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LIMITED REPORT

Relationships of Forest, Climate, Wildfires and Respiratory Ailments in Northern Saskatchewan

for

Climate Change Impacts and Adaptation Program
Natural Resources Canada
Agreement A573

by

L. Langford, V. Wittrock, M. Johnston,
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SUMMARY

Climate change has the potential to significantly alter environmental and human conditions over much of the country and indeed the planet over the coming decades. The need to better understand how ecosystems including humans will be impacted is paramount. This study has been undertaken to assess the relationships between forest wildfire conditions, respiratory health and climate change and is but a small step toward a better understanding of complex relationships between human condition, environmental condition and future climate.

The study area is situated in northern Saskatchewan and includes three northern Saskatchewan health authorities known as the Keewatin Yatthé, the Mamawetan Churchill and the Athabasca Health Authorities. These authorities cover about 46% of the land area of the province (predominantly boreal forest) with a population of about 35,000 people spread over at least 60 communities. Over 83% of the population is Aboriginal. The three northern health authorities have had the highest hospitalization rates for respiratory conditions in the province. Due to the proximity of residents to the forest and exposure to smoke from wildfire and the already high indicators of respiratory illness, this northern population would be vulnerable to the potential impact of climate change on wildfires.

The study involved several key components including an analysis of key parameters (forest fires, hospitalizations, evacuations), an analysis of specific case studies, smoke dispersion and an assessment of climate change trends and future fire activity. The methodology applied indicates that the relationships between wildfire smoke and hospitalizations appear weak. It is assumed that there may be a number of factors which influences the capacity of significance and the reasons for findings should be determined and tested because continued climate change will increase the risk of wildfires and their smoke emissions in northern Saskatchewan.

From a fire management perspective, current management practices including the selective evacuation of individuals and communities at risk appear to be helping to minimize current health risks, however, anticipated increases in fire activities in the future will increase the health risk to residents as forest fire activities increases. Provincial policy to suppress or not to suppress wildfires may be challenged as fire activity increases. Pressures from northern communities for additional fire suppression measures or improved evacuation measures may have implications for the provincial budget and associated government agencies.

Recommendations for future study include further development of the methodology some of which will increase the power of the study e.g. combining diagnostic groups together, lumping health authorities together, testing different time periods as well as undertaking further discussion and assessment of adaptation options.

Contributions of this study toward the advancement of knowledge relating to climate change and human health include the development of a comprehensive, integrated climate, wildfire and health database, a literature review of particulate matter and human health, plus a workshop regarding the impact of and adaptation to the effects of wildfires and smoke on human health. This study is also one of the first assessments of climate, wildfire and health relationships over several years and lays the groundwork for future work.

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LIST OF ABBREVIATIONS AND ACRONYMS

°C	degrees Celsius
ha	Hectare
mm	Millimeters
RHA	Regional Health Authority
RHA 9	Prince Albert Parkland Health Region
RHA 11	Mamawetan Churchill River Health Region
RHA 12	Keewatin Yatthé Health Region
RHA 13	Athabasca Health Authority

1.0 BACKGROUND

Within the last several years, the Province of Saskatchewan has been reviewing provincial forest management and fire management policies. At the same time, the potential for global climate change is challenging government agencies and others to begin factoring in possible global warming impacts as policy decisions are being made.

In addition, there is growing public concern regarding air quality and other environmental conditions and the linkages between these environmental conditions and human health.

Canadian statistics show that Saskatchewan's asthma hospitalization rates are one third above the national average. Northern residents in Saskatchewan appear to have some of the highest hospitalization rates in the province for respiratory and cardio-respiratory ailments. Previous studies in the United States, Europe and Canada have suggested associations between air pollution in general and fine particulate air pollution (PM10) and mortality and hospitalizations from respiratory and cardiovascular causes (Zanobetti 2000; Brunekreff 2002; Morris 2001, Bates 2002). Other studies have revealed the impact of fires on respiratory and cardiovascular health through population surveys of symptoms, emergency department visitations, and hospitalizations (Johnston 2002; Mott 2002; Lipsett 1994; Frankenberg 2005; Emmanuel 2000; Aditama 2000; Sastry 2002).

According to Saskatchewan Environment, the most prevalent source of outdoor generalized particulate matter affecting humans in northern Saskatchewan is smoke from forest wildfires. Other sources of particulate matter include forest harvesting and processing activities and mining however, these activities are considered to be minor sources. Tobacco smoke and smoke from wood heating systems may be other sources impacting individuals.

Because climate change has the potential to impact the number and frequency of forest wildfires in northern Saskatchewan, Saskatchewan Environment, Saskatchewan Health and the Saskatchewan Research Council initiated efforts to examine the relationships between forest wildfire occurrences and (respiratory and cardio-respiratory) hospitalization rates as well as assess the potential for increased forest fire activity in the future.

2.0 INTRODUCTION AND RATONALE

There are increasing concerns regarding climate change and the influence on health. The detection and measurement of health effects of climate change is challenging due to the complexity of influences on population health (WHO 2003). There has been concern that climate change could influence temperatures, precipitation, wind, lightening and length of the fire season and thus an impact on forest fires (Flannigan et al. 2000). Respiratory and cardiovascular health is influenced by air pollution including fine particulate pollution. What indirect effect is there potentially for climate change to influence human health through forest fires and smoke? To get a better understanding of the relationship of climate, forest fires and human health in order to predict future ramifications of climate change, a study of these relationships was done over two decades in northern Saskatchewan (1981-2003).

International studies show wildfire smoke can or has caused many health problems including increased respiratory symptoms, increased risk of respiratory illness, decreased lung function, increased cardiovascular hospitalizations and increased daily mortality (Bates et al. 2003, Brauer 1999, Burnett et al. 1999 and Morris 2001). Factors considered important to respiratory health are the effects of smoke on the local residents including the density and duration of the smoke in the community (Irvine 2005). A literature review of particulate matter and human health completed for this study substantiates these linkages and is provided as a companion document to this report (Froese 2005 Appendix A).

Smoke from forest fires contains compounds that can adversely affect human health. Particulate matter is the most consistently elevated pollutant associated with biomass smoke (Brauer 1999). Although wildfire is recognized as one of nine main issues affecting air quality in Saskatchewan, it is not known what the relative contribution of wildfires is to particulate levels in the province (Wheaton et al. 1995). Respiratory ailments have many possible causes including genetics, a variety of environmental factors and infectious agents, and socio-economic conditions. Environmental factors may be more important in the clinical expression of respiratory conditions, such as asthma (Osei 2002). Asthma hospitization rates in Saskatchewan are one third above the national average (Klomp et al. 2005).

West central and northwest portions of Canada, including Saskatchewan, have the highest wildfire occurrences and area burned in Canada (Stocks et al. 2003, SERM 2001). The number of forest fires in Canada has increased by about 65% during the 1930 to 1990 period (Stocks 1991). While many parts of Saskatchewan are allowed to burn (i.e., no fire suppression techniques are applied), it has been found in areas even where fire suppression is utilized, there has been an increase in area burned (Van Wagner 1988).

While fire suppression influences the area burned (Stocks et al. 2003), weather and the patterns of weather (climate) are the most important factors for fire occurrence in Western Canada (Stocks et al. 2003, Hely et al. 2001). Future changes in climate are expected to increase the risk of forest wildfires in northern Saskatchewan in the next decades (e.g. Wheaton 2001*a*).

Weather and its synthesis, climate, are the most important natural factors influencing forest fires (e.g. Flannigan and Wotton 2001; Hely et al. 2001). Wittrock and Wheaton (1997) compared forest fire characteristics in northern Saskatchewan with several climate variables. Fire numbers and area burned were closely related to variables such as temperature. Flannigan and Harrington (1988) also found that temperature seems to be the best predictor of area burned. Large forest fires occur during weather conditions that are considered extreme in terms of fire weather conditions, that is, hot, windy and dry (Flannigan et al. 2005).

The largest areas burned in Canada are in the west-central and north-west boreal forest and taiga. The area burned in Canada has increased over the past 40 years along with the increase in temperatures and length of the warm season. This increase in area has occurred despite an increase in both the area under fire suppression management and more efficient fire suppression techniques. Gillett et al. (2004) demonstrate that human emissions of greenhouse gases and sulfate aerosol have made a detectable contribution to this warming.

3.0 PURPOSE AND OBJECTIVES

This project examines the relationship between forest wildfire conditions and respiratory ailments in northern Saskatchewan and estimates possible impacts of climate change on these relationships to assist in the identification of future management issues and possible adaptation options. The conceptual framework of these linkages is overviewed in Figure 1.

This ecologic study is intended to assess linkages between air quality and human health, particularly the vulnerability of northern residents to health impacts generated by increased fire activity and exposure to smoke as a result of climate change. This work will provide information that will assist in the identification of future forest and fire management issues, air quality concerns, public health issues and adaptations challenges. It will support long-term adaptation strategies by fire and resource managers and emergency services for northern Saskatchewan as well as decision makers in and beyond the study area as described in the project's feasibility study (Warnock et al. 2003). The contributions of this work include the development of integrated databases and their documentation and methodologies for assessing these health-environment linkages, as well as the identification of future management issues and possible adaptation options. No other work has examined the relationships between respiratory health and forest wildfires over a number of fire seasons and assessed the possible effect of climate change.

The purpose of the study is to examine the relationships between wildfire conditions and respiratory ailments in residents of northern Saskatchewan and to estimate possible impacts of climate changes on these relationships to assist in the identification of adaptation options. The objectives are to:

1. describe the respiratory health, fire/fuel and meteorological conditions associated with significant wildfires in northern Saskatchewan over a 25-year period. Significant wildfires are defined, for this work, as wildfires that have resulted in evacuations and/or may be associated with respiratory health impacts.
2. examine the relationship between fuel types and smoke characteristics, then assess the relationship between wildfires and respiratory health for significant wildfires.
3. provide preliminary estimates of possible respiratory health concerns for northern communities for a range of climate change, fuel type, smoke and wildfire scenarios.
4. explore adaptation options and formulate recommendations.

In this study, hospitalizations for cardio-respiratory causes will be assessed as an indicator of morbidity which is potentially a more sensitive indicator than mortality.

The report is organized into the following main sections: study area overview; database development including climate, fire and health data; methods, results, discussion of the main findings, conclusions and recommendations for further work. Appendices include a literature review of particulate matter effects on health, figures, and the workshop report which explores adaptation options and documents presentations given.

4.0 STUDY AREA DESCRIPTION

The study area (Figure 2) is the area covered by three northern Saskatchewan health authorities (Keewatin Yatthé and Mamawetan Churchill River Health Regions and the Athabasca Health Authority) which covers 46% of the province (Irvine and Stockdale 2004). This area approximates the Northern Administration District of Saskatchewan and Statistics Canada's Census Division Number 18 for Saskatchewan. The Prince Albert – Parkland Health Region was also included for some of the analysis as it is a more densely populated health region lying on the southern fringe of the boreal forest and is impacted some by fires and by smoke from northern fires.

The three northern Regional Health Authorities (RHA) were chosen because these RHAs are all within the boreal forest and thus potentially impacted by forest fire smoke, and have had the highest hospitalization rates for respiratory conditions in the province based on previous studies from 1992 to 1996 hospitalization rates with relatively stable rates from 1982 to 1994 (Osei and Virage 1999; Irvine et al 1999). The Athabasca RHA has respiratory hospitalization rates ranging from 220 per 1000 population per year to Mamawetan Churchill River RHA's rate of 300 per 1000 population per year (Osei and Virag 1999). Saskatoon and Regina's RHA hospitalization rates are lower at 60 per 1,000 and 70 per 1,000 respectively (Osei and Virag 1999).

The geography of the three northern RHAs regions of about 270,000 square kilometers is predominately boreal forest with most of the communities in this area being in close proximity to the forest and thus impacted by both the threat of forest fire as well as the smoke generated by forest fires. The health status of Saskatchewan's northern residents is already vulnerable with higher infant mortality rates, and lower life expectancy than other populations in the province.

4.1 Population and Health

The population of RHA 11 (Mamawetan Churchill River), 12 (Keewatin Yatthé) and 13 (Athabasca Health Authority) in 2003 was approximately 34,495 people spread among at least 60 communities that include towns, villages and Reserves (Figure 2). Over 83% of the population is Aboriginal (Irvine and Stockdale 2004). The majority of these people live in the Mamawetan Churchill River RHA with the smallest number living in the Athabasca RHA (Irvine and Stockdale 2004). The Prince Albert-Parkland Regional Health Authority had a population of 76,759 in 2003.

The population of northern Saskatchewan has historically been considered highly mobile. In 2001, compared with 1996, the percentage of people moving out of northern Saskatchewan has slowed. This is mainly due to employment opportunities developed in the north that allow people to stay or to move back (Irvine and Stockdale 2004).

Respiratory diseases include a variety of illnesses including chronic obstructive pulmonary diseases, asthma, bronchiolitis, respiratory distress syndrome and many others (Irvine and Stockdale 2004). Respiratory diseases contribute to 9% of deaths in northern Saskatchewan as the fourth most common cause of death following injuries and poisoning, circulatory diseases and cancer. Deaths from chronic obstructive lung disease and lung cancer are greater in northern Saskatchewan than the rest of the province (Irvine and Stockdale 2004).

Respiratory diseases can be influenced by many factors including genetics, socio-economic status, race, exposure to smoking, indoor air quality, outdoor air quality and others. In Canada, the two most important preventable risk factors for respiratory disease are considered to be smoking and air quality (indoor and outdoor) (Irvine and Stockdale 2004).

4.2 Climate

Northern Saskatchewan is characterized as having a harsh continental climate with long, cold winters and short, cool summers. Usually, the mean annual temperatures are near or below freezing (Bauer 1976). Average January (July) daily temperatures range from about -20ºC (18ºC) in the southern part of northern Saskatchewan to -27ºC (15ºC) in the northern part of Saskatchewan (Environment Canada 1984).

Zhang et al. (2000) show that the mean daily maximum temperature has increased by 1 to 2°C over the 1900-1998 period over northern Saskatchewan. The mean daily minimum temperatures have risen by more than 2°C during 1900-1998. The greatest amount of warming has occurred during winter and early spring.

Drought is a recurring phenomenon in the boreal forest and has been associated with large-scale fires (Simard et al. 1987). A drought is a prolonged and abnormal moisture deficiency. A drought is a time interval when the moisture supply of a region is consistently less than the normal moisture supply (Palmer 1965). A forest drought has been described as a long sequence of days without rain (<1.5 mm) and with low relative humidity (<60%) (Flannigan and Harrington 1988).

A forest drought has a strong relation to area burned. Drought conditions influence the fuel moisture content (Clark 1991; Harrington and Flannigan 1993). Extended dry spells provide dry fuel plus time for fire ignition, fire spread and at least one strong wind episode (Harrington and Flannigan 1993). Drought conditions make the forest susceptible to fire starts as the fine fuels as well as the larger lumber becomes drier. Prolonged dry spells also have a strong correlation with intense hot fires (Byram 1954).

5.0 DATABASE DEVELOPMENT

Several databases were obtained and processed for use in the analysis. These databases include information on climatic elements, forest fire area burned, population, health and evacuations (Table 1). The database characteristics, including period of record used, station networks, and completeness are described in this section. Quality assurance characteristics of the data were detailed in Warnock et al. (2003).

The 1981 to 2003 period was chosen because that is the earliest date when digitized information was available for all fires from Saskatchewan Environment. Also, the data from health, climate, and population are also considered good for that period (Warnock et al. 2003).

Sources of error can be found in all the data bases. These typically arise from observational error, instrumental error, reporting and data handling. Data are also missing from most data bases and this is discussed in each section.

5.1 Forest Fire Database

A computerized forest fire database has been compiled for Saskatchewan by Fire Management and Forest Protection Branch, Saskatchewan Environment for 1981 to present. Information in this database includes fire discovery and extinguished dates, area burned, location and other related information.

As illustrated by Figure 3, the study area roughly corresponds with three forest protection regions as defined by Saskatchewan Environment called East Boreal, Shield and West Boreal Forest Protection Regions. The southern-most portions of the East Boreal and West Boreal regions, although not within the study area RHAs, are included in the analysis since fires in the southern portion of these regions may affect people living in northern Regional Health Authorities. The database was imported into Microsoft Excel 2003 for analysis.

5.2 Population Database

A computerized population database was complied for Saskatchewan by Saskatchewan Health for the years 1981-2003. Missing years are 1982-1985 and 1988-1989 (Table 2). The population data are based on eligibility for health insurance benefits in Saskatchewan and therefore only include Saskatchewan residents. The data were imported into Microsoft Excel 2003 for analysis.

Saskatchewan Health estimates population within each Regional Health Authority yearly based on the postal code of the latest Saskatchewan Health registration address. While this method of assigning a residence code estimates population in a region, the numbers may not accurately indicate the actual residence within the RHA as the persons could be living on a reserve or in a neighboring municipal community (Irvine and Stockdale 2004). The Saskatchewan Health population values tend to overestimate town and village populations and underestimate reserve populations in northern communities because it is difficult to distinguish reserves from the northern towns and villages (Saskatchewan Health 2003). Also, the population information used for the communities in the case study is for the communities named. They do not include surrounding population such as near-by Reserves.

Statistics Canada census data for 1996 were used to obtain a standardized population base for use in population and health analysis.

5.3 Health Database

In this study, hospitalizations for cardio-respiratory causes was used as an indicator of morbidity which is potentially a more sensitive indicator than mortality as they involve greater numbers of subjects (Morris 2001). Outpatient and emergency department data are not routinely available and primary care billing data is less complete and accurate within incomplete capture through primary care health centers involving primary care nurses and salaried physicians. Hospitalization data is routinely and reliably collected by Saskatchewan Health for Saskatchewan residents and information is available for all in-patient hospitalizations by diagnostic cause for the population of specific regions no matter where they are admitted to hospital including those outside of the province.

For this study, hospital separation information was obtained to assess the changing rates of hospitalization for cardio-respiratory diagnosis by the same populations over time.

A computerized database containing hospital admittances information was obtained from Saskatchewan Health for individuals from the four Health Regions (9 to 13) with hospital separations from 1979-1980 to 2000-2001 by week of week of separation with a cardio-respiratory diagnosis.

These data contain weekly information for the years 1979-1980 to 2000-2001. The information is for four Regional Health Authorities: Prince Albert Parkland (RHA 9), Keewatin Yatthé (RHA 12); Mamawetan Churchill River (RHA 11) and Athabasca (RHA 13). Registered Indian persons were assigned to their place of residence using the place of residence indicated on the Health Insurance Registry File/Person Registry System at the time of hospitalization. The health data were received in Microsoft Excel format.

The data on cardio-respiratory diagnosis on discharge were provided by Saskatchewan Health and were divided into four diagnostic groups based on International Classification of Disease – Ninth Edition (ICD-9) codes:

- Diagnostic Group 1: 490-496 (Chronic Obstructive Pulmonary Disease and Allied Conditions including bronchitis, emphysema, asthma, bronchiectasis, alveolitis and pneumonitis),
- Diagnostic Group 2: 500-508.9 (Pneumoconiosis and other Lung Diseases due to External Cause),
- Diagnostic Group 3: 410-417 (Ischemic Heart Disease including acute myocardial infarction, angina pectoris, coronary atherosclerosis, aneurysm, and chronic ischemic heart disease), and
- Diagnostic Group 4: 428 (Heart Failure)

Any hospitalization by residents of the four health regions (RHAs 9 to 13) were included for the specified diagnosis but were included not contingent on location of hospitalization. Thus, individuals determined by their Saskatchewan Health information to be residents of those four regions who were hospitalized in facilities outside of those regions were included in the data. For some of the areas of northern Saskatchewan, the primary location of hospitalization may be out of the health region such as in Fort McMurray (Alberta), Flin Flon (Manitoba), Meadow Lake, Prince Albert or Saskatoon.

5.4 Evacuation Database

A computerized evacuation database has been compiled for Saskatchewan by Saskatchewan Community Resources and Employment. The data provide the number of people evacuated from specified evacuation sites and time period of evacuation. The data also include the location to which the people were evacuated.

The standards and policies for evacuation decisions based on smoke exposure have changed through the years. Prior to the mid-1990s, the strategy for evacuation was less developed than recent guidelines (Irvine personal communication 2005). In the late 1990s and early 2000s, a guideline for assessing forest fire smoke and other threats to a community was developed (Irvine 2005). This document includes criteria for visibility and implications for particulate levels for the community being affected by the fire. It emphasizes the need for municipal and community leaders and provincial organizations including Saskatchewan Health and Saskatchewan Environment to work together to determine the appropriate evacuation strategy but the final decision for evacuation is made by the elected local officials (Irvine 2005). When the evacuation order is issued, it is recommended that consideration be given to the following individuals, in order of priority, keeping family units together:

- citizens with respiratory and/or cardiac problems
- elderly and infirm people and young children (with their mothers)
- people requiring special care (wheelchair, stretcher cases, institutionalized residents)
- prenatal clients
- any others, on a case by case basis.

5.5 Climate Database

Climate information was obtained from Environment Canada and Fire Management and Forest Protection Branch, Saskatchewan Environment for 1981-2003 (Figure 4). Data variables analyzed include temperature (maximum, minimum, mean), precipitation and wind speed and direction (where available). This data was imported into Microsoft Excel 2003 for analysis.

5.6 Developing Climate Change Scenarios

To develop possible future possible climate scenarios of the study area, some of the main Global Climate Models (GCMs) were used. A climate model is a numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes (Watson and the Core Writing Team, IPCC 2001). A major advantage of using GCMs is that they are the only tool for estimation of changes in climate due to increased greenhouse gases for a large number of climate variables in a physically consistent method (Carter et al. 2000). The future climates described here include similar experiments and time periods used for estimating future fire characteristics. Recent experiments with the GCMs and the emission scenarios of greenhouse gases are described in Barrow et al. (2004). They provide results for the second version of the Canadian Model (CGCM2), the UK Hadley model (HadCM3), and several other GCMs.

These GCMs are forced with the emissions of greenhouse gases and aerosols described in Carter et al. (2000). These emission scenarios are called the SRES type based on the name of the Intergovernmental Report, i.e., *Special Report on Emissions Scenarios* (Nakicenovic and Swart 2000). About forty emission scenarios were developed for that work and classified into four main families, depending on the focus of the scenarios. The emission scenario families differ by emphasis on regional or global development and environmental or economic considerations. The simulations are labeled by family and number within that family, for example, A1, A2, B1 and B2. The A1 scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines after, and the rapid introduction of new and more efficient technologies. The A2 family is a more heterogeneous world with greater preservation of local identities. Economic development is more regionally oriented and technological change is more fragmented and slower than the other families. The B1 family is a convergent world with the same population dynamics as A1, but with rapid change in economic structures toward a service and information economy with the introduction of clean and resource-efficient technologies. Lastly, the B2 family depicts an emphasis on local solutions to economic, social and environmental sustainability. Global population continuously increases, but at a lower rate than A2 (Watson and the Core Writing Team 2001).

6.0 METHODS AND RESULTS

The study involved several key components including an analysis of key parameters, an assessment of climate change trends, the selection and more in depth analysis of specific case studies and an examination of smoke dispersion for the case study areas. A set of case studies was selected to provide more detail regarding the nature of the relationships particularly between fire and health data. The trend data were used to select the most appropriate years for the cast studies.

6.1 Analysis of Key Parameters

Three main types of analyses were applied to the databases. First various characteristics of the time series of each type of data were calculated and graphed. Secular trends of each data type are described and compared with one another to begin to assess possible relationships. Then regression methodologies were used to explore the nature of the relationship between the independent variables (fire characteristics) and the dependent variables (disease outcomes). The Pearson Product Moment correlation analysis SPSS 13.0 (2004) was used to measure the linear relationship between area burned and hospital admissions for example. Non-parametric correlations were also calculated using SPSS 13 (2004). Kendall's tau b and Spearman's rho correlations were calculated to determine if there was a non-linear relationship between area burned and hospital admissions.

6.1.1 Forest Fire Time Series

Ideally, smoke concentrations near populations should be used as the independent variable, however, these data are not collected nor are they readily available from remote sensing sources. Therefore fire data such as area burned was used as proxy variables, except for the case studies.

This section describes the extremes of the numbers and area burned of both total fires and large fires (those equal to or greater than 200 ha). Large fires are important as they account for 87 to 98% of the total area burned (Curren 1991), and therefore much of the smoke emissions.

The differences from average for annual number of fires (1981-2003) were calculated and plotted (Figure 5). The three years with the highest number of fires were 1998 (1260 fires), 1988 (1025), and 1989 (997). The four years with the lowest number of fires (numbers in brackets behind the year) were 2000 (398), 1996 (426), 1983 (432), and 1986 (489). The five year running mean illustrates that in general the early eighties had below average fires, the late eighties had above average number of fires and the 1990s were generally below average in terms of number of fires.

The differences from average for total annual area burned for northern Saskatchewan (1981-2003) were calculated and plotted (Figure 6). The three years with the largest area burned are 1981, 1995, and 1998. The three years with the smallest areas burned are 1997, 1996, and 1986. The five year running mean further illustrates that most of the eighties and early nineties had below average area burned while the mid-nineties had above average area burned and from 1999 onwards there was about average amount of area burned.

The number of fires greater than 200 ha average 47 per year. This is considerably lower than the average of 726 for all fires. The five year running average shows that the early 1980s were well below average in the number of fires. During the rest of the period, the five year running average hovered around average (Figure 7).

The patterns of the maxima and minima for the difference from average for area burned equal to or greater than 200 ha were the same as the patterns for all the fires (Figure 8). The three years with the highest area burned were 1981, 1995, and 1998. The three years with lowest area burned were 1997, 1996, and 1986. The five year running average again illustrates that the early 1980s had below average amount of area burned and the mid 1990s had above average area burned.

When the yearly time series trends are examined, 1995 and 1998 were two years with both a large area burned and a large number of fires. The years 1996 and 1997 were low both in number and area burned. This illustrates that while one year is extremely high in terms of area burned and number for fires, subsequent years may not be as extreme due in part to weather, as well as other effects.

6.1.2 Population Time Series

Total annual population data for the study area and for each Regional Health Authority were plotted (Figures 9 and 10). The population has increased by 10,214 people over the 1981-2003 period for the total of all four Regional Health Authorities. Population in Keewatin Yatthé (RHA 12) and Mamawetan Churchill River (RHA 11) has increased over the period. The population of all RHA's was below average prior to 1995 and above average after 1995 with the greatest increases in RHA 11 and 12 in the early 21st century. Population in Athabasca (RHA 13) has decreased since 1981, but that may have been due to closure of the Eldorado mine in Uranium City in 1982 with the subsequent decline in its population. When the data in this RHA are analyzed from 1986-2003, the population is increasing. The data are also split into sex and age categories for each year for each Regional Health Authority.

