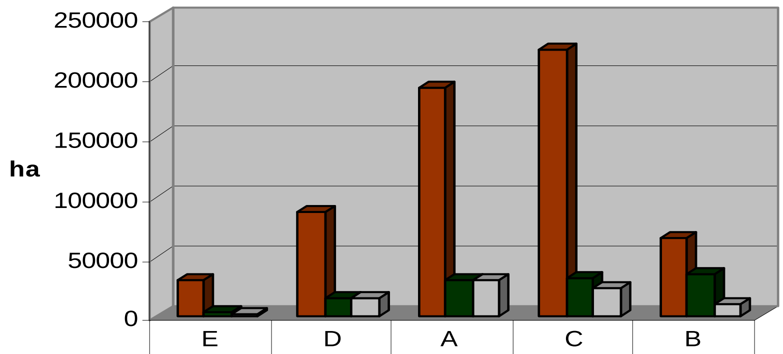


Figure 5-19: Comparison of regeneration rates and area burned beyond the Park boundary

5.5 Area burned by Wildfires in Between Break and Boundary

As outlined in the previous section, the success of each fire break design varies with its proximity to the Park boundary. With these different fire break layouts, the wildfire activity and associated area burned in between the break and Park boundary varies significantly, under all vegetation re-growth conditions. With reference to Figure 5-20, it is apparent fire break E exhibits the lowest area burned from wildfires. Fire breaks A and C exhibit high areas because ignition points fell in between the break and boundary. Hence, the barrier offered no protection against wildfire escape. In contrast, the other prescribed burns from designs D and E were situated in the same geographic location as some of the ignition points and the wildfires could not spread since there was no fuel to sustain the wildfire.



	E	D	A	C	B
accelerated	29960	87122	190697	223321	65191
regular	4568	15460	29887	32741	35429
decelerated	2643	15460	29887	23255	10074

Scenario

Figure 5-20: Area burned from wildfires in between break and Park boundary with different regeneration rates

Figure 5-21 plots the mean distance of each fire break from the Park boundary and how this influences the area burned by wildfire activity between the fire break and boundary. With these two variables graphed, the closer the fire break is located to the boundary, the less acreage burned. The implications lay in the park’s management practices to plan burns so close to the Park boundary. Positioning a fire barrier close to the boundary is important because wildfire ignitions can start in this space and fires move quickly eastwards outside the Park. This is a concern for fire fighters, timber companies, communities and others as a fire could spread quickly outside of the Park.

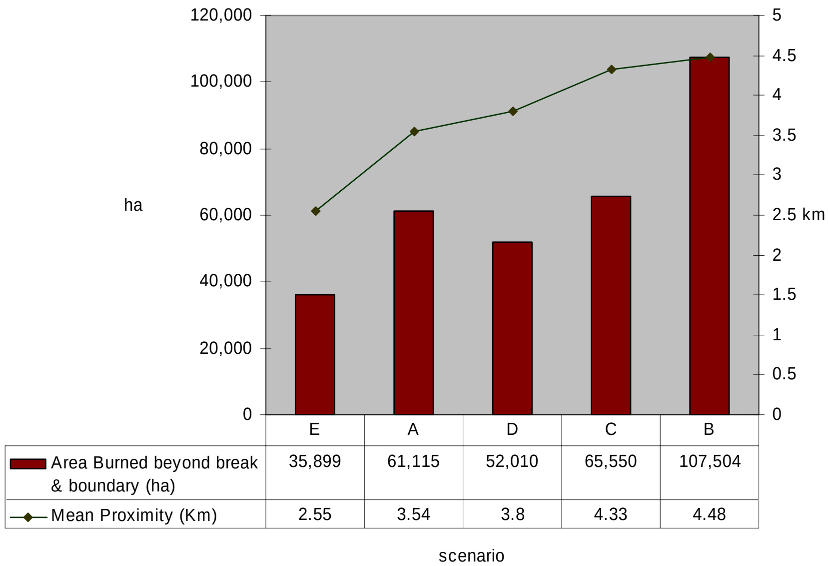


Figure 5-21: Comparison of fire break's proximity to boundary with area burned in between break and boundary

ANOVA analysis was conducted on the fire break scenarios to measure their success in reducing the area burned by wildfires in between the break and boundary. A summary of results marked by an asterisk (Table 5-16) show that all regeneration rates differ significantly in wildfire area burned.

