AN ASSESSMENT OF GEOSPATIAL TECHNOLOGIES AS USED FOR WILDLAND FIRE SUPPRESSION

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By

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ABSTRACT

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Wildland fire fighting is complex due to climatic variation, risk and uncertainty, and the proximity of human and resource values. Information about fire environments, resource availability and logistics, fire behavior, and values at risk are important issues fire managers must consider in allocating scarce resources. Improved information thus, has value in reducing risk and costs and damages. Geospatial technology, which includes remote sensing tools, geographic positioning systems (GPS), geographic information systems (GIS) and various maps are widely used in wildland fire management. My research evaluates geospatial tools in three different ways: their role in risk reduction, their effect on wildland fire costs and damages, and wildland fire managers' perceived costs and benefits.

A theoretical model was developed to analyze the role of geospatial tools in reducing the risk. Risk-averse fire managers were found to use more geospatial technologies compared to those who did not incorporate risk in their decision making, resulting in a creation of value for these technologies. A simultaneous equation system of fires was estimated using the two-stage and the three-stage least squares estimation methods to examine the impact of geospatial tools on fire size, cost and damages. The effect of geospatial technology on fire size was significant in the Full Response Zone. Fire size was positively related to drought and duff moisture codes. Damages and cost of suppression were not affected significantly by the use of digitized maps.

The survey of wildland fire managers revealed that geospatial tools are useful in integrating information and provide more clarity, flexibility and accuracy in decision-making. It was also discovered in the survey that geospatial tools are most commonly used when multiple fires are burning at the same time and threatening high resource values. Overall, the findings from this research indicated that risk-averse fire managers use geospatial tools more intensively; that maps play a significant role in reducing the fire size in the Full Response Zone, and, finally, the fire managers' view that these technologies are more economically efficient in the Full Response Zone makes a case for more investment in developing and employing them on fires. Record keeping and data collection as well as understanding the human element in terms of risk aversion will be important for future studies and for adopting new technology and allocating resources efficiently.

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CHAPTER 1

INTRODUCTION

1.0 Background

Canada has 402.1 million hectares of forest representing 10% of the world forest cover and 30% of the world's boreal forests (NRC 2009). Forests in Canada constitute almost 44% of the total land area and provide both economic and ecological benefits. The forest industry's contribution to Canadian gross domestic product (GDP) in 2008 was approximately 1.9% ($23.2 billion in 2002 constant dollars and $28 billion in 2008 current dollars). Additionally, the forest sector directly employs approximately 273,700 people in forestry and forest-related industries, which represents 5% of all jobs in Canada (NRC 2009). The forest sector in Canada created approximately $68.5 billion in revenues from manufactured goods in 2008. Forests also offer numerous ecological benefits related to non-timber goods and services (e.g. fish and game), amenity values (e.g. scenic beauty), passive use values (e.g. flood control) and existence values (e.g. preservation of species) (Schaberg et al. 1999). Such values are important to consider when developing forest use and protection policy that strive to maintain biodiversity and sustainability for the benefit of both current and future generations (Loomis and Gonzales-Caban 1994).

With respect to Saskatchewan, forests and other wooded land account for almost 41% of the total land area. In Saskatchewan, revenue from manufactured goods from the forestry sector was approximately $677.5 million in 2007 and directly provided employment to about 3,200 Saskatchewan residents. The value of forest product exports alone was approximately $265 million in 2008. Forests in Saskatchewan are also important for recreation and tourism, as well as for providing economic opportunities for outfitters and traditional activities for First Nations. For these reasons, wildfire protection is an important component of land management.

Fire in Canada is a prevalent natural disturbance in many forest ecosystems and has many economic, social and ecological implications. The number of forest fires in Canada from 1970-2008 has ranged from a minimum of 5,349 per year to a maximum of 12,185 per year, with an average of 8,688 fires per year (CCFM n.d[1].a). What is important to note is the variability from year to year of the number of forest fires. During the same period, variability measured by standard deviation was 1,627. This is an important statistic in terms of risk and uncertainty as it affects planning and budgeting for fire suppression: the greater the variability, the more difficult it is to position resources and to manage wildfire efficiently. Area burned in Canada has also shown increasing variability over the period 1970-2008 with a standard deviation of 1.8 million acres (CCFM n.d.a).

This is true also for fire behavior across the United States where area burned is steadily increasing (Prestemon et al. 2008), and, more importantly, fire activity is becoming more variable (Brown et al 2004). This trend has been well documented in the literature and has been linked to several factors including the fuel load accumulation (Arno and Brown 1991; Mercer et al. 2007), historical land management and fire policy (Stephens and Ruth 2005; Franklin and Agee 2003; Mercer et al. 2007), and changes in climate resulting in hotter and dryer weather conditions (Flannigan and Van Wagner 1991; Gillett et al. 2004; Flannigan et al. 2006 & 2005; Tymstra et al. 2007; Mercer et al. 2007).

The area burned in Saskatchewan is also increasing, as is the variability of fire numbers, making it difficult to budget and plan (CCFM n.d.a). From 1970-2008, the total area burned ranged from 3,885 ha to 1.6 million ha, with an average of 387,899 ha annually. Area burned in Saskatchewan is also increasing, as is the number of fires, ranging from 197 per year to 1,266 per year, with an average of 600 and a standard deviation of 250.

[1] n.d refers to "no date" which is commonly used for citing sources that are undated.

The economic cost of wildland fire can be substantial. Annual fire suppression costs are continually rising in Canada and currently average about $500 million annually (CCFM 2005, Flannigan et al. 2005 and stocks et al. 2008). With respect to wildland fire management, budgets are divided between preparedness (action that occurs prior to the fire season) and suppression (action that occurs during a fire event). From 1990-2001, the average annual total cost of fire management was $417 million for Canada and about $50 million for Saskatchewan. Fire protection expenditures in Canada and Saskatchewan have ranged from $285 million to $846 million (in Canada) and $24 million to $89 million (in Saskatchewan). Additionally, every year on average more than 20 communities in Canada are evacuated affecting about 70,000 people (CCFM 2005), which adds to the total economic and social costs. Furthermore, structural and property losses have averaged approximately $8 million annually in Canada. Although, fire protection agencies have been able to avoid civilian casualties, on average there have been about two fatalities of fire personnel every year as a result of fire-related accidents (NRC n.d).

The Fire Management and Forest Protection (FM&FP) branch is responsible for all aspects of wildfire management. Their objective is to make wildfire suppression more efficient and cost effective (Saskatchewan Environment 2003). More specifically, the objective is to minimize the costs and damages of wildfire yet balance the economics with environmental and ecological integrity. The cost reduction objective is superseded when there is danger to human life and structures. Saskatchewan Environment uses a "values at risk" (VAR)[2] approach to fight fire that prioritizes resources and suppression priorities based on threats to human life, property, commercial forest resources and non-market forest values. VAR is defined as "specific or

[2] Values at risk (VARs) in Saskatchewan include communities, structural and non-structural values, infrastructure such as power stations, telecommunications lines, hydro lines, and mines, and resource values. For example FM&FP maintains a database and adds information as values change and additional information is acquired (Saskatchewan Environment 2003).

collective sets of natural resources and man-made improvements/developments that have measurable or intrinsic worth and that may be destroyed or otherwise altered by fire in any given area,"(CIFFC 2004).

1.1 Problem Statement

Not only is fire management expensive, damage to resources adds to total economic costs in terms of timber losses, damage to property and public infrastructure, costs associated with community evacuations, disruption of traffic and other economic activities, and adverse health effects for example. Estimates of damages are difficult to quantify, with the exception of property losses, and in many cases are not recorded. The National Forestry Database Program (NFDP) abandoned reporting forest management expenditures because of reporting inconsistencies and increasing difficulty in measuring expenditures on non-timber objectives and damages (CCFM n.d.b).

Fire agencies are keen to reduce costs and damages and have employed various information tools at both tactical and strategic levels of management. Risk and uncertainty are inherent in fire management, particularly for complex fires (a suite of wildfires burning simultaneously in close proximity). Weather conditions, forest cover, less-than-perfect information about VAR, and other factors introduce uncertainty and risk in all decision-making processes. Furthermore, current economic models developed to evaluate wildfire do not consider risk or the value of reducing risk in decision-making

Geospatial tools have been increasingly used to provide information about factors such as weather conditions, fuel types, topographic characteristics, access routes, location of resources, and fire behavior (Hamilton et al. 1989). However, because there are significant investments required to develop and employ these technologies, they often require substantial budget allocations. The Saskatchewan government owned 18 aircraft in 2005 for forest suppression, including helicopters. Maintenance costs of the aircraft averaged approximately $5 million annually. The cost of geospatial technology, which includes trained geospatial specialists, aircraft with remote sensors for scanning and collecting data, fuel costs, and map production and its interpretation can be significant. Helicopters and other aircraft cost between $2,000 - $2,500/hour for suppression operations. For complex fires, geospatial platforms such Airborne Wildfire Intelligence System (AWIS) are contracted privately and can cost a significant amount. The wages for geospatial staff often increase due to overtime. For example, the cost for two people employed at a rate of $80/hour at 12 hours a day for a period of 12-18 days would be $20,160. If a helicopter is used for seven days at a rate of $2,500/hour for an average of 4 hours a day, the cost would be $70,000.

While geospatial tools can play a significant role in providing information for forest fire management and planning (Burchfield et al. 2002), it is important to determine whether the benefits of using such technology outweigh the costs, the latter of which can be substantial. Despite the widespread use of geospatial technologies, there have been few studies to determine the effectiveness of these technologies or the value of the information they produce in terms of value and risk reduction (Hesseln et al. 2009; Burchfield et al. 2002; Hamilton et al. 1989).

1.2 Geospatial Technologies in Forest Fire Management

Geospatial tools have been touted as a means to mitigate costs and damages (U.S. GAO 2003) by providing information for managers to make better decisions. Information is useful only if it reduces the uncertainty or risk involved in an activity. If there is no risk involved or there is no consequence of making a wrong decision based on faulty or incomplete information, then information does not carry any value. Geospatial tools provide information and thus reduce risk. Reducing risk and uncertainty about an event or an activity helps to avoid making bad decisions and thus helps in reducing costs and losses. However, geospatial information comes at a cost. There can be significant investment required to not only develop such technologies but to train staff and to consistently gather relevant information. Estimates of the costs and benefits of using geospatial technologies for forest fire suppression are not well known. Such information would enable decision makers to better allocate resources among competing needs. Use of geospatial technologies can only be justified if the marginal benefit (through reduced risk and avoided losses and costs) is greater than the marginal cost.

"Geospatial technology" is a general term used for spatially analytical tools such as remote sensing, global positioning systems, processing and computer software, and spatial output that can be used to provide a vast array of maps. Information from such technology has great potential to provide timely and accurate information to better allocate resources (Burchfield at al. 2002) and, ultimately, reduce fire management expenditures, costs, losses and damages related to fire activity. Fire agencies have been increasingly using these tools to carry out both strategic and tactical fire management activities. For example, geospatial technologies help to provide the most up-to-date information regarding fire location, VAR, topography and weather, and can be used to monitor fire spread, access and transportation routes and conditions, existing and proposed fuel breaks and fire lines, water sources, aviation routes, and administrative boundaries.

Maps generated using new geospatial technologies provide an advantage over traditional maps (e.g. topographic maps) in that they can be easily and quickly updated with new information (Burchfield et al. 2002; Hamilton et al. 1989). Similarly, such maps can be accessed digitally at remote locations and thus can be utilized for planning, given that they provide data integration. Geospatial technologies also facilitate exchange of information among fire and emergency organizations and with governments, communities and the media. While geospatial technologies can be used at strategic, tactical and operational levels, in this research I focus on tactical and operational uses. Specifically, I focus on the time when suppression of an active fire has begun. Geospatial technologies used at the tactical and operational levels help managers monitor fire spread and are useful in resource positioning and resource allocation.

1.3 Research Objectives

The primary objective of my research is to estimate the value of maps generated using an array of geospatial tools for wildland fire suppression. I will estimate the value of maps generated from geospatial tools in terms of the information they provide and the degree to which they reduce risk and enhance decisions, thereby enabling fire managers to make better strategic and tactical decisions. Moreover, by making more informed decisions, I expect that fire managers will be able to reduce fire size, suppression costs and losses/damages caused by wildland fire. Specifically, my objectives are:

1. To develop a theoretical framework to analyze the role maps generated using a range of geospatial tools play in reducing risk,

2. To empirically estimate the effects of maps generated using geospatial tools to reduce fire size, fire suppression costs and damages,

3. To understand how information provided by a range of geospatial tools is used in the field by fire managers and the value or usefulness of such tools,

Achieving the above objectives will help to inform decision makers in assessing the objective value of these technologies and also help to identify areas where more investment in geospatial technologies might be warranted for further development.

1.4 Research Approach

As fire activity increases, fire management agencies have become increasingly concerned with how to allocate scarce resources more efficiently. In the fire literature, economic models generally focus on the balance between fire suppression expenditures and the expected reduction in wildfire activity and damage. Typically models focus on minimizing the sum of costs plus losses. However, most models do not include the role of risk and uncertainty. Fire managers rarely have perfect knowledge or information about weather conditions, topography, location of resources, and how a fire will behave. Notwithstanding, geospatial technologies can be employed to reduce risk by providing better information.

Most fire management decision-making has been studied in the context of how to use resources efficiently to minimize the sum of cost and losses (Donvan and Rideout 2003) without explicitly dealing with the risk. Some research (Hesseln et al. 2009; Lankoande and Yoder 2006) tries to incorporate risk by simply minimizing the expected value of the sum of costs and losses. My approach is different in that I study whether information produced using geospatial tools helps to reduce risk, and thereby costs, caused by wildland fire. I specify a fire economics model based on maximizing expected utility. This approach has also been tested in the agricultural production economics literature (e.g. Just and Pope 1979). My objective is not only to maximize expected values (the negative of damages and costs)[3] but also to understand how

[3] The general practice in economics is to focus on utility of "goods" rather than "bads" (Meyer 2002).

geospatial tools affect variance (Just and Pope 1979; Tveteras 1999; Pope and Kramer 1979; Feder 1979; Lambert 1990; Horowitz and Lichtenberg 1994; Farnsworth and Moffitt 1981; Hurd 1994) and to determine whether an input is increasing or reducing the risk of the objective variable. I estimate the impact of geospatial tools on area burned, losses and damages to determine the impact of these tools empirically using an econometrics approach. Finally, I develop a survey to gain a better understanding of how these tools are perceived by fire managers.

1.5 Organization of the Dissertation

The purpose of this research is to determine whether the use of geospatial technologies plays a role in reducing fire damage, costs and area burned, and whether information leads to more efficient use of such technology. Chapter 2 provides details about the development of a theoretical model to evaluate the role of geospatial tools in reducing the risk of loss, and about how data can be collected to evaluate the model. In Chapter 3, I use the data to estimate the impact of geospatial tools on area burned, losses and suppression costs. Chapter 4 summarizes the perception of forest fire managers about how geospatial tools are used, their perceived usefulness, and barriers to complete implementation of such technologies for use in forest fire suppression. Data were collected using an in-depth survey of personnel involved in forest fire operations in Saskatchewan. Chapter 5 discusses the implications and conclusions of the study.

CHAPTER 2

A THEORETICAL MODEL TO ESTIMATE THE ECONOMIC VALUE OF GEOSPATIAL TOOLS USED FOR WILDLAND FIRES

2.0 Introduction

Wildland fires are fought in increasingly complex environments due to climate change and a growing wildland-urban interface (Hesseln et al. 2009). Many forested areas are becoming warmer and experiencing more drought-like conditions resulting in highly flammable fuels. Additionally, past forest management practices have been blamed for an accumulation of forest fuels. These factors, combined with a growing population living in and around forested areas, have created often deadly situations resulting in more severe wildland fires and increasing costs and losses (Stephens and Ruth 2005). Fire management agencies also increasingly face public pressure to control and mitigate losses caused by fires every year.

Faced with such pressures, fire management agencies have started investing in better technologies, enhanced crew training and higher quality information to better understand the fire environment (Hamilton et al. 1989). Geospatial tool use has gained widespread adoption within fire management to obtain information critical for planning. Agencies have recognized the role of information in reducing losses and costs by learning more about the fire environment and making better decisions. Such technologies have been found to be economically beneficial, in spite of their costs.

Barrager and Cohan (1986) contend that new or improved information has value only if it reduces uncertainty and enables forest fire managers to make better decisions, thereby reducing suppression costs and losses. Bernknopf et al. (1997) states that if a decision maker is risk-averse, then information that reduces the risk has a value for him and, therefore, he not only tries to maximize an expected value but also tries to reduce risk.

Geographic information systems (GIS) have value in that they enable managers to make better decisions, thereby reducing risk and avoiding damages (Taupier and Willis 1994). Technological approaches to valuing information are prevalent in the agriculture literature. Larson et al. (2002) summarize GIS use for precision farming[4] where geospatial technologies are used as risk management tools to improve the accuracy or precision of operations. Similarly, Pope and Kramer (1979) argue that an input is risk-reducing in nature when a decision maker who is risk-neutral demands less than the risk-averse individual, resulting in resource savings and thus real value.

Input use in any production system plays different roles. For example, fertilizer applications might result in directly increasing crop yield, and pesticide use might increase yields by preventing or reducing insect damage. Geospatial tools for my research purposes are modeled as inputs into fire management: specifically maps. Geospatial tools reduce the sum of losses and costs by providing better information, thereby reducing risk and uncertainty, which ultimately results in cost savings. Risk and uncertainty in wildland fire situations arise from factors such as a lack of information pertaining to values at risk (VAR), fuel types and conditions, weather behavior, and fire behavior. Geospatial tools can integrate and overlay all such information in a timely manner (Hamilton et al. 1989; Barrager and Cohan1986).

Although the costs of employing geospatial tools are difficult to determine, they are necessary in order to assess the economic benefits of using such tools. Despite often substantial

[4] Sometime called variable rate, prescription, site specific or soil specific farming technology involves collecting, displaying and analyzing site-specific information through various tools such as mapping, GIS, GPS, remote sensing, aerial photography and satellite imagery in order to make better management decisions (Larson et al. (2002).

investments in such technologies, there have been few analytical studies to estimate their value. Therefore, this study is an important step in developing a framework to measure and estimate the effects of using geospatial technology to reduce the wildland fire risk.

I aim to examine the role of geospatial tools/maps in reducing risks in fire management decision-making and to provide a framework to estimate the value of such tools. This research is important to show whether geospatial tools are useful and whether their continued development and employment are warranted in reducing costs and losses from wildland fires. The first part of this chapter outlines a general theoretical model that can be used to examine the optimal level of inputs under risky and uncertain fire-fighting conditions. I am specifically interested in knowing how geospatial tools are used depending on the risk behavior of the fire managers. I apply the expected utility maximization approach to the well-established theory of Cost Plus Net Value Change (C+NVC) of fire management developed by Donovan and Rideout (2003) and approximate it using a mean-variance approach (Markowitz 1952). In the second section, I briefly review the literature that is relevant to my problem. The third section of the chapter explains the theoretical model, and the final section summarizes the model.

2.1 Literature/Background

Most of the economic literature regarding forest fires attempts to evaluate the impact of forest fires on harvest rotations, or when to harvest a forest in the event of fire risk, and focuses on maximizing the present value of the forest rotation (Reed 1984, Reed 1987, Reed and Errico 1985, Reed and Errico 1986, Martell 1980, Routledge 1980, Strang 1983). Similarly, there has been much study on optimizing fire suppression efforts in the event of damaging wildfires – to which the long history of the C+NVC model is testament (for example, Sparhawk 1925; Parks 1964; Rideout and Omi 1990; Lankoande and Yoder 2006). Finally, there is also a large body of literature that examines the value of information with respect to weather forecasting and other activities that reduce risk (for example, Brown and Murphy 1988; Kite-Powell and Solow 1994; Murphy 1994; Sol 1994; Fox et al. 1999). I look at both bodies of literature and develop an optimization model based on the biophysical factors affecting wildfire behavior, the value of information produced using geospatial technology and the general fire suppression objective of minimizing suppression costs subject to increasing damage. I begin with a brief review of the relevant literature for each aspect of my model.

Pyne et al. (1996) provide a history of economic theories concerning wildfire that stem from fire management objectives based on (i) an insurance model with a view to adequate protection, (ii) a biological model that minimizes damages, and (iii) a market model that optimizes efforts based on least-cost-plus-loss (LCPL). This last model includes the value of the resource in relation to fire fighting expenditures and also the fact that resource damage is typically inversely related to expenditures. The LCPL model evolved into cost-plus-net-value-change (C+NVC) to reflect the positive ecological value of some wildfires.

Taking a different approach, Rideout and Omi (1990) compare the objectives of the C+NVC minimization model to profit maximization for fire management decision-making. They argue that researchers have preferred the criteria of cost minimization rather than profit maximization due to the immeasurability of damages averted. They contest the traditional view of pre-suppression and suppression inputs being substitutes and state that this view may or may not hold as it has neither been proved nor refuted empirically. They also reformulate the C+NVC model in the profit maximization paradigm and prove that cost minimization is identical to profit maximization due to the similar first order conditions for both problems. I too look at a maximization approach. Additionally, I am interested in the relationship between suppression efforts and how better information provided through geospatial technology affects net value change, or the damage to the resource.

Donovan and Brown (2005) observe that suppression expenditures have been increasing over time due to aggressive fire suppression strategies in the past. They studied existing incentive structures for fire managers and suggest an alternative incentive structure to encourage fire managers to control costs and consider benefits of wildfire when minimizing fire damages. This is an important finding in that suppression costs in Saskatchewan are also increasing and changing incentive structures for fire managers with respect to using geospatial technology could favorably affect costs in the long run.

Also, with respect to the human factor, Gonzalez-Caban (1997) find that managerial and organizational factors affect treatments costs more than the physical characteristics of a fire or landscape, and therefore attitudes such as those pertaining to risk could explain the differences in fire costs. They identify two main problems embedded in the existing incentive structure that cause fire managers to ignore the potential benefits of fires and the true costs of fire expenditures. They show that fire managers overspend when the benefits of fires are not considered, compared to when fire benefits are considered. The availability of an emergency suppression budget also encourages fire managers to overuse suppression resources as the opportunity costs of such actions are none or minimal. Also, the unconstrained availability of the budget encourages fire managers to spend so long as they get even a small increment in damage savings. Therefore, the constraint is not on budget but on resource availability. This is also true in Saskatchewan where budgets are not specified for each fire, but fires are fought based on values at risk and the availability of resources such as air tankers and fire crews.

Literature regarding the value of information derived from geospatial technologies or the decrease in risk associated with geospatial technology use has been deficient. It is important to understand the biophysical factors affecting fire behavior, the history of fire economics models, fire management activities and approaches to measuring the value of information in order to be able to estimate the value of geospatial technology as it is used in fire suppression. Hamilton et al. (1989) explain in detail how geospatial technologies are used for forest fire planning. They argue that information about the wildfire environment plays a very important role in fighting and controlling fires efficiently. They see an increasing role for geospatial technologies to store, analyze and display information about fuel types, weather, topography, resource deployment, fire behavior and to assist in fire planning and decision-making. While maps have always been used, geospatial technologies provide more advantages, such as the ability to update information, analytical capability, integration with other related data layers and flexibility to manipulate data according to the needs of fire managers in a timely and accurate manner. They note that research has shown that geospatial technologies are useful in fire planning, yet there is much potential to utilize it in fire suppression for information about the fire environment, fuels, weather, topography, etc. They suggest that geospatial technologies could lead to cost savings by identifying fire location, fire characteristics, administrative boundaries, and condition of access routes, helispots, heliports, fire camps, water resources, etc. Similarly, geospatial technologies become almost indispensable during an intensive fire season as fire suppression resources are inadequate to respond to all events, making it difficult to decide which fire to suppress. The authors also saw an increasing use of geospatial technologies for communication among fire agencies, fire planners, governments, communities and the media. They suggest that geospatial technologies be made highly portable and that more people be trained to ensure successful utilization in forest fire management.