6.1.3 Health and Evacuation Time Series

The health data were plotted in a yearly time series difference from average (1980-2001) for each of the four diagnostic groups for the four regional health authorities (RHAs) in northern Saskatchewan (Figures 11 to 20). The four diagnostic groups are chronic obstructive pulmonary disease and allied conditions (Group 1), pneumoconiosis and other lung disease due to external agents (Group 2), ischaemic heart disease (Group 3) and heart failure (Group 4).

The Prince Albert Parkland (RHA 9) had a high number of admissions for the four diagnostic groups in the late 1980s and early 1990s with the highest number of admissions in 1990. Since 1993 the number of admissions in this RHA has generally been declining with a low in 2001 (Figure 11). The Keewatin Yatthé (RHA 12) had peak admission years occurring in the 1990s with the highest admission year in 1994. The lowest admission year was in 2001. The Mamawetan Churchill River (RHA 11) had peak admission years in the 1990s with the highest admissions in 1996. The lowest admissions were in 2001. The Athabasca (RHA 13) had a high number of admissions in the early eighties, but the peak year for admissions was in 1997. The lowest admissions were in 2001 (Figure 11 and 12).

The highest and lowest admission years for each health authority and each diagnostic group were determined. Group 1's highest admission years all occurred in the 1990s, while Group 2 highest admissions occurred in the early part of the 21st century except for the Athabasca RHA when an equal number of admissions occurred in 1981, 1999 and 2001. There were no admissions in any of the RHAs involved in this study for Group 3 (Ischaemic Heart Disease). This lack of hospital separations for this group of diagnosis under Ischemic Heart Disease for this time period is suspicious and likely indicates an error in capture of the ICD-9 codes for this diagnostic group. Thus, interpretation of the cardiovascular effects is severely limited in this analysis. This would also result in some loss of power in the overall study with a decrease in the overall number of hospitalizations. Group 4's highest number of admissions varied among the health authorities. Keewatin Yatthé (RHA 12) highest admission year for Group 4 was 1999. 1995 and 2000 were the years with the highest group 4 hospital admissions in the Mamawetan Churchill River (RHA 11) Regional Health Authority (Figure 13 to 20 and Table 3).

The highest number of evacuations in Northern Saskatchewan occurred in 1993, followed by 1989 and 1995 (Figure 21). The overall trend appears to be toward decreasing evacuations, especially since 1993.

6.2 Regional Climate Trends

Past climatic trends of areas including northern Saskatchewan were examined by several authors including Wittrock and Wheaton (1996), Wittrock and Wheaton (1997), Wheaton (2001*b*), Wheaton (1979), Bonsal et al. (2001), Zhang et al. (2001), Zhang et al. (2000), Shabbar and Bonsal (2004) and most recently by Vincent et al. (2004).

Wheaton (2001*b*) interpreted the maps created by Zhang et al. (2000). Based on this interpretation, conclusions relating to the temperature change over the 1900 to 1998 period are as follows:

- The mean daily maximum temperature exhibits statistically significant warming in the Prairie Provinces as compared to the rest of Canada, with the greatest warming in Saskatchewan at about 1.5 ºC for the annual value (Figure 22). The season of greatest warming is spring, with winter a close second, but not statistically significant. Summer warming is about 1.0 ºC and is statistically significant.
- The greatest increase in mean daily minimum temperature in Canada is in the prairies. Fall minimum temperature increases are highest for all of Canada in Alberta and Saskatchewan in the forest region at about 3.0 ºC (Figure 23).
- The daily temperature range has significantly decreased by about 0.5 ºC on an annual average basis. This change is a result of more rapid increases in the daily minimum temperatures as compared to the maxima.

Daily minimum and maximum temperature with an emphasis on trends and variability were examined for the 1950 to 1998 period (Bonsal et al. 2001). They found fewer days with extreme low temperatures during the winter, spring and summer and more days with extreme high temperatures in winter and spring. The length of the frost-free period is significantly longer than over most of Canada including the forested regions of the Prairie Provinces.

Shabbar and Bonsal (2003) show a general decrease in the frequency of cold spells and increase in the frequency of warm spells since the 1950s in Northern Saskatchewan. However, the duration of both the winter warm and cold spells has lengthened but not significantly.

Trends in annual precipitation have changed very little to about 15% increase over the Prairies (Figure 24). Generally, only the northern portions of the forest region and most of Manitoba have had statistically significant increases in precipitation amounts. Winter has the strongest increases seasonally followed by autumn. Summer generally shows little change to about a 10% increase over much of the Prairies.

6.3 Case Studies

The communities chosen for the case studies include Pelican Narrows, Hall Lake, Stanley Mission, Creighton, and Brabant Lake. These centres were chosen because they were affected by fires in 1995 to such an extent that people were evacuated from four out of the five communities. In 1992, no communities were evacuated from anywhere in Saskatchewan. The study area communities were also chosen because they had a climate station relatively close to them (Table 4 and Figure 25). Also, the population for the communities is underestimated because they do not include people living on Reserve lands. For example, in the 2001 census, the population for Pelican Narrows is about 650 plus 1153 = 1803 and for Stanley Mission 124 + 1248 = 1372.

Population information for 1992 and 1995 was not available for Hall Lake and Brabant Lake, but evacuations did occur. Of the other three communities chosen as study sites, Creighton was the largest with nearly 2,000 people and Stanley Mission was the smallest. However, Stanley Mission had the largest number of people evacuated followed by Hall Lake and Pelican Narrows. The large number of people evacuated from Stanley Mission could be the result of the close proximity of the fire or other factors influencing the smoke. Sometimes the location of the fire in relation to the road leading from the community can influence the evacuation notice as well with a community like Stanley Mission have a single access road compared to Creighton with several access and exit roads. While it is not known which fires had the most effect on the communities some large fires were close to the communities (Table 5 and Figure 25). The size of the fires ranged from 2,300 ha to over 100,000 ha. The fires started at the end of May to mid-June with some not being extinguished until mid August.

The population of RHA 11 has been increasing at a steady rate, just over 300 people per year for 1981 to 2003 (Figure 26). The age and sex break-down of RHA 11 (Figure 27) shows that the population of the area is young, with over 45% of the population being under the age of 20 in 1992 and 1995. The age grouping of 20 to 64 comprises 49% of the population.

The individual communities' demographics generally reflect the overall demographics of the entire RHA (Figures 28 to 30). However, there are some differences. For example, Pelican Narrows, Stanley Mission and Creighton had a younger population in 1992 than 1995.

The number of hospital admissions during the April to October fire season increased during the 1990s as compared to the 1980s in the Mamawetan Churchill River RHA with 1996 and 1993 being the highest admission years (Figure 31). The three lowest admissions in the 1990s were 1999, 1990 and 1992. The highest number of admissions for both men and women is for chronic obstructive pulmonary disease and allied conditions. Women in both 1992 and 1995 had above average number of admissions for this disease during the fire season. Men had below average occurrences in 1992, but had above average numbers in 1995. Heart failure in women was double the average in 1995 and below average in 1992. Heart failure in men was above average in both 1992 and 1995 but more than 10 higher in 1995.

There were no reported incidences of Pneumonconioses and other lung Diseases due to external agents as well as Ischaemic Heart Disease in either 1992 or 1995. The average number of occurrences of Pneumonconioses and other lung diseases due to external agents is 0.6 occurrences in women and 1.2 occurrences in men based on the 1981-2000 April 1 to September 30 averaging period. No occurrences of Ischaemic Heart Disease were reported in either women or men during 1981-2000 for the April 1 to September 30 fire season.

Figure 32 shows the weekly admission rates in 1992 and 1995 for the Mamawetan Churchill River RHA. There appears to be two relatively high peaks in 1992, one in the mid-May to early June period and the second in early to mid September. In 1995 the peak admissions were mid-April to end of May and a secondary peak mid-September to early October. The period of evacuation is also plotted on this graph and there appears to be a decrease in the number of admissions after the evacuation.

The highest number of admissions during the April to September fire season occurred in mid-April to mid-May, before the fires were discovered beginning on May 28th. The second wave of high admissions occurred in mid September to early October, after all the large fires were extinguished on August 29th. The apparent result of this pattern is the correlations between area burned and admissions are very low (Table 6).

These analyses were carried out in SPSS 13.0 (2004) using the regression statistics where Pearson Product Moment r is calculated. The correlations cover the period of week 22 (end of May) to week 40 (early October). The analysis began for week 24 in 1992 and week 22 in 1995 because no fires were reported prior to that period in either 1992 or 1995. The r values would be considered significant at 0.4.

6.4 Smoke Dispersion Modeling

Due to a lack of a network of ambient air quality monitoring stations in northern Saskatchewan, smoke production was modeled using FOFEM – The First Order Fire Effects Model. FOFEM is a computer program that was developed by the US Forest Service to meet the needs of resource managers and fire planners in predicting and planning for fire effects such as predicting tree mortality, fuel consumption, smoke production, and soil heating caused by prescribed fire or wildfire (Reinhardt et al. 1997).

FOFEM Version 5 is currently available online from US Forest Service (http://fire.org). Inputs required are fuel type as described by the Society of American Foresters "Forest Cover Types of the United States and Canada" (SAF 1980). The model also requires qualitative descriptions of fuel loading, fuel moisture, depth of forest floor and proportion of the fire burning as a crown fire. For most of the input parameters, we used the default values for each fuel type.

GIS computer technology was used to overlay the case study fire locations on top of the Saskatchewan forest inventory and determined in which forest type each fire occurred. The forest type was then converted to the corresponding forest cover type in SAF (1980) as required by FOFEM. For the case study fires, the forest types were limited to jack pine (SAF cover type 1), white spruce (SAF 201) and black spruce (SAF 204). Smoke production was quantified in terms of the following variables for both the flaming and smoldering components of the fire:

PM_{10}
$PM_{2.5}$
CH_4
CO
CO_2
NO_X
SO_2

In addition, total fuel consumption is calculated. Total emissions in kg ha^{-1} for each smoke component were generated for each case study fire.

7.0 DISCUSSION AND OBSERVATIONS

This section examines the relationships between key parameters including area burned and health and climate and fire as well as discusses the case studies, smoke dispersion, estimating future climate and estimating future populations.

7.1 Area Burned and Health Relationships

This section compares hospital admissions with both total area burned as well as characteristics of fires greater than or equal to 200 ha.

The differences from the mean hospital admissions for all diagnostic groups for the total population of Northern Saskatchewan were calculated to compare admissions with population changes (Figure 33). The admissions for the years 1980 to 2001 follow a pattern where 1980-1986 were below the mean. The years 1987 to 1996 had above the mean number of admissions and 1997-2001 declined very dramatically below the mean. This latter decline is unexpected because the number of people living in the north has risen during the same time period (1997-2001). Hospitalization rates are associated with a wide variety of factors that can change over time or are different between populations in addition to the overall health status and illness patterns including access and availability of hospital beds, socio-economic conditions, physician practice patterns, the availability and utilization of ambulatory care (Irvine 1998, Brewer and Freedman 1982). What factors influencing this decrease in hospitalization numbers during the 1997 to 2001 period is not obvious but there has been increasing emphasis on ambulatory care and a slight reduction in hospital beds within the province over the past 15 years. Factors within the Prince Albert Parkland RHA would have the greatest influence in the absolute numbers of hospitalizations with its population about double that of the three northern RHA's.

The difference from average time series of yearly hospital admissions and area burned for 1981 to 2001 are illustrated in Figure 34. This figure shows yearly variations of the two variables and how some years such as 1995, had a large area burned, but had a decrease in the number of hospital admissions compared with the previous five years. Also in 1996 little area was burned, but the total number of hospital admissions increased. This unexpected type of pattern indicates that other factors besides forest fire smoke seem to be more strongly influencing hospital admissions. The scatter plot comparing hospital admissions to area burned (Figure 35) illustrates no correlation between the two variables ($r = -0.0357$ (Table 7)). The Kendall Tau b and the Spearman rho non-parametric correlations were lower but positive (Table 7). This could be the result of many factors including the critical smoke level may be different from the admissions.

A scatter plot comparing hospital admissions to area burned (total and area greater than 200 ha) data was produced and linear trend line applied (Figure 36). This graph illustrates little to no relationship between area burned and hospital admissions in the four RHAs ($r = -0.0356$). There does appear to be clustering at and below the 500,000 ha burned level suggesting a possible threshold in hospital admissions. This needs further examination in future work.

There does not appear to be any linkages between area burned (based on both all fires and fires greater than 200 ha) and number of admissions using these methods. The year 1995 had the maximum area burned, but did not have abnormally high hospital admissions. However, years with relatively lower area burned such as 1996 and 1997 had as high or a higher number of hospital admissions than 1995. The highest correlation was when the 1981, 1995, 1998 and 1994 area burned outliers were removed from the analysis (Figure 37). The outliers were removed because Pearson Product Moment Correlation is sensitive to outliers. However, the r value of

0.3556 is not considered significant. The correlation became worse (r = -0.1502) when additional two more outlier years were removed (1989 and 1993) (Figure 38 and Table 7).

The population data were standardized or age-adjusted to allow a comparison of hospital admissions over time in northern Saskatchewan with the changing population. The age-adjusted rates level the differences in demographic factors, but do become an artificial number in the process. Age-adjusted rates are not an indicator of the absolute level of hospital admission in the population but are useful for comparison purposes.

The direct method of standardization (age-adjusted) methodology was obtained from the Pennsylvania Department of Health (2001). The equation is:

(Hospital admissions/population (Saskatchewan Hospitalization Information) =
*(age-specific rates * Standard population (1996 Census Data)) = expected hospital admissions*

This analysis was then applied to hospital admissions in Regional Health Authorities 9, 11, 12 and 13 for the four diagnostic diseases described previously. Figure 39 illustrates there was no correlation (r = -0.0663) between standardized hospital admissions for the four Regional health Authorities and total Area Burned based on fires greater than 200 hectares (Table 7).

Besides the extreme fire years, another possible influence may be the differences in population and hospitalizations between the RHAs. Prince Albert health data were removed from the analysis because they appeared to be overwhelming the other RHAs because of its large population base. The Prince Albert RHA population may also be less impacted by northern forest fires influencing air quality as compared to the three northern RHAs. When the Prince Albert Regional Health data were removed, the r value improved r = 0.2254), but was not statistically significant (Figure 40 and Table 7).

The year 1981 was an extreme fire year so this year was removed from the statistical analysis (Figure 41 and Table 7). The r value improved again (r = 0.3482) but is not statistically significant.

The Standardized Hospital Admission data for the period of April to October were compared to the total burned area data for Regional Health Authorities 11, 12 and 13. This period was chosen because wildfire smoke would have the most influence during the wildfire season. This may also reduce the variation in yearly hospitalization rates due to factors that may have a greater influence during the other time of the year such as seasonal influenza outbreaks, community air quality detriments from wood smoke, and cold temperatures increasing hospitalization rates for cardio-respiratory conditions. However, even when looking at only the months of April to October, the correlations dropped to an r value of 0.1208 (Figure 42). Again, the extreme fire year 1981 was removed, increasing the r to 0.2653 but it is not statistically significant (Figure 43 and Table 7).

The highest r (0.3482) was obtained when fires greater than 200 hectares were correlated with standardized hospital admission data for Regional Health Authorities 11, 12, 13 (Table 7). This weak correlation indicates that there may be only cursory influence of wildfires on cardio-respiratory health with other factors having a larger influence which is not an unreasonable assumption. Or, perhaps the evacuations undertaken greatly assisted the population at risk from experiencing the more detrimental effects of wildfires on their health. It is the practice to first evacuate children and older adults in the initial stages of the fires. These two population segments normally have the highest risk of succumbing to health effects of smoke exposure that would require admission. As well, the availability of beds could influence the decision to admit certain classes of patients.

Almost all individuals requiring hospital care during exposure to smoke are first seen in the emergency departments of the hospital. After resuscitation and stabilization of their conditions, a large majority of them would be discharged home. Only a few serious cases would require admission. Emergency room transactions are not included in the hospital database we used to assess the health effects of smoke from wildfires.

Another factor that drives the probability of hospital admission is the availability of beds. Closures of hospitals and reduction in beds have been part of public policy during the last 12 years.

Thus low admissions resulting from early evacuation of the vulnerable population groups as well good treatment and response in emergency rooms may be partly responsible for the low correlations found.

There may be a number of factors which influences the capacity of significance. This is an ecologic study looking at the overall northern hospitalization rates for respiratory disease compared to the overall area burned. Exposure to the smoke from these factors is influenced by location of the fire in relation to the communities, wind direction, etc. Not all fires will expose significant populations. There may be some influence from fires northwest of the province with the prevailing winds as well which could alter the exposure pattern. Looking at hospitalization rates of cardio-respiratory conditions, though certainly more sensitive than looking at mortality from cardio-respiratory conditions, will not be as sensitive as the influence on symptomatology. There may be influences on health status as symptoms that do not require hospitalization though they may result in contact through the emergency department or primary care ambulatory care setting. The other factor that may have reduced the chance of picking up a significant finding is the lack of data from the 3rd Diagnostic Group of Ischemic Heart Disease.

Respiratory illness is multi-factorial in its causation including genetic, infectious and environmental conditions. Forest fire smoke is only one of many influences. It is not reasonable to expect a large influence of the number of forest fires or the area burned for a particular season because of the interplay of many of these other factors. With the limitations in our study such as using forest fires and area burned as a proxy for air quality and using hospitalizations as an indicator of overall effect on respiratory health, a small change only would be anticipated from forest fires with all the other influences involved.

7.2 Climate and Fire Relationships

Forest fire characteristics are dependent on weather and climate (e.g., Flannigan and Harrington 1988). Weather is considered the most important factor for fire occurrence in Western Canada (e.g. Hely et al. 2001). Weather and climate affect many fire characteristics including frequency, size, intensity, seasonality, type and severity. Temperature, precipitation, humidity and wind speed and direction are the climatic elements that affect fire (Flannigan et al. 1998).

Drought conditions are an example of the strong linkage between climate and fire. Fire risk increases with increasing drought duration and intensities (e.g. Wheaton 2001*b*). Hot dry spells promote drying of fuels and result in high fire risks (Torn et al. 1998).

7.3 Area Burned and Evacuation Relationships

The area burned (fire sizes greater than 200 ha) in 1995 was the second highest since 1981, but fewer people were evacuated than in 1989 or 1993. Also 1989 and 1993 had only slightly above average area burned, while 1995 had the second highest area burned. The relationship of area burned and evacuation numbers also appears weak for these cases. Other factors must be dominating. These may include proximity of the fire to the community.

7.4 Case Studies and Controls

For the case studies, Figures 44 to 53 show the climatic conditions during the fire season in 1992 and 1995 at Creighton, La Ronge, Pelican Narrows, Southend, and Tracey. The graphs show daily total precipitation (mm), the Fire Weather Index, Temperature (°C), and Relative Humidity (percentage). The Canadian Fire Weather Index system is a weather based system that models fuel moisture using a system that tracks the drying and wetting of distinct fuel layers in the forest floor (Flannigan et al. 2005). The Fire Weather Index gives an indication of the severity of dryness of the forest and the resulting potential implications if a fire started. Wind speed and direction and evacuation period for the community are also shown for 1995. Wind direction is not available for 1992. The period for the 1992 graphs is May 5th to Sept 1st to illustrate the full season fire potential, while the 1995 graphs for the fires start time and community evacuation dates. Appendix B illustrates these parameters for the sites selected.

Creighton district did not have any large fires in 1992. This is reflected in the fire weather index (FWI) which was 20 or under except on three occurrences (Figure 44) for the May 5th to Sept 1st period. In 1995, between May 1st and June 30th there were 12 occurrences when the FWI was above 20 (Figure 45). Two fires were in the Creighton District in 1995. The largest one started on June 11 when the FWI was 28 and the previous two days were above 20. This fire lasted until July 31, but was considered under control on July 1st.

The La Ronge District did not have any large fires in 1992. This district had 15 occurrences of FWI being greater than 20 for the May 5 to Sept 1 period (Figure 46). In 1995 between May 25th and August 13th there were 33 occurrences of FWI being greater than 20 (Figure 47). The majority of these occurred in the end of May to end of June period. There were eight fires in this district in 1995. Two caused the most forest damage. They both started on May 31st and were extinguished on August 8th. The FWI on May 31st was 69 and the previous four days well over 20. The 29th had an FWI of 72. The community of Stanley Mission had evacuations between June 9 and 20th when the FWI was close to or above 30. When the evacuations were initiated the winds were from the East and did not consistently switch directions until the 18th to the North and then South. During the evacuation period the relative humidity went above 70 % once but for 10 days out of the 12 day evacuation period it was at or below 50%.

The Pelican Narrows District did not have any large fires in 1992. This district had 11 occurrences of FWI being greater than 20 for the May 5th to Sept 1st period (Figure 48). There were two distinct periods in 1992 when the FWI was higher than the rest of the period. The first was in June and the second was in mid-August. Pelican Narrows did however record an unusual amount of rain on July 15 when 84.2 mm was recorded. In 1995, six fires were in the Pelican Narrows district. All of these fires started between May 31st and June 16th with three of them being extinguished in June and three others in August. Pelican Narrows had 17 occurrences between May 27th and July 7th when the FWI was 20 or higher (Figure 49). Two major fires were in the district, one was discovered on May 31st, the other June 14th with a combined fire size of 33,000 ha. The first fire was discovered when the FWI was 39, the temperature was 26.7°C and the relative humidity was 39%. The second fire was discovered when the FWI was 27, the temperature was 28.6°C and the relative humidity was 40%. The preceding six days had FWI higher than 20 with the 12th having a FWI of 37. Some people from Pelican Narrows were evacuated starting June 15th when the wind switched from the North and West to the East and South.

The Southend District had two fires in 1992 with a total burned area of just over 1200 ha. The first fire was discovered on June 17th and was extinguished on June 28th. This was the earliest large fire start date recorded in 1992. The second fire was discovered on August 5th and extinguished on September 2nd. Southend had only five occurrences when the FWI was greater than 20 between May 5th and September 1st (Figure 50). These occurred at the end of May and mid June, when the first fire started. Southend had 14 large fires in 1995 with all being discovered mid to late June. There were two fires, one starting June 18th, the other June 19th, that resulted in almost 112,000 ha being burned. Most of the fires were extinguished by mid-July, but the largest was not extinguished until mid August. In 1995, Southend FWI was higher than 20 eight times between May 25th and July 20th (Figure 51). The community of Brabant Lake had 39 residents evacuated from June 26 to July 6th. The weather right at Brabant Lake is not known as the nearest climate station is located at Southend. However, the weather at Southend on the day the residents were evacuated from Brabant Lake was a temperature of 27°C, a relative humidity of 89% and a wind from the SSW at 9 km/h. The FWI on the evacuation day was eight.

Dore Lake District did not have any large fires in 1992. The climate station in the area is Tracey. Tracey recorded 19 occurrences when the FWI was higher than 20. These were split into two times of the year, end of May to mid June and the second occurrence was mid August (Figure 52). Dore Lake District had two fires in 1995. They both started May 31st and were both extinguished on June 27th. They burned a total area of just over 22,000 ha. Tracey recorded 24 occurrences when the FWI was above 20 between May 1st and June 30th (Figure 53). The most severe FWI period was between May 27th and June 15th. The most severe fire weather period was between May 28th and June 3rd when on May 29th the FWI reached a high of 66, a temperature of 30.2, a relative humidity of 15 and a west wind at 23 km/h.

The analysis suggests that wildfire smoke is not having an overwhelming influence on the hospital admissions for the two case study years. This may be due to several factors including the communities were evacuated when smoke and fire became an issue. The majority of hospital admissions for both 1992 and 1995 occurred at the La Ronge Health Centre, followed by hospitals that were out of province. The data did not allow for identifying where these people were living just prior to the time of admission, other than their health card says they received their health card in the Mamawetan Churchill River Regional Health Authority. Also, Mamawetan Churchill River Regional Health Authority has a historically high number of hospitalization rates compared to the rest of the province (Osei and Virag 1999) resulting in a higher number not being determined.

7.5 Forest Fire and Smoke Relationships

Total emissions in tonnes for each smoke component were generated for each case study fire. The results are shown in Table 8.

Smoke production is primarily a function of fire size. The largest fire was L218 (58,500 ha) which produced nearly 11 million tonnes of smoke emissions. The overwhelming majority of emissions is CO_2, which generally doesn't cause health problems, but illustrates the importance of forest fires as a contributor to Canada's greenhouse gas emissions. The next most important emission is CO, which doesn't cause health problems in open conditions. It is also clear that the smoldering phase of combustion produces the majority of emissions due to incomplete combustion.

It is well known that $PM_{2.5}$ and PM_{10} emissions do cause health problems but without local air monitoring data is not possible to determine how the particulate matter generated by forest fires actually affects individuals in towns close to large fire events. Therefore the smoke emissions estimates serve to verify that the potential for health risks from $PM_{2.5}$ and PM_{10} is evident although exact concentrations are not known.

7.6 Estimating Future Populations

The Saskatchewan Health Services Utilization and Research Commission states that by 2015 the three northern health regions are predicted to increase in population (Keewatin Yatthé by 24%, Mamawetan Churchill by 49% and the Athabasca Health Authority by 9%). Also, in northern Saskatchewan the numbers of seniors are predicted to increase by 102% in Mamawetan Churchill, 51% in Keewatin Yatthé and 39% in Athabasca Health Authority (cited in Irvine and Stockdale 2004).

7.7 Estimating Future Climate and Wildfires

7.7.1 Future Climate Scenarios

Climate Scenarios for Northern Saskatchewan

Annual Changes for the 2020s and 2080s: Comparison Among Global Climate Model Experiments

Results of several GCM scenarios are available for annual temperature and precipitation and several other variables for three time slices into the future. These time slices are the 2020s (i.e. 2010-2039), 2050s (2040-2069) and 2080s (2070-2099). It is important to use several GCMs because currently all of the results are considered plausible and a range of future climate changes should be examined. Results are provided as changes from the 1961 to 1990 baseline simulated by the GCMs (Barrow et al. 2004).

Although scatter plots for these three time slices are available, we focus on the 2020s and 2080s for brevity (Figures 54 and 55). For our purposes, a northern Saskatchewan grid centered near La Ronge was chosen to show the range of future climate changes among different GCMs and emission scenarios for two future periods, the 2020s and 2080s. These annual results show less difference among scenarios for the 2020s than the 2080s, and differences increase with time. Most of the changes are well outside the range of the simulated natural variability, indicating that the projected changes in future climate are significant (Barrow et al. 2004).