Table 5-16: ANOVA analyses of area burned by wildfire in between fire break and Park boundary

* indicates significant difference at <0.05 probability level

Accelerated			
Regular	*		
Decelerated	*		
	Accelerated	**Regular**	**Decelerated**

In summary, all of the design considerations for the five fire break were examined. The number of prescribed burns and area burned, time period to create the fire break, the compactness of each break, and how closely positioned they are from the Park boundary all contribute to how effective each design was in serving as a successful fire break. Fire breaks were tested under three accelerated, regular and decelerated vegetation regeneration conditions. Several measures were examined to determine fire break effectiveness. These measures examined the reduced number of wildfires that could potentially escape the Park boundary, and the areas burned by wildfire activity, both beyond the fire break and beyond the Park boundary. These measures were tested for statistically significant differences in order to determine if there is merit to introducing the fire break approach in Parks, to test null hypotheses, and subsequently which fire break design is optimal.

With reference to the three null hypotheses:

- *There is no difference in wildfire activity with a fire break.* Statistically significant reduction in fire area and number of wildfires is achieved by having a fire break in place.
- *There is no difference in wildfire activity with respect to fire break designs*. There are significant differences between the five fire break designs and their capacity to contain wildfires and reduce the area burned beyond the Park. The mean proximity to boundary is important in reducing the area burned. The various fire break designs affect fire activity, including number of wildfires escaping the Park, area of vegetation burned in between a break and Park boundary, and area burned beyond the Park differ.
- *There is no difference in fire activity of fire breaks with different post-fire vegetation regeneration speeds*. This hypothesis can be rejected since there are statistically significant differences between area burned with accelerated, regular and decelerated vegetation re-growth. Wildfire activity is sensitive to changes in vegetation growth. The regeneration rate influences the amount of area burned and how many wildfires will spread beyond the Park.

Based on the above, fire break design “E” is best in containing wildfires, through reduction in the area burned in between break and boundary, and that beyond the boundary. Fire break E was created using 25 prescribed fires that burned 26,100 ha to create the barrier, is the closest to the Park boundary with a mean distance of 2.5 Km and is the most compact linear break with a compactness ratio of 0.44. In contrast, the other fire breaks were comprised of fewer prescribed burns, less area burned and were further away from the Park boundary. Hence, there was space for wildfires to ignite between the break and boundary and provide for an effective fire break. The next chapter contains the discussion of these results in greater detail, the impact of a proposed prescribed burn regional fire break in the context of Parks, and the overall significance of incorporating a regional fire break into Park management objectives.

Chapter 6
Discussion

In this chapter fire break designs and their success in providing a barrier against wildfires will be discussed. The significance in having a fire break within a Park or protected area will also be explored. In the Results (Chapter 5), a variety of variables were tested to define an appropriate design that will reduce the fuel load, reduce fire spread and contain wildfires within the Park and limit fire spread beyond the Park boundary. The discussion will focus on factors mentioned throughout this research of optimal fire break design that addresses:

- Need for public safety
- Economic and social costs and opportunities
- Ecological restoration of natural fire regimes
- Applicability to other Parks and protected areas

6.1 Optimal Fire Break Design

The five fire break designs varied in the suggested number of individual prescribed burns, area burned to create the barrier, number of years to construct, how compact each design is and how close the break is to the Park boundary. These breaks were evaluated for their effectiveness based on: the number of wildfires that escaped the Park boundary; the area burned beyond the boundary; the area burned in between the break and boundary; and the area burned from the break eastwards beyond the boundary.

Burning an extensive area along the boundary ensures that the fuel load is reduced and will adequately contain wildfires. Fire break design E is the most comprehensive break with 25 prescribed burns planned over 8 years and 26,100 ha burned. As a result, the least amount of area was burned beyond the boundary compared with the other designs. Creating a fire break in a short period of time will provide an efficient barrier since the fuel load will be reduced without requiring additional maintenance. As outlined in the species regeneration chart (Table 4-9), some boreal species such as black spruce and jack pine will regenerate quickly after fires. This was exemplified with design D, which was created in three years and under regular regeneration conditions, only 7 wildfires escaped. However, 36,600 ha burned outside the Park boundary so other design factors needs to be considered. Maximizing the number of prescribed burns to create a fire break in a relatively short period of time would most likely result in a successful fire break.