Gillespie (1994) uses cost-benefit analysis to measure the benefits of using geospatial technologies in two transportation studies. He defines geospatial benefits as reduced costs (efficiency benefits) or improved quality of applications (effectiveness benefits). He explains that recognizing the change in output or decision-making due to the use of geospatial technologies helps identify direct benefits. He states that government transportation managers are under increasing pressure to use their budget dollars more efficiently, and therefore they are turning to technology to achieve this objective. He notes that it is vital to measure the benefits of geospatial tool use to justify sizable initial investments as well as continuous use.

Also examining benefits, Huxhold (1991) notes three main advantages of using geospatial technology – cost reduction, cost avoidance and increased revenue. Cost reduction and avoidance result from a decrease in operating expenses as a result of increased efficiency. He also notes that the economic value of better decision-making is problematic, and comparing a task done with and without using geospatial technology could be used to assess the effectiveness of the technology. He states that hardware, software and transformation of analogue (paper) maps to digital maps are expensive up-front costs.

Bernknopf et al. (1997) use a regulatory land-use decision-making model to estimate the economic value of geological map information for identifying a waste disposal facility. To achieve this objective, they compare the economic effect of decisions made with additional geologic information based on existing map data. Any future uncertainties about the site suitability and losses avoided represent the benefits derived from improved geologic information. They compute the value of loss avoided as changes in the value of property in the region, which was estimated at $340,000. Obermeyer (1999) also uses a simple cost-benefit analysis framework to estimate the benefits and costs of geospatial technology. He notes that most organizations strive for increased efficiency and must provide reliable and defensible justification for every purchase and new initiative. He observes that cost-benefit analysis is more difficult to undertake for public sector investments because of the lack of a market and the inability to establish prices for such public sector products. This is also true for fire suppression expenditures. Similarly, Obermeyer (1999) discusses the difficulty in evaluating fixed costs associated with geospatial technology such as hardware, software and training.

There are many problems associated with estimating value reliably. For example, Gillespie (2000) notes that unavailability of reliable data on benefits and costs of geospatial technologies make accurate valuation difficult. To validate results, it may be possible to use non-market valuation techniques such as contingent valuation to estimate the nature of government investment in geospatial technologies. This is important for my study given that fire data are not always available, and the level of detail is often insufficient to make qualified estimates of value.

I learned from the literature that most of the research in wildland fire economics focuses on determining the optimal harvest age in the event of a fire or determining the efficient level of resources to minimize the sum of C+NVC. The C+NVC model has been extensively used by fire agencies to justify the budget requests as a substitute for cost-benefit analysis. I also found that the value of geospatial tools can be estimated using cost-benefit analysis where cost and damage data exist. Some studies also attributed risk reduction to the use of geospatial tools, a factor that has been neglected in most of the wildland fire economics models. I built my model based on the C+NVC model and extended it to incorporate risk to examine the value of geospatial tools.

2.2 Theoretical Model

2.2.1 Fire Management without Risk

Using the C+NVC model, the optimum level of an input occurs when the combined costs of pre-suppression and suppression and net value change (the difference between damages and benefits) are at a minimum. In the C+NVC model, C is the cost of suppression and pre-suppression, and NVC is the sum of damages (which is negative) plus the value of the beneficial effects of a fire.

I specify the C+NVC model in terms of maximizing costs saved and damages averted from a specific fire. Therefore, the problem is to maximize total benefits using production theory. I assume that fire managers maximize the negative of cost-plus-net-value-change of fire management as shown in equation 2.1.

$$Max\{-(C+NVC)\} = Max_{x_{ijt},K_{ijt}}\{B - F - w_{ijt}x_{ijt} - P_{jt}g_{jt}(x_{ijt}, z_{ijt}, K_{ijt}, \theta) - I_{ijt}(r_{ijt}K_{ijt})\} \quad (2.1)$$

where

- F is a fixed cost, such as expenditures on pre-suppression or preparedness, that occurs prior to the beginning of a fire,
- w_{ijt} is the per unit input price of inputs i (where i = 1, 2, ….,n) used on fire j (where j= 1, 2, ….,k) at time t (where t = 1, 2, …., T) and assumed to be known; (this does not include technology),
- r_{ijt} is the per unit input price/rent of geospatial technology i used on fire j at time t,
- x_{ijt} the input i used on fire j at time t,

- P_{jt} is the value per unit of output (in this case value per unit of commercial timber burned) for fire j at time t and assumed to be unknown in advance of the fire season,
- g_{jt} (●) is output (commercial timber burned for example) from fire j at time t and assumed to be unknown prior to suppression,
- z_{ijt} is a vector of the atmospheric and geographic conditions i, such as temperature, wind speed, topography, and elevation, and relevant to fire j at time t,
- K_{ijt} is geospatial technology i used on fire j at time t,
- θ is a vector of "other" variables unknown to fire managers,
- B represents the benefits of fire such as reduction in fuel loads and ecological benefits. It is assumed to be fixed,
- I_{ijt} represents an indicator variable: I_{ijt} = 1 when geospatial technology i is used on fire j at time t, I_{ijt} = 0 otherwise.

I then write the transformed cost plus net value change as follows:

$$Max\{-(C+NVC)\} = Max_{x_{ijt},K_{ijt}}\left\{B - F - w_{ijt}x_{ijt} - P_{jt}g_{jt}(x_{ijt}, z_{ijt}, K_{ijt}, \theta) - I_{ijt}(r_{ijt}K_{ijt})\right\} \tag{2.2}$$

Taking the derivative with respect to the decision variable x_{ijt}, I get equations (2.3) and (2.4)

$$\partial(-(C+NVC))/\partial x_{ijt} = -w_{ijt} - P_{jt}\,\partial g_{jt}(x_{ijt}, z_{ijt}, K_{ijt}, \theta)/\partial x_{ijt} = 0 \tag{2.3}$$

$$w_{ijt} = -P_{jt} \, {}^{\partial g_{jt}(x_{ijt}, z_{ijt}, K_{ijt}, \theta)}\!\Big/_{\partial x_{ijt}} \tag{2.4}$$

I interpret equation (2.4) as the marginal value of non-geospatial technology: expenditure of one dollar on suppression should be spent only if it reduces the losses or the marginal value of acres burned by a dollar. I use a more explicit specification of Donovan and Rideout (2003) in equation 2.1 for my research, although the result in equation 2.4 is similar to Donovan and Rideout (2003) and Lankeoande and Yoder (2006).

It is not uncommon to have the price of the non-desirable output (i.e. acres of timber burned) to be negative as shown in equation (2.4), but for the equality to hold in equation (2.4), the marginal product ${}^{\partial g_{jt}(x_{ijt}, z_{ijt}, K_{ijt}, \theta)}\!\big/_{\partial x_{ijt}}$ should be negative as well (Howitt and Taylor 1993).

Similarly for technology (K_{ijt}), if geospatial technology is used (I_{ijt} = 1) I get the first-order conditions as specified in equations (2.5) and (2.6):

$$\begin{aligned} {}^{\partial(-(C+NVC))}\!\Big/_{\partial K_{ijt}} &= -P_{jt} \, {}^{\partial g_{jt}(x_{ijt}, z_{ijt}, K_{ijt}, \theta)}\!\Big/_{\partial K_{ijt}} - r_{ijt} \\ &= 0 \end{aligned} \tag{2.5}$$

$$r_{ijt} = -P_{jt} \, {}^{\partial g_{jt}(x_{ijt}, z_{ijt}, K_{ijt}, \theta)}\!\Big/_{\partial K_{ijt}} \tag{2.6}$$

The first-order conditions tell us that, in equilibrium, the marginal cost of geospatial technology should equal the marginal value. That is to say, expenditures on additional geospatial technology should result in savings in terms of damage reductions and resources saved of an equal or greater amount.

2.2.2 Fire Management in a Risky Environment

The above model (section 2.2.1) depicts fire management in an environment without risk and uncertainty, which is not realistic. The risk fire managers face is multifaceted. For example, the value of the hectares burned is not known for two reasons: managers cannot predict the area burned and value of timber burned in advance of fire season; or the exact location of values at risk based on unpredictable fire environments. The negative value of the C+NVC that fire managers aim to maximize is affected by the above-mentioned factors introducing uncertainty in decision making (Blattenberger et al. 1984). Teeter and Dyer (1986) note that current fire models do not include explicit treatment of risk, which they define as the variability in the C+NVC model. Lankoande et al. (2006) try to minimize only the expected value of C+NVC to deal with ex ante decisions (i.e. for decisions made without knowing the outcome with certainty). Prestemon and Donovan (2008) note that most fire management decisions are made with consequences that depend on uncertain future states of nature resulting in suboptimal results. They also deal with uncertain decisions by maximizing only the expected utility when selecting an action. Just and Pope (1979) recognize the effect of an input not only on expected value of the output but also on risk. I assume that geospatial tools not only marginally contribute to the increase in the average value of the negative of C+NVC but also cause an average reduction in variance of the negative of C+NVC.

Assume that fire managers are faced with uncertainty regarding both the area burned (g_{jt}) and value of hectares burned (P_{jt}). This also makes the objective of maximizing the negative of C+NVC uncertain.

Now, suppose that fire managers' preference for risk over the negative of C+NVC are encoded in the utility function; I can write preferences or the utility function as follows:

$$U = U\{-(C + NVC)\} \tag{2.7}$$

Suppose NB = $-(C + NVC)$, where NB is net benefits equal to the negative of C+ NVC. I assume $\frac{\partial U(\bullet)}{\partial NB} > 0$ and $\frac{\partial^2 U(\cdot)}{\partial NB^2} < 0$

More specifically,, the optimum levels of x_{ijt} and K_{ijt} (the decisions variables) can be found according to Bernoulli's principle as the value of x_{ijt} and K_{ijt} that maximizes expected utility (EU), when expectations are taken over the distribution of P_{jt} and g_{jt} (●).

Under the expected utility model, I consider the utility function to be as follows:

$$MaxEU\big(-(C + NVC)\big) = Max_{x_{ijt},K_{ijt}} EU\Big[B - F - w_{ijt}x_{ijt} - P_{jt}g_{\text{jt}}\big(x_{ijt}, z_{ijt}, K_{ijt}, \theta\big) - I_{ijt}(r_{ijt}K_{ijt})\Big] \tag{2.8}$$

The concave utility function shown in equation 2.7 is represented below in figure 2.1, indicating a risk-averse fire manager (Blattenberger et al. 1984). Suppose a fire manager is faced with net benefits NB_1 with probability p and NB_2 with probability 1-p from a fire. This means that a fire manager is uncertain about the outcome and faces a lottery. Now the fire manager's maximum amount of willingness to spend to make a decision with certainty in exchange for a lottery can be termed as a certainty equivalent (CE). The utility of certainty equivalent is equally preferred to the expected utility of the lottery. This can be shown as:

$$U(NB_{CE}) = pU_1(NB_1) + (1\text{-}p)U_2(NB_2) = EU(NB) \tag{2.9}$$

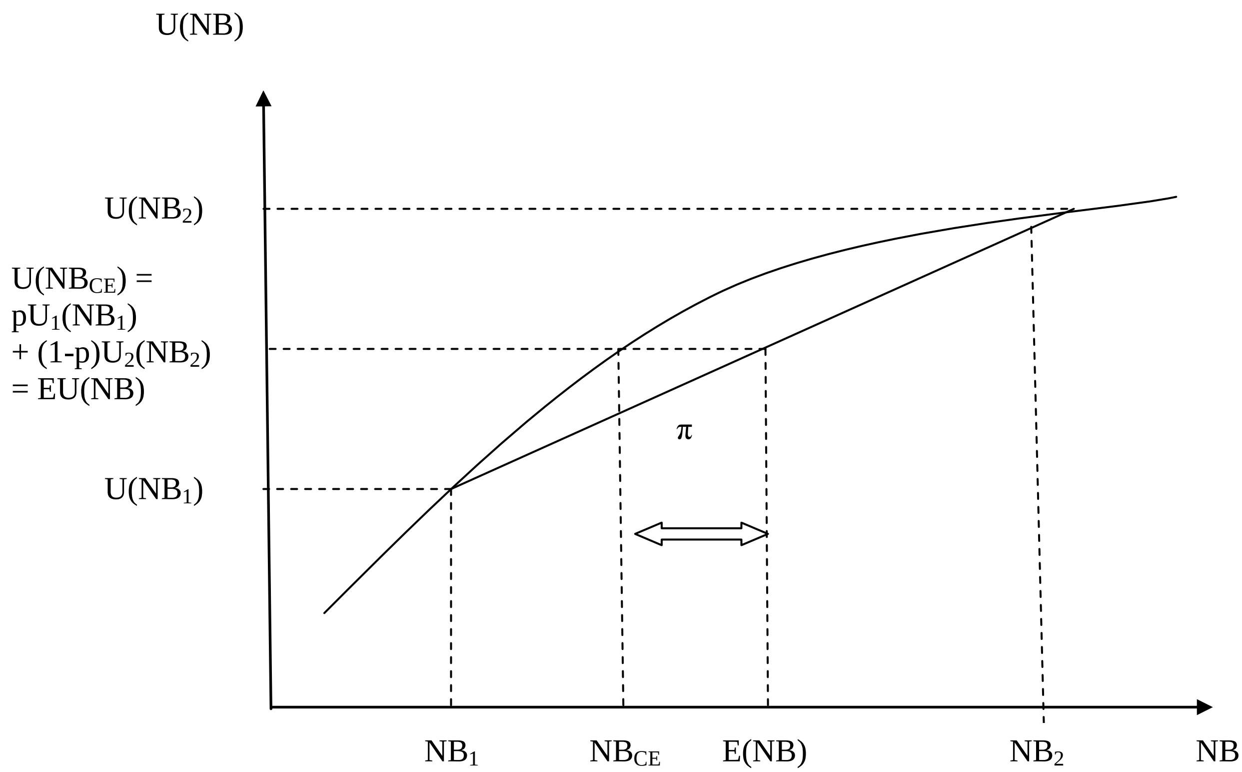

Figure 2.1 Risk-averse fire manager’s utility function

The difference between the expected value of the lottery (E(NB)) and its certainty equivalent (NB_{CE}) is called a risk premium, indicated by π in figure 2.1.

Suppose that a fire manager’s preferences are represented by an exponential utility function that has constant absolute risk aversion and average absolute risk aversion properties (Robison and Barry 1987) as captured by equation 2.10:

$$U(NB) = -e^{-\lambda NB} \tag{2.10}$$

The measure of local risk aversion indicates a point where measure of global risk aversion is too strict to be maintained, therefore, average risk aversion is preferred as it measures the risk aversion for a particular distribution (Robison and Barry 1987).

Similarly, if we assume that net benefit function is normally distributed with mean E(NB) and variance of σ^2_{NB}, then a fire manager's expected utility can be written as follows:

$$E\big(U(NB)\big) = \int U(NB)f(NB)dNB \tag{2.11}$$

where $f(NB)$ is the probability density function of the possible values of NB with E(NB) and variance of σ^2_{NB} given by:

$$f(NB) = \int \frac{1}{\sqrt{2\pi\sigma^2_{NB}}} e^{-\left[\frac{NB-E(NB)}{2\sigma^2_{NB}}\right]} dNB \tag{2.12}$$

Substituting equation 2.10 and 2.12 into 2.11, we get:

$$E\big(U(NB)\big) = -\int \frac{1}{\sqrt{2\pi\sigma^2_{NB}}} e^{\left\{-\left[\frac{NB-E(NB)}{2\sigma^2_{NB}}\right]-\lambda NB\right\}} dNB \tag{2.13}$$

We can see from equation 2.13 that the $E\big(U(NB)\big)$ is a function of the expected value of NB ($E(NB)$) and the variance of NB (σ^2_{NB}) .

Using the equation 2.9, and following Freund (1956) and Hildreth (1954), we find that:

$$NB_{CE} = E(NB) - \frac{\lambda\sigma^2_{NB}}{2} \tag{2.14}$$

Additionally, equation 2.14 can be rearranged as follows:

$$E(NB) = NB_{CE} + \frac{\lambda\sigma^2_{NB}}{2} \tag{2.15}$$

Equation 2.15 indicates that the variance of net benefits can be traded off for expected returns at a rate of λ/2 without affecting well-being or utility.

So, we maximize the expected utility in terms of expected value of NB and the variance of NB, which Robison and Barry (1987) call Expected Value-Variance analysis (E-V analysis).

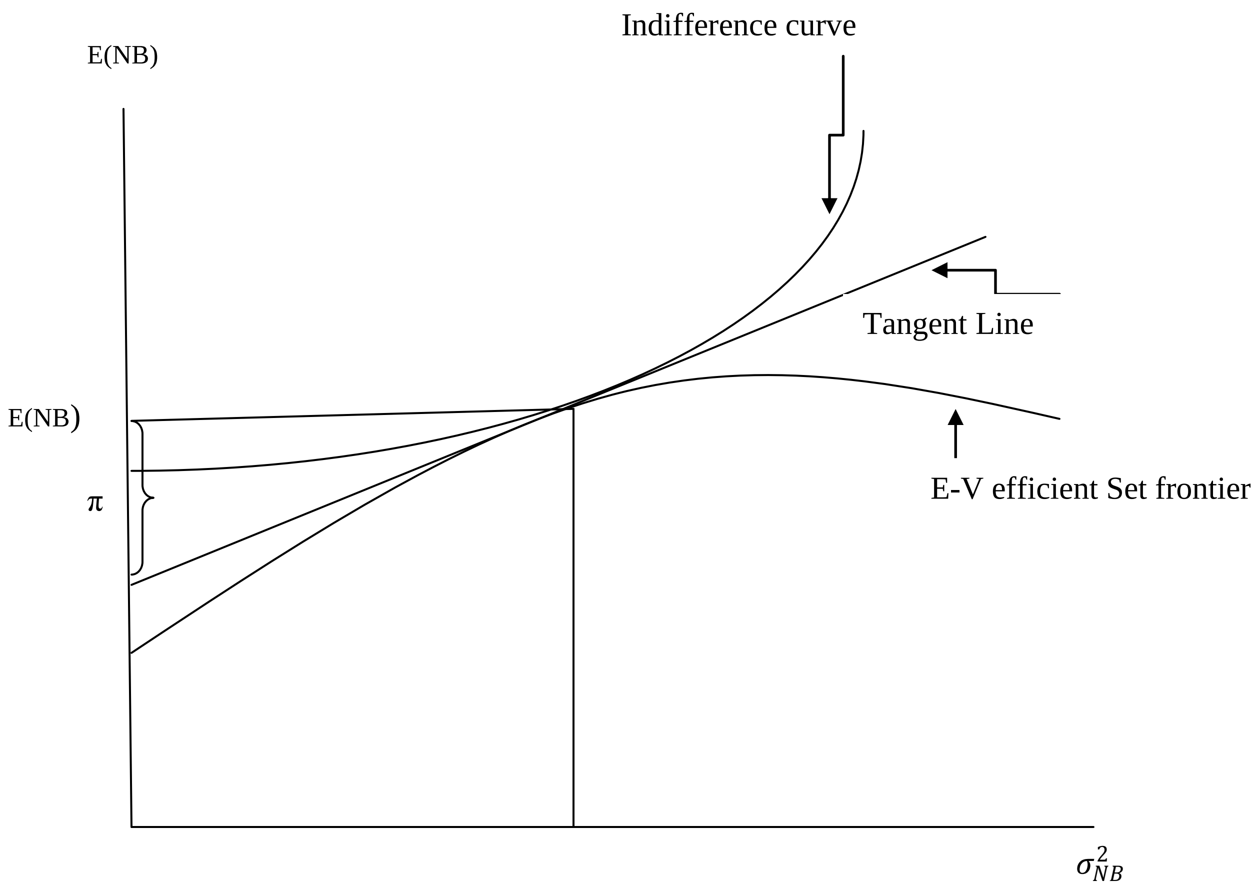

Figure 2.2 Expected utility maximization in the E-V space

A decision-maker will choose a level of an input where the indifference curve is tangent to the efficiency frontier in the expectation-variance space (Figure 2.2 indicates such a level of use of an input). The efficiency frontier, commonly called the E-V frontier (expected-value variance frontier), is the boundary of the feasible region in the mean-variance space (Chavas

2004). It is assumed that decision-makers derive utility from increased expected net benefits and disutility from increased risk (variance). At the point of tangency, a decision-maker obtains expected net benefits of E(NB) at the risk (variance) of σ_{NB}^2. The decision-maker can also choose a point on the vertical intercept, which gives the same utility when no risk is involved. The difference between the E(NB) and a point on the vertical line is referred to as a risk premium (π), which means that a decision-maker is willing to forgo net benefits to avoid the risk entirely. Choosing any point other than the tangency point on the efficiency frontier, including a point under the efficiency frontier curve, although feasible, will give less utility as that point will be lower on the indifference curve.

In figure 2.2, the optimal solution is obtained by maximizing the certainty equivalent subject to the restriction that the choice occurs from the E-V set and that its slope equals the slope of the expected utility ($\overline{E(U(NB)}$).

Maximizing the expected utility in terms of expected value and variance is equivalent to maximizing its certainty equivalent (Robison and Barry 1987), which can be written as:

$$MaxNB_{CE} = E(NB) - \frac{\lambda\sigma_{NB}^2}{2} \tag{2.16}$$

Assuming P_{jt} and g_{jt} (●) are independent of each other, the first two moments for the problem are as follows in equations (2.17) and (2.18). Variance of two independent random variables in a multiplicative form is found using the formula given in Mood et al. (1974).

$$E(NB) = B - F - w_{ijt}x_{ijt} - EP_{jt}Eg_{jt}(x_{ijt}, z_{ijt}, K_{ijt}, \theta) - I_{ijt}(r_{ijt}K_{ijt}) \tag{2.17}$$

$$Var(NB) = Var(P_{jt} g_{jt}(x_{ijt}, z_{ijt}, K_{ijt}, \theta))$$

$$= [E(P_{jt})]^2 Var\left[g_{jt}(\bullet)\right] + \left[E(g_{jt}(\bullet)\right]^2 Var(P_{jt}) + Var(P_{jt}) Var\left(g_{jt}(\bullet)\right) \quad (2.18)$$

Substituting equation 2.17 and 2.18 in equation 2.16, we get:

$$Max_{x_{ijt}, K_{ijt}} NB_{CE} = B - F - w_{ijt} x_{ijt} - EP_{jt} E g_{jt}(x_{ijt}, z_{ijt}, K_{ijt}, \theta) - I_{ijt}(r_{ijt} K_{ijt}) - \frac{\lambda}{2}\left\{[E(P_{jt})]^2 Var\left[g_{jt}(\bullet)\right] + \left[E(g_{jt}(\bullet)\right]^2 Var(P_{jt}) + Var(P_{jt}) Var\left(g_{jt}(\bullet)\right)\right\} \quad (2.19)$$

$$\frac{\partial NB_{CE}}{\partial x_{ijt}} = -w_{ijt} - E(P_{jt}) \frac{\partial E(g_{jt}(\bullet))}{\partial x_{ijt}} - \frac{\lambda}{2}[E(P_{jt})]^2 \frac{\partial Var\left[g_{jt}(\bullet)\right]}{\partial x_{ijt}} - \frac{\lambda}{2} 2E\left(g_{jt}(\bullet)\right) \frac{\partial E\left(g_{jt}(\bullet)\right)}{\partial x_{ijt}} Var(P_{jt}) - \frac{\lambda}{2} Var(P_{jt}) \frac{\partial Var\left[g_{jt}(\bullet)\right]}{\partial x_{ijt}} = 0 \quad (2.20)$$

$$w_{ijt} = -E(P_{jt})\frac{\partial E(g_{jt}(\bullet))}{\partial x_{ijt}} - \frac{\lambda}{2}\frac{\partial Var\left[g_{jt}(\bullet)\right]}{\partial x_{ijt}}\left\{\left[E\left(P_{jt}\right)\right]^2 + Var\left(P_{jt}\right)\right\} - \lambda E\left(g_{jt}(\bullet)\right)\frac{\partial E\left(g_{jt}(\bullet)\right)}{\partial x_{ijt}} Var\left(P_{jt}\right) \tag{2.21}$$

Equation 2.21 explains the optimal level of the non-technology input under risk.