Compared to the other GCMs depicted, the Canadian GCM climate scenarios tend to indicate drier, but generally median warming in all seasons. The Japanese GCM (CCSR/NIES) generally shows the largest changes of both annual temperature and precipitation. So it seems to be an outlier, but perhaps it is a reminder that the climate system is more sensitive than simulated by the other models. The range of changes are used to choose models for the study area (for high and low changes) to demonstrate the uncertainty in the projections of such futures.

The Canadian model, CGCM2 A2x (ensemble mean), indicates a 5°C increase in annual temperature and a 5% increase in annual precipitation for the 2080s (Figure 55). The HadCM3 A21,2,3 shows about a 4 °C temperature increase and about a 13% precipitation increase. So for this area, these two experiments have similar temperature results, but the Hadley model depicts more than twice the increase in precipitation. The CGCM2A2x and B2x results are similar for the 2020s (Figure 54), but the A2x results are warmer (by about 1.5° C) and slightly drier (about 3%) than the B2x results.

Seasonal Changes of the 2080s

Climate scenario building has many choices, so focus is necessary. For example, climate change scenario results are provided in map form by Barrow et al. (2004) for seven GCMs for two emissions scenarios for the 2050s and for the other periods for CGCM2. For our purposes we use the CGCM2 A2 ensemble-mean scenarios to describe spatial patterns and amounts of future possible temperature, precipitation, wind-speed and soil moisture. These elements are important factors affecting the amount of area burned. The selected period is the 2080s corresponding to the period used for the recent area burned estimates by Flannigan et al. (2005).

Changes of mean seasonal temperatures range from 2°C in the fall to about 9°C for the spring and winter (Table 9 and Figure 56). Precipitation increases up to 15 to 25% are projected for the spring and fall, while summer and winter have no change to decreases of 5% (Table 9 and Figure 57). GCMs, including these, tend to simulate observed mean temperature magnitudes and spatial patterns reasonably well in the Prairie Provinces. However, precipitation is much more difficult to model and GCMs over-predict total annual and some seasonal precipitation amounts (Toyra et al. 2005). Wind speed changes range from possible increases in the spring to possible decreases in the summer and fall, then slight increases in the winter (Table 9 and Figure 58). The changes in soil moisture capacity fraction indicate no change to decreases (Table 9).

Spatial patterns of seasonal temperature changes are relatively uniform across Canada for the fall as compared to the other seasons (Figure 56). Spring and winter show much higher spatial variability, with the study area of northern Saskatchewan exhibiting some of the largest changes in Canada.

Precipitation changes are even more spatially variable across Canada than temperature (Figure 57). Summer and winter show both increases and decreases of precipitation across the study area from about -8 to 5%. As for temperature comparisons across Canada, precipitation changes in the study area are also extreme compared to most other areas. Among the largest spring and fall precipitation increases in Canada are projected for the study area. As compared to the rest of Canada, both summer and winter precipitation change in the study area include the second largest class of decreases.

7.7.2 Future Fire Scenarios

The most recent and only estimate of future area burned by fire in Canada (including the study area) that we are aware of is by Flannigan et al. (2005). The other estimate of future area burned that we are aware of is for Alberta (Tymstra and Armitage 2005). Both papers are used to provide indicators for this report. Flannigan et al. (2005) used output from two Global Climate Models (GCMs), the Canadian First Generation Coupled GCM (CGCM1) and the UK Hadley model (HadCM3GGa1). These two GCMs are often selected for use in climate change impact studies for several reasons, including the range of results, recent experiments, and the availability of data. The Canadian model was the First Generation Coupled GCM (CGCM1) forced with a 1% increase in CO_2 per year and sulphate aerosols. The data were selected for 2080 to 2100 for the Canadian model and 2080 to 2099 for the UK model. The Hadley model (HadCM3GGa1) was forced with greenhouse gases only. The control or baseline period is 1975 to1995 for the Canadian model and 1975 to 1990 for the Hadley model. The authors do not describe the climate scenarios created using these models, so we used more recent results for these descriptions in the previous section.

Daily data for maximum temperature, precipitation, wind speed, and humidity were used directly from the GCMs, adjusting them for excessive moisture (Flannigan et al. 2005). The more common method is to adjust temperature and precipitation using the difference and ratio method (e.g. Barrow et al. 2004) rather than using daily data directly from the GCMs.

Flannigan et al. (2005) assessed the relationships between area burned and several climate and fire weather index system variables by using a linear forward stepwise regression for each spatial unit or ecozone, and for each time period (half month, month or season). The variables best related to historical monthly area burned were temperature and fuel moisture. The explained variance ranged from 36 to 64% and all regressions were highly significant. The best relationships with area burned were then used to estimate future changes in area burned for each GCM experiment.

Results from both GCMs suggest large increases in the risk of future area burned (Flannigan et al. 2005). The UK GCM produces much higher increases for the study area than the Canadian GCM (Figures 59 and 60). The Canadian CGM1 results for northern Saskatchewan range from a 9% increase in area burned for the southern ecozone (#9) to a 67% increase in the northern ecozone (#61) of northern Saskatchewan. The UK GCM results are an increase of 245% in the southern ecozone and 92% for the northern ecozone. The increase for the Hadley model for ecozone nine is the second highest in Canada. Results are only available for the entire ecozones, not for smaller areas.

Tymstra and Armitage (2005) used a somewhat different approach than Flannigan et al. (2005) to estimate fire area burned for Alberta. Their findings can be used as another indicator of possible future area burned for our study area, especially the west side. Tymstra and Armitage (2005) used the Canadian Regional Climate Model because of its much enhanced spatial resolution. These results were used with components of the Canadian Forest Fire Danger Rating System to run the fire growth simulation model Prometheus. Their results suggest a 29% increase in area burned for 2080-2089. Information about spatial patterns was not provided.

Other recent results, even though they are not for area burned, also indicate an increase in fire behavior for central Saskatchewan. Parisien et al. (2004) calculated changes in head fire intensity using the climate scenarios of the Canadian Regional Climate Model. They found that the number of days that could support extreme fire behavior potential would more than quadruple and that fires would be more intense in last decades of this century. This type of fire behavior is expected to be associated with an increase in area burned.

The increases in area of forest fires projected by Flannigan et al. (2005) and Tymstra and Armitage (2005) are underestimates because changes in several other factors also affect the area burned. These factors include length of the fire season and changes in lightning activity. For example, increases in the length of the warm season have already occurred, and future continued increases in the length of the fire season are expected. An increase in season length would increase the time during which additional area could be burned, especially in the spring. A counteracting factor would be the possibility that more area burned could result in less available fuels for fire spread (Parisien et al. 2004), depending on the rate and type of regeneration. However, this factor has not been assessed, to the authors' knowledge.
Wotton and Flannigan (1993) found an increase in fire season length of an average of 16% or 16 days for a future time period in about the 2050s in the forested areas of Alberta and

Saskatchewan. They used the Canadian GCM scenario for doubled carbon dioxide-equivalent atmospheric concentrations.

In summary, considerable evidence indicates that the area burned by forest fires will increase and at a considerable rate. Therefore, communities will come under increasing threat from both smoke emissions from fires and the resulting potential health problems. The implications for adaptive management are important and include increased attention to this challenge at the very least.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The three northern health districts had respiratory hospitalization rates of 22% (Athabasca Health Authority), 23% (Keewatin Yatthé Regional Health Authority) and 30% (Mamawetan Churchill Regional Health Authority) as compared to 6% for Saskatoon and 7% for Regina and the provincial average of 12% during 1992 to 1996 (Osei, pers. comm.. 2005).

Factors considered related to respiratory health include genetics, environmental conditions, socio-economic statues race, sex, age of mother, education level of mother, low birth weight, exposure to smoking, previous respiratory and presence of cat or wood heat in the household.

The research study tested the correlations between forest fire occurrences, evacuations and hospitalizations.

8.1 Main Findings

General results suggest that the relationship between wildfires and hospitalizations for cardio-respiratory ailments is not strong and that other factors are no doubt affecting the health of the study area residents:

- No correlation between standardized hospital admissions for four northern regional health authorities (3 health authorities in the study area plus Prince Albert) and total area burned based on fires greater than 200 hectares.
- Weak correlation between fires greater than 200 hectares were correlated with standardized hospital admission data for Regional Health Authorities, Mamawetan Churchill River, Keewatin Yatthé and Athabasca.
- This weak correlation indicates that there may be only cursory influence of wildfires on cardio-respiratory health with other factors having a larger influence. This is not unexpected with the many influences on respiratory health. The small numbers of population in the area may not allow adequate power to assess the statistical significance of the weak correlation. Not having the complete data for ischemic heart disease hospitalizations would also have reduced the power in this study.
- The relationship of area burned and evacuation numbers also appear weak.

Analysis of the case study areas also suggests that wildfire smoke is not having a strong influence on hospital admissions. Again, this is not unexpected because of the many factors involved in respiratory health and hospitalizations though what the study was assessing was the potential increase in respiratory hospitalization based on the potential increase of forest fires. There did appear to be a small correlation with area burned and the hospitalization rate for respiratory conditions for the three most northern RHAs though this was not found to be statistically significant.

However, as indicated, wildfire activity will increase and this will enhance the health risks to northern residents. The impacts of increased wildfire occurrences or increases in area burned may alter these observed relationships as the cumulative effects of enhanced wildfire activity are felt.

Relationships between smoke, particulate matter levels, human exposure levels and duration and health impacts are complex. More regular exposure to smoke from wildfires may be a determining factor in tipping the scales towards increased cardio-respiratory risks for northern residents.

8.2 Implications for Adaptation

Current management practices to evacuate individuals and communities at risk from exposure to wildfire smoke appear to be helping to minimize current health risks. However, anticipated increases in fire activities in the future will increase the health risk to residents as forest wildfire activity increases. The other factor that will influence the impact on the northern communities is the increasing population (increasing the number of those exposed), and the aging of the population with the corresponding increase in chronic diseases such as cardio-vascular and respiratory ailments (increasing the number of vulnerable individuals).

Provincial policy to suppress or not to suppress wildfires in specific areas of the province may be challenged as fire activity increases.

There has been ongoing improvements in evacuation guidelines for northern communities however, additional improvements or contingencies may be required if the threat from wildfires increases.

Pressures from northern communities for additional fires suppression measures or evacuation measures may have implications for the provincial budget and associated government agencies.

8.3 Recommendations

For any future study:

- Look at cardio-vascular and respiratory diseases together as a group (all four diagnostic groups together) with a sub-analysis of respiratory and cardiovascular (not four separate groups) in order to increase the power of any future study.
- Look at the three northern-most health authorities together, separate from the Prince Albert Regional Health Authority because of the potential lesser impact on the Prince Albert population.
- Look at hospitalizations for the April to October time period to help reduce some of the impact on other seasonal influences on cardio-vascular health such as some

respiratory infections (seasonal influenza usually but not always occurring November to March) and environmental factors (cold weather influence on cardiovascular disease and wood smoke influence on cardio-respiratory symptoms).

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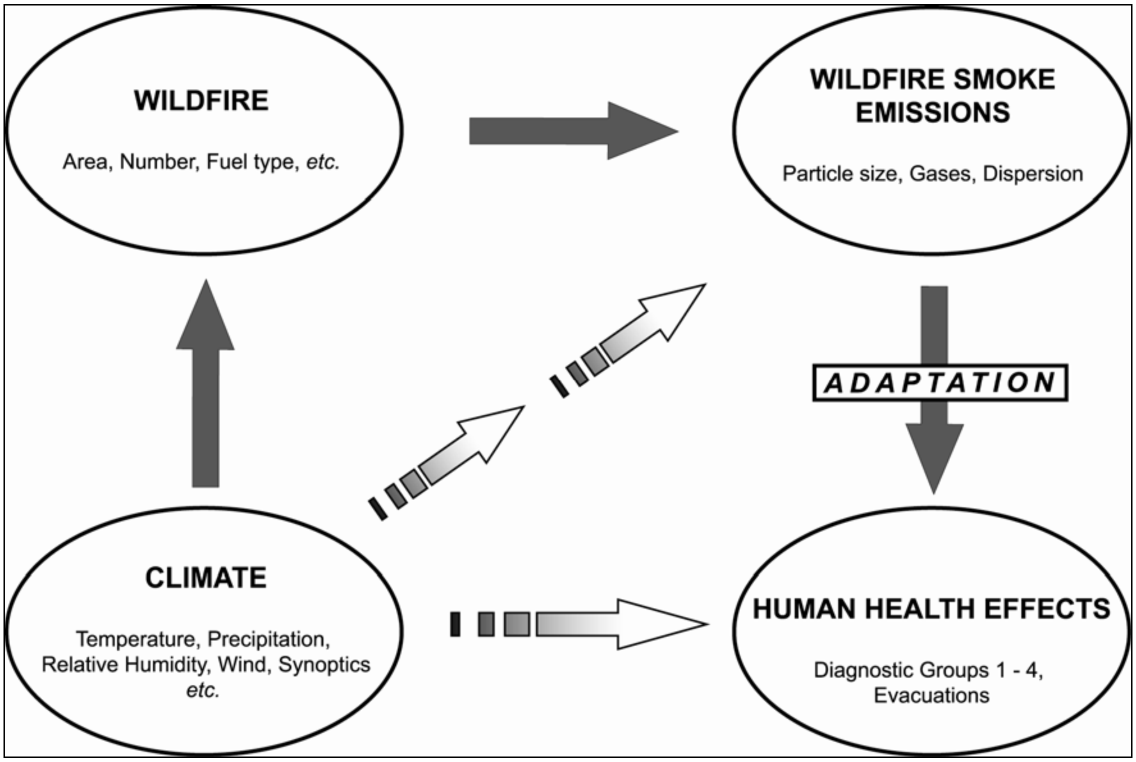


Figure 1 A Conceptual Framework of the Linkages among Climate, Wildfire and Associated Smoke with Human Health Effects (Dashed arrows depict relationships not considered here)

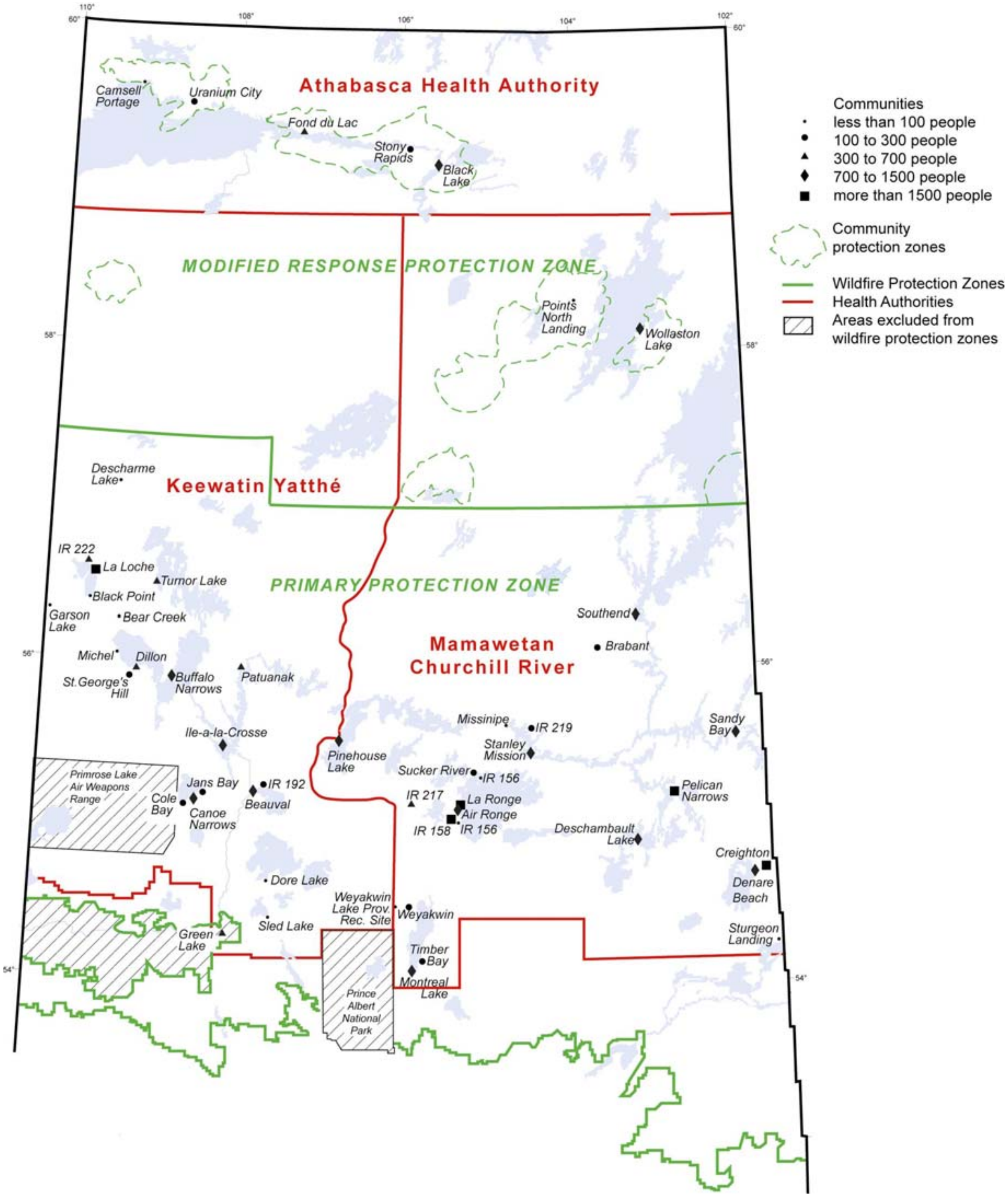


Figure 2 Northern Administration District of Saskatchewan (Keewatin Yatthé, Mamawetan Churchill River and Athabasca Regional Health Authorities) and Population Density of Northern Saskatchewan (community size adapted from Irvine and Stockdale 2004, Saskatchewan Health 2002, Fung 1999, Saskatchewan Environment 2003)

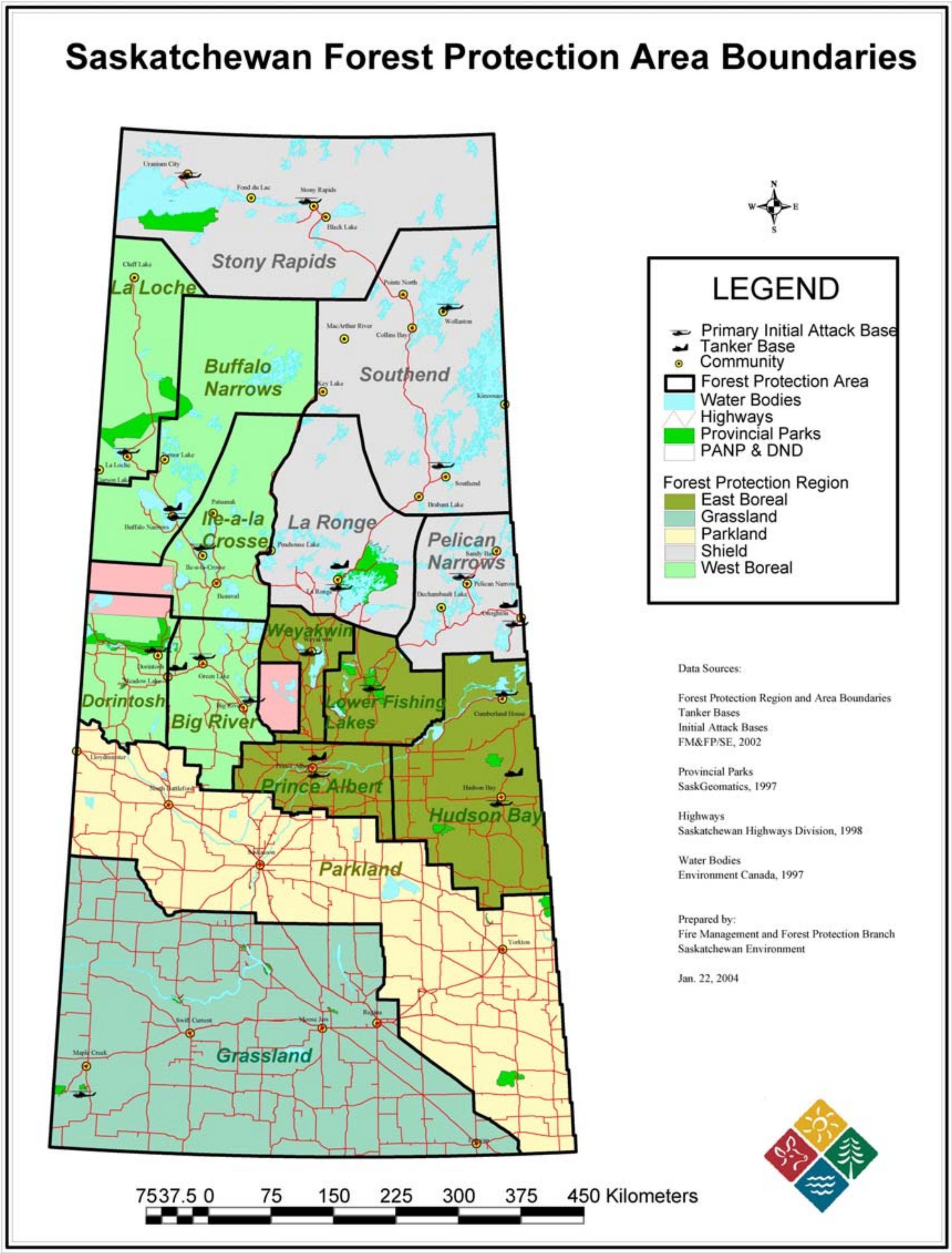


Figure 3 Saskatchewan Forest Protection Area Boundaries (Fire Management and Forest Protection Branch 2004)

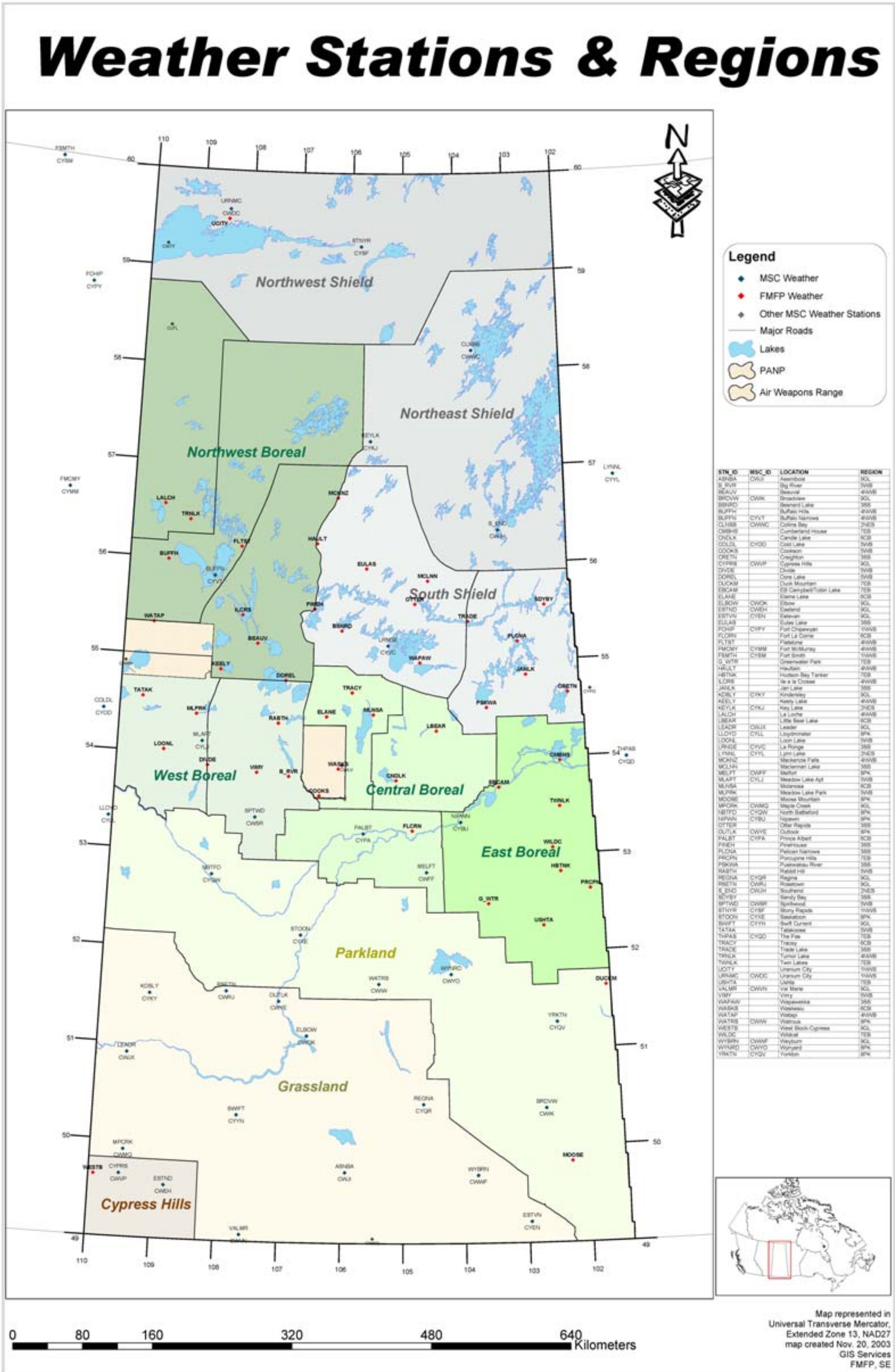


Figure 4 Weather Stations and Wildfire Protection Regions (Fire Management and Forest Protection Branch 2003)