The compactness and proximity of fire breaks to the boundary were explored. The more compact the shapes, the more defensive it will be against wildfires. This was exemplified in fire break design E, which is the most compact and therefore a better barrier than the least compact shape, (design C) from which the greatest number of wildfires escaped. Compaction is typically used in understanding fragmented landscapes. The more fragmented the landscape, the less continuity and in contrast, the less fragmented the more continuous. This analogy can be applied to the fire break and how many fires escape or are contained as a result from the break.

The last design consideration is how close a break is to the Park boundary. This is significant because it is not known where lightning will strike and ignite a fire. If a wildfire starts between the break and boundary, there is no break to reduce fire spread and a fire will probably spread quickly into the commercial Crown lands. This fire break design weakness was exemplified in the wildfire overlay maps (Figure 5-10 to Figure 5-14). A fire break will provide an effective barrier to slow down a fire moving eastwards and potentially stop the spread, or at least give fire crews a chance to take control, as happened in BWCA in the summer of 2006 when a wildfire slowed down as it hit a previously burned area (refer to Chapter 2). Fire break E, with the mean proximity to boundary of 2.5 Km, had the least burned area in between the break and boundary (4,600 ha) compared with 35,400 ha in design B that had a mean distance of 4.5 Km. Design E was successful because prescribed burns were situated right against the North and eastern Park boundary thus, wildfire or lightning ignitions cannot be sustained in this area. The width of the fire break is adequate, accounting for spotting of wildfires that potentially carry 1.5 – 2.0 Km (Curran, 2006; Weyenberg, 2006). In addition, the layout of design E is ideal because larger prescribed burns were subsequently burned up against smaller prescribed burns to create a more protective break from wildfire. This is a practice currently implemented in Voyageurs National Park to reduce hazards, and to stop the spread of wildfires (Weyenberg, 2006). Although design

E is effective, other solutions are feasible such as design D, which would be more efficient to build (time and cost) but not as effective.

The post-fire regeneration rate influenced the fire break effectiveness. Although the values explored are for the regular regeneration rate, it is noted that fluctuations in vegetation re-growth affect the success of a break. Hence, reducing the fuels over a longer period, perhaps even with intermittent thinning will produce a more effective break. In addition, multiple burns in the same location will change the type of vegetation re-growth from coniferous to deciduous forest species. With re-burning and the changes in vegetation type, this may increase the effectiveness of a fire break.

6.2 Need for Public Safety

Planning a prescribed burn fire break planned for civilian safety as a priority is paramount. Safety for humans and their livelihoods (tourism, recreation and resource extraction) is an important consideration in building a successful fire break. Although precautions are taken to ensure that a prescribed burn does not become an uncontrolled wildfire, one is aware that this might occur. In contrast, there is a risk in not having a fire break established along the Park boundary. In Quetico for example, as a result of fire suppression, flammable fuels from downed woody debris and insect infestations are building up in the northeast and, if left in the current state, can contribute to a large wildfire. It is important to consider maximizing the success of each prescribed burn and minimizing failure. This includes making sure a planned burn is sustained but does not become a wildfire, in accordance with the OMNR prescribed burn standards (Ontario Ministry of Natural Resources, 2000).

Prescribed burns are effective in reducing hazardous fuels that contribute to larger wildfires and even in containing wildfires from spreading (Weir, Chapman, & Johnson, 1995). This was confirmed in Chapter 5 where the number of wildfires decreased by an average of 64% and the area burned decreased by an average of 92% with the different arrangement of prescribed burns. It is suggested that prescribed burning will disrupt continuous fuels and change the age mosaic of the forest landscape. These younger forests act as a fire break to reduce the likelihood of large wildfires. Hesseln's 2000 study indicates that an increase in the area burned by prescribed burning is correlated with a decrease in acres burned from wildfires. This directly corresponds with these results. Any amount of area burned by prescribed burning decreased the area burned by wildfires. However, in design E, there was an impressive 93.5% reduction in area burned by constructing a barrier.