The optimal level of geospatial technology when used for forest fire suppression can be obtained by the following equations:

$$\frac{\partial NB_{CE}}{\partial K_{ijt}} = -r_{ijt} - E(P_{jt})\frac{\partial E(g_{jt}(\bullet))}{\partial K_{ijt}} - \frac{\lambda}{2}\left[E\left(P_{jt}\right)\right]^2\frac{\partial Var\left[g_{jt}(\bullet)\right]}{\partial K_{ijt}} - \frac{\lambda}{2}2E\left(g_{jt}(\bullet)\right)\frac{\partial E\left(g_{jt}(\bullet)\right)}{\partial K_{ijt}} Var\left(P_{jt}\right) - \frac{\lambda}{2}Var\left(P_{jt}\right)\frac{\partial Var\left[g_{jt}(\bullet)\right]}{\partial K_{ijt}} = 0 \tag{2.22}$$

$$r_{ijt} = -E(P_{jt})\frac{\partial E(g_{jt}(\bullet))}{\partial K_{ijt}} - \frac{\lambda}{2}\frac{\partial Var\left[g_{jt}(\bullet)\right]}{\partial K_{ijt}}\left\{\left[E\left(P_{jt}\right)\right]^2 + Var\left(P_{jt}\right)\right\} - \lambda E\left(g_{jt}(\bullet)\right)\frac{\partial E\left(g_{jt}(\bullet)\right)}{\partial K_{ijt}} Var\left(P_{jt}\right) \tag{2.23}$$

Equation 2.20 is the first-order condition when both P_{jt} and $g_{jt}(\bullet)$ are uncertain to obtain an optimal level of geospatial technology.

Equation 2.23 indicates that geospatial technology is applied until the expected reduction in average losses, the variability in losses and the reduction in the variability of the value of losses, all weighted by the risk-aversion parameter, just equals the cost of using the technology. Where the first term on the right-hand side is equal to the left-hand side, the optimal level of geospatial technology (K*) is achieved when the rent of using the geospatial input equals the expected marginal value of the product (the expected reduction in losses). This relationship is shown in figure 2.3.

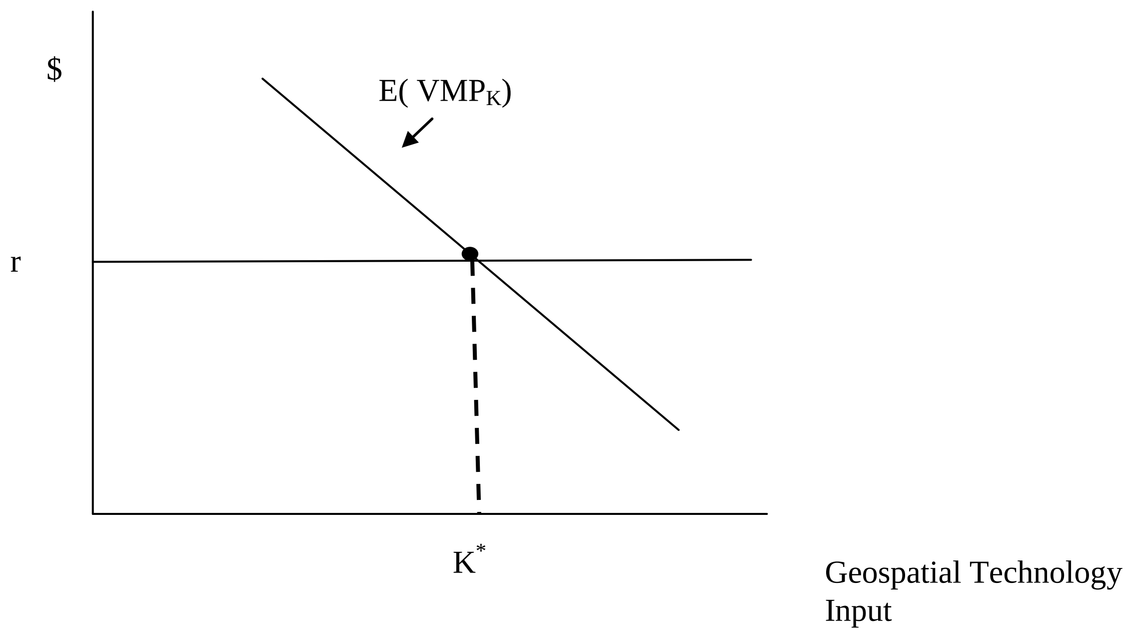

Figure 2.3 Determination of optimal level of geospatial technology input (K*) in a risky environment when only expected value is considered (risk-neutral fire manager).

When risk is accounted for, the optimal level of input is affected by both how fire managers behave in the event of risk (i.e. whether a fire manager is a risk averter ($\lambda>0$), risk neutral (λ=0) or a risk taker (λ<0)) and the nature of the input (whether an input is risk-reducing $\frac{\partial Var\,[g_{jt}\,(\bullet)]}{\partial x_{ijt}} < 0$, risk-neutral$\frac{\partial Var\,[g_{jt}\,(\bullet)]}{\partial x_{ijt}} = 0$ or risk-increasing$\frac{\partial Var\,[g_{jt}\,(\bullet)]}{\partial x_{ijt}} > 0$).

Figure 2.4 illustrates how fire managers make decisions based on their behaviors to risk. Assuming the certainty of events, the manager will use input level K* which is where expected utility is maximized ($r_{ijt} = -E(P_{jt})\frac{\partial E\,(g_{jt}\,(\bullet))}{\partial K_{ijt}}$) . When faced with uncertainty regarding P_{jt} and $g_{jt}\,(\bullet)$, and assuming that the geospatial input is risk reducing, an optimal level of geospatial technology is achieved at K**, resulting in a net gain equal to the area of triangle ABC as shown in figure 2.4. This net gain is attributed to the use of geospatial technology, meaning that fire managers should use technology to the point where K**>K*. Similarly, when an input is risk increasing, fire managers will use less input at K***.

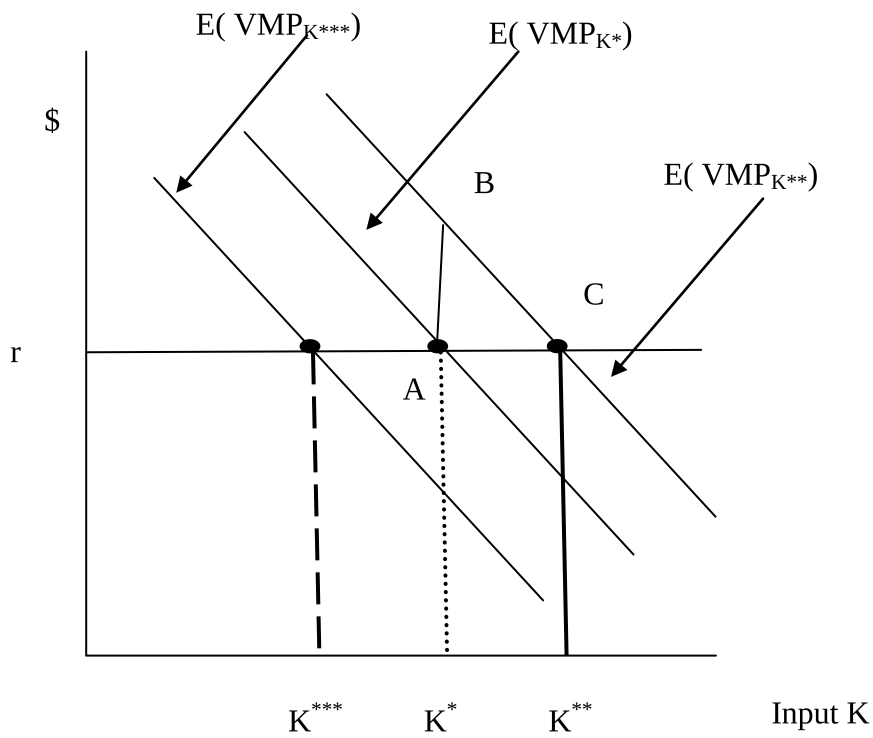

Figure 2.4 Determination of optimal level of geospatial input use (K) in a risky environment for various types of input.

2.3 Conclusion

In this chapter, I introduced uncertainty into the C+NVC model using an expected utility maximization approach. I also assumed that fire managers maximize expected utility of the negative of C+NVC rather than using the traditional approach of minimizing the expected sum of costs plus losses. Assuming that fire managers are risk averse and geospatial tools help reduce risk, the model predicts that geospatial tools will be used to a greater degree as managers become more risk averse.

These findings have two very important and practical implications for assessing the optimal use of geospatial tools. The first is that fire agencies need to collect better data to be able to determine how geospatial tools affect the risk of fire loss. Given the improved ability to identify and protect highly-valued assets, these tools are also risk reducing. The question is, by how much. The second implication is of the need to elicit the risk aversion of decision-makers. If fire managers are risk averse, it is important to understand the level and the extent to which they are willing to give up resources in order to reduce the risk of fire damage. One would assume that high cost outcomes, i.e. "disasters", would weigh heavily on the minds of decision-makers who often face ex-post public scrutiny of their actions. The degree to which they are willing to incur costs to avoid negative outcomes will be an important factor in the demand for risk-reducing inputs.

Casting the demand for geospatial tools within an inherently risky environment should help optimize the use of these tools. In particular the theoretical model clearly identifies the need to collect data about the efficacy of geospatial tools in reducing risk as well as the need to elicit the risk preferences of decision-makers. Unfortunately, historical data pertaining to fire suppression in Saskatchewan was not collected in such a way as to empirically examine risk reduction and risk preferences. By developing the theoretical model and identifying the need to collect this data, perhaps future studies can examine these important aspects of fire management.

CHAPTER 3

EMPIRICAL MODEL TO ESTIMATE THE VALUE OF GEOSPATIAL TOOLS IN WILDFIRE SUPPRESSION

3.0 Introduction

Information availability through the use of geospatial technologies and remote sensing plays a crucial role in preventing losses and saving costs during fire suppression. In addition, the information could help to facilitate evacuation and to save lives. In general, geospatial tools help to coordinate almost all firefighting activities. The main use of geospatial technologies in fire suppression is to provide more accurate information so that more informed decisions can be made to help suppress forest fires. The provision of information to managers does affect fire management resulting in different decisions as compared to when information is not available. I analyze how information provided through the use of geospatial technologies affects area burned, suppression cost and fire damages. The conventional approach is to estimate costs avoided and/or savings by making better-informed decisions.

Economic efficiency of forest fire suppression efforts requires that the marginal value of resources protected or saved from being burned is equal to the marginal cost of suppression. The cost of suppression expenditures, both using geospatial technologies and not, is compared to estimate the effect of the technology. Similarly, the comparison of losses for fires that employed geospatial technologies versus those that did not would also provide an estimate of savings attributable to the technology. The estimate of costs and loss savings is the value of geospatial technologies. In general, use of geospatial technologies is warranted if resource values saved due to the use of geospatial technologies are greater than the expenditure on the use of such technologies.

This chapter explains my data collection techniques and my estimates of the value of geospatial technologies used in Saskatchewan for fires greater than 10 hectares that occurred from 2001-2004. I provide a summary of the data, how they were collected, my statistical techniques and my findings.

3.1 Data and Empirical Approach

In the province of Saskatchewan, a total of 2,708 fires ignited from 2001 to 2004. The Fire Management and Forest Protection Branch (FM&FP) of Saskatchewan Environment (SE) records fire information in the Daily Forest Fire Situation Reports for fires equal to or greater than 10 hectares in size (Class D-G).[5] Reports provide general fire characteristics including fire code, name, and location, zone, discovery date, estimated total area burned (ha), status, cause of fire, resources and technology used. Data for each forest fire are identified by a unique code. Because daily reports are collected until a fire is extinguished, there are often several reports for each fire.

I also examined daily and yearly data for climatic, topographic and geographic characteristics such as temperature, relative humidity, wind speed, wind gusts, longitude and latitude for each fire. Unfortunately, daily records were not in a digital format before 2004. Paper records were photocopied and data transferred to a spreadsheet to complete the database. It is important to note there are many incomplete records. Additionally, digital and paper records of expenditures on labor and capital equipment such as helicopters, aircraft, and ground resources were also obtained from FM&FP for each fire. Ultimately, my database consisted of 535 fires greater or equal to 10 hectares that

[5] Fires in Canada are divided into eight size classes represented by single characters-A (up to 0.1 ha), B (0.11-1.0 ha), C (1.1-10 ha), D (10.1-100 ha), E (100.1-1000 ha), F (1000.1-1000 ha), G (10000.1-100000 ha) and H (over 100000 ha).

occurred between 2001 and 2004. Furthermore, consistent data on cost and expenditures on each fire were available for only 234 fires.

Forest Management and Forest Protection (FM&FP) branch of Saskatchewan Environment estimates total market losses from fire by multiplying the volume of timber per ha (in cubic meters) for various classes of forests by the historical market value to determine relative market value per cubic meter for each forest class. To estimate the value of timber damage, I overlaid fire locations on forest inventory maps. Additionally, because Saskatchewan's commercial forests are divided into different forest management areas (FMAs), it is possible to estimate the types of products produced in each area. Because not all fires are in the commercial timber area and no account of non-market values is considered, I have many zero observations, which are legitimate values.

Saskatchewan is divided into discreet zones based on firefighting strategies as shown in figure 3.1. For my research I focused on the Full Response Zone, the Modified Response Zone and the Observation Response Zone.

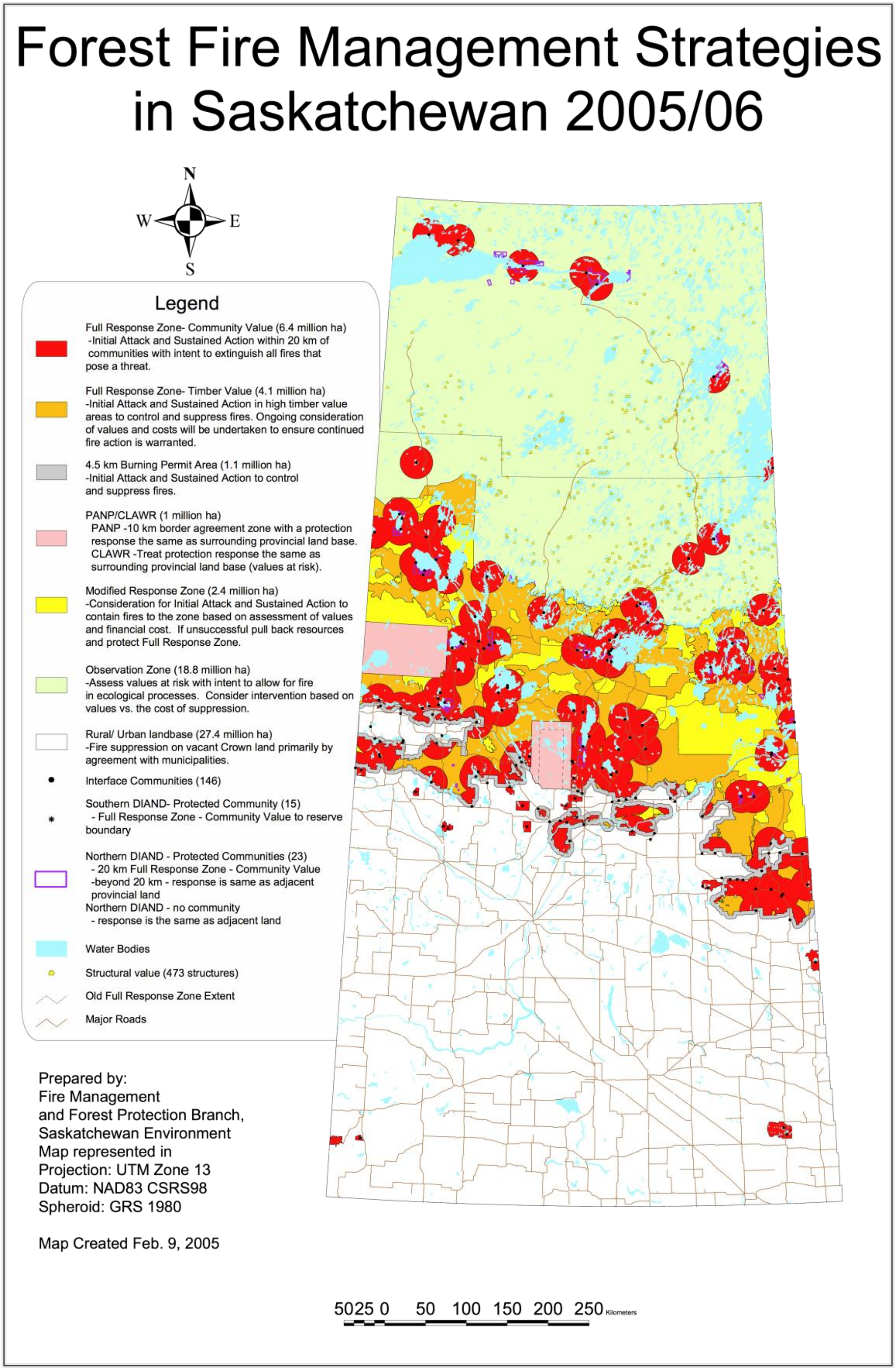

Figure 3.1: Forest Fire Management Strategies in Saskatchewan 2005/06.

3.1.1 Data Explanation and Descriptive Statistics

Data used in this analysis are described and summary statistics are provided in table 3.1. Also, it is important to note that while to this point I have used the term "geospatial technology" I will now refer to technology as "map". While I was interested in estimating the value and effectiveness of a range of geospatial technologies, the reports do not differentiate between technologies. Rather, the reports record whether a map was used or not. Therefore, I analyze the impact of map use on wildfire size, damages and cost of suppression.

Out of 234 fires selected for the analysis, the mean value of map measured as a categorical variable (0 when not used compared to 1 when used) was 0.82, which indicated that more fires used geospatial support than did not. The fire environment affects fire size, costs and damages and is included through variables describing weather, fuel and topography (Countryman 2004). Fire weather is explained by the changes in temperature, relative humidity, wind speed and precipitation as each effect fuel moisture. Weather data such as temperature (degrees Celsius), relative humidity (%), wind speed (KM/hr) and precipitation (mm) were obtained for each fire for every day burned. These weather variables were averaged for the duration of the fire to come up with a single figure for each fire.

Table 3.1. Summary statistics of variables used in regression estimations (2001-2004)

Variable	Description	Units	Expected effect on fire size (HA)	Expected effect on damages/ losses ($)	Expected effect on cost of suppression ($)	N	Mean	Standard Deviations
Map Provided	Digitized map used: 1– yes, 0-no	0,1	-	-	-	234	0.82	0.39
Temperature	Average temperature over the duration of the fire	Degree Celsius	+	+	+	226	22.24	5.82
Relative Humidity	Relative Humidity - Ratio of the amount of moisture in the air to the amount that the air could hold at the same temperature if it were saturated	%	–	–	–	226	43.26	14.60
Wind Speed	Wind speed - Horizontal movement of the air relative to the earth's surface caused by temperature differences	Km/hr	+	+	+	226	13.02	7.04
Precipitation	Amount of rain	mm	-	-	-	226	1.26	3.21
Fine Fuel Moisture Code	A numerical rating of the moisture content of litter and other fine fuels. The code is an indicator of the relative ease of ignition and flammability of fine fuel.	Unit Less	+	+	+	226	85.15	10.46
Duff Moisture Code	A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. The code gives an indication of fuel consumption in moderate duff layers and medium-sized woody material	Unit Less	+	+	+	226	50.25	26.24
Drought Code	A numerical rating of the fuel moisture content of deep, compacted organic matter	Unit Less	+	+	+	226	332.05	111.28
Drought Code (Lagged)	A numerical rating of the fuel moisture content of deep compacted organic matter lagged one year	Unit Less	+	+	+	225	332.30	111.45

Table 3.1. Continued

Initial Spread Index (ISI)	A numerical rating of the expected rate of fire spread. Combines the effects of wind and the FFMC on rate of spread without the influence of variable quantities of fuel	Unit Less	+	+	+	226	7.92	7.18
Build up Index (BUI)	A measure of the amount of fuel available to the spreading fire.	Unit Less	+	+	+	226	70.01	30.52
Fire Weather Index (FWI)	Numerical rating of fire intensity - combines the ISI and BUI	Unit Less	+	+	+	226	20.29	14.61
Head Fire Intensity (HFI)	The frontal fire intensity expressed as energy released per unit length of fire front	kW/m	+	+	+	231	11869.09	12894.97
Total number of firefighters	Personnel used for each fire	#	_	_	+	229	447.06	1197.60
Lightning as cause of fire	Lightning as a fire cause: 1 – yes, 0 – no	0,1	?	?	?	234	0.85	0.36
Aircraft used	Aircraft used on a fire: 1 – yes, 0 – no	0,1	_	_	+	229	0.07	0.26
Helicopter used	Helicopter used on fire: 1 – yes, 0 - no	0,1	_	_	+	229	0.04	0.20
Pump Trailer used	Pump trailer used on fire: 1 – yes, 0 – no	0,1	_	_	+	229	0.10	0.31
Fire in the Full Response Zone	Fire in Full Response Zone: 1 – yes, 0 – no	0,1	+	+	+	234	0.39	0.49
Fire in the Modified Response Zone	Fire in Modified Response Zone:1 – yes, 0 – no	0,1	+	+	+	234	0.34	0.48
Interaction of Full Response Zone and Map	Interaction term	0,1	_	_	_	234	0.27	0.44

Table 3.1. Continued

Interaction of Modified Response Zone and Map	Interaction term	0,1	_	_	_	234	0.30	0.46
Interaction of helicopter cost and Map	Interaction term	CAN$	_	_	_	125	76154.19	220517.00
Interaction of aircraft cost and Map	Interaction term	CAN$	_	_	_	164	54620.43	241504.00
Distance to nearest community	Distance (in kilometers) from the fire's centre to the nearest community	KM	_	+	+	234	60.22	42.68
Labour expenditure	Personnel cost on a fire	CAN$	_	_	+	155	113941.87	248623.00
Helicopter expenditure	Cost of helicopter use on a fire	CAN$	_	_	+	113	1155550.00	258603.00
Aircraft expenditure	Cost of aircraft use on a fire	CAN$	_	_	+	149	64790.82	252602.00
Size of fire	Total area burned by fire	Hectare		+	+	234	5853.40	14382.15
Cost of fire suppression	Total suppression expenditure	CAN$	_	_		228	356800.00	1003280.00
Timber losses (Max)		CAN$				234	6463000.00	34488000.00
Timber Losses (Min)		CAN$				234	4549700.00	24145100.00

Wildfires losses are estimated both through area burned (hectares) and damages ($). The mean value of area burned in Saskatchewan for the data set in 2001-2004 was 5,853 hectares. On average, fires in Saskatchewan burned timber worth approximately $6.5-4.5 million when maximum and minimum amounts for each type of timber are considered for the period between 2001 and 2004 for my data set. Suppression costs averaged $ 356,800/fire over the study period for the data set chosen.

In Canada, the Fire Behavior Prediction (FBP) system divides the fuel types into five major groups composing a total of 16 discrete fuel types (Pyne et al. 1996). I did not use these fuel types in my analysis as they would have consumed too many degrees of freedom. To account for the fuel effects on wildfire size, damages and costs of suppression, I used fuel moisture codes (the fine fuel moisture code, the duff moisture code and the drought code) explained in the Canadian Fire Weather Index (FWI) system. The average index values for the fuel moisture codes were 85.15, 50.25 and 332.05 respectively (Table 3.1). A fine fuel moisture code value of 85.15 indicates a moderate level of ignition danger of the fine fuels. Similarly, a duff moisture code (50.25) and a drought code (332.05) indicate a high danger of ignition and flammability of moderate and deep organic layers.

The location of a fire can also be an important variable determining the cost, damages and area burned by a fire. Also, the location of a fire relative to a population centers can have an influence on decision-making regarding suppression expenditures (Lankoande and Yoder 2006). Wildfires closer to population centers often use more resources to protect lives and properties. On average, fires burned at a distance of 60.22 km from communities in Saskatchewan in the years from 2001 to 2004 for the data set chosen for this study. I obtained access to geospatial images produced at FM&FP to calculate distances of some of the important values at risk, including distance to communities and distance to fire bases. I also accounted for expenditures on resources, such as labor, aircraft and helicopter. In Saskatchewan, the average cost of labor, helicopter and aircraft use has been $113,000, $1 million and $64,791 respectively for the period from 2001-2004 for the data chosen for this study.