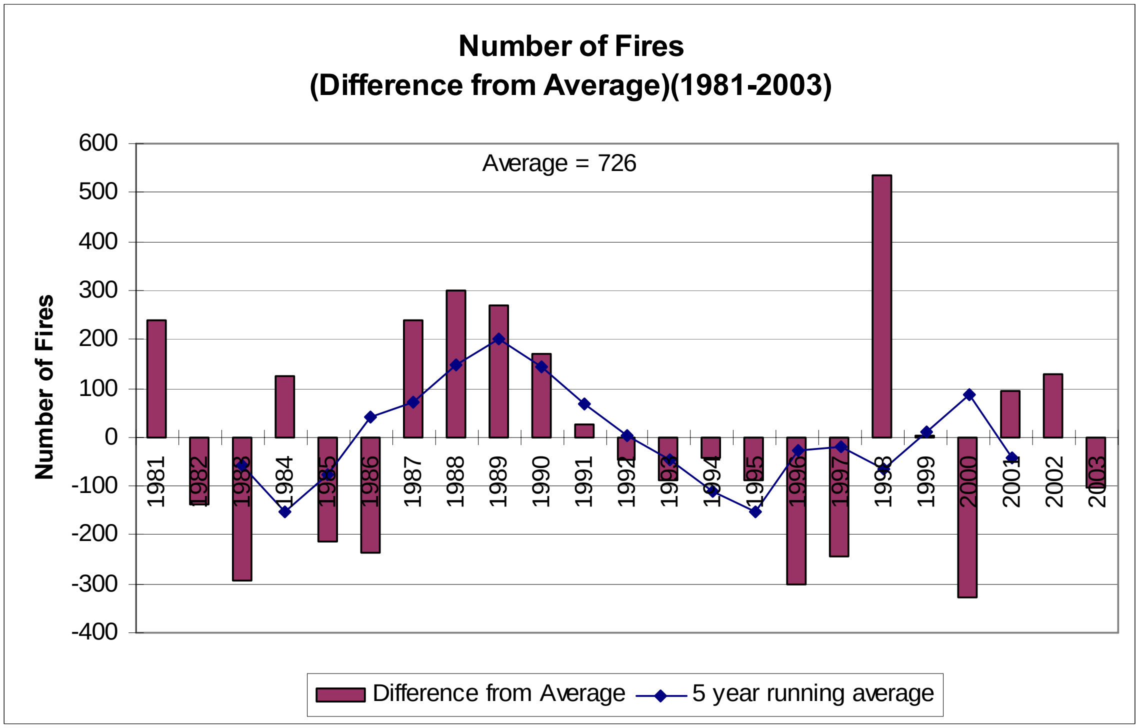


Figure 5 Number of Fires in Northern Saskatchewan (Difference from Average and Five Year Running Average) (Data Source: Saskatchewan Environment 2004)

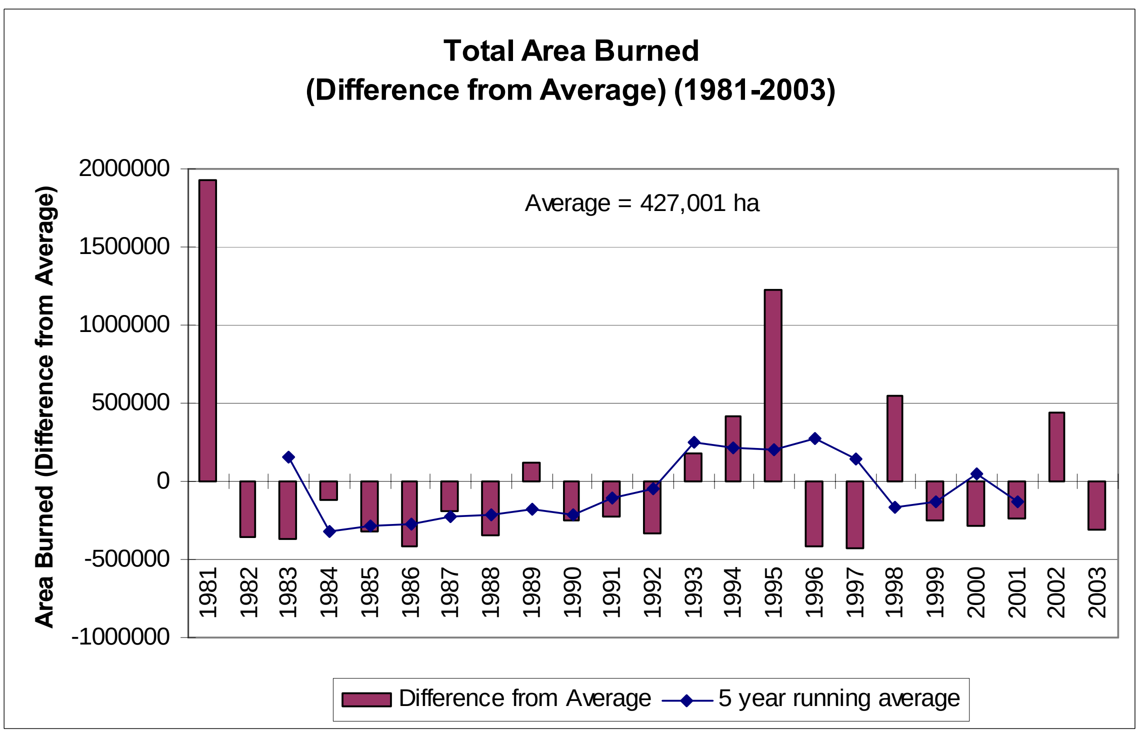


Figure 6 Total Area Burned in Northern Saskatchewan (Difference from Average and Five Year Running Average) (Data Source: Saskatchewan Environment 2004)

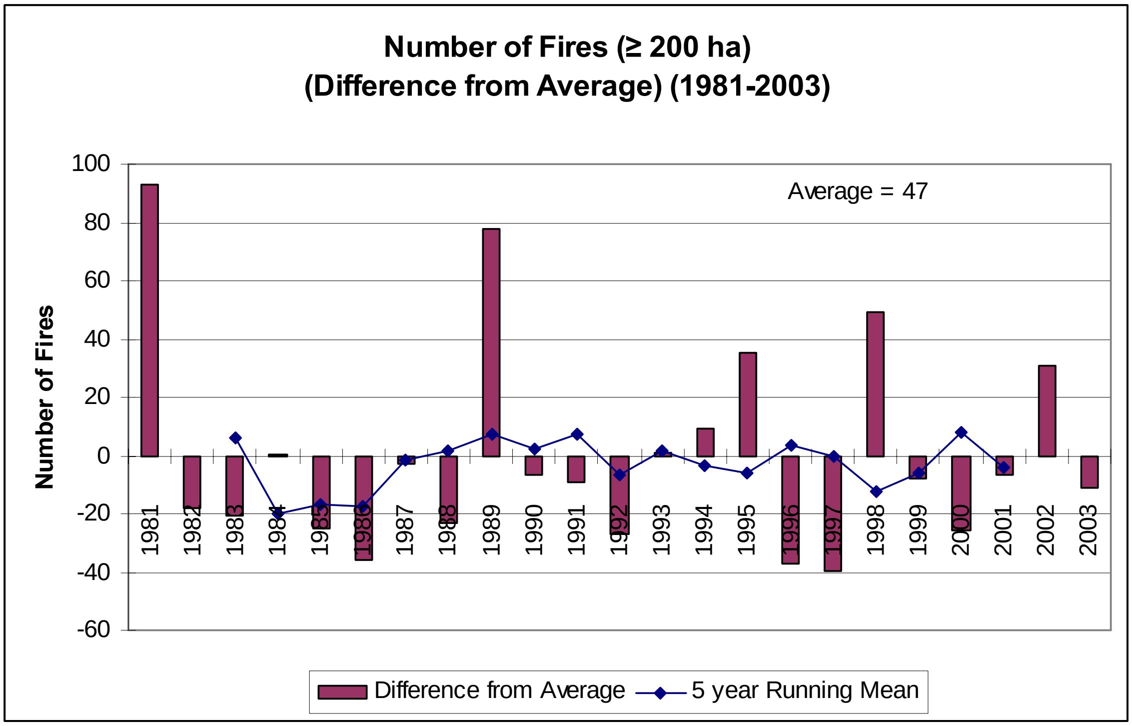


Figure 7 Number of Fires ≥ 200 ha in Northern Saskatchewan (Difference from Average and Five Year Running Average) (Data Source: Saskatchewan Environment 2004)

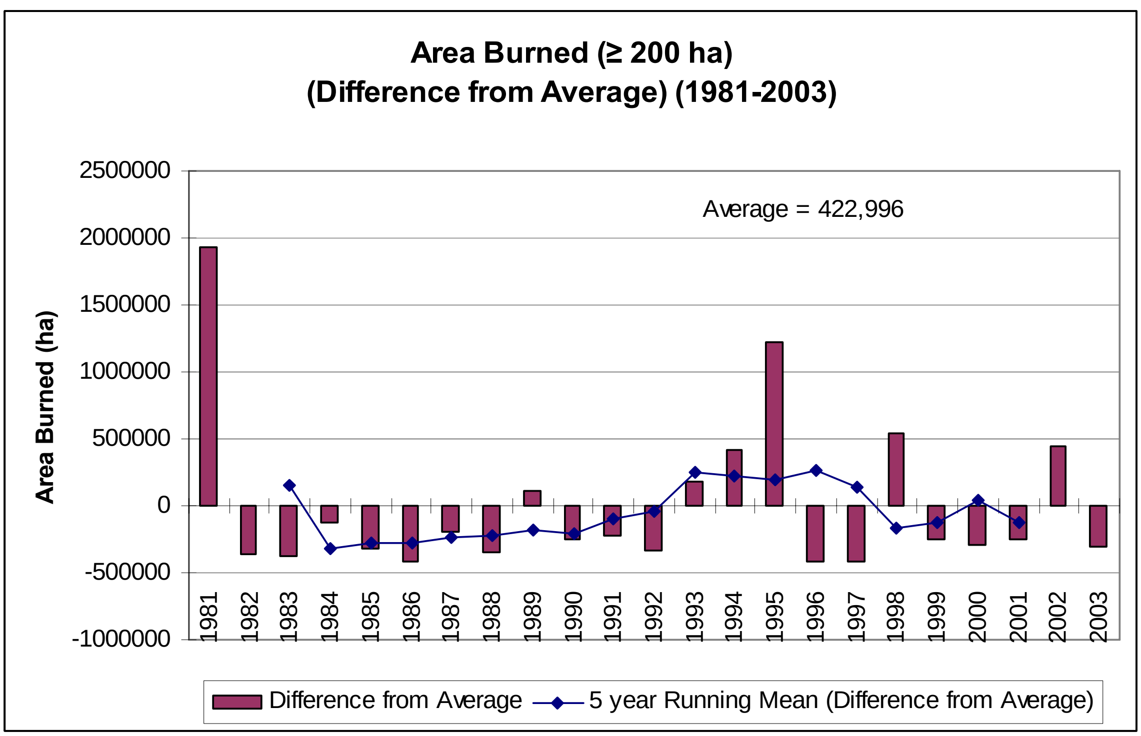


Figure 8 Total Area Burned ≥ 200 ha in Northern Saskatchewan (Difference from Average and Five Year Running Average) (Data Source: Saskatchewan Environment 2004)

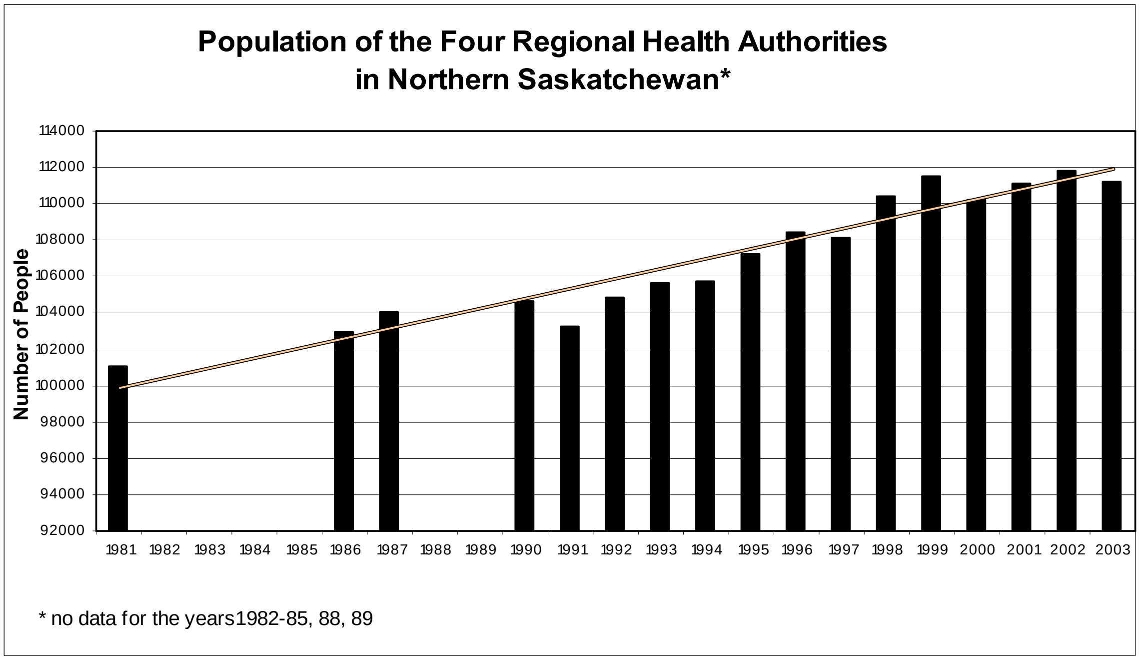


Figure 9 Total Annual Population of the Four Regional Health Authorities in Northern Saskatchewan (1981 – 2003) (Data Source: Saskatchewan Health 2005)

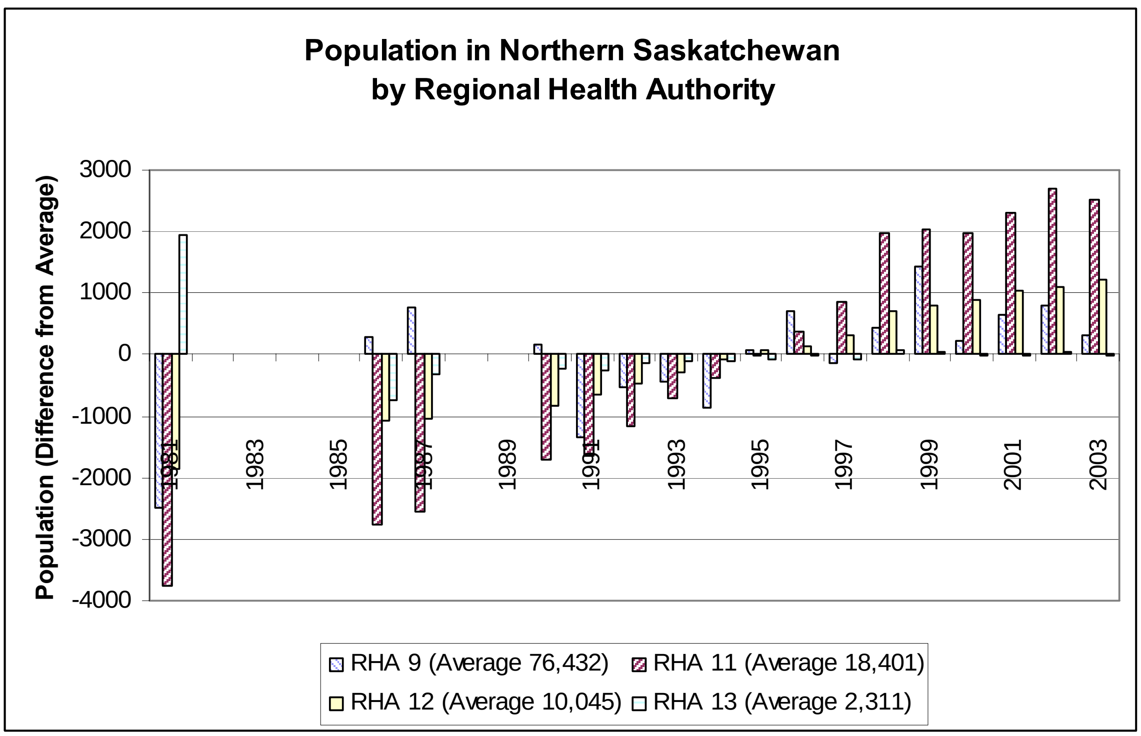


Figure 10 Annual Population Comparison of the Four Regional Health Authorities in Northern Saskatchewan (Data Source: Saskatchewan Health 2005)

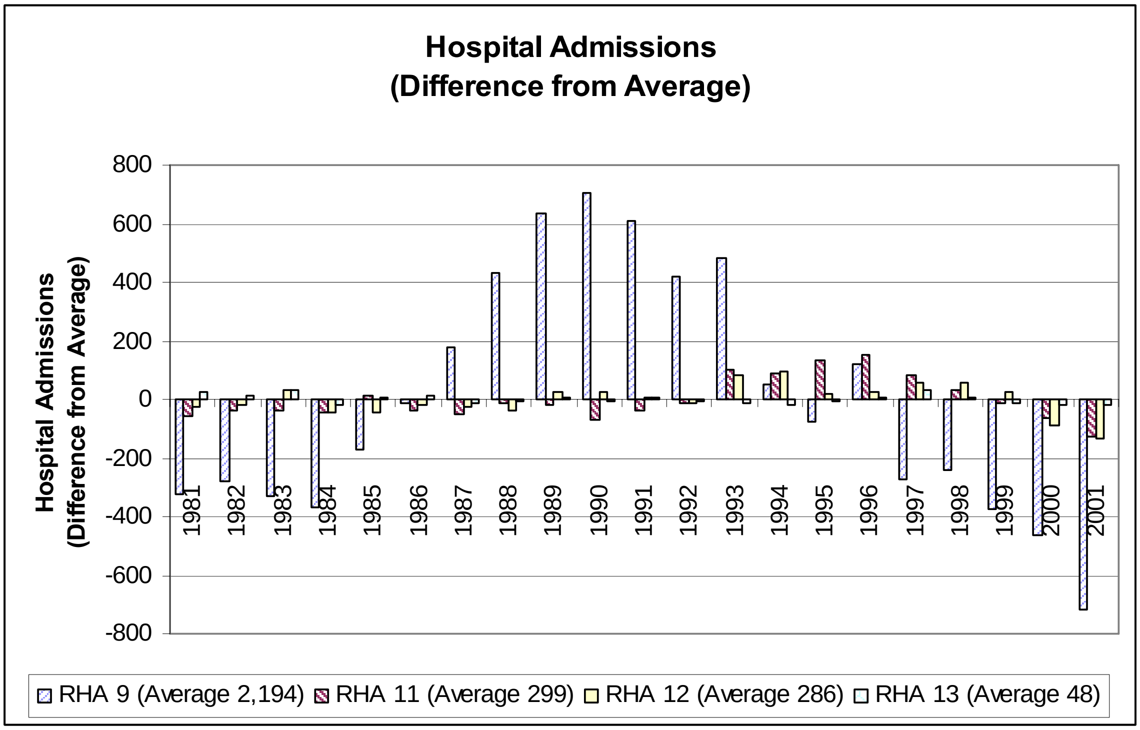


Figure 11 Total Annual Hospital Admissions divided by Regional Health Authority in Northern Saskatchewan (Data Source: Saskatchewan Health 2005)

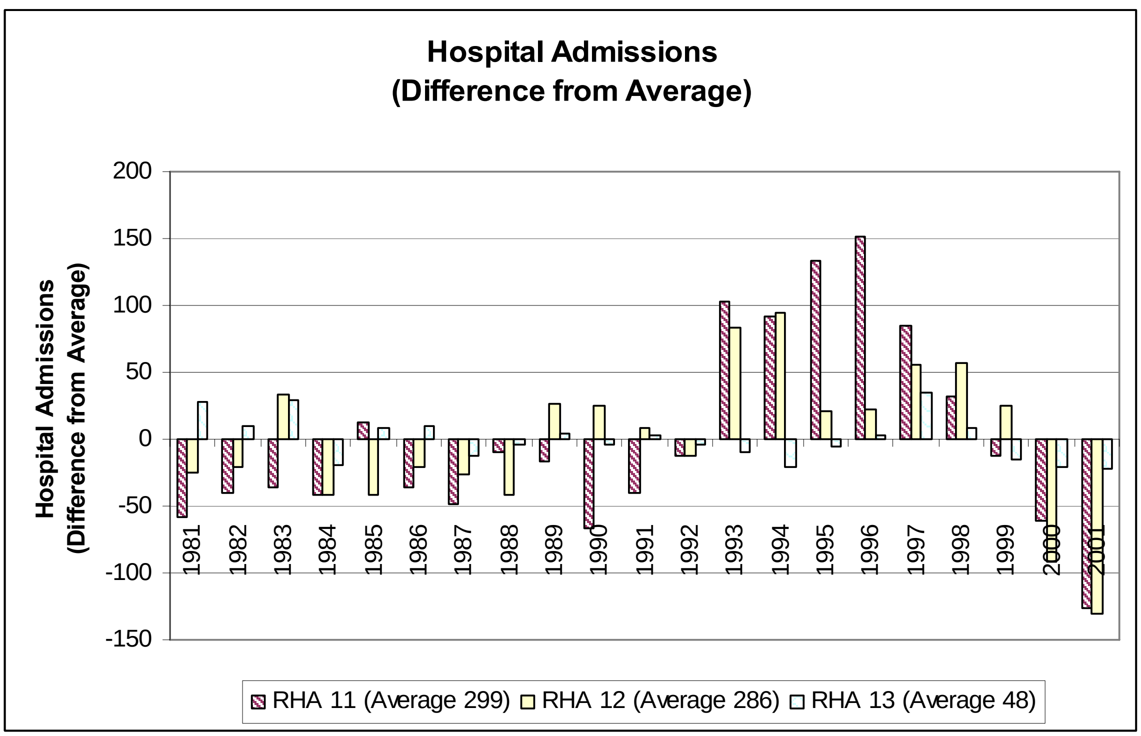


Figure 12 Hospital Admissions for Regional Health Authorities 11, 12 and 13 (Data Source: Saskatchewan Health 2005)

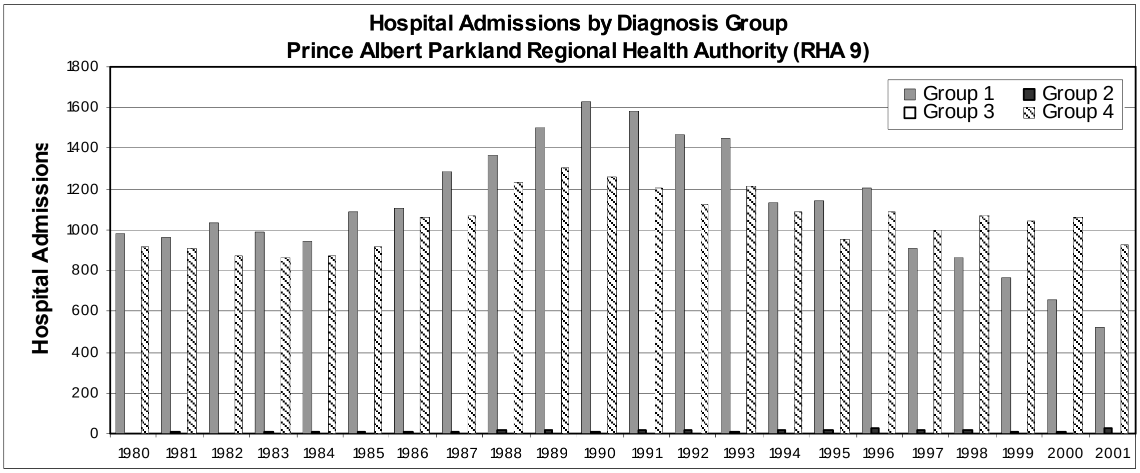


Figure 13 Hospital Admissions by Diagnosis Group RHA 9 (Data Source: Saskatchewan Health 2005)

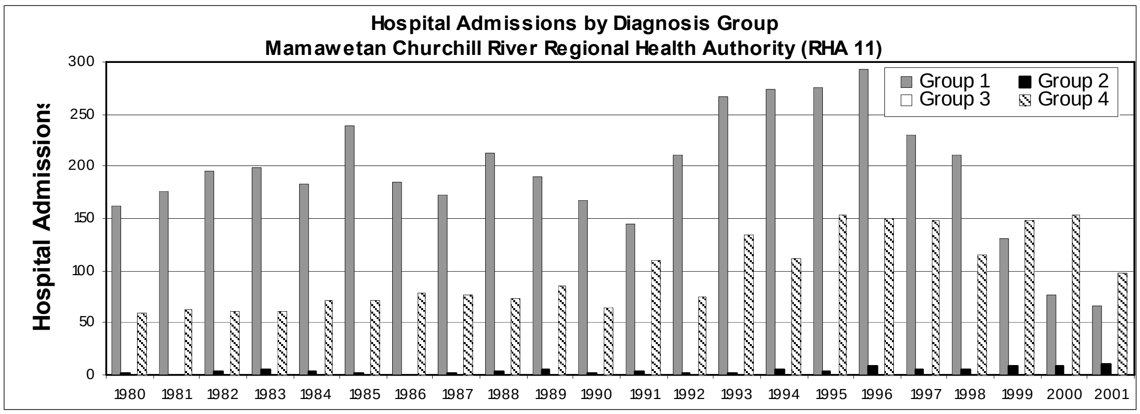


Figure 14 Hospital Admissions by Diagnosis Group RHA 11 (Data Source: Saskatchewan Health 2005)

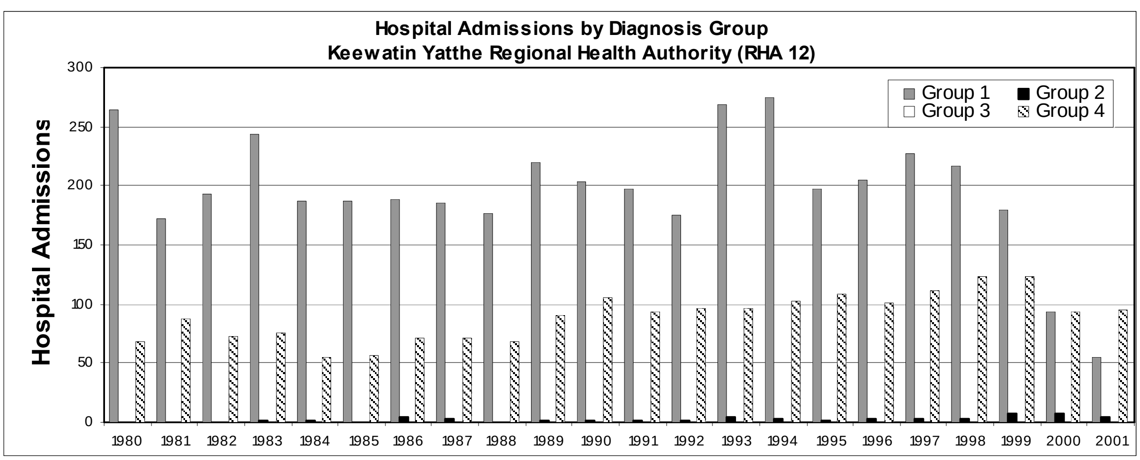


Figure 15 Hospital Admissions by Diagnosis Group RHA 12 (Data Source: Saskatchewan Health 2005)