6.3 Social and Economic Costs and Opportunities

The status quo and implementing a prescribed burn fire break imply social and economic losses and gains. As outlined in Chapter 2, social costs need to be considered, such as smoke dispersing and bothering neighbouring communities, industry and Park visitors (Hesseln, 2000). With the planning of a fire break, notices can be put up with detailed explanations of what occurs in the Park. However, the creation of these fire breaks is proposed for fall months when there are few visitors. The perception of fires is typically negative, so communicating with and educating people about the benefits of this initiative will help with implementation. It is ideal to plan ahead and conduct prescribed burns rather than waiting for a greater threat to wildfires and potentially greater damage (Hesseln, 2000). The reduction of a potential wildfire risk also needs to be made clear to the public. Although the social costs cannot be modeled in the software, all input received for the fire break designs emphasized the importance of lessening disruption of neighbouring activities.

The economic costs of prescribed burning and fighting wildfires differ significantly. When a wildfire occurs, Park visitation may be reduced. This results in lost enjoyment, lost revenue for the Park and in neighbouring outfitters and nearby towns. There may also be additional expenses for Park evacuation, highway closures, and lost revenue from nearby timber harvesting shutting down. With prescribed burning, it is recommended to conduct as big a burn as financially possible because assembled fire personnel and equipment should be utilized efficiently (Isherwood & MacQuarrie, 1985). The average cost to conduct a prescribed burn is approximately $100 Cdn/ha for an area of physiography similar to Quetico (Ontario Ministry of Natural Resources, 2000). Prescribed treatments tend to be much less expensive than battling wildfires, with a higher probability of successfully meeting objectives, such as reducing fuel load and hazardous fuels (U.S. Department of Agriculture, Forest Service, 2006). Cost will differ depending on topography, access, and personnel. The cost to fight wildfires is estimated at $500 Cdn/ ha for both direct and indirect planning and administration costs (U.S. Department of Agriculture, Forest Service, 2006; Wilkinson, 2006). Hence, the fire break is less expensive and less risky than battling wildfires. The breaks can be viewed as an "insurance premium" where they are established as a preventative method to reduce the detrimental effects of wildfires. Although prescribed burning may be viewed as expensive, the cumulative effects over time will show the true value of this investment (Hesseln, 2000). For example, fire break design E may cost about $2.81 million spread over several years. However, the estimated savings to fight fires could be immense. For example, Quetico's fire 141 burned approximately 5,000 ha beyond the boundary that cost $2.5 million (when calculated at $500/ha for fire fighting), but only for one fire! In addition, every hectare burned outside the Park onto logged Crown lands is a financial loss. Atikokan forest products are expected to harvest 17,000 ha of timber in 2008 in the Sapawe river Crown forest. Abitibi-Consolidated company of Canada is also scheduled to harvest 34,000 in the Crossroute forest, two areas surrounding Quetico (McKinnon, 2007). The value of mature forest per hectare is approximately $7,000/ha. This does not consider loss of employment, labour, equipment, different aged forest stands, lost productivity and end market value. In relation to the fire break designs and the amount burned into the timber lands, there is a huge potential loss that extends into the hundreds of millions of dollars.

6.4 Ecological Costs and Opportunities

Fires are a natural way to manage and balance forest resources including restoring and maintaining healthy fire dependent vegetation. In terms of the environment, many boreal plant species are dependent on fire for regeneration, thinning the fuel load and ecosystem renewal, including black spruce and jack pine. In addition, many animal species rely on post fire conditions for habitat and food. Without burning, the boreal ecosystem changes as vegetation succession occurs. Results from (Vaux, Gardner, & Mills, 1984) indicate that prescribed burns provide a better alternative to wildfires.

Prescribed burning can be used to initiate pre-European settlement fire disturbances for Park management. The fire rotation or fire frequency must be increased otherwise fire dependent species such as jack pine will be replaced. Jack Pine's life expectancy is approximately 200 years (U.S. Department of Agriculture, Forest Service, n/a). After 75 years, there are signs of decay and the tree health decreases with subsequent years. Jack pine regenerates by releasing seed during extreme heat of at least 60^0C. The rest of the tree is protected with its thicker bark to withstand hot temperatures. Without fire, shade tolerant species such as balsam fir will replace the pine, and needle litter and other debris that builds up in the forest. The average stand age of black spruce is 80 years with a fire interval between 50-150 years in BWCA. Black spruce also needs fire to release seed promptly after fire activity for quick establishment. Without fire, shade tolerant species will dominate. In the BWCA, fire suppression is evident. Shade tolerant balsam-spruce-birch communities are replacing jack pine, black spruce and aspen-birch forests. In addition, older stands of white and red pine are not regenerating due to long fire intervals (Heinselman, 1996; Woods & Day, 1977). Fire frequency needs to be considered, which includes probability of a species surviving and reproducing before a fire (Johnson, 1992; Suffling, 1995). There are similar changes to BWCA along the eastern boundary of Quetico. There are uneven stands resulting from fire restrictions. There may also be locations within Quetico or elsewhere that should not burn. For example, an area with seedlings for regeneration, or an area recently burned because seeds could be destroyed if burned a second time and other species could grow instead that are not representative of the landscape. A fire history map or stand origin map should be incorporated when planning fire restoration since it will represent an age mosaic pattern of the landscape.