Financial reports for each fire included data on resources used for a fire. I used rent for helicopters and aircraft, as well as the number and cost of personnel used on a fire. Additionally, individual fire reports provided information about map requirements and whether the department provided maps. Out of 234 fires, 191 fires used maps generated by geospatial technologies compared to 43 fires that did not use maps. Unfortunately, detailed information was not available regarding the type of maps, the geospatial technologies used, or fixed and variable costs.

To analyze the impact of maps generated through geospatial tools on wildfire size, damages and cost of suppression, I first describe means of wildfire size, damages and cost of suppression with and without map use. I also use an econometric approach to estimate area burned, damages and cost functions to evaluate the impact of a range of variables including map use.

I estimate damages in terms of general wildfire area burned as well as commercial area burned. In previous research (Hesseln et al. 2009), area burned in hectares has been considered as a proxy for damages as there are no reliable market or non-market data available that fully capture damages. The value of commercial timber burned may be a good estimate but it is also based on the type and age of the forest and an approximate historical market value. I assume that area burned is affected by resources used such as helicopters, labor, map use, and physical and climatic characteristics. I also control for fire management zones as the extent of damages often depends on location. For example, the Full Response Zone has high values related to human and economic resources, which require a quick protection response in the event of a wildfire. The Modified Response Zone also have high values, but when a fire is burning in the Full Response Zone, it is possible that resources could be diverted to a higher-valued zone. There are no high values in the Observation Response Zone and most often fires are merely observed.

I specify my damage function as follows:

$$D_j = D(k_{ij}\ , l_{ij}, \alpha_{ij}, R_j, Z_j, M_{ij}) \tag{3.1}$$

where D represents damage either in hectares burned or commercial timber losses ($) associated with fire j (where j=1,2, …,k).

k_{ij} is the capital resource i (where i = 1,2, …,n) used for fire j such as helicopters, tankers, etc.

l_{ij} is the labor i used for fire j

α_{ij} represents the climatic condition i for fire j such as temp, wind speed, humidity, etc.

R_{ij} shows the physical characteristics i for fire j such as topography, elevation

Z_{ij}, represents a dummy to indicate a zone i in which the fire j is burning

M_{ij} is a dummy variable for map i used for fire j

I expect that damages are a decreasing function of the resources used. Damages are also assumed to be positively related to the temperature and wind speed because temperature during a fire has the propensity to increase both the intensity and rate of spread. Similarly, wind speed is a major factor in the spread of fire. I expect that relative humidity (RH) will affect damages negatively because as RH increases, fuel moisture contents rise, reducing the risk of further ignition. When a map is used, I expect the fire damages to be less as compared to not using a map. Finally, damages in terms of dollars are expected to be more in the Full Response Zone compared to other zones, given the higher values at risk.

The cost function is usually specified in terms of wages and rents for the resources used on wildfires, along with other physical and climatic characteristics. I specify a dual cost function in terms of prices and wages as follows:

$$TC_j = C(w_j, r_{ij}, g_j, \alpha_{ij}, R_j, Z_j,) \qquad (3.2)$$

Where TC represents total cost of suppression ($) associated with fire j (where j=1,2, …,k)

w_{ij} is the wage for labor i (where i = 1,2, …,n) used on a fire j

r_{ij} is the rent of capital resource i (where i = 1,2, …,n) used on fire j excluding geospatial technologies

g_{ij}, is the rent for a map i used on fire j

α_{ij}, R_j , Z_j,,are defined same as earlier for equation 3.1

As wages and rents are usually fixed or predetermined and there is no variability in them, and as there is no market for map use in wildland fires, similar to the damage function, I specify the cost function as a function of resources such as helicopters, labor, map use, and physical and climatic characteristics given as follows:

$$TC = C((k_{ij} , l_{ij}, \alpha_{ij}, R_j, Z_j, M_{ij}) \qquad (3.3)$$

Variables in the cost function in (3.3) are the same as those explained for the damage function. Similar to the damage function, I control for various zones. I expect that a fire agency will spend more on fires that are burning in the Full Response Zones as compared to other zones given higher values at risk. Also, I hypothesize that, when maps are used, they reduce the cost of suppression by allocating resources more efficiently.

3.2 Results and Discussion

3.2.1 General Fire Characteristics

First, I examine whether there is a difference in average fire size, suppression costs and timber losses when maps are used in suppression operations as compared to when they are not used. Table 3.2 reports mean and standard deviation for fire size, suppression costs and timber losses with and without using maps for fire suppression. Of the 234 fires in the data set, there were 191 fires that reported using maps during a suppression event. Fire size for operations that used geospatial tools was 4,787 ha on average as compared to 10,589 ha for operations that did not employ maps. Table 3.2 also indicates that, on average, fires where maps were used were smaller.

Table 3.2. Fire Size, suppression costs and timber losses by map use on fires in Saskatchewan (2001-2004)

Variable	Map Used	Observations	Mean	Standard Deviation
Fire size (hectares)	Yes	191	4,787.07	8,797.35
	No	43	10,589.92	27,735.40
Market losses due to fire to timber area (hectares)	Yes	190	306.75	1,829.01
	No	43	456.31	1,676.77
Minimum market losses due to fire to timber (Can$)	Yes	191	$4,151,300.00	$24,493,900.00
	No	43	$6,319,000.00	$22,719,700.00
Maximum market losses due to fire to timber (Can$)	Yes	191	$5,903,800.00	$35,000,700.00
	No	43	$8,946,900.00	$32,385,900.00
Fire suppression cost (Can$)	Yes	185	$352,380.00	$1,040,800.00
	No	43	$375,810.00	$833,145.00

Source: Author's calculations

The timber damaged in the commercial forest is also presented in Table 3.2. Area burned in the commercial forest is on average 307 ha when maps are provided compared with 456 ha when maps are not provided.

Similarly, I found minimum damages estimated for fires that did not use maps to be $6,319,000 compared to $4,151,300 when maps were used (table 3.2). Finally, maximum damages estimated were $8,946,900 and $5,903,800 respectively (table 3.2). In each case, losses were less if a map was provided. Note that I estimated minimum and maximum damages based on a range of timber market values. Non-market losses could be significant, but data do not exist to make such estimates possible.

Table 3.2 also provides the mean total cost of suppression expenditures by map utilization. Total cost is less on average in absolute terms when a map is provided.

The impact of geospatial tools in determining fire size, damages and suppression costs may not be important as it depends on where the fire is burning and values at risk (VAR). If a fire is burning in an area with low VAR, a fire manager might let a fire burn for beneficial ecological reasons, and, therefore, access to geospatial tools might not be relevant. On the other hand, if a fire were burning in a zone where commercial and social values are relatively high, efforts would be made to control and contain the fire to minimize damage regardless of the availability of geospatial tools. The relationship between fire size and values at risk as they relate to fire management zone will be addressed later.

3.3 Use of Geospatial Technologies by Strategic Zones

I found that in general, average area burned, damage to the commercial forest and suppression expenditures overall are lower for fires that use maps. The results might be misleading in the sense that area burned, damages and suppression costs might not be important factors in areas where there are no values at risk (VAR). In this section I extend the analysis by incorporating fire strategic zones – an important factor that influences how fires are suppressed in Saskatchewan.

Saskatchewan FM&FP has divided the forest into various firefighting zones based on values at risk. I analyzed forest fires in only three zones as the majority of fires burned in those zones: the Full Response Zone, which has more communities and great timber values given a relatively high population, substantial recreation use and values, and the location of the majority of the timber industry; the Modified Response Zone, which is farther north, and, although it is populated and has moderate forest industry activity, values at risk are lower and less concentrated; and the Observation Response Zone, which includes most of northern Saskatchewan where there is no timber industry, and the population is sparse. In this area, fire suppression is used to protect communities and infrastructure such as mines. Non-threatening fires are observed and monitored only. To understand the value of geospatial technology, I now look at the variation in suppression strategies by protection zone.

3.3.1 Area Burned by Fire Management Strategy and Map use on Fires in Saskatchewan (2001-2004)

Area in the Full Response Zone consumed by fires in the years from 2001 to 2004 was larger than the other zones for the same years (table 3.3). The Full Response Zone is a combination of values at risk including commercial timber, communities and other important values such as recreation sites and infrastructure. Larger areas burned in the Full Response Zone could be attributed to the greater availability of fuels, firefighting complexity given the proximity of communities, and an expanding wildland-urban interface. One would have expected areas burned in the Full Response Zone to be smaller given that fires would have been fought more intensely based on higher VAR. Also, areas burned in the Full Response Zone when maps were used appeared to be larger compared to other zones, although this could imply that for larger fires in the Full Response Zone, maps were used in larger numbers.

Table 3.3. Area burned (hectares) by fire management strategy and map use on fires in Saskatchewan (2001-2004)

		Size (ha)		
Protection Zone	Map provided	Mean	N	Std. Deviation
Full Protection Zone – General	No	14311.23	28	33449.23
	Yes	5322.48	58	10742.54
	Total	8249.05	86	21230.57
Modified Response Zone	No	2670.40	10	6774.22
	Yes	4966.95	70	9290.02
	Total	4679.88	80	9010.66
Rural-Urban Zone	No	26498.00	1	-
	Yes	1880.33	3	2300.01
	Total	8034.75	4	12451.27
Observation Response Zone	No	362.48	4	255.61
	Yes	4273.76	59	5988.36
	Total	4025.42	63	5871.49
Full Response Community	Yes	147.10	1	-
	Total	147.10	1	-
Total/Overall	No	10589.92	43	27735.40
	Yes	4787.07	191	8797.35
	Total	5853.40	234	14382.15

Source: Author's calculations

3.3.2 Cost of Fire per Hectare by Fire Management Strategy and Map use on Fires in Saskatchewan (2001-2004)

The average cost of suppression between 2001 and 2004 for fires greater than 10 ha in all zones was $278/ha (table 3.4). When the cost is examined within each zone, the cost per hectare was the highest for fires in the rural-urban zone ($852) followed by the Full Response Zone ($617), Modified Response Zone ($86) and Observation Response Zone ($5). Similarly, I also observed a pattern for the cost per hectare on the basis of VAR when a map was employed compared to no use of maps for fires in different response zones. This suggests that costs were more on average when fires were closer to values at risk.

Table 3.4. Cost of fire per hectare ($) by fire management strategy and map use on fires in Saskatchewan (2001-2004)

Protection Zone	Map provided	Cost of Fire per Hectare ($)		
		Mean	N	Std. Deviation
Full Protection Zone - General	No	431	28	652
	Yes	707	58	767
	Total	617	86	739
Modified Response Zone	No	165	10	264
	Yes	74	64	266
	Total	86	74	266
Rural-Urban Zone	No	85	1	-
	Yes	1108	3	1661
	Total	852	4	1449
Observation Response Zone	No	26	4	31
	Yes	4	59	10
	Total	5	63	13
Full Response Community	Yes	110	1	-
	Total	110	1	-
Total/Overall	No	323	13	558
	Yes	267	185	587
	Total	278	228	581

Source: Author's calculations

3.3.3 Maximum Damage by Fire Management Strategy and Map use on Fires in Saskatchewan (2001-2004)

Maximum average damage caused by fires over the period 2001-2004 was $6.5 million (table 3.5). As expected, most of the damage occurred in the Full Response Zone with negligible damage in other zones. Most damage estimates are, at best, just estimates. Damages in absolute terms also seem to be relatively high for the Full Response Zone as compared to other zones.

Table 3.5. Maximum damages ($) by fire management strategy and map use on fires in Saskatchewan (2001-2004)

Protection Zone	Map provided	Maximum Damages ($) Mean	N	Std. Deviation
Full Protection Zone - General	No	13702168.73	28	39550976.85
	Yes	19440730.73	58	61771419.30
	Total	17572361.71	86	55344141.00
Modified Response Zone	No	105425.62	10	293607.61
	Yes	0.00	70	0.00
	Total	13178.20	80	105128.09
Rural-Urban Zone	No	0.00	1	-
	Yes	0.00	3	0.00
	Total	0.00	4	0.00
Observation Response Zone	No	0.00	4	0.00
	Yes	0.00	59	0.00
	Total	0.00	63	0.00
Full Response Community	Yes	66535.60	1	-
	Total	66535.60	1	-
Total/Overall	No	8946860.02	43	32385855.85
	Yes	5903816.32	191	35000653.90
	Total	6463008.11	234	34487986.64

Source: Author’s calculations

To determine if there is a difference in per hectare damage by strategic zones and map use, I show the interaction of map use and protection zones and the impact on damages per hectare in table (3.6). It is evident that per hectare damages are far greater in the Full Response

Zone as compared to any other protection zone. This is in line with my expectations given that there are higher values at risk such as commercial timber and other infrastructure in the Full Response Zone. However, the values in the following tables capture damages caused only to commercial timber.

Table 3.6. Maximum per hectare damages ($) by fire management strategy and map use on fires in Saskatchewan (2001-2004)

Protection Zone	Map provided	Maximum Per Hectare Damages ($) Mean	N	Std. Deviation
Full Protection Zone - General	No	2416.1576	28	4310.17655
	Yes	2704.5474	58	3981.12817
	Total	2610.6531	86	4067.92485
Modified Response Zone	No	674.0122	10	1431.40020
	Yes	0.00	70	0.00
	Total	84.2515	80	532.66963
Rural-Urban Zone	No	0.00	1	-
	Yes	0.00	3	0.00
	Total	0.00	4	0.00
Observation Response Zone	No	0.00	4	0.00
	Yes	0.00	59	0.00
	Total	0.00	63	0.00
Full Response Community	Yes	452.3154	1	-
	Total	452.3154	1	-
Total/Overall	No	1730.0590	43	3649.31270
	Yes	823.6443	191	2511.33463
	Total	990.2077	234	2768.97505

Source: Author’s calculations

Forest fire is a complex phenomenon, and there are many variables that affect the behaviour of forest fires. Analysis describing the relationship of map use with the fire size, cost and damages for various fire strategy zones has limited application and might lead to misleading conclusions. Therefore, it is important to control for the multitude of factors that affect the fire. I use more rigorous econometrics methods in the next section to control for those factors.

3.4 Econometric Results

In this section, I examine the effectiveness of map use in reducing fire size, cost of fire suppression and damages using the data set explained in section 3.1.1. Given that I was unable to assess wages by personnel category, rent to capital based on hourly production, usage of geospatial tools by type, equipment numbers used for each fire and fire managers' risk behavior, I estimated the effect of map provision using an econometric model specified in section 3.1 rather than the model specified in the theoretical section.

Wildfire economics models often exhibit endogeneity due to simultaneous relationships, selection bias and the omission of relevant variables (Butry 2006, and Lankoande and Yoder 2006). Simultaneity problems arise when fire size, suppression costs and damages are jointly determined. Also, another source of endogeneity can be reverse causality, such as whether fire size influences the decision of suppression resource use or suppression resources affect fire size. Using ordinary least squares (OLS) when an endogeneity is present causes the estimates to be biased and inconsistent (Butry 2006; Green 2003; and Lankoande and Yoder 2006).

Lankoande and Yoder (2006) found that suppression tends to reduce damages but suppression efforts also tend to be higher for larger and more damaging fires. They concluded that, since wildfire area burned, suppression expenditures and damages are jointly determined, it is better and more appropriate to use a simultaneous equations system. Following the approach in Lankoande and Yoder 2006, I specify my estimated structural equation model as follows:

$$\begin{aligned}\text{SIZE (g)} = {} & \alpha_{g1} + \gamma_{g1}\text{FINALCOST} + \beta_{g1}\text{MAPPROVIDED} + \beta_{g2}\text{WEATHERFFMC} \\ & + \beta_{g3}\text{WEATHERDMC} + \beta_{g4}\text{WEATHERDC} + \beta_{g5}\text{HFI} \\ & + \beta_{g6}\text{TOTNUMFF} + \beta_{g7}\text{ DUM215AIRCARFT} \\ & + \beta_{g8}\text{DUMHELICOPTER} + \beta_{g9}\text{DUMFULLRZ} \\ & + \beta_{g10}\text{DUMMODIFRZ} + \beta_{g11}\text{INTERDFULLMAP} \\ & + \beta_{g12}\text{INTERDMODMAP} + \beta_{g13}\text{YEAR02} + \beta_{g14}\text{YEAR03} \\ & + \beta_{g15}\text{YEAR04} + \epsilon_g\end{aligned} \tag{3.4}$$

$$\begin{aligned}\text{FINALCOST(c)} & \\ = {} & \alpha_{c1} + \gamma_{c1}\text{SIZE} + \beta_{c1}\text{MAPPROVIDED} + \beta_{c2}\text{TEMP} + \beta_{c3}\text{WSPD} \\ & + \beta_{c4}\text{RH} + \beta_{c5}\text{RN24} + \beta_{c6}\text{WEATHERDC} \\ & + \beta_{c7}\text{HFI} + \beta_{c8}\text{TOTNUMFF} + \beta_{c9}\text{ DUM215AIRCARFT} \\ & + \beta_{c10}\text{DUMHELICOPTER} + \beta_{c11}\text{COMMDIST} + \beta_{c12}\text{DUMFULLRZ} \\ & + \beta_{c13}\text{DUMMODIFRZ} + \beta_{c14}\text{INTERDFULLMAP} \\ & + \beta_{c15}\text{INTERDMODMAP} + \beta_{c16}\text{YEAR02} + \beta_{c17}\text{YEAR03} \\ & + \beta_{c18}\text{YEAR04} + \epsilon_c\end{aligned} \tag{3.5}$$

$$
\begin{aligned}
\text{MKT\_LOMA(d)} \\
&= \alpha_{d1} + \gamma_{d1}\text{SIZE} + \gamma_{d2}\text{FINALCOST} + \beta_{d1}\text{MAPPROVIDED} \\
&+ \beta_{d2}\text{TEMP} + \beta_{d3}\text{WSPD} + \beta_{d4}\text{RH} + \beta_{d5}\text{RN24} + \beta_{d6}\text{TOTNUMFF} \\
&+ \beta_{d7}\ \text{DUM215AIRCARFT} + \beta_{d8}\text{DUMHELICOPTER} \\
&+ \beta_{d9}\text{COMMDIST} + \beta_{d10}\text{DUMFULLRZ} + \beta_{d11}\text{DUMMODIFRZ} \\
&+ \beta_{d12}\text{INTERDFULLMAP} + \beta_{d13}\text{INTERDMODMAP} \\
&+ \beta_{d14}\text{YEAR02} + \beta_{d15}\text{YEAR03} + \beta_{d16}\text{YEAR04} + \epsilon_{d}
\end{aligned}
\tag{3.6}
$$

In equation 3.4, fire size is modeled as a function of map (0,1), fine fuel moisture code, duff moisture code, drought code, head fire intensity, cost of fire suppression, total number of fire fighters, aircraft (0,1), helicopter (0,1), fire in the Full Response Zone (0,1), fire in the Modified Response Zone (0,1), interaction of Full Response Zone and map (0,1), interaction of Modified Response Zone and map (0,1), and year 02 (0,1), year 03 (0,1), year 04 (0,1) respectively. Similarly, suppression cost is assumed to be related to size of fire, map (0,1), temperature, wind speed, relative humidity, precipitation, drought code, head fire intensity, total number of fire fighters, aircraft (0,1), helicopter (0,1), distance to nearest community, fire in the Full Response Zone (0,1), fire in the Modified Response Zone (0,1), interaction of Full Response Zone and map (0,1), interaction of Modified Response Zone and map (0,1), and year 02 (0,1), year 03 (0,1), year 04 (0,1) as shown in equation 3.5. Finally, losses measured as maximum value of the merchantable timber dollars lost is shown as a function of fire size, cost of fire suppression, map (0,1), temperature, wind speed, relative humidity, precipitation, total number of fire fighters, aircraft (0,1), helicopter (0,1), distance to nearest community, fire in the Full Response Zone (0,1), fire in the Modified Response Zone (0,1), interaction of Full Response

Zone and map (0,1), interaction of Modified Response Zone and map (0,1), and year 02 (0,1), year 03 (0,1), year 04 (0,1) respectively. While the simultaneous equation system (equations 3.4, 3.5 and 3.6) can be estimated through OLS, results will yield inconsistent parameter estimates.

3.4.1 Endogeneity in Forest Fires

Endogenous variables in the structural model (3.4-3.6) are size of fires, suppression costs and losses. Exogenous variables that are predetermined outside the model include all other variables. I used a rank condition (Maddala 1992) for identification of the equations in the system, which is both necessary and sufficient for identification, and found them to be identified and thus can be estimated. Since the model specified in the system of equations has endogeneity and simultaneity, I can estimate the parameters of the model using ordinary least squares (OLS) with bias, two-stage least squares (2SLS), and three-stage least squares (3SLS) resulting in more consistent and unbiased results.

Two-stage least squares (2SLS) and three-stage least squares (3SLS) estimation methods are essentially instrumental variables (IV) approaches. Suppose I write the system of equation (3.4-3.6) in matrix form:

$$\mathrm{A}y + \Gamma \mathrm{x} = \mu \tag{3.7}$$

where all the endogenous and exogenous variables are moved to the left hand side. Equation 3.7 is solved for y, as follows to create equation 3.8, the reduced form equation:

$$y = -A^{-1}\Gamma \mathrm{x} + A^{-1}\,\mu \tag{3.8}$$

$$y = \Pi \mathrm{x} + \nu \tag{3.9}$$

where $-A^{-1}\Gamma = \Pi$ and $\nu = A^{-1}\,\mu$

Some of the independent variables such as suppression cost for fire size estimation, fire size for suppression cost estimation and fire size and suppression cost for loss estimation are independent variables and at the same time are dependent variables in alternate equations and are no longer uncorrelated with the error term of such equations. Also, the error terms of each equation may be contemporaneously correlated (across equations as well). Direct application of OLS to each equation in the system may result in estimates that are biased and inconsistent, even for very large sample sizes (Heck 1977).

3.4.2. Two-Stage Least Squares

The equation-by-equation estimation of the system of equations (3.4-3.6) yields:

$$b_{ols} = (X'X)^{-1}X'y \tag{3.10}$$

where X is a matrix of variables, which contains both exogenous and endogenous variables, and y is the dependent variable. Green (2003) showed that OLS introduces the simultaneous equation bias and results in inconsistent estimates. The estimators represented by the matrix b_{ols} are biased as well since E(ϵ /X) ≠ 0 because matrix X contains endogenous variables as well. Furthermore, the OLS method estimates the above system of equations one equation at a time and therefore neglects the information contained in other equations in the system as well.

In the presence of simultaneity, using the instrumental variables (IV) estimation method is appropriate. Two-stage least squares (2SLS) is the most commonly-used method for the simultaneous equation models (Green 2003), which estimates the system of equations in two stages. In stage 1, all the exogenous variables in the model serve as instruments, and we get the predicted values of the endogenous variables by regressing the endogenous variables on all the exogenous variables in the system (Green 2003; Hayashi 2000). In the second stage of 2SLS, estimates of the parameters are computed by the least squares regression of the dependent variables on the predicted values of the endogenous variables computed in stage 1 and all other exogenous variables. Two-stage least squares (2SLS) produces consistent and efficient results compared to OLS.

The predicted variables of the endogenous variables estimated in the first stage meet all the properties of good instruments, such as no correlation with the error terms and high correlation with the variables for which they are used as instruments. In the first stage of 2SLS, since the exogenous variables are uncorrelated with the error term, the predicted values obtained for the endogenous variables by regressing them on exogenous variables will also be uncorrelated with the error term.

Finally, we obtain the 2SLS parameters by:

$$b_{2sls} = (Y'Y)^{-1}Y'y \tag{3.11}$$

where Y contains predicted values of the endogenous variables as instruments and all other exogenous variables in the system. Furthermore, in the presence of the contemporaneous correlation between the error terms in the equation system, the three-stage least squares (3SLS) estimation method is more efficient. The third stage entails simultaneous solutions of all the equations, incorporating the additional information on the error term correlations (Heck 1977). In table 3.7, 3.8 and 3.9, results from the ordinary least squares estimation (OLS), the two-stage least squares (2SLS) and the three-stage least squares estimation (3SLS) methods are presented.

The three-stage least squares (3SLS) method provides results that are more efficient than both OLS and 2SLS.