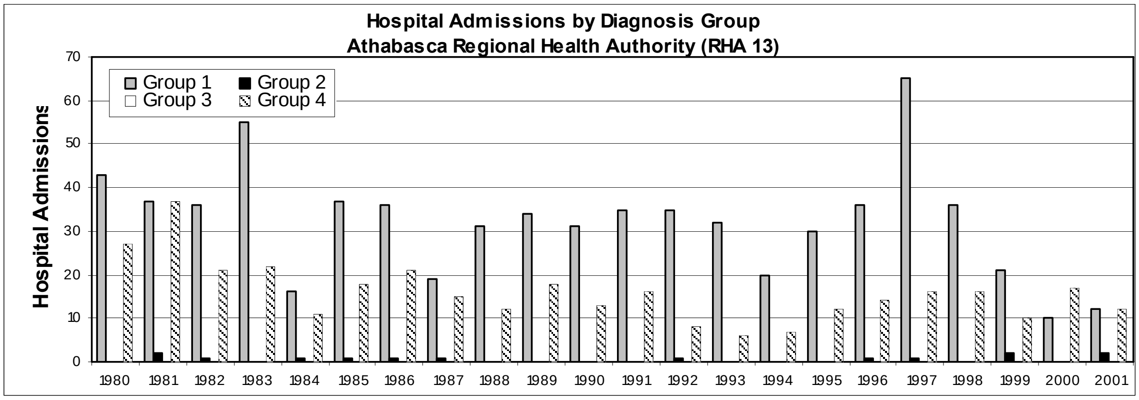


Figure 16 Hospital Admissions by Diagnosis Group RHA 13 (Data Source: Saskatchewan Health 2005)

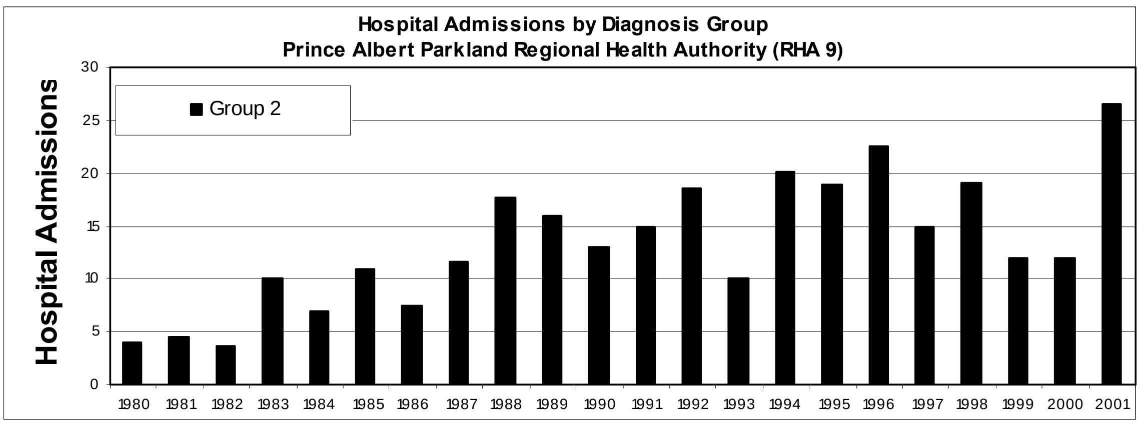


Figure 17 Hospital Admissions by Diagnosis Group 2 RHA 9 (Data Source: Saskatchewan Health 2005)

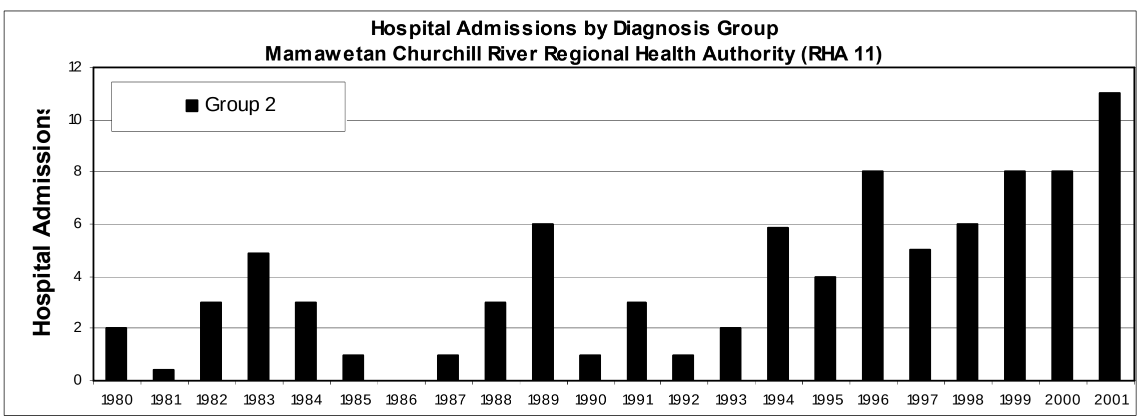


Figure 18 Hospital Admissions by Diagnosis Group 2 RHA 11 (Data Source: Saskatchewan Health 2005)

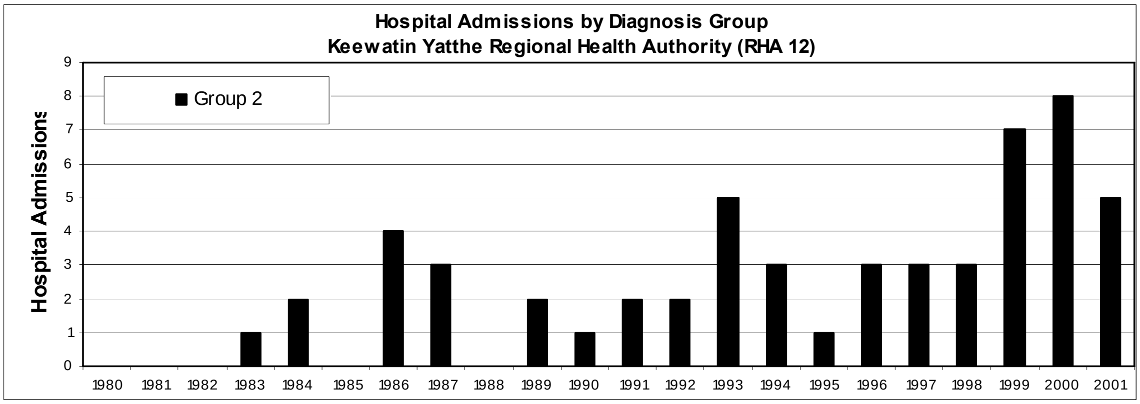


Figure 19 Hospital Admissions by Diagnosis Group 2 RHA 12 (Data Source: Saskatchewan Health 2005)

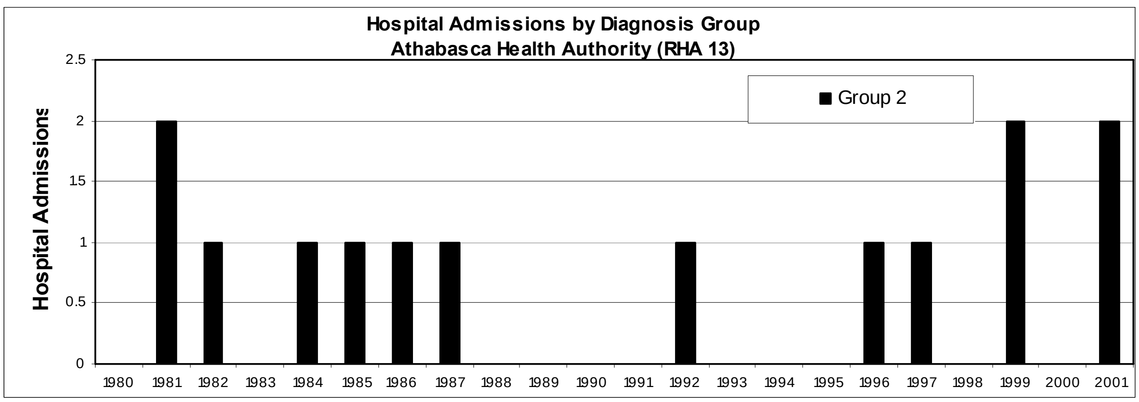


Figure 20 Hospital Admissions by Diagnosis Group 2 RHA 13 (Data Source: Saskatchewan Health 2005)

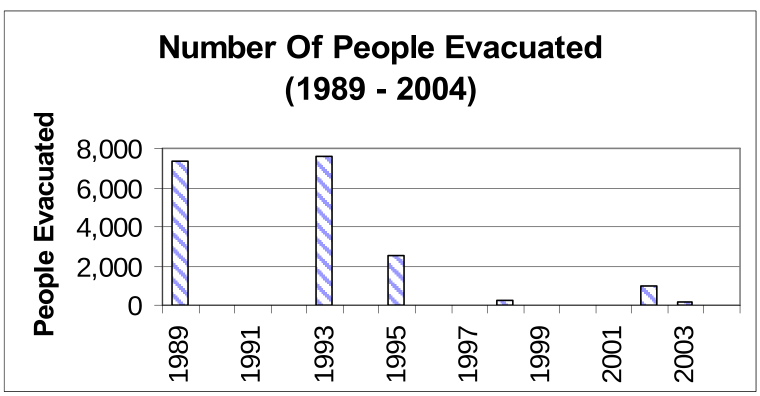


Figure 21 Number of People Evacuated (1989-2004) (Data Source: Saskatchewan Department of Community Resources and Employment 2005)

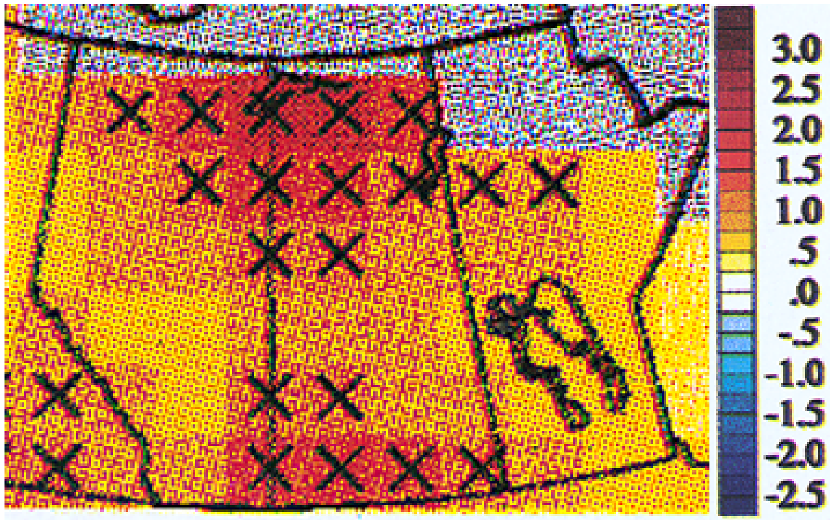


Figure 22 Trends in Daily Maximum Temperature from 1900-1998 (after Zhang et al. 2000: 407). Units are °C per 99-year period. Statistically significant trends are marked with crosses. Grey means insufficient data.

Figure 23 Trends in Daily Minimum Temperature from 1900-1998 (after Zhang et al. 2000: 407). Units are °C per 99-year period. Statistically significant trends are marked with crosses. Grey means insufficient data.

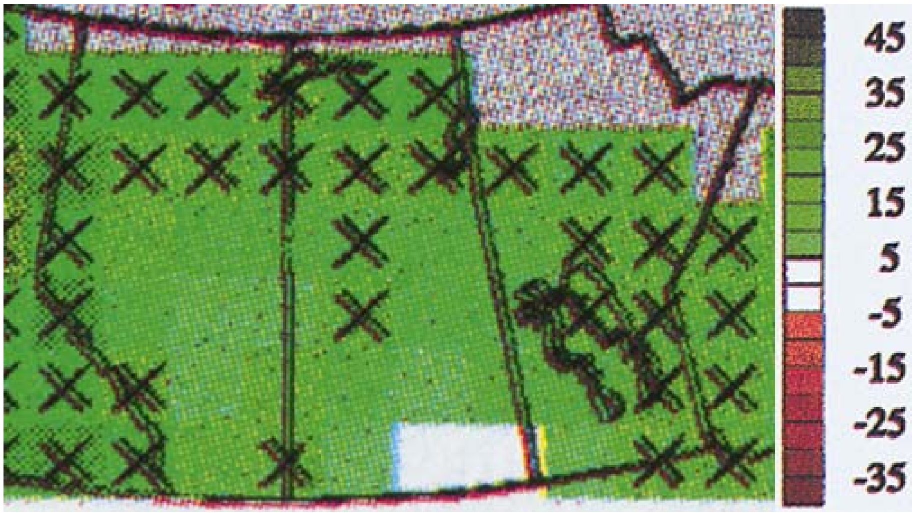


Figure 24 Trends in Annual Precipitation Totals from 1900-1998 (after Zhang et al. 2000:412). Units are percent change over the 99-year period. Statistically significant trends (5% level) are marked by crosses. Grey means insufficient data.

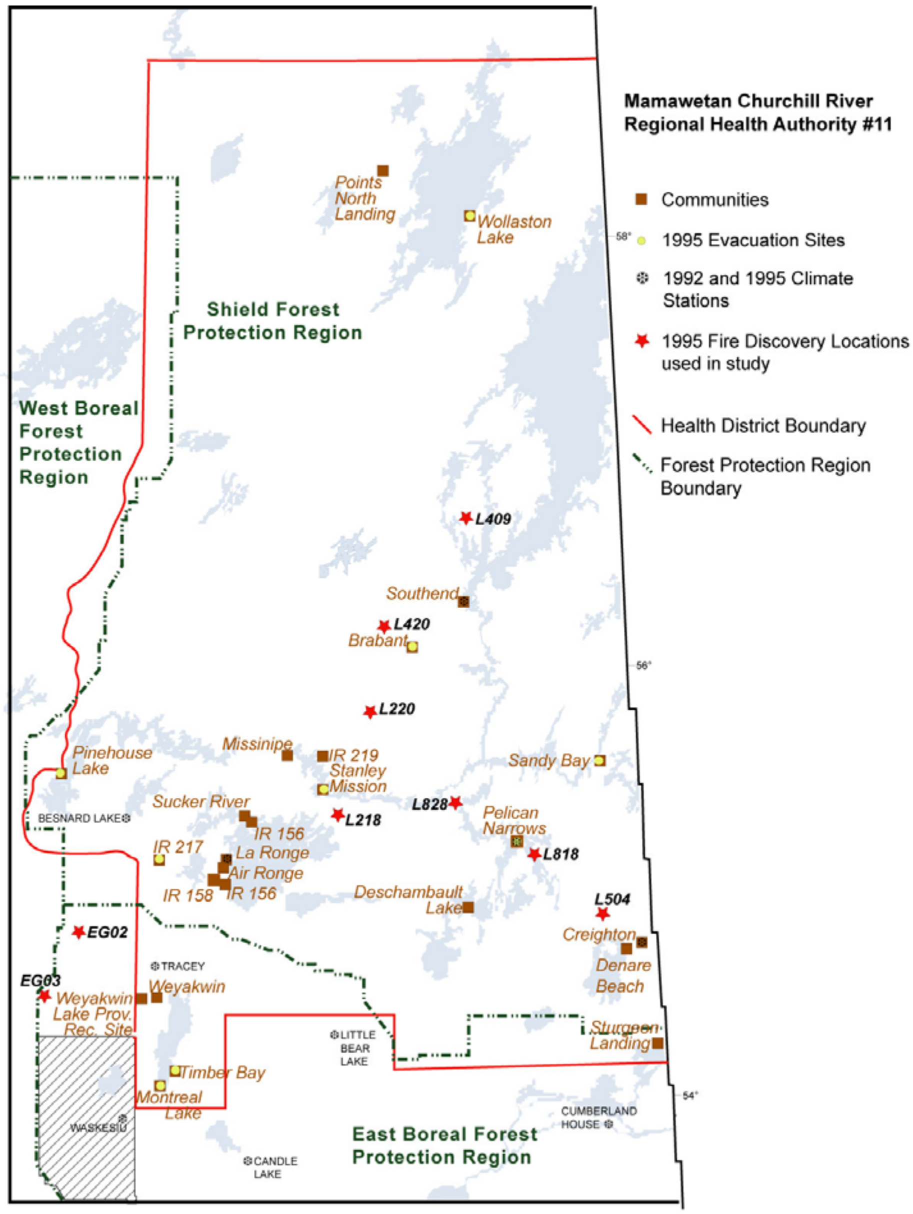


Figure 25 Mamawetan Churchill River RHA Communities, Evacuation Sites, Climate Stations, and Fire Discovery Locations (Data Source: Saskatchewan Environment 2004, Saskatchewan Department of Community Resources and Employment 2005, Saskatchewan Health 2005)

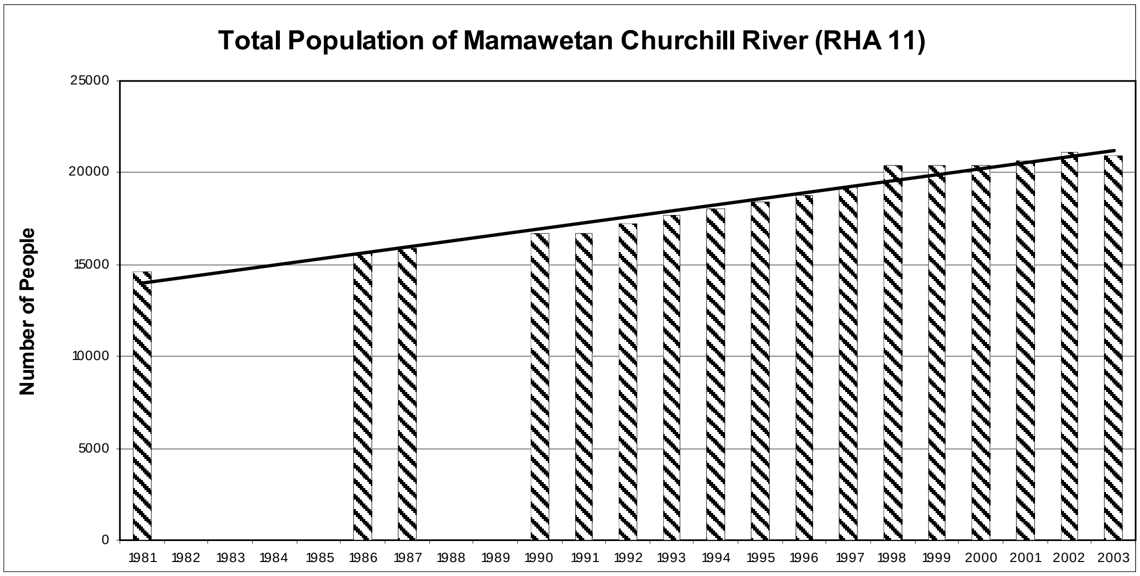


Figure 26 Population of Mamawetan Churchill River Regional Health Authority (1981-2003) (Data Source: Saskatchewan Health 2005)

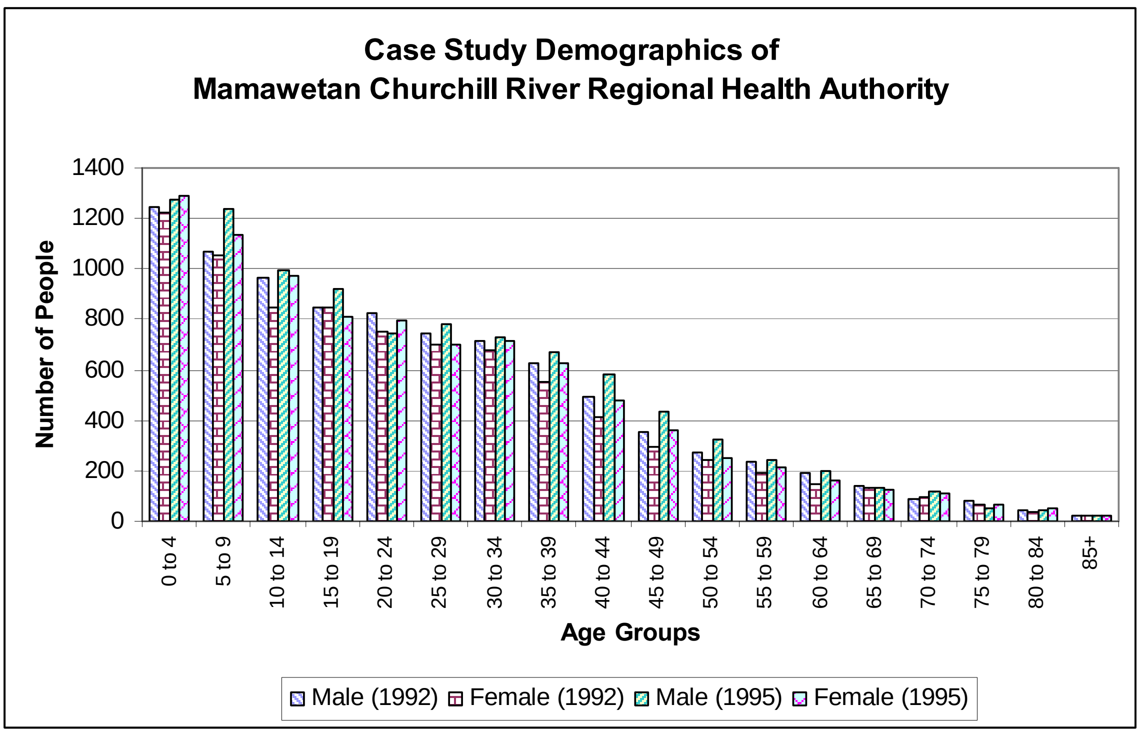


Figure 27 Demographics of the Mamawetan Churchill River Regional Health Authority for 1992 and 1995 (Data Source: Saskatchewan Health 2005)

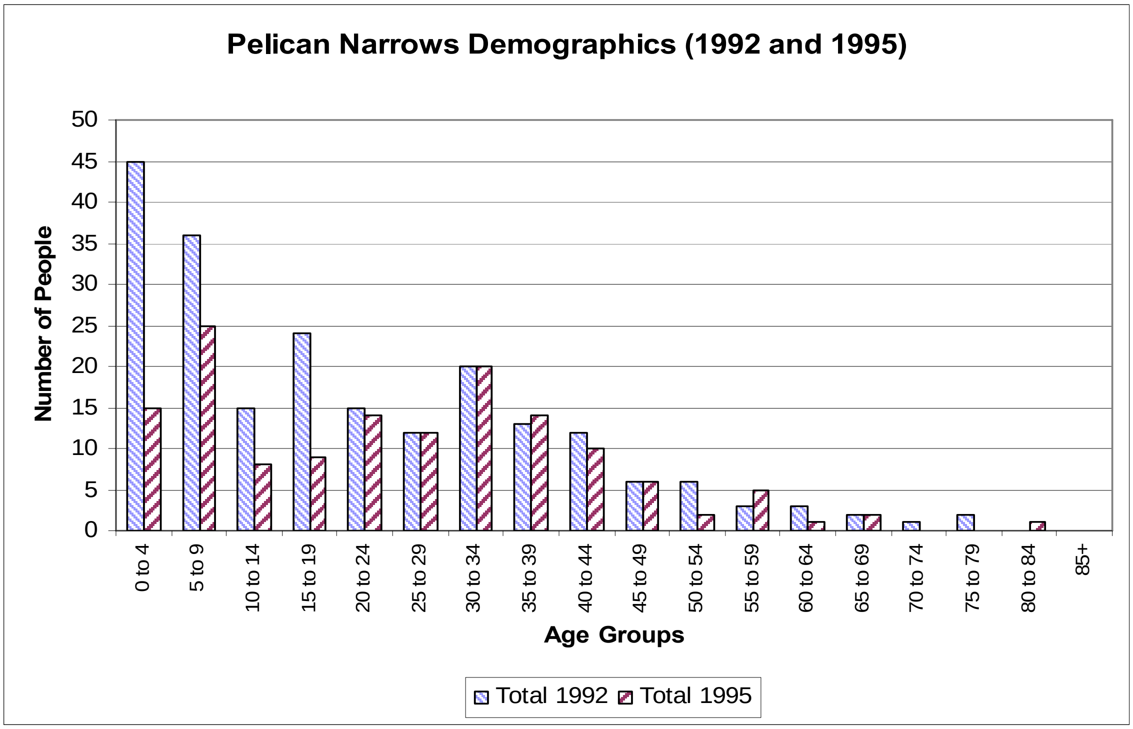


Figure 28 Demographics of Pelican Narrows (1992 and 1995) (Data Source: Saskatchewan Health 2005)

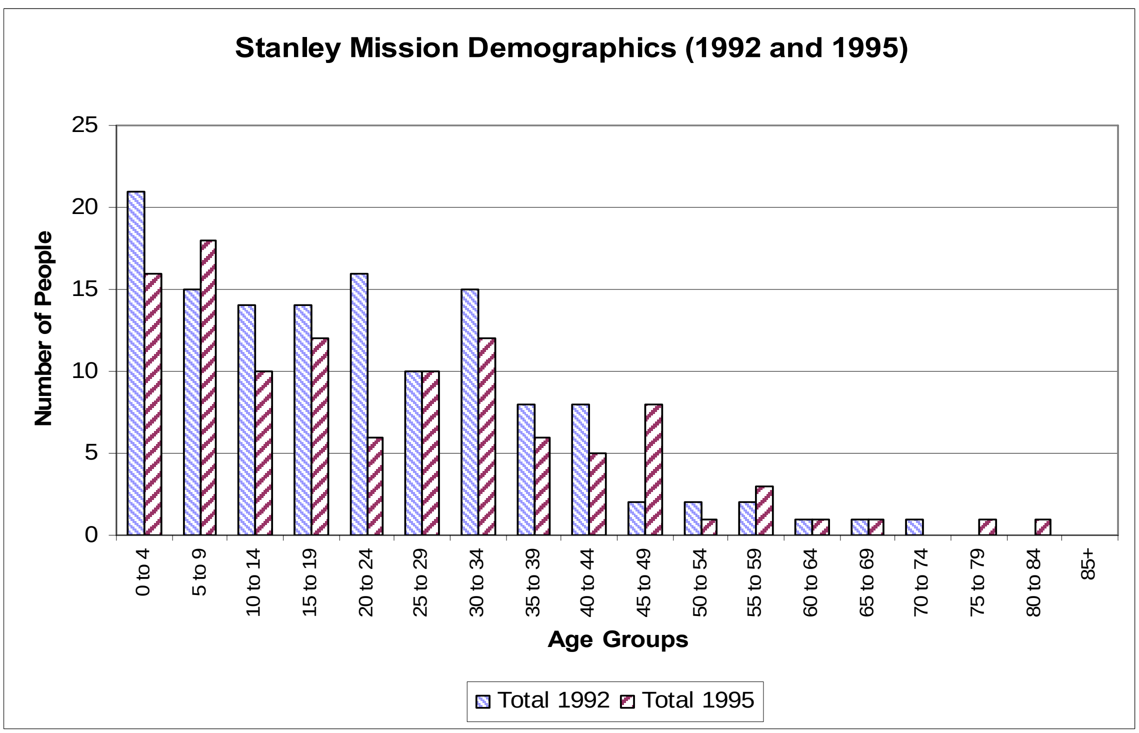


Figure 29 Demographics of Stanley Mission (1992 and 1995) (Data Source: Saskatchewan Health 2005)