A natural fire regime may never be fully implemented in Quetico due to safety concerns, budgetary constraints and daily Park management demands, but fires that ignite in the Park can be better managed with the security of a fire break situated on the eastern Park boundary. Thus, the prescribed natural fire zone might be expanded northwards and eastwards with the installation of a prescribed burn fire break (Figure 3-4). The eastern boundary area is classed as a measured zone, but with an established prescribed burn fire break, could even be defined as a new class. This change in zoning, with modified criteria to permit lightning caused fire could assist with achieving a more natural fire regime. With Quetico's fire management plan, there is a section outlining fire prevention and fireproofing existing and future human values. The introduction of the fire break could aid in achieving this management objective.

When restoring a natural fire regime, factors such as climate change and policy need to be considered. Wotton (2005) indicates that the future fire climate measured by FWI will be more severe in the summer months. Increased temperatures and increased variability in precipitation will increase the FWI for measuring fire danger. With drier and hotter summers and decreased fuel moisture, there is the possibility of increased number of wildfires of greater severity, and increased carbon emissions. The potential increase of wildfire activity increases the operating costs within and outside the Park thus a fire break situated in Quetico may alleviate the fire fighting costs. In Quetico, southerly vegetation species are becoming evident (Forester, 2004). The changing forest species is significant because it could affect the probability of fires (Wotton, 2005). Park management strategies need to be flexible to mitigate the affects of anthropogenic climate changes since vegetation composite, precipitation and temperature will change resulting in longer, drier summers (*ibid*). The implications are that summer fire crews will need to work for longer periods, the Park will need more fire fighters and highly flammable locations in the Park should be identified to predict and prepare for wildfire.

6.5 Applicability of Fire Break to Other Parks

The effectiveness of a regional fire break was demonstrated in the Quetico Provincial Park study area. Various simulated fire break designs were successful in the reduction of modeled wildfires. Although demonstrated in Quetico, this concept can be applied elsewhere across Canada and elsewhere where fire is used in parks for specific objectives and where a fire break would be beneficial in reducing the risk of escaped fires. For example, similar breaks are constructed in Banff, California, BWCA and Voyageurs (refer to Chapter 2). The benefit of fire breaks were experienced by fire fighters whereby wildfires were contained by the breaks or slowed down the fire spread enough to control the wildfire in a safe manner.

Items to consider when creating a fire break in another location include determining the objectives of the fire break. Will it be used to thin hazardous fuels or to trap wildfires within a protected area? With the Parks management objectives established, one should build a fire break perpendicular to the prevailing wind direction. In Quetico, winds are generally from the southwest so fires travel northeast. The fire break was created linearly from North to South. When planning the prescribed burns, the first burn should be close to a road or path for easy accessibility as a precautionary measure. The subsequent burns can be planned against the first burn to minimize fire spread and risk of escape to maximize effort to contain the burn and fragment the continuity of the landscape pattern. The maximum number of burns and area burned allowed in a short period would provide the most effective barrier. Creating the break as close as possible to the Park boundary is ideal. The closer the fire break was to the boundary, the less area was burned in between the break and boundary, and less potential there was for a fire to start in this location. Another consideration is using natural barriers such as water, bogs, and rocky or non-vegetated areas. Natural barriers reduce the cost by reducing the total number and area of planned burns needed. The overall shape of the break should be linear to contain wildfires, and at least 1.5 Km in width to counter wildfire spotting. The topography will influence the fire break design. Quetico is not a mountainous region, with a difference in elevation of 165m so if this break was used in mountains, the topography would need to be examined more fully. Finally, to model other locations in Prometheus, the FWI components will need to reflect changes in the location. This includes modifying provincial FWI input and data layers.