3.4.3 Estimation of Fire Losses in Terms of Area Burned

Sparhawk (1925) divided the factors that affect area burned into inflammability factors (fuel cover, weather and topography) and controllability factors (men and equipment used and accessibility to a fire from time of its detection to the arrival of crew). Others such as Martell (2001), Lankoande and Yoder (2006), Butry (2006), and Hesseln et al. (2009) used a range of indicators including weather factors - drought index, wind speed, relative humidity; cause of fire; fuel type; and type and number of resources used. In Saskatchewan, there are only small variations in topographic characteristics, therefore, I did not use these in my regressions. While there are twelve fuel type classifications in Saskatchewan, I chose not to use this measure because it would have restricted the degrees of freedom. Fuel condition and type is captured through various indices used in Canadian Wildland Fire System in the regression estimations.

The results in table 3.7 present the estimation of fire size through OLS, 2SLS and 3SLS methods. Results in table 3.7 illustrate that when a map is provided by itself, in all the estimation methods (OLS, 2SLS and 3SLS) map does not seem to be a determinant of fire size. Fuel moisture codes have the correct directional relationship with fire size, and the duff moisture code and the drought code are statistically significant. The negative relationship of the drought index of the concurrent year with the fire size in this study is consistent with the findings in Lankoande and Yoder (2006) and Swetnam and Betancourt (1998).

The positive relationship between the cost of suppression and fire size as exhibited in table 3.7 for the OLS model is an anomaly given that fire size is expected to decrease as the suppression efforts/cost increases. This relationship between suppression cost and fire size is reversed in the 2SLS and 3SLS methods but is still not statistically significant. An important finding is the negative relationship, also significant, of the interaction term of the Full Response Zone and map with fire size. It can be argued that maps, when used in the Full Response Zone, will help to restrict fires to smaller sizes. I also adjusted for variations in fire size by year by incorporating dummy variables for the years.

The results in table 3.7 indicate that 22% of the variations in fire size are explained by the explanatory variables in the model, which is although low, is not uncommon for forest fire size estimations (Hesseln et al. (2009) found adjusted R-squared to be only 13% for their model). The Durban-Watson test statistic value of approximately 2 indicates that the model does not have serial correlation (Gujarati 2003). However, most fires are different resulting in heteroscedasticity. Therefore, results in table 3.7 are also corrected for heteroscedasticity using White's consistent covariance matrix estimation method (Gujarati 2003).

Table 3.7. Estimation of fire size in hectares by individual fires in Saskatchewan (2001-2004)

	OLS Regression estimation of fire size			2SLS Regression estimation of fire size			3SLS Regression estimation of fire size		
Variable	Estimate	Std. Error	t-Stat	Estimate	Std. Error	t-Stat	Estimate	Std. Error	t-Stat
Constant	-5,675.60	15,570.27	-0.36	-7,344.39	16,867.02	-0.44	-6,613.03	16,169.79	-0.41
Map Provided (0,1)	3,425.37	7,146.75	0.48	4,285.19	7,874.02	0.54	4,117.50	7,554.43	0.55
Fine Fuel Moisture Code	103.25	114.36	0.90	98.83	116.53	0.85	93.22	111.70	0.83
Duff Moisture Code	155.99	44.78	3.48	164.46	54.87	3.00	164.43	52.66	3.12
Drought Code	-36.01	11.20	-3.21	-35.58	11.42	-3.12	-35.72	10.96	-3.26
Head Fire Intensity (HFI)	-0.03	0.09	-0.35	-0.03	0.09	-0.29	-0.03	0.09	-0.29
Cost of fire suppression	0.00	0.00	0.41	-0.01	0.03	-0.21	-0.00	0.02	-0.17
Total number of Fire Fighters	3.24	2.91	1.11	8.39	19.16	0.44	7.46	18.36	0.41
Aircraft (0,1)	-1,126.80	3,844.10	-0.29	-1,992.89	5,018.60	-0.40	-1,841.61	4,813.75	-0.38
Helicopter (0,1)	-12,159.51	5,691.84	-2.14	-8,663.59	14,078.15	-0.62	-9,296.22	13,495.03	-0.69
Fire in the Full Response Zone (0,1)	14,747.15	12,540.43	1.18	16,336.06	13,937.57	1.17	16,079.14	13,372.53	1.20
Fire in the Modified Response Zone (0,1)	3,827.11	12,316.18	0.31	5,241.64	13,472.20	0.39	5,009.16	12,926.39	0.39
Interaction of Full Response Zone and Map (0,1)	-17,359.36	7,905.12	-2.20	-18,630.19	9,244.51	-2.02	-18,380.08	8,867.90	-2.07
Interaction of Modified Response Zone and Map (0,1)	-3,721.56	8,639.99	-0.43	-4,491.10	9,165.96	-0.49	-4,345.70	8,794.88	-0.49
YEAR 02 (0,1)	5,756.43	3,146.91	1.83	5,972.58	3,273.39	1.82	5,957.82	3,141.28	1.90
YEAR 03 (0,1)	-707.99	3,668.80	-0.19	-757.41	3,706.53	-0.20	-682.71	3,556.16	-0.19
YEAR 04 (0,1)	318.48	10,196.89	0.03	709.58	10,389.38	0.07	688.52	9,970.15	0.07
Sample Size			215.00			215.00			215.00
R^2			0.23			0.22			0.22
Adjusted R^2			0.17			0.15			0.16
D.W statistic			2.15			2.12			2.13
Mean dependent Variable			6,117.98			6,117.98			6,117.98
S.D. dependent Variable			14,859.32			14,859.32			14,859.32
F-statistic			3.69						

3.4.4 Estimation of Fire Losses in Terms Commercial Timber (Maximum)

Fire loss is estimated through OLS, 2SLS and 3SLS, the results of which are presented in table 3.8. The OLS results indicate that as fire size increases, market losses increase as well. Similarly, the OLS estimation indicates that the use of more personnel is related to higher losses, which is counterintuitive. This is likely due to reverse causality, indicating that the greater the expected damages, the more personnel are employed in a suppression event. After I correct for endogeneity using 2SLS and 3SLS, the total number of personnel used is still positively related to the damages but is not statistically significant.

The insignificant results from the loss equation are likely due to the way the data are gathered, which not only ignores the non-market values but are also based on annual estimates of market values of timber. Losses are merely estimated using the historical market values based on the various types of timber involved. Additionally, data representing losses have large numbers of zeros and are averaged over the various timber types.

Table 3.8. Estimation of market losses (maximum) by individual fire in Saskatchewan (2001-2004)

	OLS Regression estimation of fire losses			2SLS Regression estimation of fire losses			3SLS Regression estimation of fire losses		
Variable	Estimate	Std. Error	t-Stat	Estimate	Std. Error	t-Stat	Estimate	Std. Error	t-Stat
Constant	-28,410,956.00	35,886,469.00	-0.79	-39,945,566.00	42,098,264.00	-0.95	-43,436,230.00	40,068,933.00	-1.08
Size of fire	474.59	163.22	2.91	624.34	759.35	0.82	679.63	722.73	0.94
Cost of fire suppression	-7.43	8.31	-0.89	-51.49	67.89	-0.76	-66.24	63.20	-1.05
Map Provided (0,1)	1,275,221.00	16,730,837.00	0.08	7,371,037.00	20,157,380.00	0.37	9,343,280.00	19,148,116.00	0.49
Temperature	461,893.60	425,903.10	1.08	735,912.70	617,249.00	1.19	817,137.50	583,771.60	1.40
Wind Speed	139,303.00	360,142.40	0.39	80,516.56	422,866.00	0.19	48,476.06	402,463.40	0.12
Relative Humidity	248,383.60	178,833.60	1.39	224,679.80	204,354.50	1.10	216,134.20	194,823.60	1.11
Precipitation	-18,854.70	738,305.00	-0.03	185,490.80	1,080,942.00	0.17	205,121.80	1,031,586.00	0.20
Total number of Firefighters	16,371.85	6,803.35	2.41	49,465.49	50,852.30	0.97	60,504.34	47,351.12	1.28
Aircraft (0,1)	-11,999,225.00	8,986,033.00	-1.34	-17,285,279.00	12,329,945.00	-1.40	-18,929,389.00	11,660,571.00	-1.62
Helicopter (0,1)	2,910,762.00	13,521,032.00	0.22	26,938,264.00	41,340,348.00	0.65	35,193,266.00	38,630,026.00	0.91
Distance to nearest community	-58,964.99	61,866.97	-0.95	-61,348.48	83,656.28	-0.73	-60,603.48	79,865.08	-0.76
Fire in the Full Response Zone (0,1)	5,765,682.00	29,805,532.00	0.19	13,268,635.00	35,394,827.00	0.37	15,950,652.00	33,705,303.00	0.47
Fire in the Modified Response Zone (0,1)	5,805,493.00	28,718,060.00	0.20	12,286,915.00	32,537,695.00	0.38	14,574,624.00	30,991,293.00	0.47

Table 3.8. Continued

Interaction of Full Response Zone and Map (0,1)	2,048,366.00	18,628,060.00	0.11	-4,220,685.00	24,405,760.00	-0.17	-6,440,449.00	23,204,605.00	-0.28
Interaction of Modified Response Zone and Map (0,1)	-1,069,388.00	20,067,883.00	-0.05	-6,414,173.00	23,138,157.00	-0.28	-8,206,618.00	22,021,126.00	-0.37
YEAR 02 (0,1)	5,976,351.00	7,451,992.00	0.80	6,110,322.00	8,372,414.00	0.73	6,024,340.00	7,993,326.00	0.75
YEAR 03 (0,1)	-4,429,077.00	8,760,179.00	-0.51	-7,010,417.00	10,693,327.00	-0.66	-7,904,980.00	10,176,040.00	-0.78
YEAR 04 (0,1)	6,265,570.00	24,218,966.00	0.26	6,278,453.00	26,079,788.00	0.24	6,216,740.00	24,900,449.00	0.25
Sample Size			218.00			215.00			215.00
R^2			0.25			0.14			0.06
Adj R^2			0.18			0.06			-0.03
D.W statistic			1.30			1.31			1.36
Mean dependent var.			6,395,460.00			6,484,699.00			6,484,699.00
S.D. dependent var.			34,947,944.00			35,183,793.00			35,183,793.00
F-statistic			3.61						

3.4.5 Estimation of Fire Suppression Cost

The estimation of fire suppression cost results through OLS, 2SLS and 3SLS are presented in table 3.9. Fire size, although positively related to the cost of suppression, is not statistically significant. Hesseln et al. 2009 found area burned to significantly affect suppression costs, although Gebert et al. 2007 found the natural log of acres burned to be negatively related to the log of suppression costs in the western and eastern United States. Most of the weather variables do not seem to be statistically significant, which could be due to averaging of variables over the duration each fire. It is also evident from the model that as more fire personnel are employed, the greater the cost of suppression, which is consistent with Hesseln et al. 2009. Use of helicopter is also positively related to the cost of suppression and statistically significant. Full and Modified Response Zones without interactions with map are positively related to suppression costs but are not significant. When map and response zone (Full and Modified) are interacted, the model shows a negative, although insignificant, relationship. Hesseln et al. (2009) found the use of geospatial technology as related to suppression cost positively although insignificant.

All the regression estimations in table 3.9 have significant F statistics and the adjusted R-squared values are relatively high indicating a good fit of the data. All models in table 3.9 do not exhibit auto-correlation, which indicates that the error terms are not correlated (the Durban-Watson test statistic is approximately 2). Finally, because of a strong possibility of heteroscedasticity, I used White's test (Gujarati 2003).

Table 3.9. Estimation of the fire cost by individual fire in Saskatchewan (2001-2004)

	OLS Regression estimation of fire cost			2SLS Regression estimation of fire cost			3SLS Regression estimation of fire cost		
Variable	Estimate	Std. Error	t-Stat	Estimate	Std. Error	t-Stat	Estimate	Std. Error	t-Stat
Constant	-338,243.20	323,720.40	-1.04	-341,833.00	332,493.60	-1.03	-368,261.50	315,288.20	-1.17
Size of fire	0.86	1.42	0.61	5.49	6.87	0.80	3.98	6.43	0.62
Map Provided (0,1)	136,268.30	143,064.00	0.95	131,875.50	147,061.70	0.90	132,670.50	140,024.70	0.95
Temperature	4,736.20	3,876.58	1.22	4,966.84	3,995.23	1.24	4,819.71	3,785.52	1.27
Wind Speed	-4,520.88	3,708.04	-1.22	-3,865.69	3,925.24	-0.98	-4,503.64	3,650.34	-1.23
Relative Humidity	138.17	1,664.34	0.08	-260.80	1,804.85	-0.14	224.77	1,688.15	0.13
Precipitation	2,557.13	7,690.55	0.33	5,995.27	9,345.10	0.64	4,303.42	8,826.56	0.49
Drought Code	145.75	210.44	0.69	227.43	246.55	0.92	173.25	223.41	0.78
Head Fire Intensity (HFI)	2.69	2.33	1.16	2.13	2.53	0.84	2.92	2.28	1.28
Total number of Firefighters	751.55	22.73	33.06	730.41	38.59	18.93	738.00	36.22	20.37
Aircraft (0,1)	-100,706.90	77,229.63	-1.30	-103,089.30	79,388.39	-1.30	-101,296.00	75,583.91	-1.34
Helicopter (0,1)	536,901.10	109,966.30	4.88	590,122.70	136,868.40	4.31	570,040.40	129,341.70	4.41
Distance to nearest community	195.51	532.49	0.37	-121.19	714.67	-0.17	116.95	673.23	0.17
Fire in the Full Response Zone (0,1)	245,228.50	255,616.50	0.96	180,186.20	279,002.80	0.65	215,242.20	264,955.00	0.81
Fire in the Modified Response Zone (0,1)	205,266.10	248,743.70	0.83	200,583.00	255,544.20	0.78	215,193.80	243,116.60	0.89
Interaction of Full Response Zone and Map (0,1)	-181,427.20	159,314.90	-1.14	-115,056.30	189,915.10	-0.61	-133,762.80	180,005.30	-0.74
Interaction of Modified Response Zone and Map (0,1)	-118,837.30	171,993.20	-0.69	-121,133.90	176,664.20	-0.69	-121,758.10	168,216.70	-0.72
YEAR 02 (0,1)	-15,302.29	66,327.14	-0.23	-35,787.42	74,334.72	-0.48	-28,645.74	70,277.09	-0.41
YEAR 03 (0,1)	-64,521.20	75,901.48	-0.85	-47,637.84	81,717.45	-0.58	-52,450.14	77,783.63	-0.67
YEAR 04 (0,1)	36,343.02	209,970.50	0.17	31,705.42	215,739.70	0.15	45,123.06	205,214.90	0.22
Sample Size			215.00			215.00			215.00
R^2			0.94			0.93			0.93

Table 3.9. Continued

Adj R^2	0.93	0.92	0.93
D.W statistic	2.00	2.04	2.02
Mean dependent var.	358,262.70	358,262.70	358,262.70
S.D. dependent var.	1,015,783.00	1,015,783.00	1,015,783.00
F-statistic	147.79		

3.5 Conclusion

In this chapter, I used an empirical model to estimate the impact of map on forest fire losses (area burned, damages and suppression cost). I did not have data to indicate the types of geospatial tools used to derive maps or the associated costs of such technology to be able to determine their economic effects. Similarly, area burned was used to represent losses, which is only an incomplete measure. Also, the commercial timber damage estimate is not accurate and does not reflect ecological damage. Therefore, due to data limitations, I was not able to apply the theoretical model to estimate the reduction in risk derived from using geospatial technologies for fire suppression.

Forest fire economic models, when estimated to look at both suppression costs and losses, often exhibit endogeneity due to a simultaneity bias. To account for endogeneity, I compared an OLS model with 2SLS and 3SLS methods. After accounting for the endogeneity, the empirical model shows that maps, when used in the Full Response Zone, lead to reductions in fire size. This is likely due to the fact that maps are more widely used in the Full Response Zone than the modified and Observation Response Zones where there are fewer values at risk.

I found from the empirical model that losses due to forest fires are not significantly affected by map use. In the OLS estimation, the significant relationship of fire size with losses becomes statistically insignificant in the 2SLS and 3SLS methods. The OLS method may be overestimating the impact of fire size on losses. The insignificant relationship of fire size with losses is likely due to the fact that not all large fires occur where there is commercially valuable timber.

The complexity of modeling fire economics combined with data limitations and missing variables are all important barriers to assessing the economic effects of using geospatial tools for wildfire suppression. Future research should focus on distinguishing fires based on size, damage to commercial timber and other resources such as structures, and the occurrence of multiple fires. One would expect that for large, more catastrophic fires, and in situations where multiple fires are burning, geospatial tools would result in savings.

CHAPTER 4

UTILITY OF GEOSPATIAL TECHNOLOGIES FOR WILDLAND FIRE SUPPRESSION – A SURVEY-BASED APPROACH

4.0 Introduction

I have used two approaches to estimate the value of geospatial tools used for fire suppression: a theoretical model to determine reductions in risk and an empirical model to estimate the effects maps have on cost and damage reduction. However, due to the lack of appropriate data, I was unable to determine the effects of geospatial tools on risk. To address this problem more fully, I use a survey-based approach.

In economics, the value of an item can be assessed in terms of willingness to pay or in terms of what consumers would give up to use a product. As maps are mostly produced within the Forest Management and Forest Protection (FM&FP) branch of Saskatchewan Environment, and therefore no market exists for them, I could not assign monetary values in terms of willingness to pay or establish map values using price. Also, there is no alternative industry that could be used to gain a proxy price or value for geospatial products used by the FM & FP. For this reason, I used survey methodology to assess map value and to validate the empirical results from the analytical model. The survey approach attempts to estimate the value of a range of geospatial tools based on willingness to pay for an improved product by creating an alternative hypothetical market for the geospatial technologies.

This work is important in that it will provide insight into the value and beneficial effects of geospatial technologies. Such information can be used to determine the value of developing new products and to enhance the understanding of existing products. Two factors are of primary concern: (1) personnel awareness, adoption and use of mapping technologies and products, and (2) the value of such technologies and products. My goals for this analysis are:

1. To assess respondents' perceptions about the relative advantage, accuracy and benefits of geospatial technologies, and
2. To understand the socio-economic reasons for respondents' decisions regarding the use of geospatial technologies on fires within the last five years.

To gain a better understanding of the human component, I also recorded respondents' demographic and social characteristics including education, training in geospatial technologies, experience using geospatial technologies, age, time of employment, and fire experience. This chapter provides an explanation of the survey methodology, survey implementation and results. Finally, I conclude by providing an assessment and interpretation of my findings.

4.1 Literature Review

Qualitative research has been used in many fields to elicit perceptions of value and to assess the usefulness of technologies. While forest fire managers' views about the usefulness of geospatial technologies for wildfire suppression and management have not been well studied, there is an emerging body of literature attempting to gain a better understanding of such qualitative factors.

With respect to technology in general, Curlee and Tonn (1987) present a framework to analyze how information systems are used and what factors cause their success and failure within organizations. They report that individuals use new technologies to maximize their utility compared to the goals of an organization, which aim to increase productivity. They argue that information quality, quantity and speed of dissemination are all important factors determining the usefulness of these technologies. Additionally, hardware and software itself and users' training, experience and risk behavior all determine the acceptability and use of new technologies. Other factors, such as divergence of organizational goals and individuals' objectives concerning the use of technologies, organizational constraints in terms of availability of labor, training facilities, and polices in regards to accountability and rewards, can all affect the use of new technologies. They also argue that users' attitudes and perceptions of technology affect the level and use of new technology.

González-Cabán et al. (1997) found economies of scale in prescribed burning resulting in lower per acre costs as fire size increased. While they were able to measure the effects of many physical and economic factors, they stated that site parameters alone do not explain all of the variability in prescribed burning costs, and therefore it is important to measure the institutional and managerial factors. Because fire managers view fire situations differently, the use and effectiveness of technology will vary by manager. To that end, they look at fire objectives such as containment and cost minimization as a function of education, experience and managers' self-perceived risk.

The authors used a survey that simulated repeated burns of the same site under modification of the burn plan. The simulation approach allowed repetitive burning of the sites under varied conditions by the same burn boss and variation by burn boss across a controlled set of sites. The changes in cost and damage estimates were therefore attributed to fire managers.[6] Results suggest that survey methodology was effective in determining the personal factors that influenced the cost of prescribed burning and that costs could be partially explained based on managers' behavior.

Hardwick and Fox (1999*)* report that fire incident personnel in California identified many qualitative benefits of using geospatial technologies in actual fire management of especially large

[6] In studies of actual burn costs, such repetition is not possible as a site usually burns only once, and there is only one fire manager or burn boss in charge.

fires, as well as its value in communicating information to the public. Fire personnel who were interviewed viewed new technologies as more cost effective, efficient, timely and accurate, and thus thought that such technologies helped to make better decisions. They identified savings in terms of avoiding unnecessary tasks when on a fire, improving safety of firefighters, reducing the physical reconnaissance time, and helping brief new personnel who were not locals. Fire incident personnel also pointed out that data quality and time availability, communication facilities and training, etc. were also important for the successful use of these technologies in fire management.

Burchfield et al. (2002) used participant observation techniques to study the perceived benefits of fire personnel involved in fire management. They note that fire personnel found geospatial tools useful in supporting decisions on large, complex fires.[7] They also reported that high quality and timely provision of maps of topography and fuel loading, suppression infrastructure, containment and efficient allocation of resources was important to fire managers. Respondents reported that the reliability and completeness of data were important for the utility of these products. It was also observed that geospatial technologies have been largely used for mapping production compared to other potential uses such as landscape analysis and archiving inventory. Some apprehensions were also raised by the users of these tools about the availability of reliable data and limited facilities, such as hardware and communication connections, at remote fire locations. These are key concerns for fire managers in Saskatchewan too. Finally, it was observed that hardware, data and trained personnel all determine the usefulness of these technologies in forest fire management.

Canton-Thompson et al. (2008) took a qualitative approach by employing an in-depth interview methodology to obtain views of the members of Incident Management Teams (IMT)

[7] A "complex" fire is one where individual fires grow together geographically to become one fire.

about growing wildland fire suppression costs. They reported that IMT identified outside factors over which IMT do not have control, including institutional policy and regulations, external decisions affecting costs, use of modern technologies, increased use of contracted equipment, public demand for the use of sophisticated technology, and increased use of aircraft, to be responsible for increased costs of suppression. They also noted that personnel with knowledge, training and hands-on experience could provide valuable information about the situation under consideration.

Based on the effectiveness of the survey methodology and results suggesting that human and institutional factors affect suppression costs and forest damage and to confirm and expand the results of my empirical analysis, I developed a survey to assess the usefulness of geospatial technologies to fire managers in Saskatchewan.

4.2 Survey Design and Implementation

In this chapter, one of my aims was to evaluate the value of the geospatial tools for forest fire suppression through the use of contingent valuation methodology (CVM). Contingent valuation methodology elicits responses to questions such as "What is the maximum somebody would be willing to pay (called willingness to pay –WTP) for a service or a product for which no market exists." Since values elicited through CVM are contingent on a hypothetical market constructed in a survey, the method is called a contingent valuation method.

Geospatial technologies that are used for forest fire suppression are mostly produced in the public sector and, therefore, there is no sale market for these tools. To assess the value of these tools, I asked fire managers their maximum willingness to spend on a particular type of technology given their fixed budget. WTP values can be compared with the cost of providing the technology, and, if the former is greater than the latter, I could conclude that the technology is useful as the benefits are more than the costs in a traditional cost-benefit analysis. One of the problems in applying CVM in my research was the problem of no fixed budget for forest fire suppression. The managers did understand that spending on geospatial tools would take money away from other potential uses, and therefore they have opportunity cost. Also, in traditional CVM methods, WTP is based on the income of the individual, but in fire scenario cases the fire funding is public money. Getting WTP from the general public could have been an option, but it is the forest fire managers who gain the most utility from using them, such as providing better information and thereby reducing the risks associated with fires. Also, fire managers are more informed about the use of the tools in forest fire operations. The true economic benefits of geospatial technologies would have been the estimate of the true cost and benefits of these tools for forest fire suppression. The estimate of the willingness to spend on geospatial technology depends on the cost savings and damage reduction as well as other factors such as age, sex, and education.