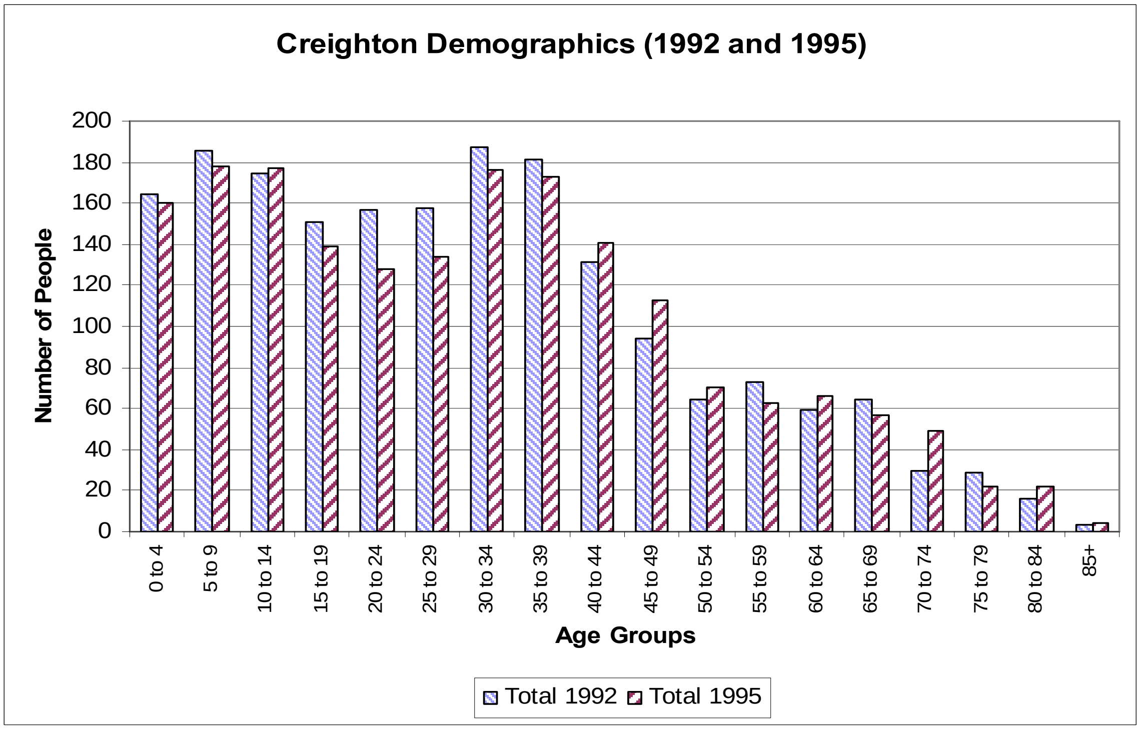


Figure 30 Demographics of Creighton (1992 and 1995) (Data Source: Saskatchewan Health 2005)

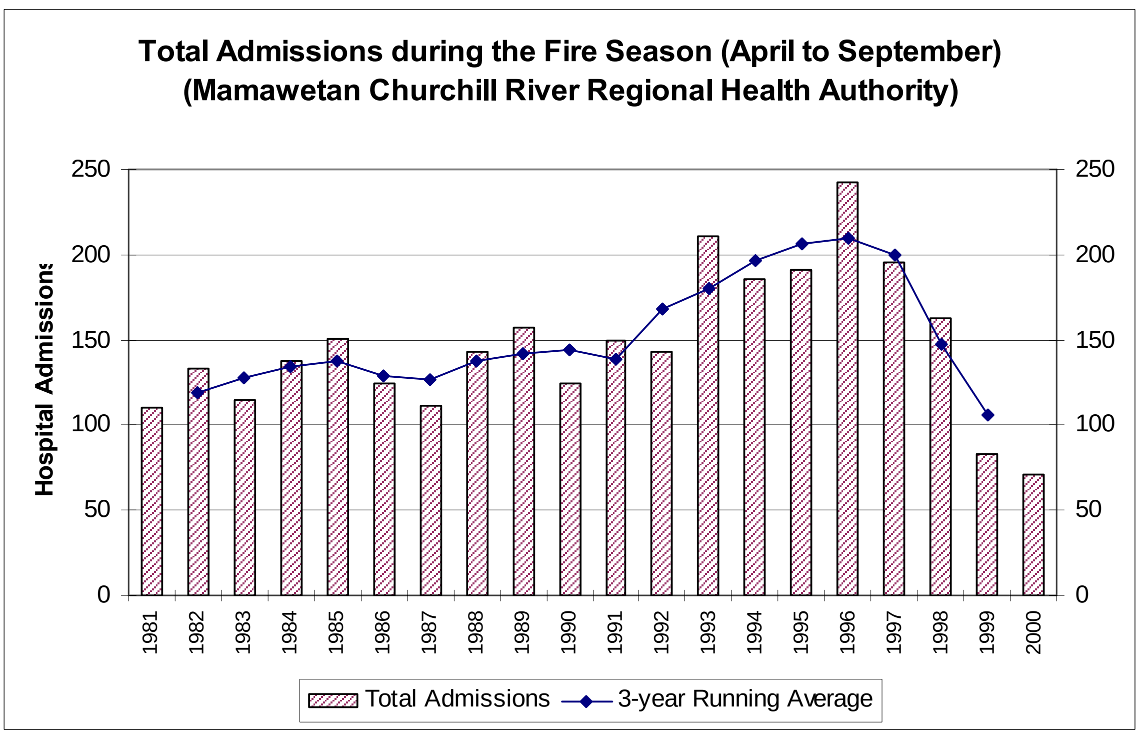


Figure 31 Hospital Admissions during the April 1 to September 30 Fire Season in the Mamawetan Churchill River Regional Health Authority (1081-2000) (Data Source: Saskatchewan Health 2005)

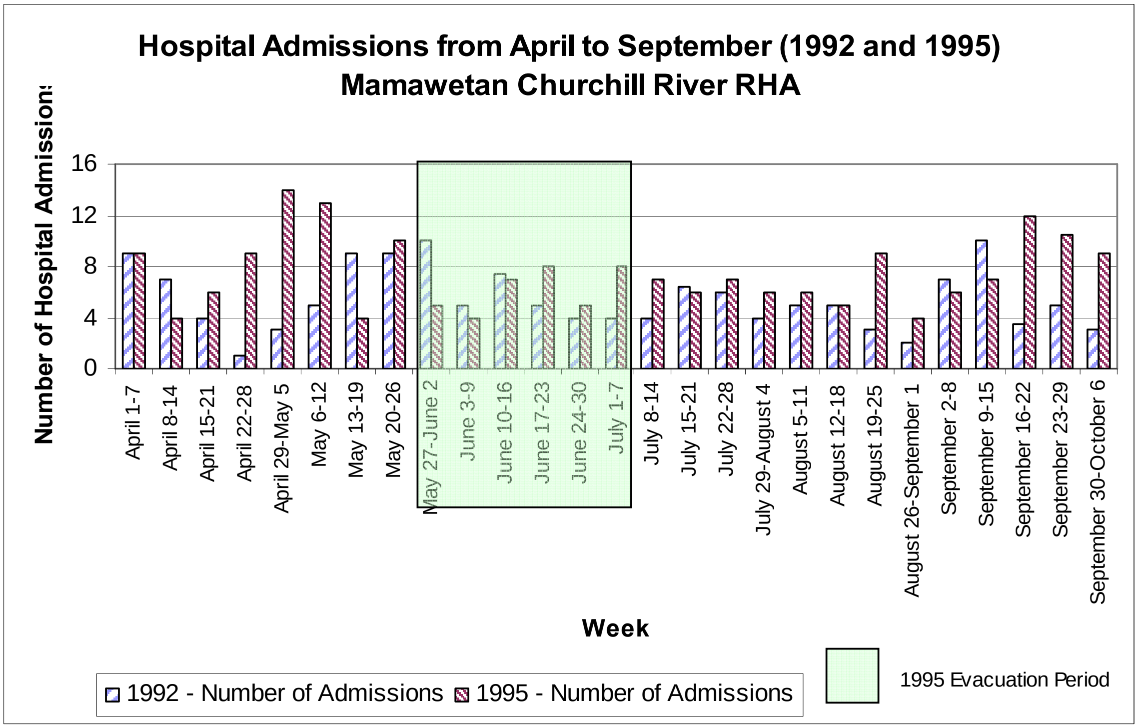


Figure 32 Hospital Admissions for the April 1 to September 30 period in 1992 and 1995 in the Mamawetan Churchill River Regional Health Authority (Data Source: Saskatchewan Health 2005, Saskatchewan Department of Community Resources and Employment 2005)

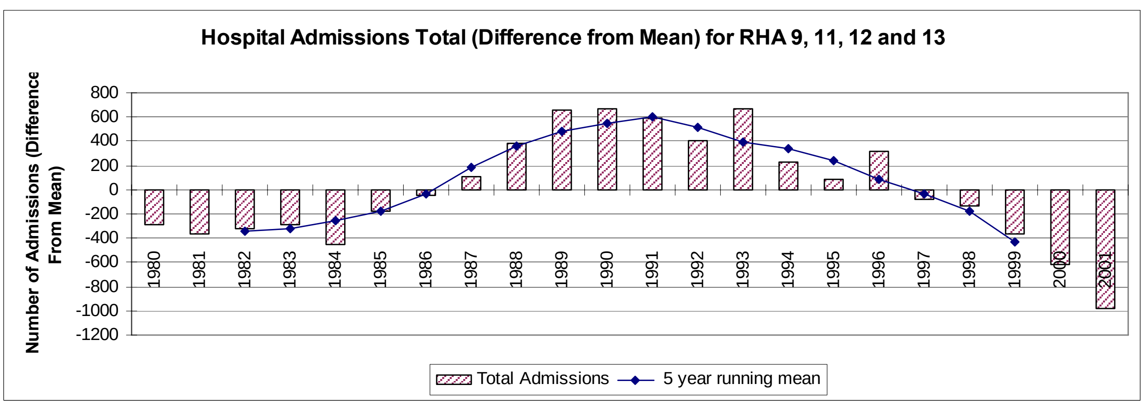


Figure 33 Hospital Admissions Difference from the Mean for RHA 9, 11, 12 and 13 (Data Source: Saskatchewan Health 2005)

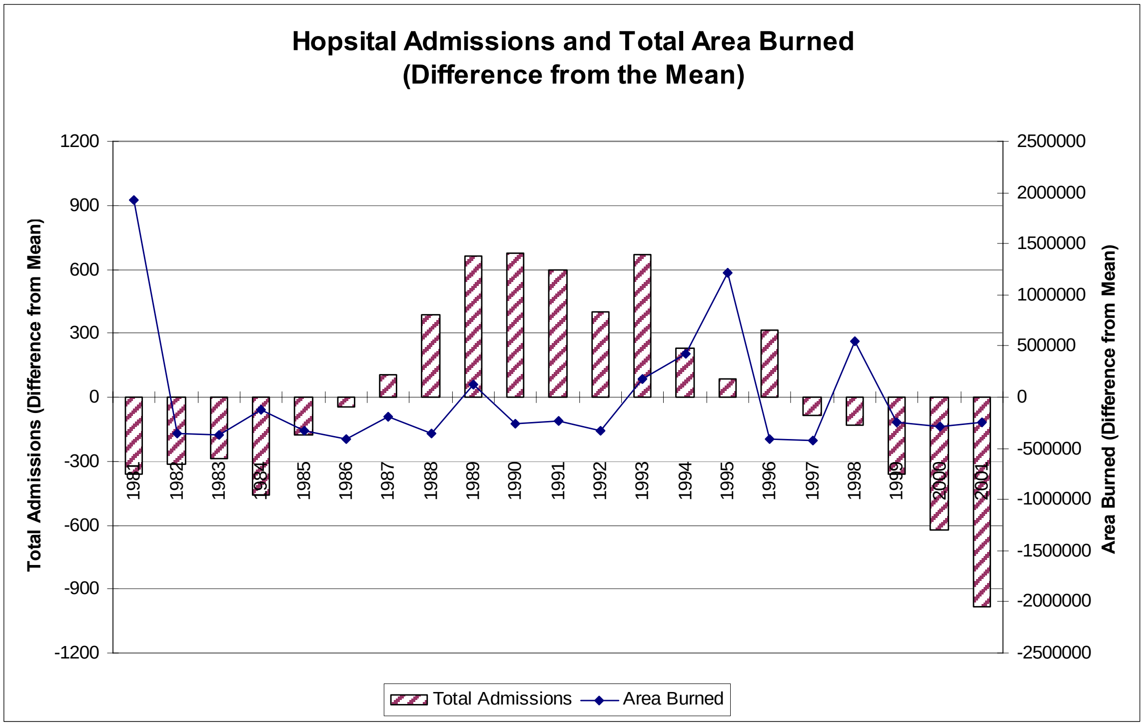


Figure 34 Hospital Admissions and Area Burned in RHA 9, 11, 12 and 13 (1981-2001) (Data Source: Saskatchewan Health 2005 and Saskatchewan Environment 2004)

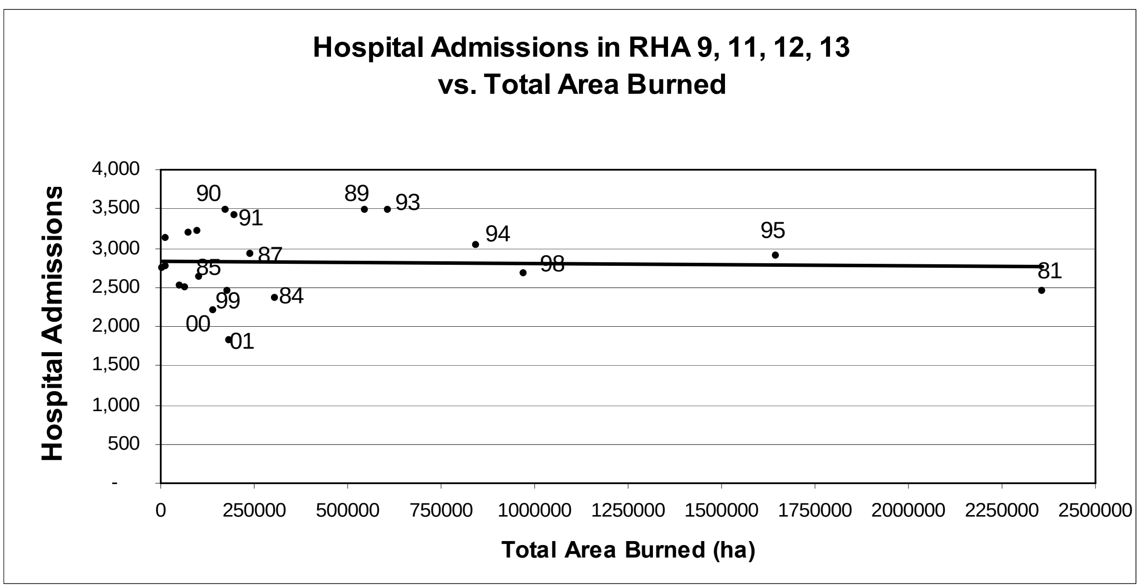


Figure 35 Scatter Plot of Hospital Admissions in RHA 9, 11, 12 13 and Total Area Burned (Data Source: Saskatchewan Health 2005 and Saskatchewan Environment 2004)

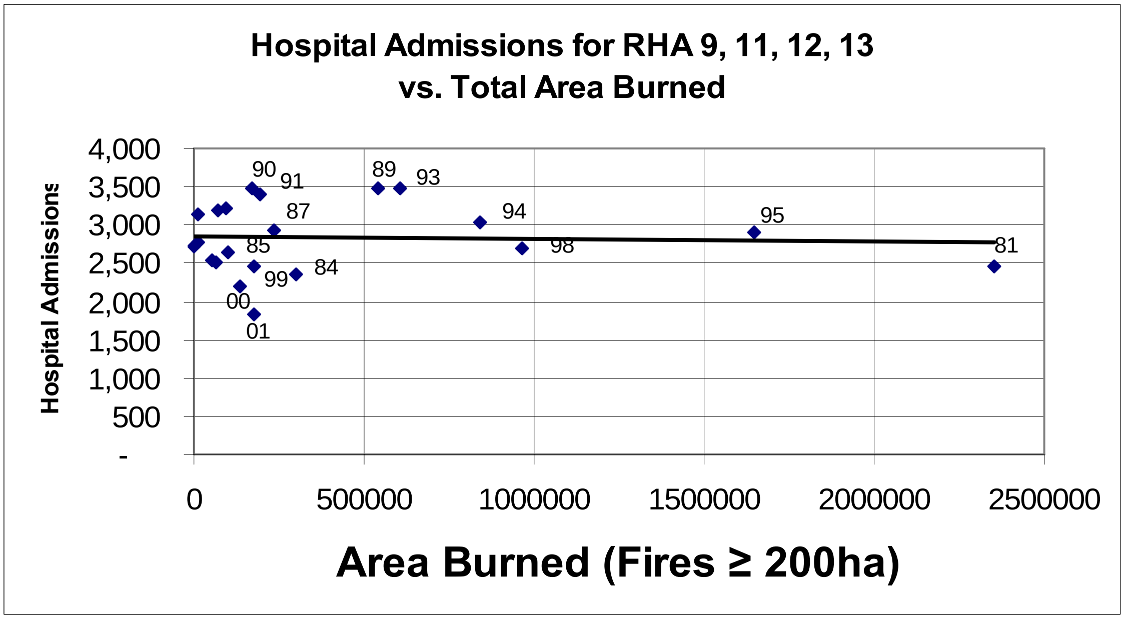


Figure 36 Scatter Plot of Hospital Admissions in RHA 9, 11, 12 13 and Total Area Burned for Large Fires (≥ 200 ha) (Data Source: Saskatchewan Health 2005 and Saskatchewan Environment 2004)

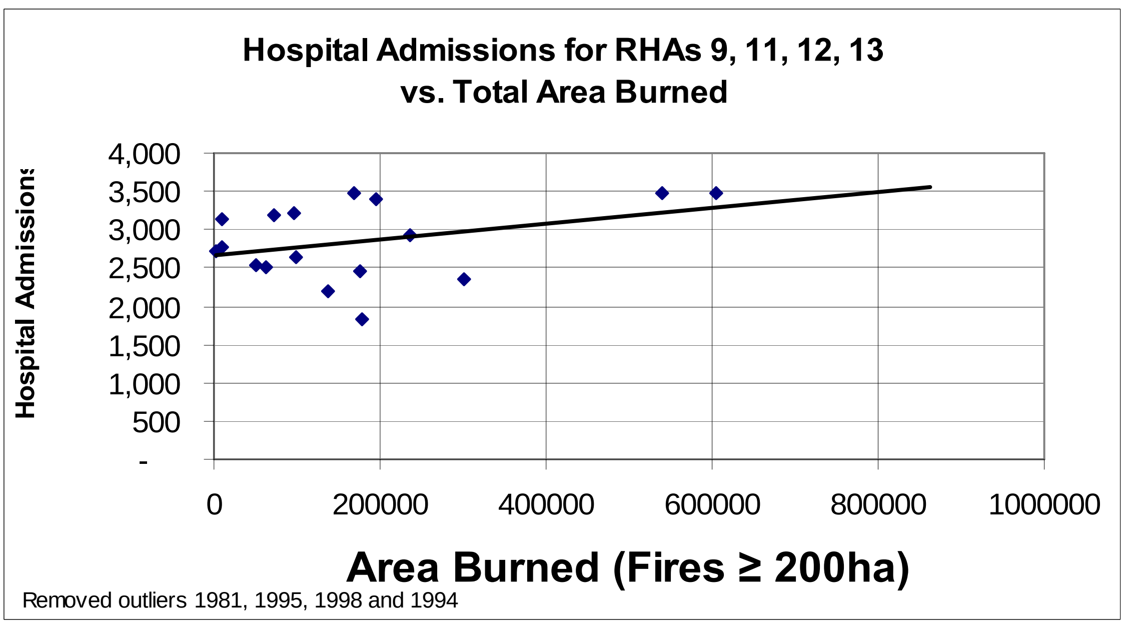


Figure 37 Scatter Plot of Hospital Admissions in RHA 9, 11, 12 13 and Total Area Burned for Large Fires (≥ 200 ha) with Four Outliers Removed (Data Source: Saskatchewan Health 2005 and Saskatchewan Environment 2004)

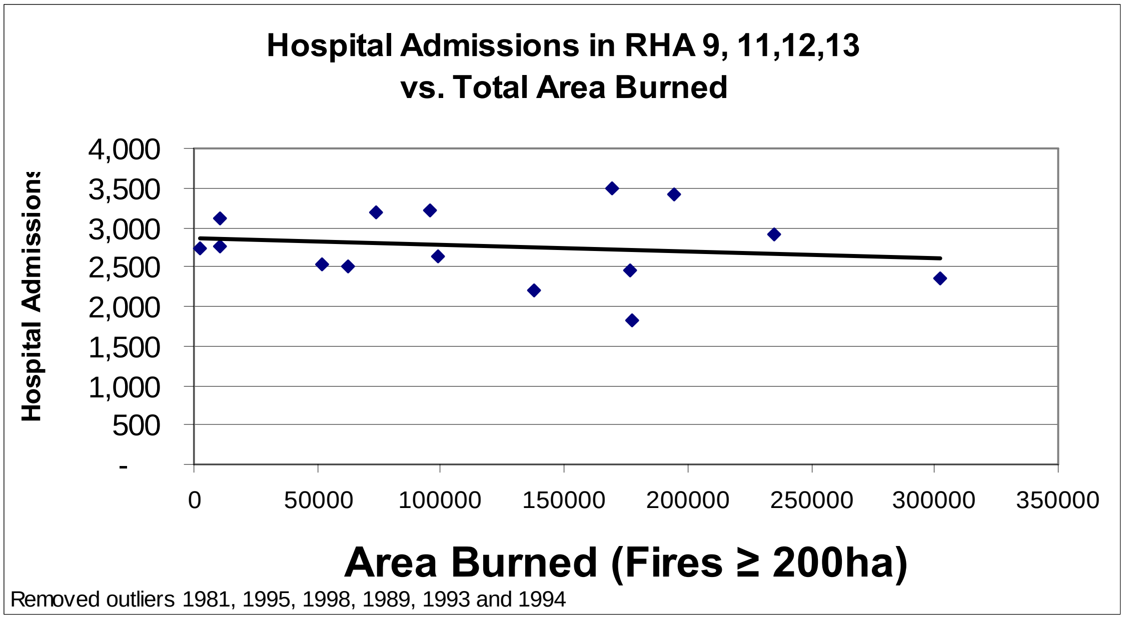


Figure 38 Scatter Plot of Hospital Admissions in RHA 9, 11, 12 13 and Total Area Burned for Large Fires (≥ 200 ha) with Six Outliers Removed (Data Source: Saskatchewan Health 2005 and Saskatchewan Environment 2004)

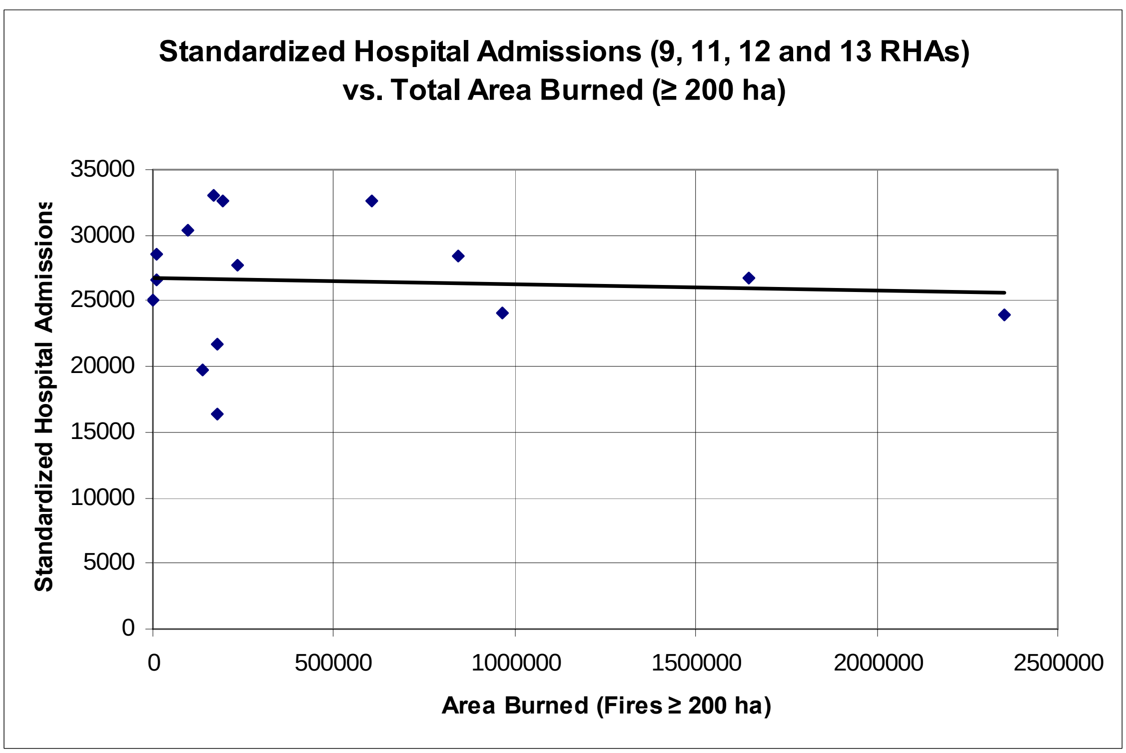


Figure 39 Scatter Plot of Standardized Hospital Admissions in RHA 9, 11, 12 13 and Total Area Burned for Large Fires (≥ 200 ha) (Data Source: Saskatchewan Health 2005 and Saskatchewan Environment 2004)