6.6 Summary of Discussion

A fire break reduces area burned within the Park and extending beyond the break and Park boundary. Without a fire break, there is no barrier to reduce the wildfire's rate of spread and in Quetico's case, it may accelerate as it approaches the eastern boundary due to high occurrence of flammable vegetation. Even under extreme weather and vegetation re-growth conditions, all of the five fire break designs should significantly contain wildfires and reduce fuel.

Building a successful fire break should consider all aforementioned factors including the design, social and economic costs, ecological opportunities, and whether the design can be implemented to other protected areas. The physical, environmental and management factors will be different for each Park. Prescribed burn fire breaks can be incorporated into Parks management. In Ontario for example, the OMNR has a goal for provincial Parks and conservation reserves to manage fire in the context of restoring and maintaining ecological integrity, or the maintenance of biodiversity. Quetico Provincial Park has a fire management plan and the creation of a prescribed burn fire break could potentially be incorporated as part of the Park's fire strategy. The Park also uses prescribed burns to reduce fuel buildup around human values that are hazardous. A regional fire break can be incorporated into the fire management plan with the purpose to allow fire to burn within the Park.

In summary, five fire break designs were analyzed in detail to determine how successful they are in limiting the spread of wildfire, containing wildfires and reducing the amount burned beyond the Park boundary. The need for public safety when planning the fire break, economic, social and ecological considerations, restoring natural fire regimes and applicability of the fire break to other Parks all encompass an optimal fire break design.

Chapter 7
Conclusions and Future Considerations

Uncontrolled wildfires occur in Ontario and across Canada each year during the fire season. Fire suppression in Parks and property (private, Crown land) coupled with warmer and drier summers are causing increasingly hazardous conditions that add fuel to the fire resulting in more intense and prolonged wildfires. With the recognition that fire is significant in restoring ecosystem health, particularly in the boreal ecosystem, prescribed burning is a practice that can regenerate fire dependent ecosystems, reduce hazardous fuels, and hence reduce wildfire spread, protect resources and infrastructure and be incorporated into management decisions.

Examining fire's role in the ecosystem and understanding the significance of re-introducing fire achieved the first goal of this research. The second goal was to examine fire management strategies for the province, Parks and other protected areas and the re-introduction of fire for defined management objectives have been evaluated (OMNR, 2004a). Using fire needs careful planning. Hence, in the third objective, creating, testing and implementing a regional fire break from planned burns addressed the first two concerns of re-introducing fire but, with Park planning incorporated. In achieving the fourth objective, five fire break designs were modeled in Prometheus fire growth modeling software using Quetico Provincial Park as a case study. The Park has a problem of fuel building up to hazardous levels and has few natural fire barriers along its eastern boundary. Surrounding the Park is valuable commercial production of timber that needs to be protected against a wildfire, where it could potentially spread quickly beyond the boundary into these Crown lands so they are important to protect.

The fifth objective involved modeling the prescribed burn fire breaks and testing against potential wildfires. The results revealed that an effective fire break is one that reduces the amount of area burned and the number of wildfires spread beyond the Park boundary. A successful barrier needs to be built with the most prescribed burns feasible within a year to maximize its effectiveness. By increasing the area burned and minimizing the number of burn years to create the break, less vegetation re-growth will result in another build up of flammable fuels. Forest litter will build up eventually and some manual thinning may be required or re-burning to reduce the fuel load. In addition, the break needs to be situated close to the Park boundary, compact in shape to provide a robust barrier and utilize natural breaks that will not ignite such as rock and water.

With regards to the sixth objective, the regional fire break can be incorporated into Park management strategies. Specifically in Quetico, there is an update to the Parks master plan. With the understanding that more fire needs to be allowed in Quetico to regenerate the boreal forest, the fire break should be incorporated into the fire management plan. The fire break will protect valuable timber resources outside the Park, reduce the hazardous fuels along the eastern boundary, and contribute to restoring Quetico's natural fire regime and regenerating the landscape since the break is created by prescribed burns.