Due to the unique nature of the forest fire operations, where most fire managers do not think that fires cause damage unless the fire burns commercial timber, the lack of fixed forest fire budgeting, little or no opportunity cost of using the technology for those who are using them, and lack of an alternative market for the geospatial tools all make it difficult to get reliable and valid estimates of the amount they are willing to spend on these tools. A scenario was prepared and questions asked about the maximum they were willing to spend on maps not produced in the FM&FP branch. Most of the responses were that they would spend whatever resources available to protect the values at risk. I could not get estimates for the CVM method and therefore used in-depth interview method to look at the impact of these tools such as providing accurate information and its prediction capabilities, to name a few, and thereby assess the usefulness of these technologies.

I employed an in-depth interview approach to assess the value of geospatial technologies as used for fire suppression given that I could not get WTP values for the use of geospatial tools. I asked both quantitative and qualitative types of questions to obtain the responses of the fire managers about the usefulness of geospatial technologies in forest fire operations. I designed both open- and close- ended questions according to the literature and my objectives. I provided a brief overview of map types and uses, as informed by FM&FP staff (Appendix A) and the survey in full (Appendix B).

The survey was designed in four parts. Part I explains the purpose of the survey, my interests in how fire managers use geospatial tools and how geospatial tools can be used for strategic purposes. This part assesses managers' knowledge of geospatial tools and whether such tools are perceived as useful in reducing wildfire damages and suppression costs. Part II illustrates three wildland fire scenarios of varying degrees of danger and complexity based on an actual fire event near the city of Prince Albert. Fire managers were provided with maps, asked how they would allocate resources and which geospatial products they would use. In this section, I also tried to elicit a monetary value for the range of geospatial products available. Managers were also asked to estimate the types of resource used such that I could estimate the suppression costs. The final section was used to collect demographic information and to allow fire managers to add information not captured by the survey.

FM&FP identified a list of 22 fire managers to participate in the survey. Of the 22 fire managers, 11 were based in Prince Albert. One of the fire managers had left the branch for industry and could not be interviewed. I interviewed all fire managers in Prince Albert personally as well as one who was in Saskatoon. One fire manager each from Hudson Bay, Stony Rapids, Wayakwin, and Maple Creek was interviewed over the phone. Two fire managers each from the La Ronge and Buffalo Narrows, and one from Denar Beach/Creighton did not reply to repeated calls and emails. Ultimately, I was able to interview 16 of the total population of 22 fire managers, which constituted 73 per cent of the total population.

4.3 Results and Discussion

The average age of fire managers interviewed was 47 years, and respondents had held their positions of employment for an average of 7.5 years with overall average fire experience of 24 years. Yet age was not significant in describing different levels of technology usage. The majority of respondents had either a technical diploma or some university training. Regarding technology, while the majority of the respondents (69%) did not get any formal training in geospatial technologies, those who did were typically forest protection officers or base supervisors. Additionally, those who did not receive formal training did have exposure to new technology through workshops, departmental training or learning on the job.

4.4 Part I: Knowledge and Perceptions of Geospatial Tools

Results indicate that respondents use maps for different purposes, largely based on their positions within the department. This information provided us with a broad range of map uses for different levels of fire management. Whereas some respondents used maps and other technologies at a strategic level, others used the same technology for operational or tactical purposes. In either case, I used a Likert scale to evaluate respondents' opinions regarding the importance of geospatial technologies (Figure 4.1).

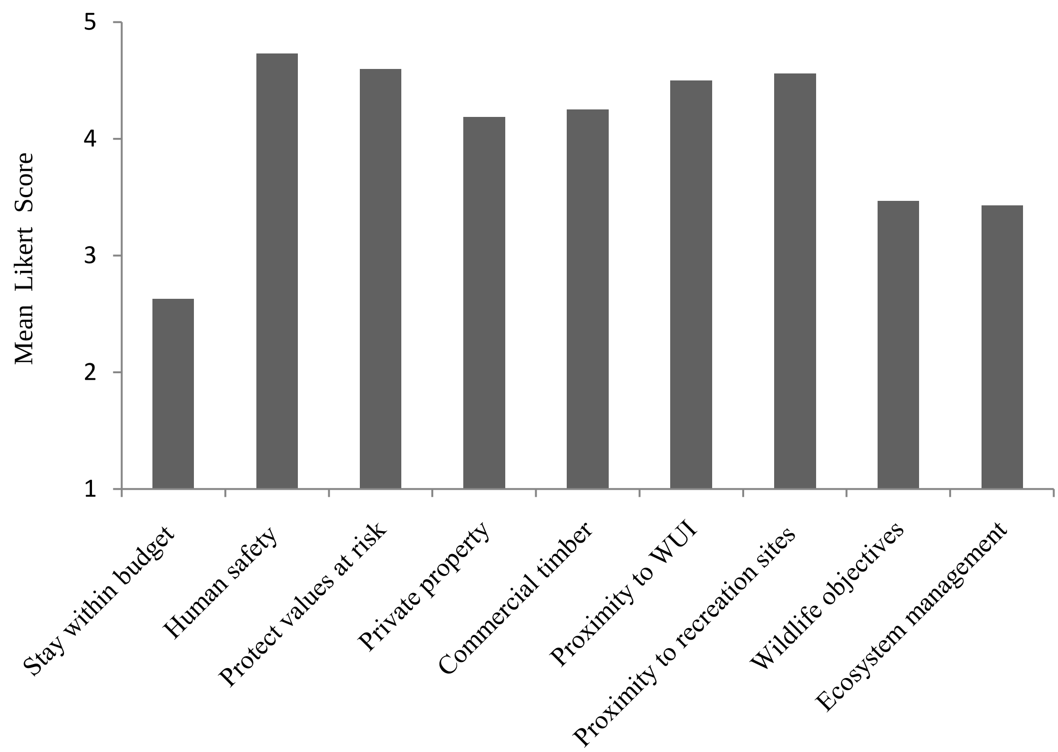

Figure 4.1 Important factors in choosing a map produced through geospatial technologies as used for wildland fire suppression in Saskatchewan.
Source: Author's survey data

Managers responded that the highest importance in choosing a map was to provide information to assist in protecting human safety (4.73), followed by recreation sites (4.56) and values at risk (4.6). Their opinion is consistent with FM&FP's VAR approach to protection and prioritizing decision with regards to fire management. This also indicates that staying within budget (2.63) is not as important for selecting mapping technologies.

Respondents were also asked to rank the importance of uses for a range of geospatial products (see Figure 4.2). The highest-ranked use of geospatial technologies in forest operations was for tactical planning (4.29), followed by the ability to provide accurate information (3.95), clarity (3.91) and improve analytical capabilities (3.9).

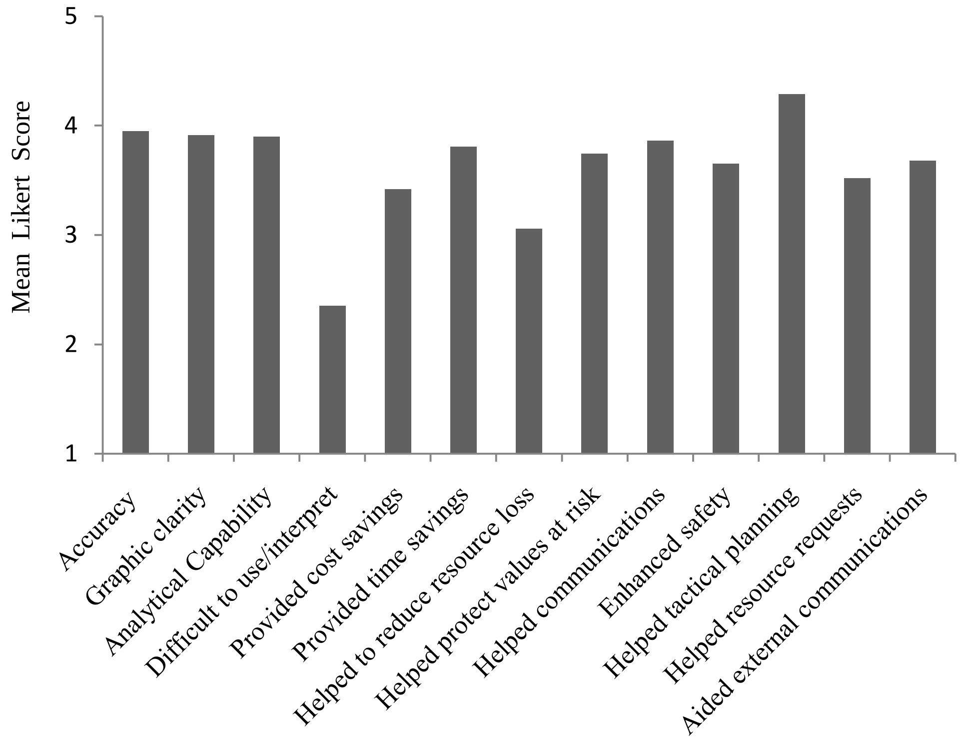

Figure 4.2 Importance of maps produced through geospatial technologies in wildland fires in Saskatchewan.
Source: Author's survey data

New developments in geospatial technology often require specialized training for use and interpretation as well as access to increasingly more powerful communications technologies with which to send and receive increasingly larger data files. Because many locations in Saskatchewan are remote, not all products are of use in all locations, so I asked respondents about the potential problems they faced (figure 4.3) Two of the biggest problems were remoteness of fires and the limited number of trained staff available (both 93.75%). A second problem was the lack of high-speed connections, which is related to remoteness in many cases (81.25%). Only 62% of respondents reported that timeliness was a problem, and even fewer (18.75%) reported difficulties in interpretation.

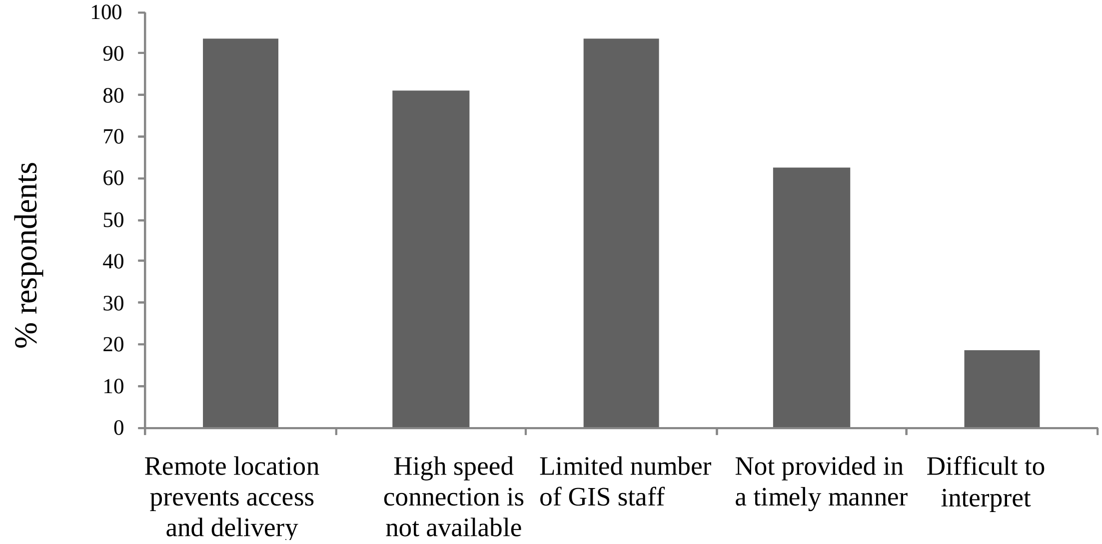

Figure 4.3 Problems faced by respondents in using geospatial products for wildland fire suppression in Saskatchewan.
Source: Author's survey data

Finally, respondents were asked about possible cost savings or reductions in damages as a result of better information due to mapping technologies. The majority of respondents agreed that using geospatial technologies led to both reduction in damages and suppression costs. Two respondents gave an estimate of 15% and 20% reductions respectively for costs and damages. I measured damages both in terms of area burned and loss of timber, I found in chapter 3 that area burned, especially in the Full Response Zone, is smaller when maps are used, but did not find that map use leads to reduction in damages. Similarly, although map use in the Full Response Zone was negatively related to cost of fire suppression, the relationship was not statistically significant. So the perception of the fire managers about the damage and cost-reducing role of geospatial use in general is consistent with the findings in chapter 3.

4.5 Part II: Fire Scenario and Map Use

In conjunction with the geospatial unit and based on advice from FM&FP, I developed three different scenarios with descriptions and maps based on the Crutwell Fire near Prince Albert. The scenarios were developed using the fire simulator Prometheus that estimated fire spread over 48 hours as a function of wind speed. I presented three scenarios based on different wind speeds to all fire managers and asked them to allocate resources listed in the interview schedule, assuming both availability and unavailability of geospatial technologies and the corresponding maps and information provided. I also asked managers about the types of geospatial technologies that they would use and invited them to provide a monetary value or allocation of the budget to either have them produced within FM&FP or to have them provided by a service contractor. Most of the fire managers were unable to provide any estimates of value because no realistic alternative market exists for the production of these technologies for wildfire suppression. Therefore, the use of contingent value methodology was abandoned.

While I expected resource allocation to be different for each scenario, the proximity of the Crutwell fire to Prince Albert resulted in similar responses regardless of wind speed. Managers found that such fires would be fought with all possible resources available due to high VARs and regardless of geospatial technologies availability. However, two respondents noted that in the scenario where wind speed was moderate, resources assigned in both cases with and without geospatial technologies would be the same. For the scenario where winds were seriously threatening, resulting in a fire blow up, these managers estimated that without geospatial technologies, 10% more resources would be used including remote sensing through AWIS, which is very costly. One of the respondents explained that, *"The presence of geospatial technologies in this case would have no bearing on the numbers and types of resources ordered. Basically, an incident management team, because of the values at risk in this area, would order a very significant number of resources of all types."*

Most managers showed concern about the wind switching direction and, therefore, would like to have as many resources as possible available. Because managers did not allocate resources differently for each fire, I was unable to assess marginal costs across resources. Future research based on scenarios in different response zones could be used to determine cost differentials.

4.6 Qualitative Analysis

In trying to assess the value of geospatial tools as used for fire suppression, I explored the possibility that employees did not have access to tools because of technical problems or lack of infrastructure or because the manager had not been trained. The following summarizes this discussion in terms of benefits and costs.

4.6.1 Benefits

How information is used depends on a manager's position within FM&FP. Employees involved with policy making usually examine information at the landscape scale and require less detail, while those directly involved in fire management use information more for operations and tactical support and therefore require more detail.

At the landscape level, maps help synthesize and compare various types of information to help managers make more informed tactical decisions, including values at risk. Also, managers require maps that show the positions of resources available at each base. At the landscape level, these maps provide information to help managers allocate resources and brief other agencies such as police, government and the public for the purpose of safety briefings, evacuations, etc. Most fire managers agreed that geospatial tools help to identify the locations of camps, fire resources, VARs, fire boundaries and fuel locations as well as to allocate fire suppression resources more quickly and efficiently.

Most respondents agreed that geospatial tools, including GIS, remote sensing through MODIS and GPS, can all be used to overlay layers of data, such as fuel types and political boundaries, and to help position resources quickly to control fires before they become large, especially in the high VAR zones. This is true operationally and strategically. Geospatial tools help to map fire boundaries and can easily include information pertaining to topography, roads and infrastructure to be more helpful in planning and decision-making. Furthermore, managers expressed the importance of knowledge regarding the exact locations of outfitters' camps, recreational outbuildings and staging areas. Additionally, geospatial tools can be used to help analyze data and predict fire behavior under different environmental circumstances. In general, fire managers listed the benefits of having/using geospatial technology to be:

- Greater ease in providing and receiving updated information,
- Greater speed in providing and disseminating information,
- The availability of more accurate data,
- Enhanced information for fire simulations,
- Enhanced ability to inform people at all levels of forest management, and
- Better communications with media, the public and government.

Most managers agreed that while often cost-prohibitive, AWIS, a high-altitude remote-sensing technology, is highly useful, particularly for complex fires and where VAR include infrastructure, such as power lines, mines and roadways. Managers also stated that AWIS is advantageous in that it can be used in heavy smoke where fire fronts cannot be detected using other technologies. Additionally, AWIS helps to detect heat sources quickly and enables managers to reposition resources, resulting in faster suppression.

Just as other resources are scarce, so too are geospatial tools. It was noted that central management in Prince Albert tries to maintain a balance in providing information in such a way that high priority fires, where Type I Incident Command Teams are required, get GIS staff and products more quickly because of the high costs of suppression and priority from a risk perspective. It was agreed that real time information availability is very important as fire behavior can change rapidly, and time sensitive mapping can help in allocating resources and reducing damages.

4.6.2 Costs

While information can greatly benefit fire management staff, there is a cost associated with it that must be considered in an economic analysis. Delivering/receiving information depends on various factors such as the nature of each fire, proximity of fires to fire bases and how equipped a base is with geospatial technologies, personnel and equipment. Some fire bases in Saskatchewan, such as Prince Albert, La Ronge and Buffalo Narrows, are equipped with plotters and can produce large maps while others have to send information to those bases with plotters or to Prince Albert to get maps either through the internet as JPEG files or delivered as hard copy.

The range of geospatial tools is extensive, and there are many costs associated with each type of technology, including hardware and software, updates and maintenance, variable costs associated with use, and training for personnel. Additionally, problems such as delays, the inability to collect data, limited number of designated trained personnel or infrastructure unavailability often add to costs or make using such technologies prohibitive. In the case of remote-sensing tools attached to aircraft, the lack of high-speed communication networks or the lack of resources such as fixed-wing aircraft make certain technologies impossible to use.

> *"I have got problems getting my staff, training my staff just to do some basic things like to take basic tracks and emailing them and stuff like that. I am not there yet, because a lot of my staff is seasonal, and they work only 20 weeks in a year. They have got a lot of other duties too, so learning to use GPS is a struggle for some of them, and to train them is trouble as well for us".*

It was also noted that geospatial tools help to allocate resources more efficiently resulting in cost savings and damage reductions.

> *"I plan my cost strategies based on values at risk and tie them together, and therefore maps are very critical to us. So I plan how to proceed with the suppression."*

> *"I could place the resources if I know how the fire is going to behave based on the fire projections. So, they (geospatial tools) are really important".*

> *"I use GPS locations a lot. It increases the efficiency of aircraft, increases the efficiency of getting people from one spot to another."*

The demonstrated usefulness of these technologies in fire operations helped change the views of people who were uncertain about the usefulness of such new technologies. One fire manager very succinctly and bluntly stated:

"I know even myself years ago said that they expect us to fight fire with computers and that's what I seem to be doing today and definitely it is valuable information as long as I don't get so wrapped up with maps and computer screens and all that good stuff… and not to forget I do have to have people on the ground to put out the fire. Years ago, I remember I used to say what a waste of time it's going to be and now that's good stuff."

Fire managers also found mapping technologies very useful in their meetings and briefings. They noted that it helped them to improve communications among individuals. Some fire managers stated that:

"The information is very valuable; it is the centerpiece for everything…you try to explain to people and you know that they have hard time [understanding], and if you got a map there, everyone is looking at the same thing, and it just makes communication easier".

"It is very important information to have; without a map [management is] very difficult. I can use visual tools to talk around and plan accordingly and [it] is a very critical piece of information from that perspective".

"Definitely, from operational and planning perspectives, it is the most important piece of information of the whole operation process."

Fire managers also mentioned that geospatial tools help with safety and noted that:

"For occupational health and safety and safety of firefighters, I think I really can't do without using the GIS technologies on fires".

While geospatial tools are very powerful, interpretation and decision-making requires fire experience and technical knowledge. A concern was also raised about the widespread availability of information as it creates illusions among some individuals far from a fire incident that they know more about the fire, thus creating potential problems with the command system through unwanted and unnecessary intervention in decision-making. Geospatial tools also provide managers with fire growth modeling that enables technical staff to predict fire spread and allocate resources accordingly to reduce damages and costs.

Some fire manager specifically listed two remote sensing tools (MODIS and AWIS) that are used to collect and provide information. They further explained that MODIS is used in low resource areas north of the Churchill River, and, while it is not that accurate, it is free and can be combined with the weather information and other data to predict fire activity. For more accurate information they fly helicopters. It was also noted that AWIS is very expensive and contracted only if a fire is near highly-valued resources, communities, mine sites, or when there are several fires in high-density areas.

Finally, most of the respondents in my sample confirmed that when a fire becomes large and poses increasing risks, managers use more geospatial tools even though it will increase suppression costs: cost is not a major factor when it comes to protecting high values at risk, such as human values and infrastructure.

4.7 Conclusion

Fire managers surveyed believed that both damages and costs can be reduced if fires are detected early and fire suppression starts promptly. It was found from the survey that geospatial tools play a major role in early detection of forest fires and help to allocate and divert resources quickly to such fires. Thus, help in controlling fires results in savings through reduced costs and reduced damages. For the more costly geospatial tools such as AWIS to be economical, fires have to be large enough and a serious threat to resources to justify employment. Additionally, I found from the survey that in the Observation Response Zone where VARs are relatively low, geospatial tools are not often used unless fires are threatening to public infrastructure and communities. The only exception is for MODIS technology, which is used on a daily basis from the fire base/center through internet access for detection and monitoring. Although MODIS is not accurate, it helps to identify fires, and for further assessment helicopters and fixed-wing aircraft are used to monitor situations.

To assess the value of geospatial tools, it will be important to ensure information is gathered such as the number and types of geospatial tools used, trained GIS staff, data on both variable and fixed costs, and the outcomes in terms of area burned, suppression costs and reductions in damages. Also, information about fire managers responsible for a specific fire, such as their perceived risk behavior, education, age and sex, would be important. It is difficult to assess the value of geospatial tools without this information.

Chapter 5

SUMMARY AND CONCLUSIONS

5.1 Summary and Conclusions

Wildland firefighting is a complex, dynamic process affected by a multitude of factors such as weather and climatic variability, biophysical landscape characteristics, and unpredictable fire behavior. Fire managers often make decisions with imperfect information about resource availability, access, values at risk, and many other factors. Decision-making in an uncertain environment has significant consequences in terms of suppression expenditures and damage to the environment and capital assets. To minimize risk, fire managers use many means to access better and timely information, particularly geospatial technologies.

While Hesseln et al. (2009) and Burchfield et al. (2002) have done preliminary studies on the value of geospatial technologies, to date there has been little other research to assess values in spite of large investments in such technology. My objective was to assess the value of geospatial tools as they are used for wildland fire suppression, using Saskatchewan as a case study. I assumed these tools to be useful in terms of providing information to reduce the risk of damage and to reduce suppression expenditures. To accomplish this, I developed a theoretical model to estimate the value of geospatial tools in terms of reducing risk in decision-making for forest fire management. Furthermore, I used data collected from the Ministry of Saskatchewan Environment's Forest Management and Forest Protection branch to estimate values empirically. Because data were incomplete, I also assessed the views and opinions of fire managers who use geospatial technologies.

In most of the forest fire literature, risk is not addressed explicitly so I adapted a well-established risk model used in production economics and precision agriculture to evaluate the role of geospatial tools in reducing the risk of loss from wildland fire. Economic efficiency of the fire management effort is measured through minimization of the expected value of the cost plus net value change (C+NVC). Past research studied suppression effort or strategy in terms of minimizing the expected value of the cost plus net value change (C+NVC) and ignored its risk even though there is a trade-off involved between risk and expected value of C+NVC.

In this research, I specified a theoretical model which not only deals with economic efficiency but also risk. My theoretical model suggests that the optimal use of resources will be different for a fire manager who incorporates risk into decision-making compared to one who only minimizes the C+NVC. Specifically, I found that risk-averse fire managers will use geospatial technologies beyond a point where cost equals the reduction in losses in a traditional C+NVC minimization analysis, and I concluded that such tools have value in terms of managing risk.

I also aimed to use the theoretical model to value geospatial tools empirically, but data limitations prevented me from accomplishing this. Detailed GIS information was not readily available in the fire records. The 209 forms used to keep daily records of forest fires did include a category that indicated whether a map was required, and if a map was provided. However, this information did not indicate the type of map or other technology that might have been used. In an effort to generate more detailed information, I attempted to work with personnel assigned to each fire. Unfortunately, due to the large number of records, it was not possible to assess the type of information provided.