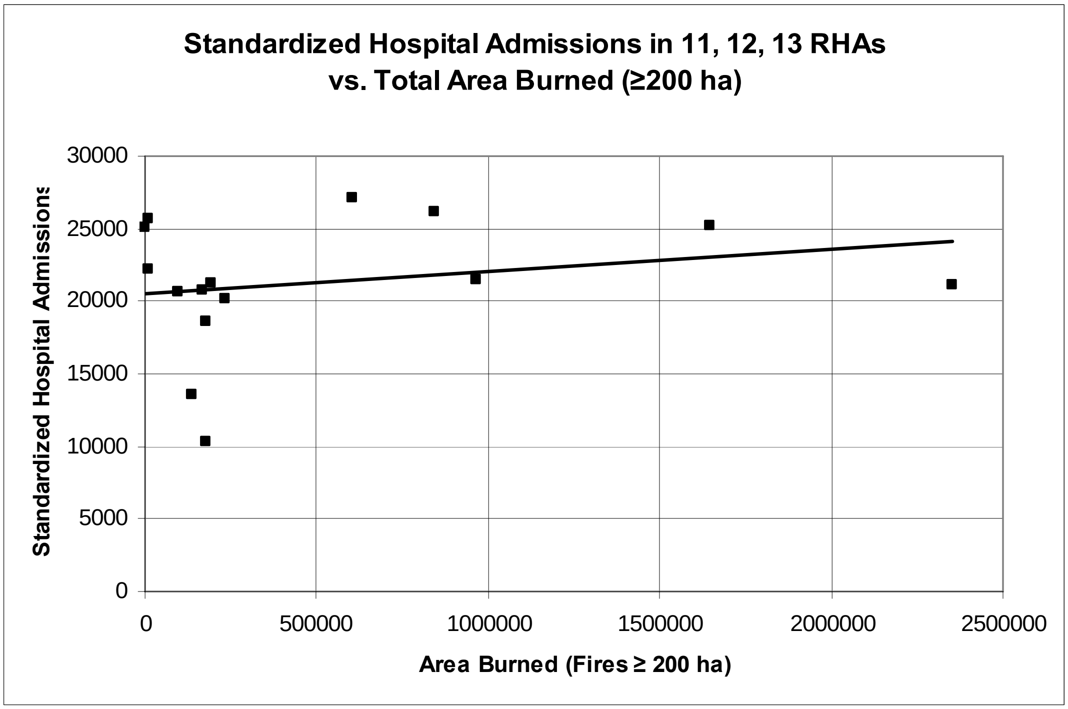


Figure 40 Scatter Plot of Standardized Hospital Admissions in RHA 11, 12 and 13 and Total Area Burned for Large Fires (≥ 200 ha) (1981-2001) (Data Source: Saskatchewan Health 2005 and Saskatchewan Environment 2004)

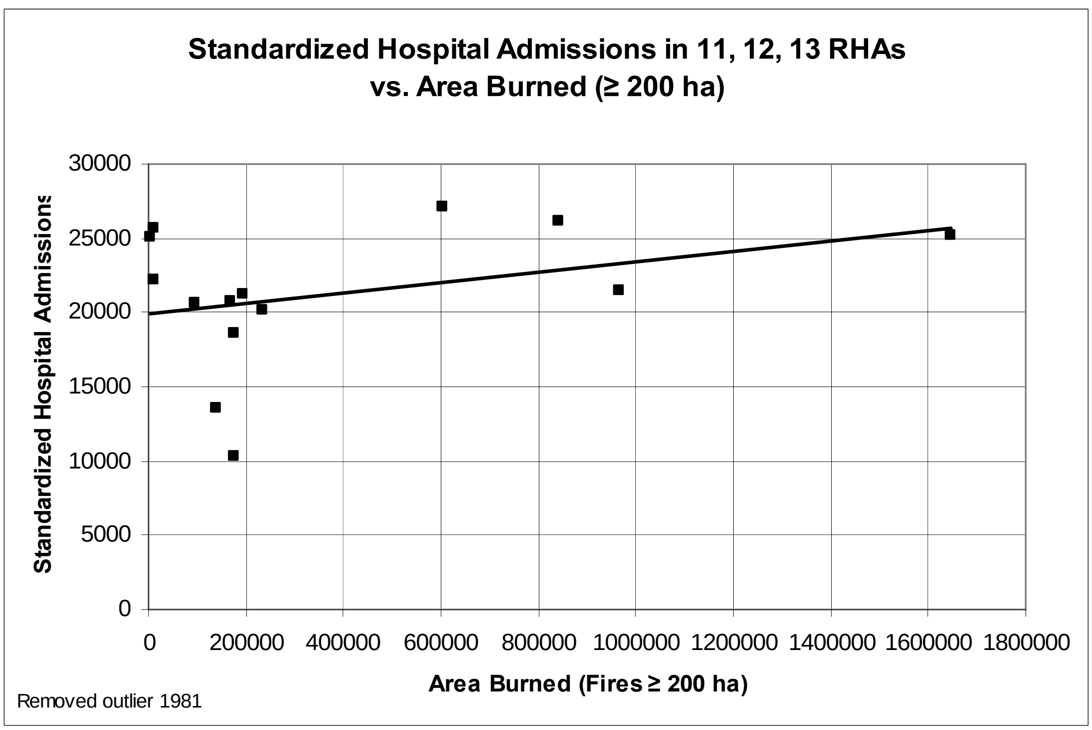


Figure 41 Scatter Plot of Hospital Admissions in RHA 11, 12 13 and Total Area Burned for Large Fires (≥ 200 ha) with 1981 Outlier Removed (Data Source: Saskatchewan Health 2005 and Saskatchewan Environment 2004)

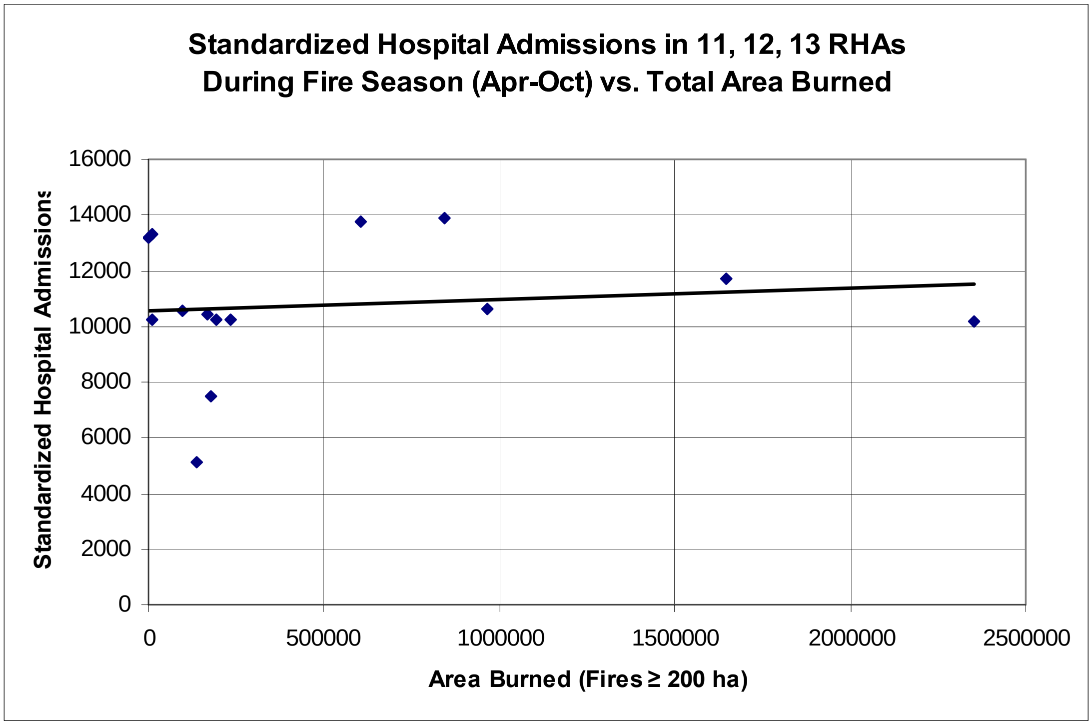


Figure 42 Scatter Plot of Hospital Admissions in RHA 11, 12 13 and Total Area Burned for Large Fires (≥ 200 ha) in the April to October Fire Season (Data Source: Saskatchewan Health 2005 and Saskatchewan Environment 2004)

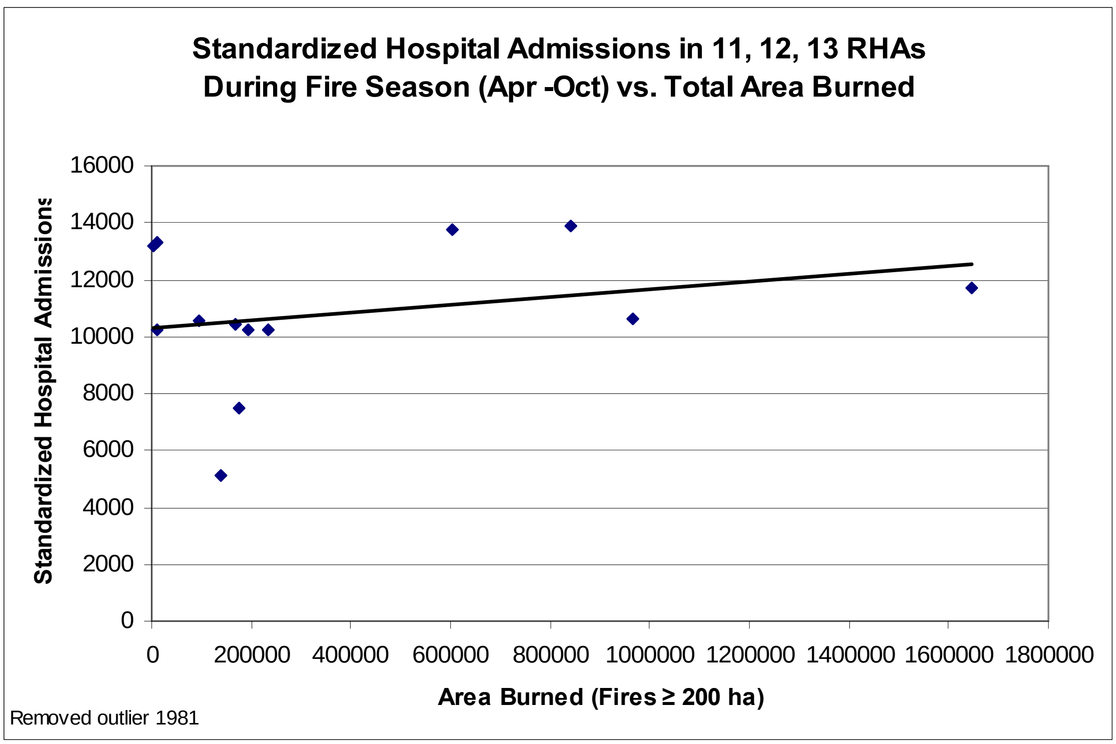


Figure 43 Scatter Plot of Hospital Admissions in RHA 11, 12 13 and Total Area Burned for Large Fires (≥ 200 ha) in the April to October Fire Season with the 1981 Outlier Removed (Data Source: Saskatchewan Health 2005 and Saskatchewan Environment 2004)

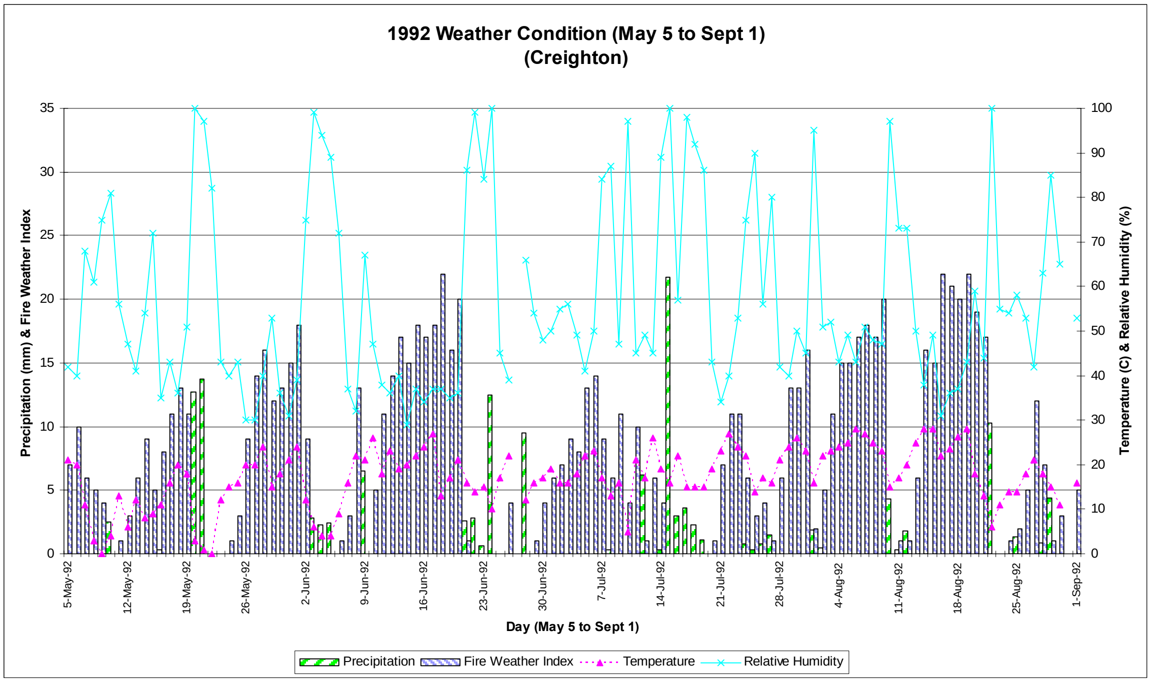


Figure 44 1992 Creighton Weather Conditions (May 6 to Sept 1) (Data Source: Saskatchewan Environment 2004)

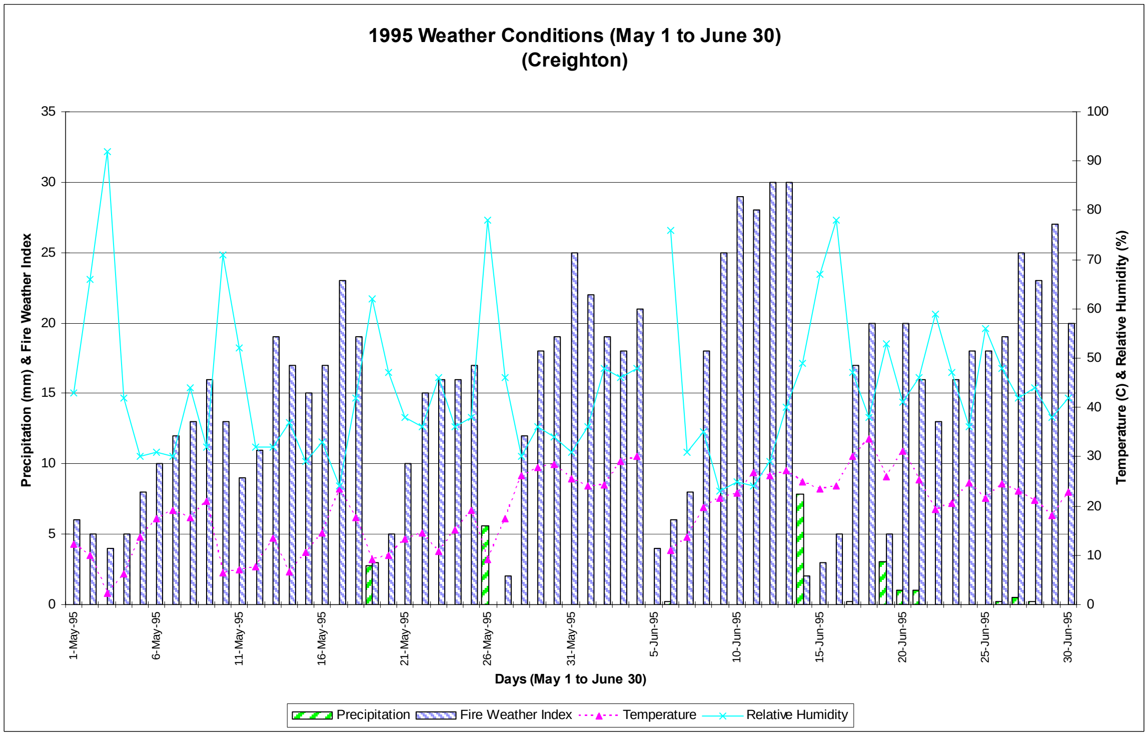


Figure 45 1995 Creighton Weather Conditions (May 1 to June 30) (Data Source: Saskatchewan Environment 2004)

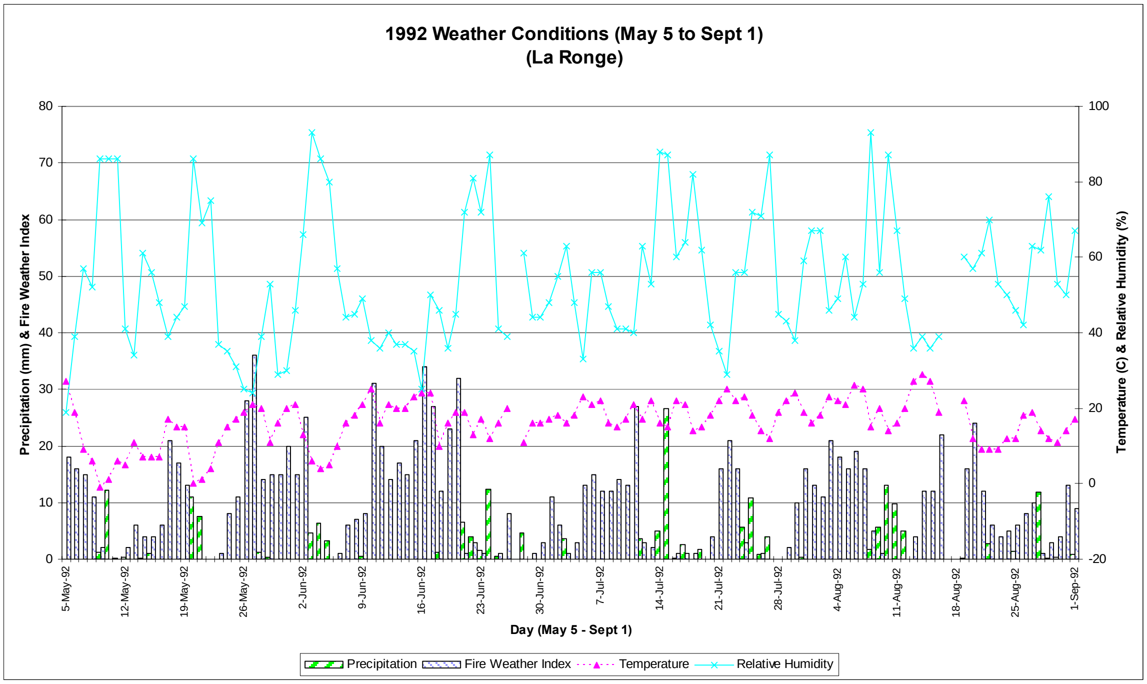


Figure 46 1992 La Ronge Weather Conditions (May 5 to Sept 1) (Data Source: Saskatchewan Environment 2004)

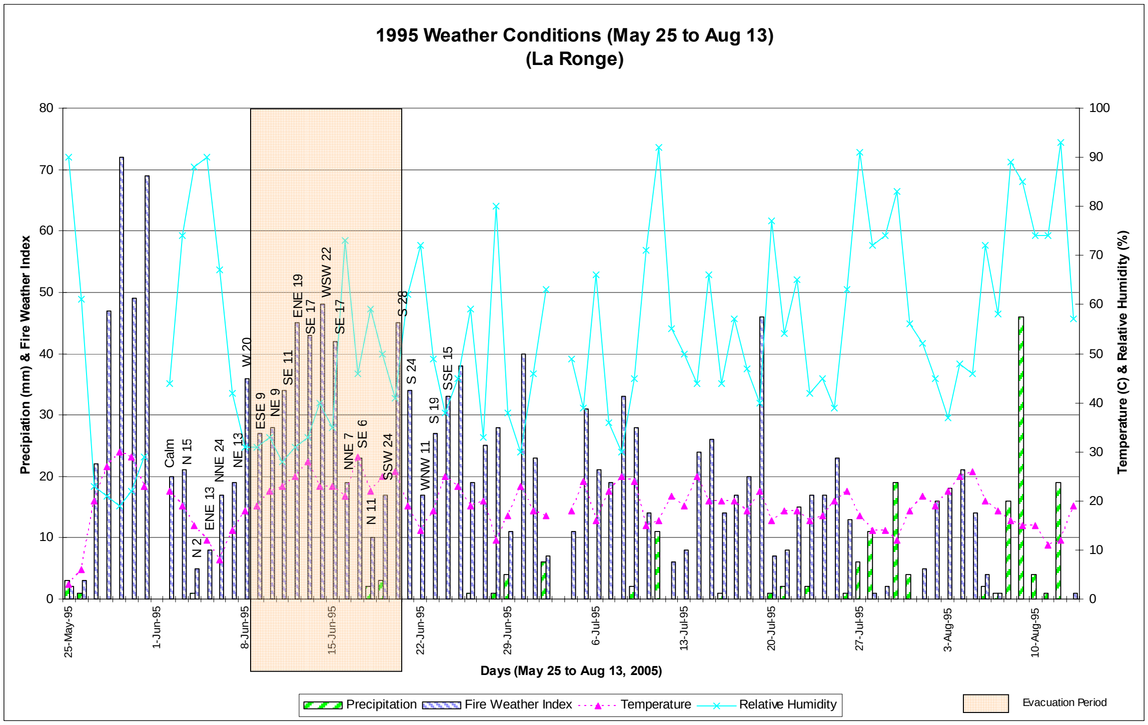


Figure 47 1995 La Ronge Weather Conditions (May 25 to August 13) (Data Source: Saskatchewan Environment 2004)

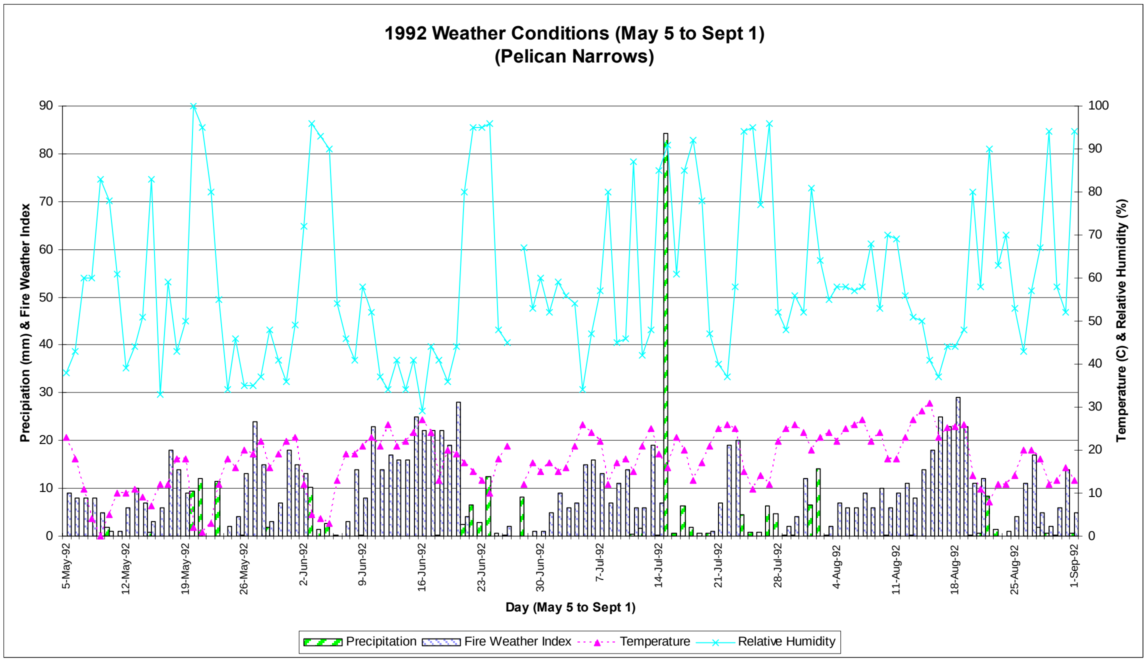


Figure 48 1992 Pelican Narrows Weather Conditions (May 5 to September 1) (Data Source: Saskatchewan Environment 2004)

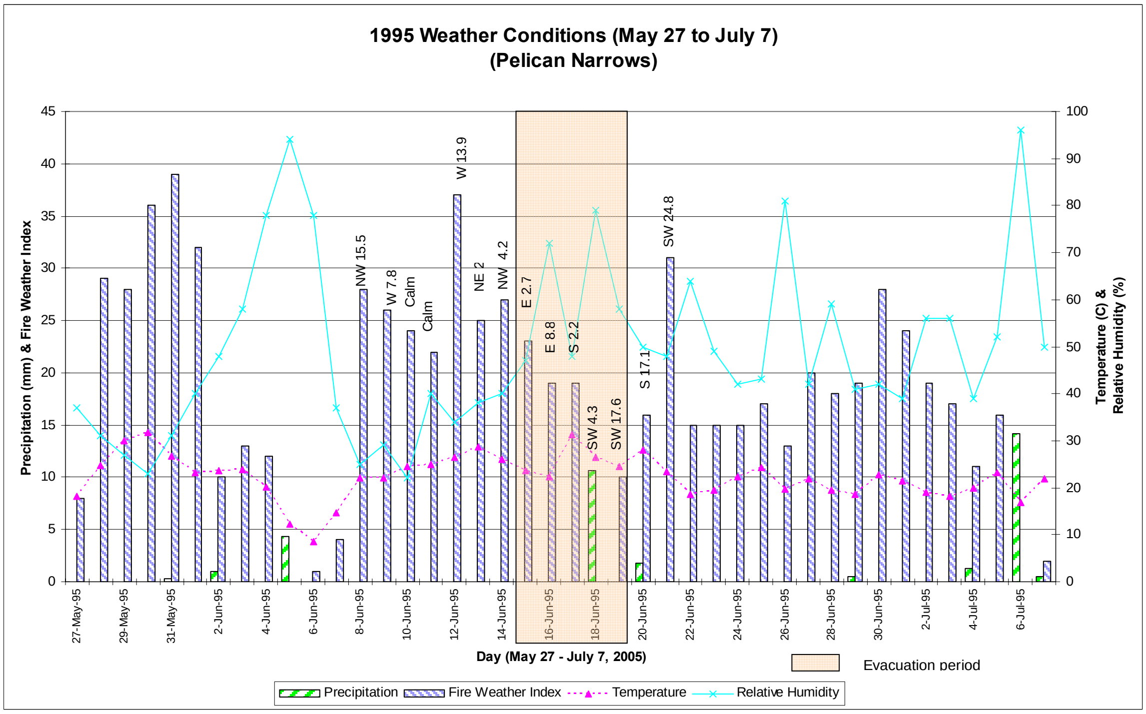


Figure 49 1995 Pelican Narrows Weather Conditions (May 27 to July 7) (Data Source: Saskatchewan Environment 2004)