The potential of the regional fire break extends beyond Quetico Provincial Park. This design can be studied and applied to other Parks across Canada and elsewhere. In mountainous regions, the fire break can still be a linear, compact shape, surrounding natural breaks such as water and bare earth. However, the topography and weather and what needs to be protected play an important role in situating the break appropriately (along ridges or slope of a specific grade, wind patterns in mountainous areas, and considering settlements).

Concerning the seventh objective, it is recommended that fire modeling software be used to help answer "what-if" scenarios. Ideally, one could incorporate modeling into park operations. The potential to quickly determine high risk locations for wildfires, and modeling changes with weather, can assist with operational activities. The regional fire break could be extended into the US, especially Voyageurs National Park or BWCA in Superior National Forest. There is currently a memorandum of understanding between these Parks when wildfires cross the Park boundaries. With similar ecological objectives and similar vegetation types, this particular kind of break can be applied there.

To summarize, the potential for Parks to use regional fire breaks is promising, given a set of objectives for the Park operation is feasible. A fire break is effective in reducing flammable fuels, regenerating boreal species and reducing the spread of and containing wildfires. In conclusion, it is evident that fire is an important factor in Park management for maintaining ecosystem diversity. Regional fire breaks should be incorporated for fire and vegetation fuel management in Parks. The use of software modeling should also be included with Park operation. Modeling different scenarios prepare fire managers for potential risks of wildfires in the Park. Overall, the integration of fire in Parks for regeneration, hazardous fuel reduction and containing fires can be achieved with an established regional fire break. This implementation will be a great challenge, but not as challenging as dealing with the detrimental effects of diversity and ecological integrity loss associated with fire suppression.

7.1 Future Research and Management Considerations for Fire Break Creation

Future considerations should include the following:

- Fire modeling should be supplemented with more field observations in order to realistically simulate fire activity.

- There are many combinations and styles of fire breaks and therefore further examination of distances of breaks to park boundaries, perhaps a linear break right on the boundary and incrementally working westwards to test thresholds. This study could potentially answer "How far can the break be from the boundary and still be deemed an effective barrier?"

- Another recommendation is to examine the minimum size of the fire break for it to remain effective. A study could involve burning 1,000 ha in the North, then incrementally working southwards to determine how little or extensive of an area needs to be burned to remain an adequate fire barrier.

- A future researcher could repeat the same prescribed burns a second time along the break to determine any advantages or disadvantages in effectiveness. In addition, examine the sequence of prescribed burns and different influences of forest regeneration in creating an effective fire break.

- The fire plans should be updated as needed and remain flexible, especially as new information becomes available that would impact management decisions.

- A follow-up study could focus on economic analysis for the potential of cost and savings for prescribed burning and wildfires.

- Further studies could include examining the social acceptability of fire breaks, particularly with nearby communities that may be affected.

7.2 Software Modeling and Data Recommendations

The following are recommendations for future research in terms of using digital data and software modeling:

- The five fire breaks tested in this research were not validated, only simulated safely from a computer workstation. It is recommended that if a prescribed fire occurs that a simulation be run in tandem or immediately following to confirm accuracy of modeling. For example, this was performed recently in Pukaskwa National Park (Smit, 2006).

- When modeling wildfires and prescribed burns, the microclimate and microbursts of fire weather need to be considered. This is not currently a modeling option in Prometheus.

- The Albini spot model calculates distance of embers thrown from wildfires (wildfire spotting) and should be incorporated into fire modeling software. This is not currently a modeling option in Prometheus.

- The FBP fuels data layer for Quetico is not entirely accurate or up to date and it is recommended to update for accurate analysis.

- In addition to field observations and the FBP fuel layer, it is recommended to incorporate higher resolution airborne imagery and use of hyperspectral imagery to assist with accurately mapping the remote areas of Quetico.