The theoretical model conclusion could not be verified through an empirical model due to lack of data. However, I specified a simultaneous equations system model to estimate the impact of map use on fire size, damages and suppression cost. Theoretically, geospatial technology should play a significant role in reducing fire size, suppression costs and damage by providing more detailed and timely information to fire managers. After accounting for the potential endogeneity problem, I estimated the model using the two-stage (2SLS) and the three-stage least (3SLS) squares estimation methods. I used area burned (ha) as a function of map use while controlling for other factors such as weather, labor and equipment used, and fire management strategy zones to estimate the impact of geospatial tools on fire losses. I found that use of a map helped to reduce the fire size (results were statistically significant) in the Full Response Zone. I concluded that geospatial tools and maps, while expensive, are used mostly in full-response zones to protect high values at risk. This finding could be related to the theoretical part in that the fire managers would be more risk averse when fighting fires in the Full Response Zone, and therefore geospatial tools use will be more prevalent in those areas. In other areas where there are few high values at risk, the map use relationship may not be significant as fire managers might be less risk averse.

I also found that the duff moisture code and drought code had positive significant effects on fire size. I also found a significant and negative relationship between fire size and use of helicopters in the ordinary least squares (OLS) estimation method, but this impact may be overestimated as 2SLS and 3SLS did not prove a significant relationship between the two after controlling for endogeneity.

In terms of map impact in reducing damages, I did not find it to be statistically significant. To assess the impact of maps on cost of suppression, I found that resource use had a positive relationship with the cost of suppression, which is consistent with the economic theory. It was also found that, although the cost of suppression was positively related with the Full Response Zone, it was not statistically significant. Similarly, the interaction of the Full Response Zone and map, although negatively correlated with the cost of suppression, was not statistically significantly.

Through my survey, I aimed to identify the different types of geospatial technologies used in forest fire operations as well as how these technologies were used. I was also interested in knowing how these technologies are perceived in terms of usefulness by the people who actually use them in field operations. Fire managers placed high importance on usefulness of geospatial tools in planning, resource allocation, and resource requests and to communicate at various levels of the fire management hierarchy as well as with public, media and government agencies.

My survey provided me with valuable insight as to how these technologies are used in forest fire operations. It also provided information about barriers to widespread use for wildland fire management. Respondents viewed these tools as providing information in a map or database, which helps them to make more informed decisions. They also stated that geospatial tools provide more clarity of an incident and operational flexibility for a range of situations. Managers revealed that particular tools are only economical for large fire complexes and are more advantageous for fire incidents that threaten highly-valued resources. In general, my survey results confirmed that expensive geospatial tools are more often used to protect high-valued resources, such as human populations, public infrastructure, communication infrastructure and higher timber values. Furthermore, this survey finding is consistent with the findings in the theoretical and empirical model.

With respect to limitations of geospatial tools, fire managers articulated their concerns about data quality, data acquisition in busy seasons, the lack of standardized tools and protocols to collect data, limited trained personnel due to the seasonal nature of the job, and poor communication infrastructure at remote locations. Fire managers suggested more standardized data collection tools, more coordination among various agencies involved in data collection, incorporating more analytical capabilities in geospatial tools, training, and improving communication infrastructure, especially in remote locations, to improve and expand the use of geospatial tools in forest fire operations.

The general view of the wildfire managers that geospatial technologies help reduce both cost and damages could not be verified through data, although when area burned is taken as proxy for damages, then their perception of reduction in losses is consistent with the results in the empirical model. Furthermore, although cost in the Full Response Zone showed a negative relationship with map use, it was not statistically significant.

Finally, the contingent valuation method (CVM) method could not be applied to find economic values of geospatial tools because maps are only produced at FM&FP. Therefore, establishing a simulated market was a challenge. Also, public agencies' and especially wildfire managers' views of unconstrained budget are impediment to eliciting proper values for their willingness to pay or spend.

5.2 Study Limitations

I faced many limitations and constraints in collecting reliable data to estimate the theoretical model. I received both digital and analog data, the latter being difficult to verify and incomplete. Also, reports included many variables without information, making it difficult to determine whether information was missing or whether certain resources were simply not used. Much of this information had to be discarded.

The weather and climatic data were averaged for the entire duration of the fire burning, and therefore effects could not be properly captured for fire size, damages and suppression costs. To assess the effects of technology, I had to use a dummy variable for map use, which captured only whether a map was used or not, without specifying the type and number or the cost. Information about specific technologies such as AWIS, MODIS, or airplane with remote sensors owned by the FM&FP, and the type of geospatial team dispatched to a fire would have different implications for fire cost and damages. The timing of the technology dispatched to fire operations would be important in cost savings and damages but no such data from forest fire reports could be obtained. Managers' demographic characteristics, such as age, education and risk behavior, might have an effect on employing these tools and also the overall resultant fire size, damages and suppression costs, but no identification or characteristics of fire managers were maintained in the daily records to be able to examine such effects. My survey results should also be viewed with care as my sample size was only 16 fire managers of a possible 22 who were chosen with the help of FP&FM. While my survey findings might be biased, there remain no other such studies.

5.3 Policy Implications and Recommendations for Further Research

The conclusion from the theoretical model, as stated earlier, is that risk-averse wildfire managers would use geospatial tools more often compared to risk-neutral managers. It has also been emphasized that geospatial technologies are expensive and therefore cost of fire suppression and damages could be different for different fire managers with different risk postures. Consequently, data on the managerial characteristics of the fire managers such as their age, sex, experience and risk attitude are very important in explaining the variations in cost, damages and use of geospatial tools. The incentive and punishment structure favors more risk aversion on the part of wildfire managers. The more risk-averse a fire manager is, the more he spends to assume greater certainty of avoiding any negative consequences because of his decisions. This is also precisely the reason that damages weigh heavily on their minds when making decisions compared to cost savings.

To better estimate the value of geospatial tools as they are used for wildland fire suppression, I recommend that more accurate records be kept for financial information, all human and capital resources used on forest fires, and an accurate assessment of the types, numbers and costs of geospatial tools used. Furthermore, it would be important to keep records of how resources are dispatched and their effectiveness. Finally, information about fire managers and other personnel who are assigned to a fire or a complex fire would be useful in assessing how managerial variables affect resources on the ground and outcomes in terms of fire protection and suppression.

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APPENDIX A

TECHNOLOGIES AND MAPS USED FOR WILDLAND FIRE SUPPRESSION IN SASKATCHEWAN

This section describes the different types of mapping technologies used for wildland fire suppression in Saskatchewan. I also discuss how different geospatial technologies are used to collect data for generating spatial products (maps).

Moderate Resolution Imaging Spectroradiometer (MODIS): MODIS is an instrument on board the Terra (Earth Observing System- EOS AM) and Aqua (EOS PM) satellite/spacecraft, which was launched by the National Aeronautics and Space Administration (NASA) – an executive branch agency of the United States government (available at: http://modis.gsfc.nasa.gov/about/). Terra's satellite-descending orbit crosses the equator at 10:30 a.m. local time from north to south. Clouds typically form over tropical land in the afternoon as the surface warms, and therefore Terra's morning view provides clearer images of the earth's surface. It orbits the earth once every 99 minutes at an inclination of 98 degrees relative to the equator and at a mean altitude of 438 nautical miles (705 kilometers). Equa (EOS PM-1) satellite passes in ascending orbit from south to north at 1:30 p.m. equatorial crossing time (local solar time) because there are few clouds over the tropical oceans in the afternoon. MODIS instruments measure surface temperature (both the land and ocean), ocean color, global vegetation, cloud characteristics, snow cover, and temperature and moisture profiles by collecting data on 36 spectral bands, or groups of wavelengths, using thermal infrared radiation. MODIS is capable of viewing the entire globe daily at moderate resolutions, ranging from 250-meters square to 1-kilometer square pixels, thus helping to see a broad area but failing to identify individual features on the earth's surface. Detection of fires in MODIS imagery is shown as centroids of the pixel and is only accurate at a margin of +/- 50 meters (CIFFC2004).

Weather conditions such as clouds and rain (Oldford et al 2006), pre-set time of orbiting, and low resolution (CIFFC 2004) are the major detection-accuracy obstacles in the operational use of MODIS in forest fire management. Saskatchewan uses the USDA Forest Service MODIS Active Fire Mapping Program (http://activefiremaps.fs.fed.us/canada/) to provide a synoptic view of active fires in Saskatchewan. Saskatchewan informally used this data during the 2004 fire season, particularly to monitor large fires and new fire starts in its 18.3 million hectare Observation Response Zone (CIFFC, 2004).

Most of the participants in the research survey (chapter 4) confirmed that MODIS is used daily to detect hotspots. This technology is used mostly to monitor and locate fire boundaries in areas with relatively low VAR. One participant noted that it helps the agency to know where fires are in relation to highly-valued resources, and it assists them in resource placement and planning. The agency, however, viewed MODIS to not be operationally useful in the field as the satellite passes through the Saskatchewan forest zone every six hours, which is not frequent enough to monitor forest fire situations. It was noted that MODIS is particularly useful to monitor the northern part of the province where VAR are low and the monitoring area is vast.

AWIS (Airborne Wildfire Intelligence System): is an infrared, remote-sensing, high altitude technology system produced by Range and Bearing Corporation (a private company). This technology is mounted on a twin-engine aircraft and can detect energy radiated by fire even in smoke, dark and haze conditions on a small scale, which could not be detected using other technology (Beck 2004). AWIS works best when remote sensing is done at night or early in the morning as there are few other reflections or energy radiation during these times. All data and images scanned during a flight are processed and corrected and could be made available through the Internet. Beck (2004) compared the performance and cost effectiveness of AWIS and forward-looking infrared imaging systems (FLIR) and found that AWIS was more accurate but more expensive than rotary wing mission or FLIR systems for fires less than 2000 hectares. AWIS can work in both smoky or cloudy conditions to detect hotspots, to generate parameter mapping and to produce high resolution maps. The cost of AWIS and unavailability of aircraft sometimes can be prohibitive unless the fires constitute large fire complexes.

Respondents in my research survey (chapter 4) agreed that if there are multiple big fires (referred as fire complexes), AWIS provides an advantage over the traditional technologies because it can be used in smoky conditions with low visibility. Respondents were also aware that because of the high cost of AWIS, it is not feasible to use it on smaller fires.

Global Positioning Systems (GPS): provide information about fire locations, helipads and resource positions. GPS is often used by crew members walking fire lines to ground truth an area and to produce maps for the main fire center. The main fire center, after producing maps, sends final fire reports/maps to the incident command for operational use in the field. It was reported in my research survey that every fire over one hectare has to be mapped, and fires greater than 100 hectares warrant digital maps. For fires less than 100 hectares, it was reported that the fire center keeps hard copy maps only.

Values at Risk (VAR): is a database server or map server that provides an inventory of values that are important to be protected and also indicates if fire is posing a threat to such values. This database helps FM&FP set fire priorities and better allocate resources. The Saskatchewan forest fire management strategy is based on giving priority to human lives, social, economic, cultural and ecological values. To protect such values, FM&FP continually updates its database and maps. Respondents in my survey viewed the VAR map/database as being very useful in knowing the location in relation to fires of important values, such as communities, subdivisions, recreation sites, camps, cottages and other infrastructure.

PUCK (Preparedness Utilization Coverage Kalculator): is a GIS-based product that has been developed at FM&FP and is used to calculate helicopter coverage. Carr (2005) reported that it is used to describe and record the placement of helicopters for the preparedness program so that helicopters can achieve 75% coverage of an area in the Full Response Zone within 20 minutes of flight time. The preparedness system is used to calculate how many resources will be required to respond to daily fire ignitions and fire danger levels in the Full Response Zone.

Prometheus Fire Behavior Prediction Program: is used to estimate fire behavior in the field based on fire behavior modeling. Field officers can send information regarding fuel type, weather and topography, wind speed and wind direction to the GIS team at FM&FP, who run Prometheus to project likely fire behavior for 24-36 hours. It was reported in my survey that in the past they have used fire behavior prediction (FBP) system 97, which is a part of the Canadian fire danger rating system (CFDRS) and has performed fairly well for large fire projection. It was also reported that Type I teams usually have a fire behavior analyst who is responsible for estimating fire projections.

Maps: a variety of maps are used to convey a wide array of information for fires of different sizes. This includes inventory maps (1:12,500 series) for fires up to 1,000 hectares and topographic maps (1:50,000 series) for fires greater than 1,000 hectares. Such maps are most commonly used for forest fire operations at the field level depending on fire size and information required. For practical purposes in the field situation, 1:50,000 and 1:12,500 scale maps are easy to handle. These maps often have layers of information about camp locations, helipads, rivers and lakes, forest cover type, access routes and fire boundaries.

APPENDIX B

THE VALUE OF GEOSPATIAL TECHNOLOGIES: QUESTIONNAIRE

OBJECTIVES

Most of the forest in Saskatchewan is owned by the crown and managed by Saskatchewan Environment (SE). The Fire Management and Forest Protection Branch (FM&FP) of SE is responsible in particular for forest fire management of which part of its operations includes development and employment of GIS technologies.[8] GIS is used to make maps that provide information at various stages of fire management and planning. For example, prior to the fire season, values at risk are assessed and mapped to show high priority areas for treatment and protection, and to position resources. GIS is also used during forest fire suppression events to identify fire-spread rates, fire perimeter, fire size and values at risk. We will focus primarily on the use of GIS technology as it is used for fire suppression, and the adoption and use of mapping technology in this context.

Geospatial technology and mapping products used during a fire event can provide important information that may lead to reduced suppression expenditures and savings in terms of lower resource damages. Similarly, up-to-date information may enhance the safety of fire crews and the public. In this sense, the value of technology and mapping products can be measured in terms of damage averted and cost savings. Understanding the level of benefits is important in assessing the usefulness of these tools, and whether tools should be further developed and employed.

New technology is rapidly being developed and implemented for use in fire suppression and monitoring. Geographic Information Systems (GIS) are continually being improved upon to generate a range of maps that offer different types information and various costs and timeliness. Some map products include the following:

1. Custom topographic maps – includes wetlands, values at risk, roads, jurisdiction, etc. GIS analysis can be used to overlay a topographic map with other information such as the following:

    a. Jurisdiction – land ownership and land use

    b. Fire History – provides information about past fires and natural firebreaks.

    c. Forest Inventory – stand type and age, species, density

    d. Fuel types – information about standard fuel classification and burn characteristics.

2. GPS – geographic positioning system – can be used to update maps by either walking a fire perimeter or flying. The cost of flying will vary by fixed or rotary wing aircraft.

[8] GIS (geographic information system) technology is used synonymously with maps, mapping products, GIS tools, etc. We are generally looking at map products derived from GIS, and remote sensing via satellites and infrared scanners on aircraft.

3. Aviation maps – useful for fire complexes where air traffic is moderate to heavy. Information provided includes travel corridors, frequencies, heli-base locations, landing strips, and pertinent fire information.

4. Satellite/fire detection – MODIS flies every six hours to generate information about a fire. This is particularly advantageous in smoky situations although information is relatively coarse.

5. AWIS (airborne wildfire intelligence system) – information collected with AWIS will provide perimeter and hotspots, and is available at night and through smoke, albeit at greater cost than other map products.

Our objectives are to determine:

- the degree to which fire managers and planners are familiar with mapping technology,
- the degree to which fire managers and planners have used map products,
- and under what circumstances is one map product or technology preferred to another.

As fire managers and planners, you are responsible for ordering maps and implementing their use in the field. We would like your views on the importance and value of these resources for forest fire suppression; the degree to which you rely on mapping information; the likelihood of adopting new map products; and the suitability of map products under a variety of field conditions. Your views will be kept strictly confidential and you will not be identified. Personal information will not be released to individuals, or public and private agencies.

Our research results may be used to inform Saskatchewan Environment in their strategic planning regarding the development and provision of new map products.

Part I: Map Characteristics

1. List all map types that you have ordered or used during a suppression event and the advantages of using that particular map:

   a. ____

   b. ____

   c. ____

   d. ____

   e. ____

2. We would like your opinion about the mapping technology you listed. For each type of map, please provide comments where 1 = strong disagreement and 5 = strong agreement.

   Map type: ______________________

a. Accuracy	1	2	3	4	5	N/A
b. Graphic clarity	1	2	3	4	5	N/A

c.	Analytical Capability	1	2	3	4	5	N/A
d.	Difficult to use/interpret	1	2	3	4	5	N/A
e.	Provided cost savings	1	2	3	4	5	N/A
f.	Provided time savings	1	2	3	4	5	N/A
g.	Helped to reduce resource loss	1	2	3	4	5	N/A
h.	Helped protect values at risk	1	2	3	4	5	N/A
i.	Helped communications	1	2	3	4	5	N/A
j.	Enhanced safety	1	2	3	4	5	N/A
k.	Helped tactical planning	1	2	3	4	5	N/A
l.	Helped resource requests	1	2	3	4	5	N/A
m.	Aided external communications	1	2	3	4	5	N/A
n.	Helped with briefings	1	2	3	4	5	N/A
o.	Other _______________	1	2	3	4	5	N/A

Map type: ______________________

a.	Accuracy	1	2	3	4	5	N/A
b.	Graphic clarity	1	2	3	4	5	N/A
c.	Analytical Capability	1	2	3	4	5	N/A
d.	Difficult to use/interpret	1	2	3	4	5	N/A
e.	Provided cost savings	1	2	3	4	5	N/A
f.	Provided time savings	1	2	3	4	5	N/A
g.	Helped to reduce resource loss	1	2	3	4	5	N/A
h.	Helped protect values at risk	1	2	3	4	5	N/A
i.	Helped communications	1	2	3	4	5	N/A
j.	Enhanced safety	1	2	3	4	5	N/A
k.	Helped tactical planning	1	2	3	4	5	N/A
l.	Helped resource requests	1	2	3	4	5	N/A

m.	Aided external communications	1	2	3	4	5	N/A
n.	Helped with briefings	1	2	3	4	5	N/A
o.	Other _______________	1	2	3	4	5	N/A

Map type: ______________________

a.	Accuracy	1	2	3	4	5	N/A
b.	Graphic clarity	1	2	3	4	5	N/A
c.	Analytical Capability	1	2	3	4	5	N/A
d.	Difficult to use/interpret	1	2	3	4	5	N/A
e.	Provided cost savings	1	2	3	4	5	N/A
f.	Provided time savings	1	2	3	4	5	N/A
g.	Helped to reduce resource loss	1	2	3	4	5	N/A
h.	Helped protect values at risk	1	2	3	4	5	N/A
i.	Helped communications	1	2	3	4	5	N/A
j.	Enhanced safety	1	2	3	4	5	N/A
k.	Helped tactical planning	1	2	3	4	5	N/A
l.	Helped resource requests	1	2	3	4	5	N/A
m.	Aided external communications	1	2	3	4	5	N/A
n.	Helped with briefings	1	2	3	4	5	N/A
o.	Other	1	2	3	4	5	N/A

3. Do you face any problems in the field when using map products? Check all that apply.

   a. ______________Remote location prevents access and delivery.

   b. ______________High speed connection is not available

   c. ______________Limited number of GIS staff

   d. ______________Not provided in a timely manner

   e. ______________Difficult to interpret

   f. ______________Other

4. In your opinion, do the use of map products lead to reductions in suppression costs?

    a. No___________

    b. Yes__________

5. In your opinion, do the use of map products lead to reductions in resource damages?

    a. No___________

    b. Yes__________

6. How important are the following in selecting mapping products? (1 = not important, 5 = very important, N/A = not applicable)

a. Stay within budget	1	2	3	4	5	N/A
b. Human safety	1	2	3	4	5	N/A
c. Protect values at risk	1	2	3	4	5	N/A
d. Private property	1	2	3	4	5	N/A
e. Commercial timber	1	2	3	4	5	N/A
f. Proximity to WUI	1	2	3	4	5	N/A
g. Proximity to recreation sites	1	2	3	4	5	N/A
h. Wildlife objectives	1	2	3	4	5	N/A
i. Ecosystem management	1	2	3	4	5	N/A
j. Other ____________________	1	2	3	4	5	N/A

Part II: Fire Scenario and map use

Consider the Crutwell Fire. We have developed three scenarios using Prometheus where fire spread over 48 hours is a function of three different wind speeds. Please refer to the maps provided to familiarize you with the fires.

SCENARIO 1: Wind Speed 10 km/h

1. What are the main considerations or challenges for Scenario 1? For example, provide more details regarding proximity of the WUI, Values at Risk (VAR), budget considerations, other fires in area, resource availability, etc.

    a. ____________________

    b. ____________________

    c. ____________________

2. Would you use or order maps for this fire?

   a. Yes __________ *(if yes, answer question 2.a.i.)*

      i. What types of maps? Please list all that apply. What would you be willing to spend on each type of map?

         i. _____________________ $ _____________________

         ii. _____________________ $ _____________________

         iii. _____________________ $ _____________________

   b. No ___________*(if no, answer question 2.b.i.)*

      i. Why not? Please list all the appropriate reasons.

         1. Too expensive

         2. Believe benefits of maps are too low

         3. Not enough mapping support

         4. Maps are unsuitable

         5. Other ______________________

3. Are there maps you feel indispensable?

   a. No____________(Please go to the next section).

   b. Yes___________ (please list all that apply and please provide a list of characteristics that are highly important to fire fighting success.)

      i. ____

      ii. ____

      iii. ____

4. List the resources you would order for this fire with and without availability of the GIS technologies/Maps:

Name of Resource	**Unit**	**# with GIS**	**# without GIS**
<u>Number of Personnel</u>			
<u>Type:</u>	1._________	1.__________	1.__________
1.Type 1 (SE/FF)	2._________	2.__________	2.__________
2.Type 2 (FN/NW)	3._________	3.__________	3.__________

3.Type 3 (EFFs)			
<u>Fire Fighting Equipment</u>			
<u>Type:</u>	4.________	4.________	4.________
4.Pumps	5.________	5.________	5.________
5.Hose	6.________	6.________	6.________
6.Pump trailer	7.________	7.________	7.________
7.Hand Tools (shovel, Pulaski, backpack, etc)	8.________	8.________	8.________
8.Burnout torch	9.________	9.________	9.________
9.Sprinkler System	10._______	10.________	10.________
10.Water Bladder	11._______	11.________	11.________
11.Chainsaw			
<u>Aircraft</u>			
<u>Type:</u>	12. _______	12. ________	12. ________
12. Tracker Team 1	13. _______	13. ________	13. ________
13. Tracker Team 2	14. _______	14. ________	14. ________
14. CL215 Team # 3	15. _______	15. ________	15. ________
15. CL215 Team # 4	16. _______	16. ________	16. ________
16. CL215 Team # 5	17. _______	17. ________	17. ________
17. CL215 # 214	18. _______	18. ________	18. ________
18. CL215 # 215	19. _______	19. ________	19. ________
19. CL215 # 216	20. _______	20. ________	20. ________
20. CL215 # 217	21. _______	21. ________	21. ________
21. CL215 # 218	22. _______	22. ________	22. ________
22. CL215 # 219	23. _______	23. ________	23. ________

23. Other Air Tanker 24. Helicopter 25. Transport AC 26. Fire Petrol AC 27. Detection AC 28. Agricultural aircraft 29. Bird Dog 30. Float Plane	24. ______ 25. ______ 26. ______ 27. ______ 28. ______ 29. ______ 30. ______	24. _______ 25. _______ 26. _______ 27. _______ 28. _______ 29. _______ 30. _______	24. _______ 25. _______ 26. _______ 27. _______ 28. _______ 29. _______ 30. _______
Heavy Equipment ***Type:*** 31. Bulldozer 32. Skidder/forwarder 33. Heavy all terrain Vehicles 34. Water truck 35. Values Protection Unit 36. Semi Lowbed 37. Excavator 38. Bus 39. Yard Vehicle	31. ______ 32. ______ 33. ______ 34. ______ 35. ______ 36. ______ 37. ______ 38. ______ 39. ______	31. _______ 32. _______ 33. _______ 34. _______ 35. _______ 36. _______ 37. _______ 38. _______ 39. _______	31. _______ 32. _______ 33. _______ 34. _______ 35. _______ 36. _______ 37. _______ 38. _______ 39. _______
Map Type			

SCENARIO 2: windspeed 20 km/h

5. What are the main considerations or challenges for Scenario 2? For example, provide more details regarding proximity of the WUI, Values at Risk (VAR), budget considerations, other fires in area, resource availability, etc.

   a. ____________________

   b. ____________________

c. ____________________

6. Would you use or order maps for this fire?

   a. Yes __________ *(if yes, answer question 6.a.i.)*

      i. What types of maps? Please list all that apply. What would you be willing to spend on each type of map?

         i. ____________________ $____________________

         ii. ____________________ $____________________

         iii. ____________________ $____________________

   b. No ___________*(if no, answer question 6.b.i.)*

      i. Why not? Please list all the appropriate reasons.