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Appendix A

Decision Key Flowchart on protocol for fire activity that occurs in Quetico Provincial Park

```
Within Prescribed Natural Fire Zone of ........... ............................................................ To be controlled
Quetico Park?  ----------------------------------- NO -----------------------------------------------> Wildfire
      |
      ↓
Lightning caused? ---------NO---> In area identified ----NO -------------------------------------> Wildfire
                                  for fire renewal?
      ↓                                  ↓
Fire is within acceptable <----------------YES
burning indices?
DC <300   BUI<50------------------------------ NO-------------------------------------------------> Wildfire
     |
   YES
     ↓
Short and long term weather  ------------------ NO--------------------------------------------------->Wildfire
and fire behaviour are within
acceptable parameters?
      |
    YES
      ↓
Threat to life, property, -------------------YES ... >--------------------------------------------------  Wildfire
Park values, boundary ?
(Social/Economic Impacts)
       |
      NO
       ↓
Regional/Provincial fire -------------------NO.... >--------------------------------------------------  Wildfire
situation manageable?
       |
     YES
       ↓
Smoke conditions acceptable? ------------NO ... >--------------------------------------------------  Wildfire
       |
     YES
       ↓
Cumulative risk factors acceptable? -------NO . >--------------------------------------------------  Wildfire
        |
      YES
        |
        |.... Prescribed natural fire
        |.... Prescribed burn
        |.... Modified response
```

Source: (OMNR, 1998)

Appendix B

Documentation sent to experts for fire break design input

INVESTIGATING PRESCRIBED BURNS FOR FIRE AND FUEL MANAGEMENT IN NORTHEAST QUETICO PROVINCIAL PARK

Overview:

For my graduate thesis, part of the research involves examining the idea of using prescribed burns to create a firebreak. I will be using data from Quetico Provincial Park, but it is anticipated that this concept could be applicable to other Parks. This firebreak it anticipated to be linear, following natural features such as water but conscious of the proximity to the Park's border. I hope to answer the question:

> *Will creating a firebreak with prescribed burns be successful for managing fuel buildup and reducing the risk of wildfire escaping out of Quetico Provincial Park?*

This research will attempt to determine whether investing into a prescribed burn firebreak would reduce hazardous or flammable fuels, and also reduce the risk of wildfire escaping out to the community, highway and neighbouring logging areas.

I would like your input on how to create a prescribed burn firebreak, the procedure in creating one, concerns and other comments with this prescribed burn firebreak.

Materials:

There are both digital and paper copies included in this package of northEastern Quetico Provincial Park (subset of Park). All the raster data is 30m resolution, with trails, roads, and the Park boundary draped over data.

Please note: the roads in the study area (eastern part of the Park), are tertiary roads not used any more, and many areas are grown in with vegetation

- FBP fuel map (merged FRI and Landsat categories to reflect updated fuels)
- Elevation
- Slope
- Aspect
- Please feel free to use your own data and send me a photocopy if it is easier.

Task for the experts:

1. In hypothetical terms, if budget was approved, political concerns were dismissed and we had the green light to proceed with a firebreak along the eastern border of Quetico, how would you determine an appropriate firebreak length that would create a defensible firebreak along the eastern border of Quetico Provincial Park? **on the map, there is a solid red line which is the Western extent of a firebreak location, approximately 12km from the eastern boundary. If you feel it could be moved further in the interior, please document.

2. If the firebreak was created using a series of prescribed burns, how would you sequence these burns, knowing you could only conduct 1 larger prescribed burn per year or a few smaller burns in the area? Please mark on the maps and label "prescribed burn 1", "prescribed burn 2", etc.

3. Is there a specific methodology in sequencing these prescribed burns?

4. How many prescribed burns would sufficiently create a defensible firebreak and over how many years? For example, only 5 or 6 larger burns or 10 smaller ones?

5. What would be the approximate size of each burn? How close to the border? What about the length of the firebreak to be successful?

6. If you do not feel a prescribed burn firebreak is suitable, what other methods are acceptable in reducing the risk?

7. Please feel free to provide other comments regarding this exercise!

What I will do with this information:

1. I will enter the potential burn sites into the fire modeling software, Prometheus, test against fall weather streams that I have extracted, and evaluate the burns.

2. I will run a "least cost path" analysis to see what a GIS would pick out as the most likely route for a prescribed burn firebreak, given a set of parameters.

3. With the firebreak simulated (all fuel changed as appropriate to burn, years of succession, etc.) I will place random wildfire ignition points over the data and simulate in Prometheus to determine if the firebreak protects areas to the northEast and East of the Park with a "worst-case scenario".

4. Overall, I anticipate your comments will help to further understand prescribed burn methods, feasibility of prescribed burn firebreaks, and strengthen the research in determining fire management within Parks.

Thanks for all your efforts! I will follow up on the progress with an email or phone call, and from there we'll arrange to get the information sent back to me. I hope to have this information within the month.