         1. Too expensive
         2. Believe benefits of maps are too low
         3. Not enough mapping support
         4. Maps are unsuitable
         5. Other ______________________

7. Are there maps you feel are indispensable?

   a. No____________(Please go to the next section).

   b. Yes___________ (please list all that apply and please provide a list of characteristics that are highly important to fire fighting success.)

      i. ____

      ii. ____

      iii. ____

8. List the resources you would order for this fire with and without availability of the GIS technologies/Maps:

Name of Resource	**Unit**	**# with GIS**	**# without GIS**
Number of Personnel ***Type:*** 1.Type 1 (SE/FF)	 1.________ 2.________	 1.__________ 2.__________	 1.__________ 2.__________

2.Type 2 (FN/NW) 3.Type 3 (EFFs)	3.________	3._________	3._________
<u>Fire Fighting Equipment</u> ***<u>Type:</u>*** 4.Pumps 5.Hose 6.Pump trailer 7.Hand Tools (shovel, Pulaski, backpack, etc) 8.Burnout torch 9.Sprinkler System 10.Water Bladder 11.Chainsaw	 4.________ 5.________ 6.________ 7.________ 8.________ 9.________ 10._______ 11._______	 4._________ 5._________ 6._________ 7._________ 8._________ 9._________ 10.________ 11.________	 4._________ 5._________ 6._________ 7._________ 8._________ 9._________ 10.________ 11.________
<u>Aircraft</u> ***<u>Type:</u>*** 12. Tracker Team 1 13. Tracker Team 2 14. CL215 Team # 3 15. CL215 Team # 4 16. CL215 Team # 5 17. CL215 # 214 18. CL215 # 215 19. CL215 # 216 20. CL215 # 217 21. CL215 # 218 22. CL215 # 219	 12. _______ 13. _______ 14. _______ 15. _______ 16. _______ 17. _______ 18. _______ 19. _______ 20. _______ 21. _______ 22. _______ 23. _______	 12. ________ 13. ________ 14. ________ 15. ________ 16. ________ 17. ________ 18. ________ 19. ________ 20. ________ 21. ________ 22. ________ 23. ________	 12. ________ 13. ________ 14. ________ 15. ________ 16. ________ 17. ________ 18. ________ 19. ________ 20. ________ 21. ________ 22. ________ 23. ________

23. Other Air Tanker 24. Helicopter 25. Transport AC 26. Fire Petrol AC 27. Detection AC 28. Agricultural aircraft 29. Bird Dog 30. Float Plane	24. ______ 25. ______ 26. ______ 27. ______ 28. ______ 29. ______ 30. ______	24. ________ 25. ________ 26. ________ 27. ________ 28. ________ 29. ________ 30. ________	24. ________ 25. ________ 26. ________ 27. ________ 28. ________ 29. ________ 30. ________
Heavy Equipment ***Type:*** 31. Bulldozer 32. Skidder/forwarder 33. Heavy all terrain Vehicles 34. Water truck 35. Values Protection Unit 36. Semi Lowbed 37. Excavator 38. Bus 39. Yard Vehicle	31. ______ 32. ______ 33. ______ 34. ______ 35. ______ 36. ______ 37. ______ 38. ______ 39. ______	31. ________ 32. ________ 33. ________ 34. ________ 35. ________ 36. ________ 37. ________ 38. ________ 39. ________	31. ________ 32. ________ 33. ________ 34. ________ 35. ________ 36. ________ 37. ________ 38. ________ 39. ________
Map Type			

SCENARIO 3: Wind speed 30 km/h

9. What are the main considerations or challenges for Scenario 3? For example, provide more details regarding proximity of the WUI, Values at Risk (VAR), budget considerations, other fires in area, resource availability, etc.

   a. ____________________

   b. ____________________

c. ____________________

10. Would you use or order maps for this fire?

a. Yes __________ *(if yes, answer question 10.a.i.)*

i. What types of maps? Please list all that apply. What would you be willing to spend on each type of map?

i. ____________________ $____________________

ii. ____________________ $____________________

iii. ____________________ $____________________

b. No ___________*(if no, answer question 10.b.i.)*

i. Why not? Please list all the appropriate reasons.

1. Too expensive
2. Believe benefits of maps are too low
3. Not enough mapping support
4. Maps are unsuitable
5. Other ______________________

11. Are there maps you feel that are indispensable?

a. No____________(Please go to the next section).

b. Yes___________ (please list all that apply and please provide a list of characteristics that are highly important to fire fighting success.)

i. ____

ii. ____

iii. ____

12. List the resources you would order for this fire with and without availability of the GIS technologies/Maps:

Name of Resource	**Unit**	**# with GIS**	**# without GIS**
<u>**Number of Personnel**</u>			
<u>Type:</u>	1.________	1.__________	1.__________
1.Type 1 (SE/FF)	2.________	2.__________	2.__________

2.Type 2 (FN/NW) 3.Type 3 (EFFs)	3.________	3.__________	3.__________
<u>Fire Fighting Equipment</u> ***<u>Type:</u>*** 4.Pumps 5.Hose 6.Pump trailer 7.Hand Tools (shovel, Pulaski, backpack, etc) 8.Burnout torch 9.Sprinkler System 10.Water Bladder 11.Chainsaw	 4.________ 5.________ 6.________ 7.________ 8.________ 9.________ 10.______ 11.______	 4.________ 5.________ 6.________ 7.________ 8.________ 9.________ 10._______ 11._______	 4.________ 5.________ 6.________ 7.________ 8.________ 9.________ 10._______ 11._______
<u>Aircraft</u> ***<u>Type:</u>*** 12. Tracker Team 1 13. Tracker Team 2 14. CL215 Team # 3 15. CL215 Team # 4 16. CL215 Team # 5 17. CL215 # 214 18. CL215 # 215 19. CL215 # 216 20. CL215 # 217 21. CL215 # 218 22. CL215 # 219	 12. _______ 13. _______ 14. _______ 15. _______ 16. _______ 17. _______ 18. _______ 19. _______ 20. _______ 21. _______ 22. _______ 23. _______	 12. ________ 13. ________ 14. ________ 15. ________ 16. ________ 17. ________ 18. ________ 19. ________ 20. ________ 21. ________ 22. ________ 23. ________	 12. ________ 13. ________ 14. ________ 15. ________ 16. ________ 17. ________ 18. ________ 19. ________ 20. ________ 21. ________ 22. ________ 23. ________

23. Other Air Tanker 24. Helicopter 25. Transport AC 26. Fire Petrol AC 27. Detection AC 28. Agricultural aircraft 29. Bird Dog 30. Float Plane	24. ______ 25. ______ 26. ______ 27. ______ 28. ______ 29. ______ 30. ______	24. _______ 25. _______ 26. _______ 27. _______ 28. _______ 29. _______ 30. _______	24. _______ 25. _______ 26. _______ 27. _______ 28. _______ 29. _______ 30. _______
Heavy Equipment ***Type:*** 31. Bulldozer 32. Skidder/forwarder 33. Heavy all terrain Vehicles 34. Water truck 35. Values Protection Unit 36. Semi Lowbed 37. Excavator 38. Bus 39. Yard Vehicle	31. ______ 32. ______ 33. ______ 34. ______ 35. ______ 36. ______ 37. ______ 38. ______ 39. ______	31. _______ 32. _______ 33. _______ 34. _______ 35. _______ 36. _______ 37. _______ 38. _______ 39. _______	31. _______ 32. _______ 33. _______ 34. _______ 35. _______ 36. _______ 37. _______ 38. _______ 39. _______
Map Type			

Part III: Socio-economic/Demographic Questions:

1. What is your current position? _____________________
2. Years and months in present position: _______________
3. Years of fire experience: ___________________
4. Regarding risk, how would *you* describe *yourself*:

a. Risk taker

b. Risk neutral

c. Risk averse

5. What is your highest level of education? Please circle one.

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Jr. High High School University or Tech Graduate School

6. What is your age? ____________

7. Are you _____________Female, _____________Male

8. Do you have formal GIS training? ____________Yes, _________ No.

For which types of mapping? List all that apply:

____

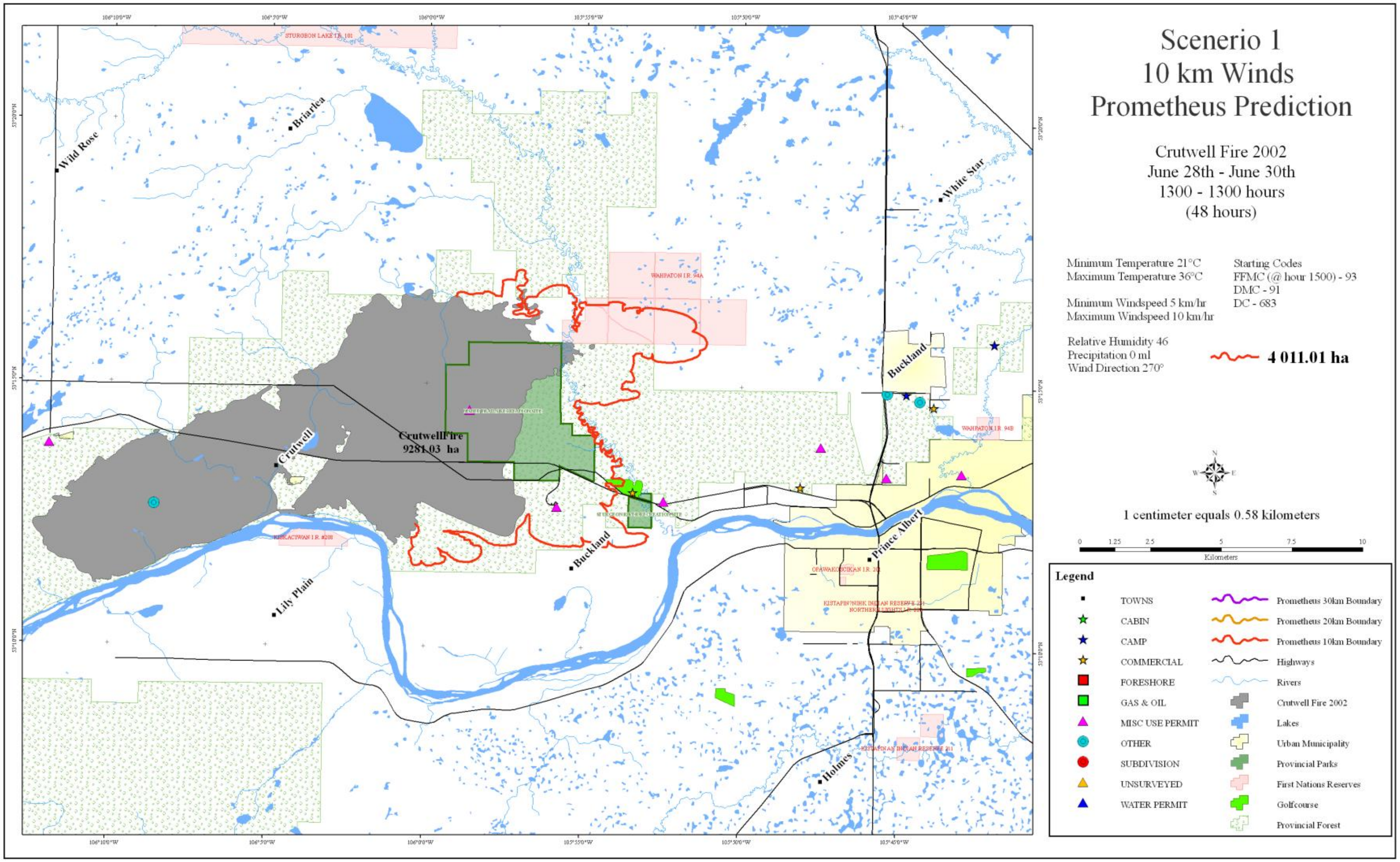
____

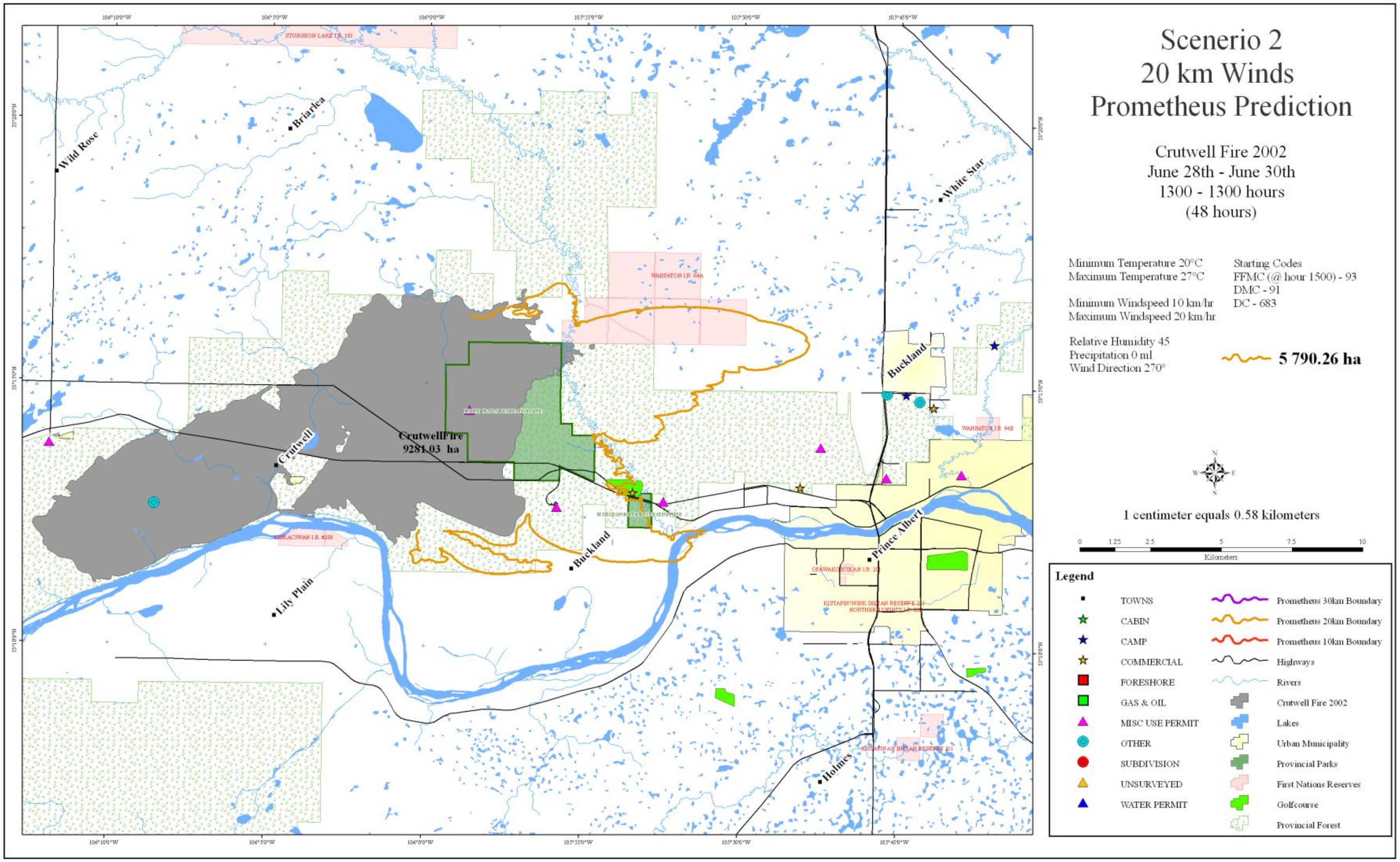
If yes, please answer the following questions where 1 = not satisfied, 5 = highly satisfied, N/A = not applicable:

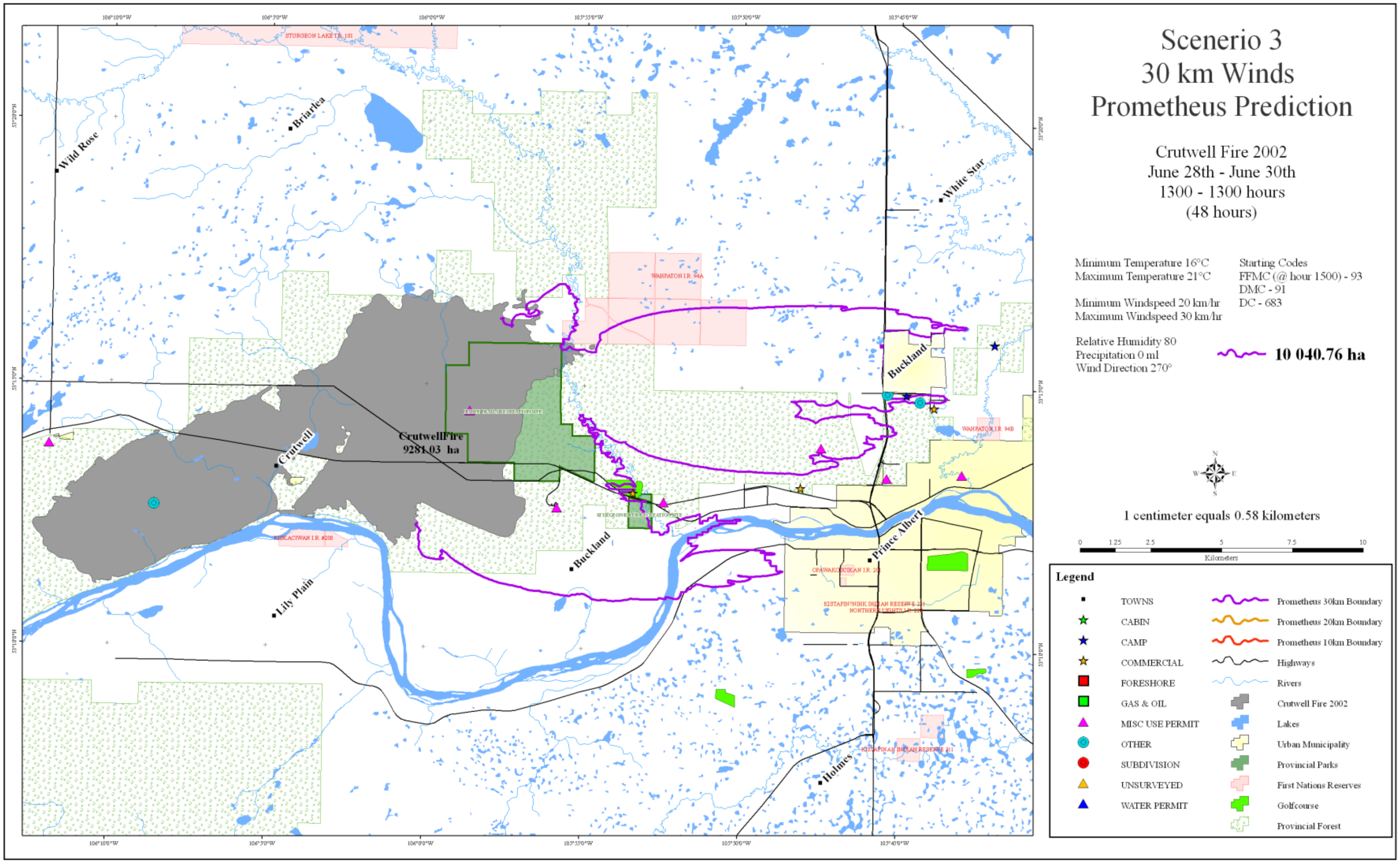
a.	GIS workshop	1	2	3	4	5
b.	Department training	1	2	3	4	5
c.	On the job experience	1	2	3	4	5
d.	Formal education	1	2	3	4	5
e.	Other ____________________	1	2	3	4	5

Thank you for participation in the Survey.

We would appreciate any additional comments – please use the back page.


Scenerio 1
10 km Winds
Prometheus Prediction
Crutwell Fire 2002
June 28th - June 30th
1300 - 1300 hours
(48 hours)
Minimum Temperature 21°C
Maximum Temperature 36°C
Minimum Windspeed 5 km/hr
Maximum Windspeed 10 km/hr
Relative Humidity 46
Precipitation 0 ml
Wind Direction 270°
Starting Codes
FFMC (@ hour 1500) - 93
DMC - 91
DC - 683
4 011.01 ha
CrutwellFire
9281.03 ha
1 centimeter equals 0.58 kilometers
0 1.25 2.5 5 7.5 10
Kilometers
Legend
TOWNS
CABIN
CAMP
COMMERCIAL
FORESHORE
GAS & OIL
MISC USE PERMIT
OTHER
SUBDIVISION
UNSURVEYED
WATER PERMIT
Prometheus 30km Boundary
Prometheus 20km Boundary
Prometheus 10km Boundary
Highways
Rivers
Crutwell Fire 2002
Lakes
Urban Municipality
Provincial Parks
First Nations Reserves
Golfcourse
Provincial Forest
Wild Rose
Briarlea
White Star
Buckland
Crutwell
Lily Plain
Prince Albert
Holmes
STURGEON LAKE I.R. 101


Scenerio 2
20 km Winds
Prometheus Prediction
Crutwell Fire 2002
June 28th - June 30th
1300 - 1300 hours
(48 hours)
Minimum Temperature 20°C
Maximum Temperature 27°C
Minimum Windspeed 10 km/hr
Maximum Windspeed 20 km/hr
Relative Humidity 45
Precipitation 0 ml
Wind Direction 270°
Starting Codes
FFMC (@ hour 1500) - 93
DMC - 91
DC - 683
5 790.26 ha
1 centimeter equals 0.58 kilometers
0 1.25 2.5 5 7.5 10
Kilometers
Legend
TOWNS
CABIN
CAMP
COMMERCIAL
FORESHORE
GAS & OIL
MISC USE PERMIT
OTHER
SUBDIVISION
UNSURVEYED
WATER PERMIT
Prometheus 30km Boundary
Prometheus 20km Boundary
Prometheus 10km Boundary
Highways
Rivers
Crutwell Fire 2002
Lakes
Urban Municipality
Provincial Parks
First Nations Reserves
Golfcourse
Provincial Forest
CrutwellFire
9281.03 ha
Wild Rose
Briarlea
White Star
Buckland
Crutwell
Lily Plain
Prince Albert
Holmes
STURGEON LAKE I.R. 101
WAHPATON I.R. 94A
WAHPATON I.R. 94B


Scenerio 3
30 km Winds
Prometheus Prediction
Crutwell Fire 2002
June 28th - June 30th
1300 - 1300 hours
(48 hours)
Minimum Temperature 16°C
Maximum Temperature 21°C
Minimum Windspeed 20 km/hr
Maximum Windspeed 30 km/hr
Relative Humidity 80
Precipitation 0 ml
Wind Direction 270°
Starting Codes
FFMC (@ hour 1500) - 93
DMC - 91
DC - 683
10 040.76 ha
1 centimeter equals 0.58 kilometers
0 1.25 2.5 5 7.5 10
Kilometers
Legend
TOWNS
CABIN
CAMP
COMMERCIAL
FORESHORE
GAS & OIL
MISC USE PERMIT
OTHER
SUBDIVISION
UNSURVEYED
WATER PERMIT
Prometheus 30km Boundary
Prometheus 20km Boundary
Prometheus 10km Boundary
Highways
Rivers
Crutwell Fire 2002
Lakes
Urban Municipality
Provincial Parks
First Nations Reserves
Golfcourse
Provincial Forest
CrutwellFire
9281.03 ha
Wild Rose
Briarlea
White Star
Buckland
Crutwell
Lily Plain
Prince Albert
Holmes
STURGEON LAKE I.R. 101
WAHPATON I.R. 94A
WAHPATON I.R. 94B