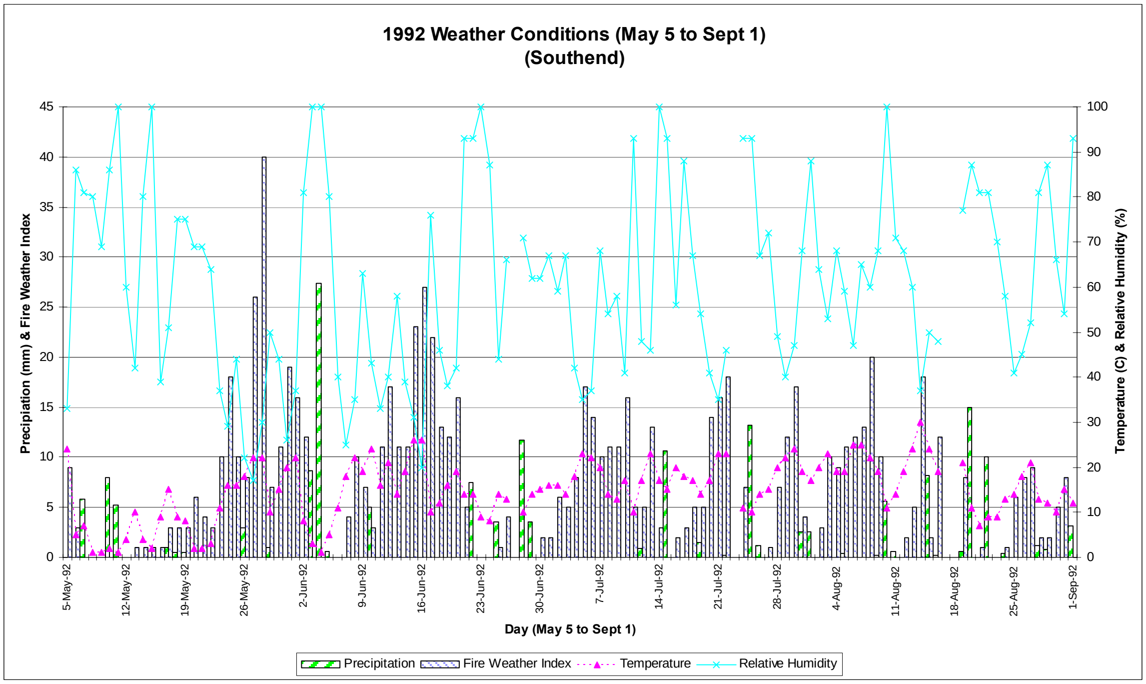


Figure 50 1992 Southend Weather Conditions (May 5 to September 1) (Data Source: Saskatchewan Environment 2004)

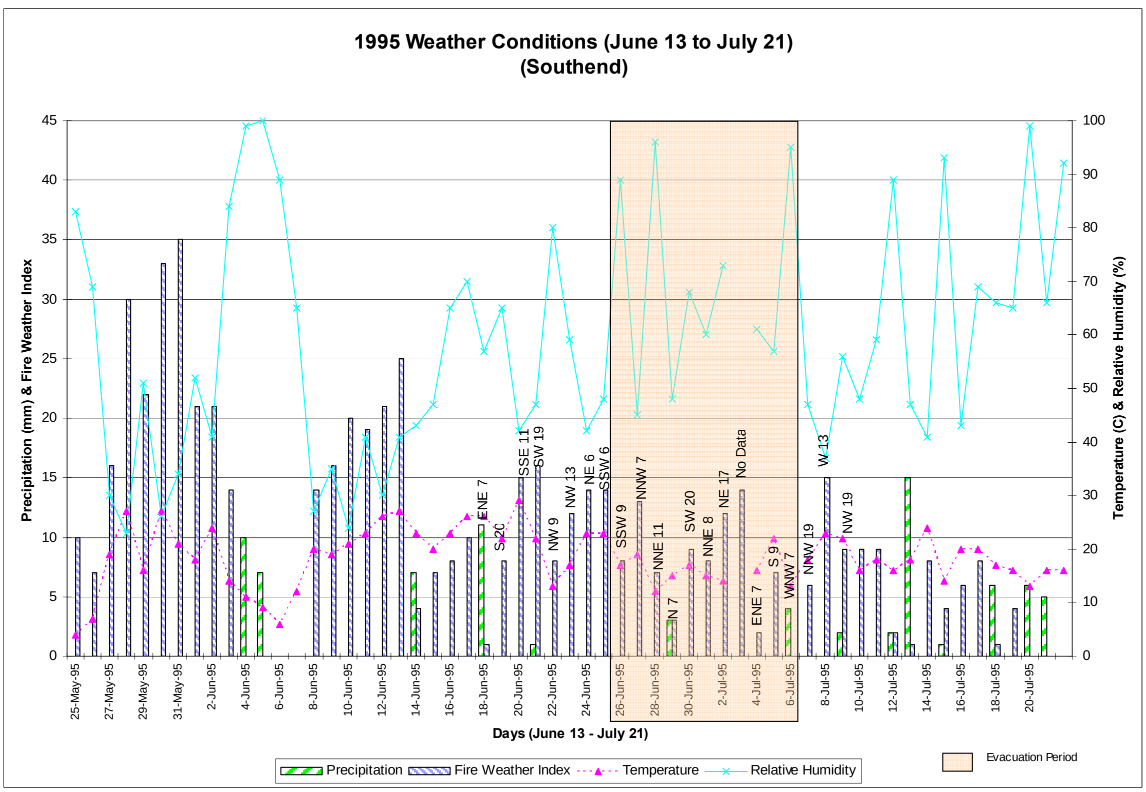


Figure 51 1995 Southend Weather conditions (June 13 to July 21) (Data Source: Saskatchewan Environment 2004)

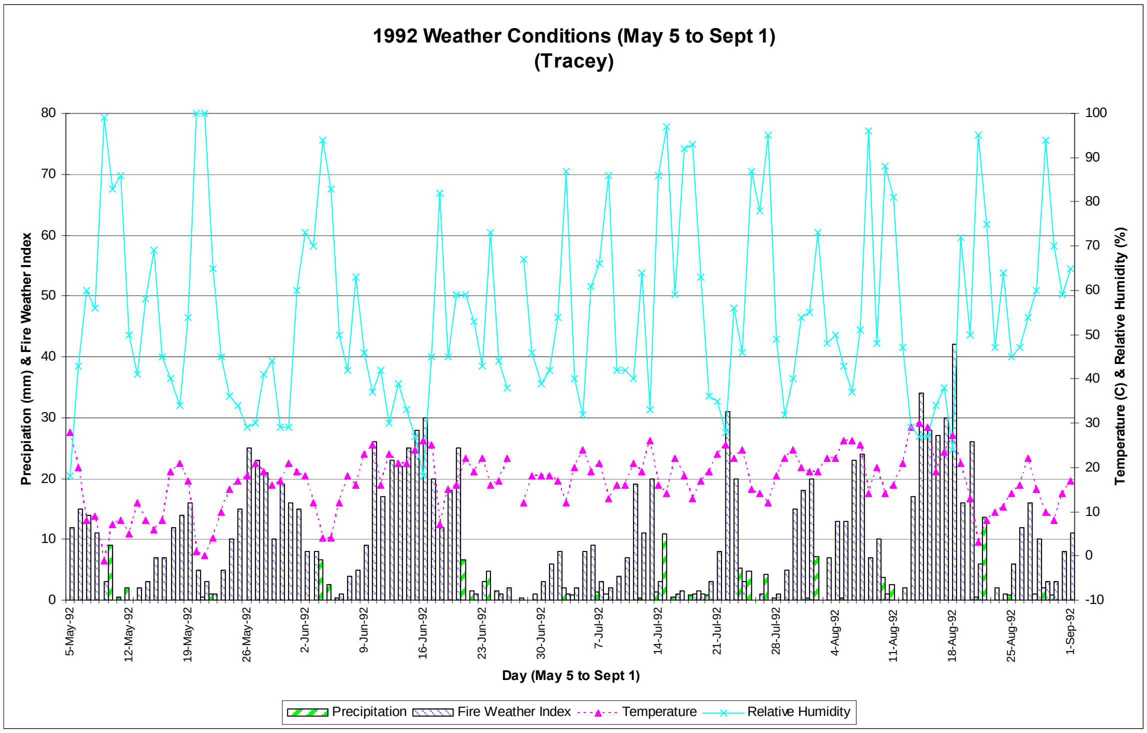


Figure 52 1992 Tracey Weather Conditions (May 5 to September 1) (Data Source: Saskatchewan Environment 2004)

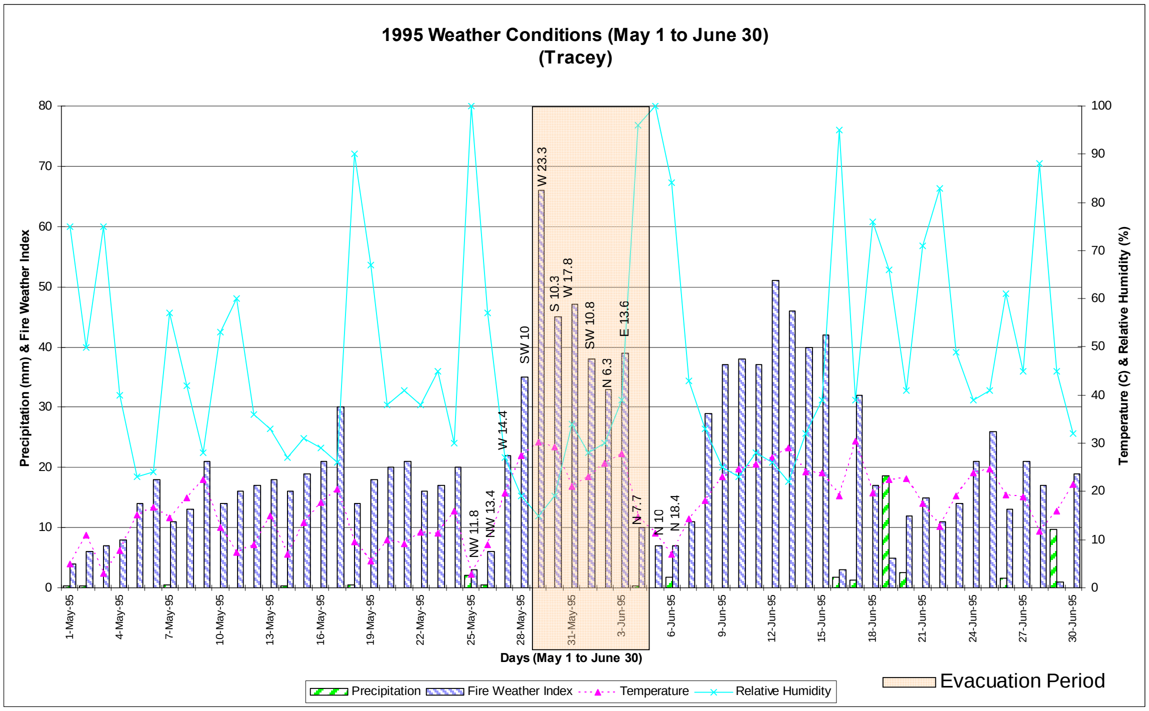


Figure 53 1995 Tracey Weather Conditions (May 1 to June 30) (Data Source: Saskatchewan Environment 2004)

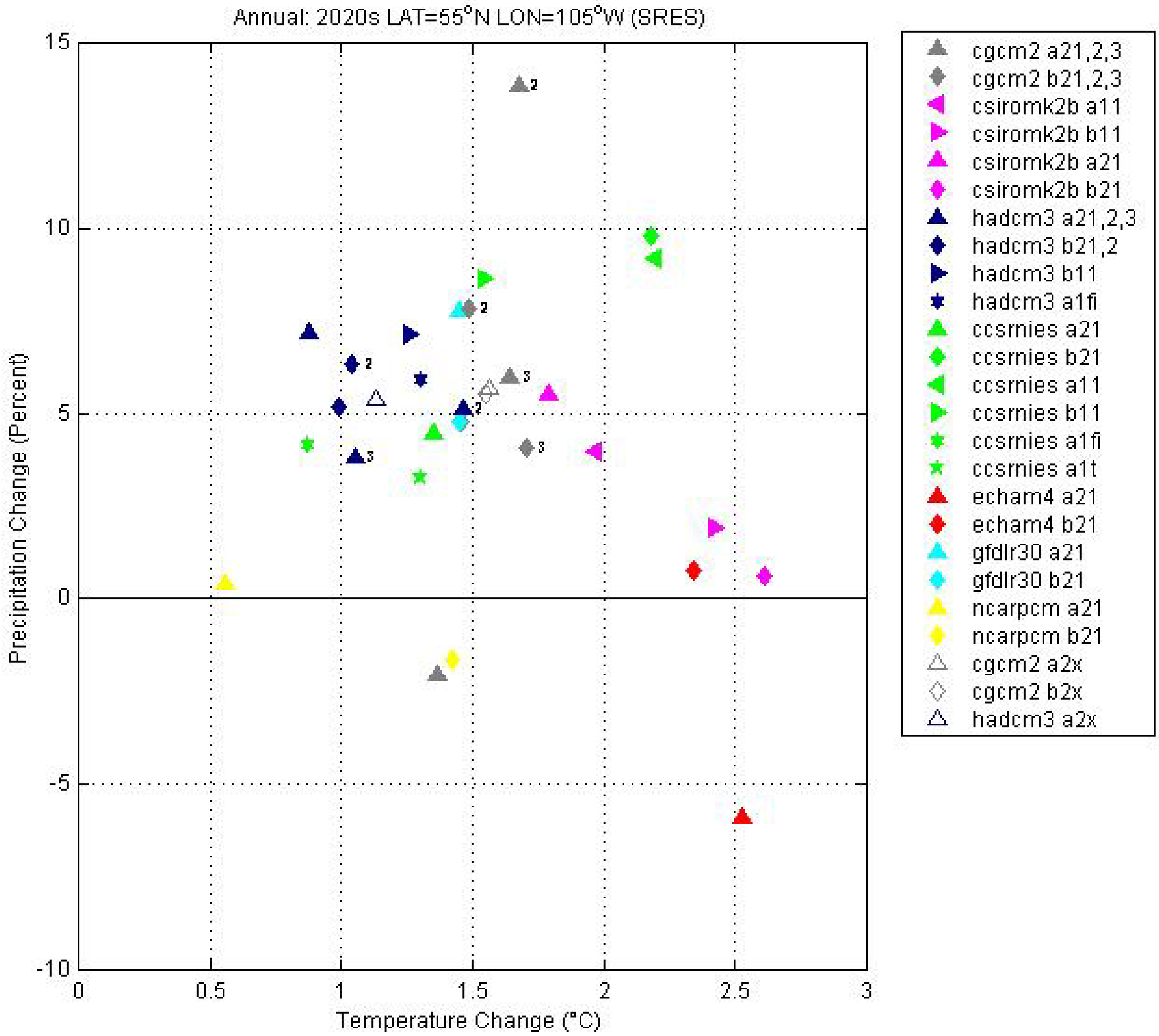


Figure 54 2020s Annual Changes in Mean Temperature (°C) and Precipitation (%) for a Grid Centered at 55° N and 105° W (near Lac La Ronge) for Several GCMs and Emission Scenarios (CCIS 2005)

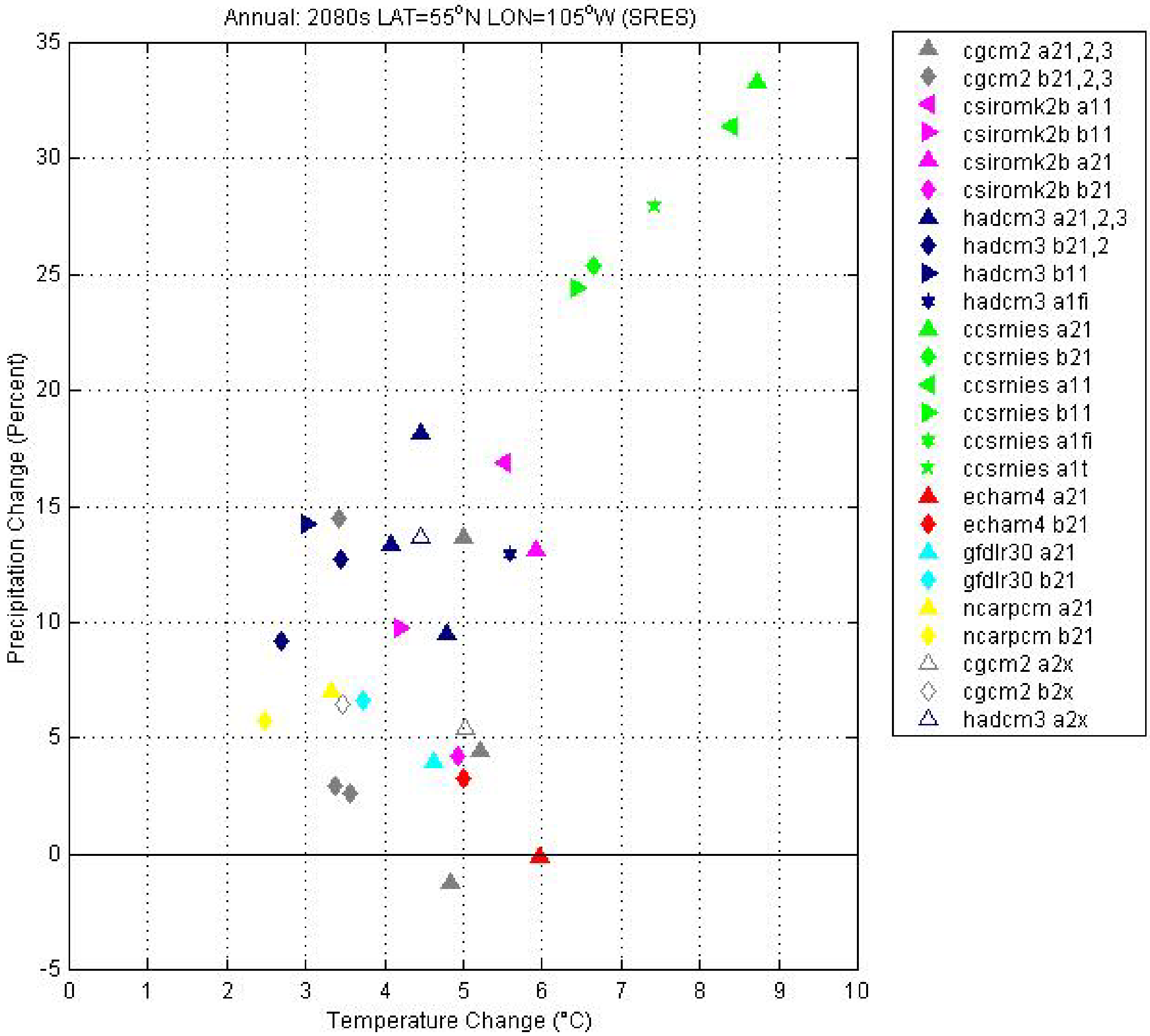
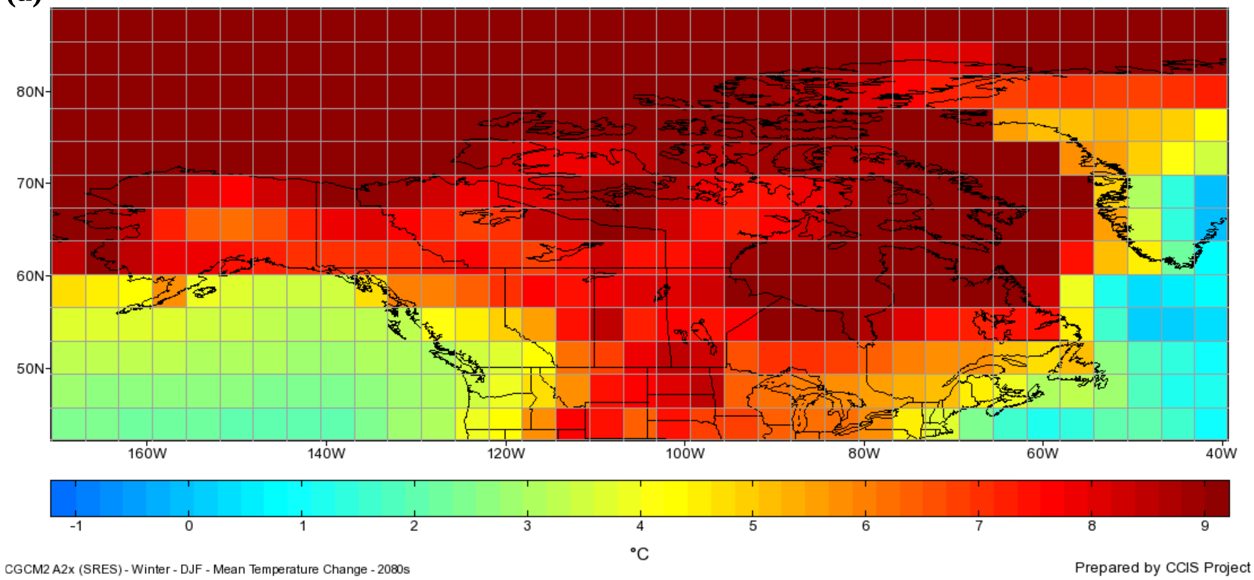
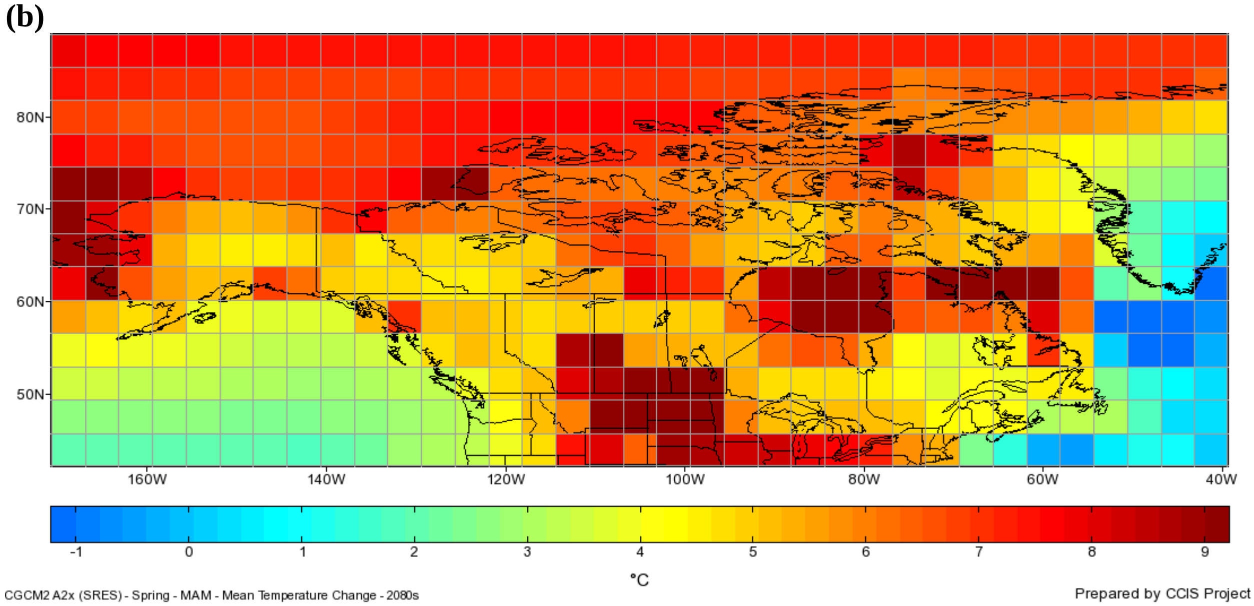


Figure 55 2080s Annual Changes in Mean Temperature (°C) and Precipitation (%) for a Grid Centered at 55° N and 105° W (near Lac La Ronge) for Several GCMs and Emission Scenarios (CCIS 2005)

(a)

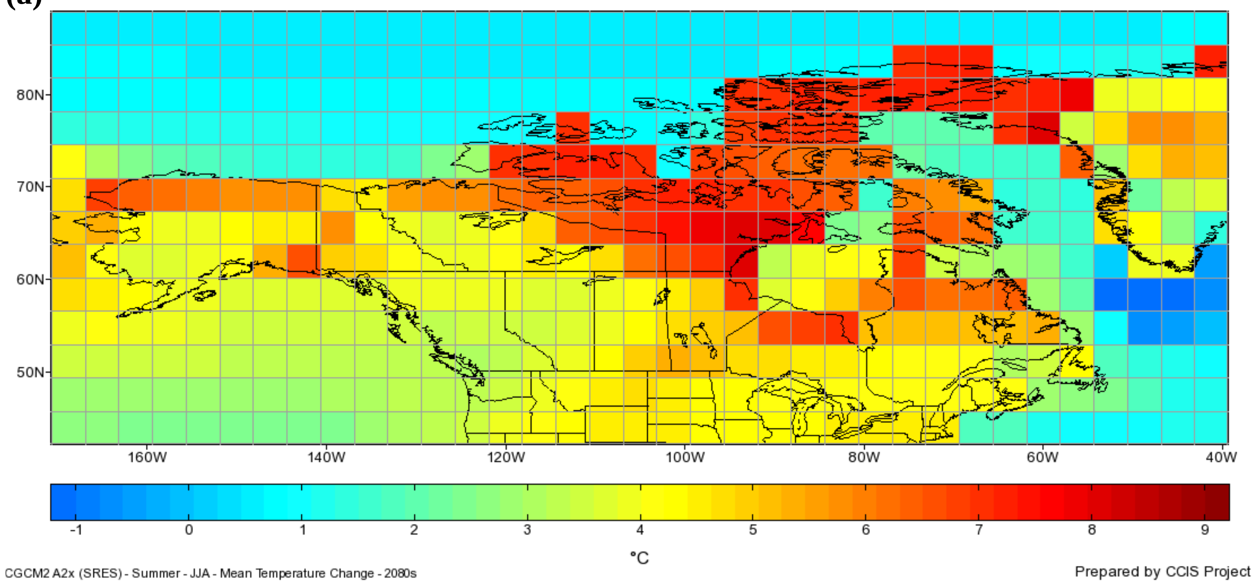


(b)

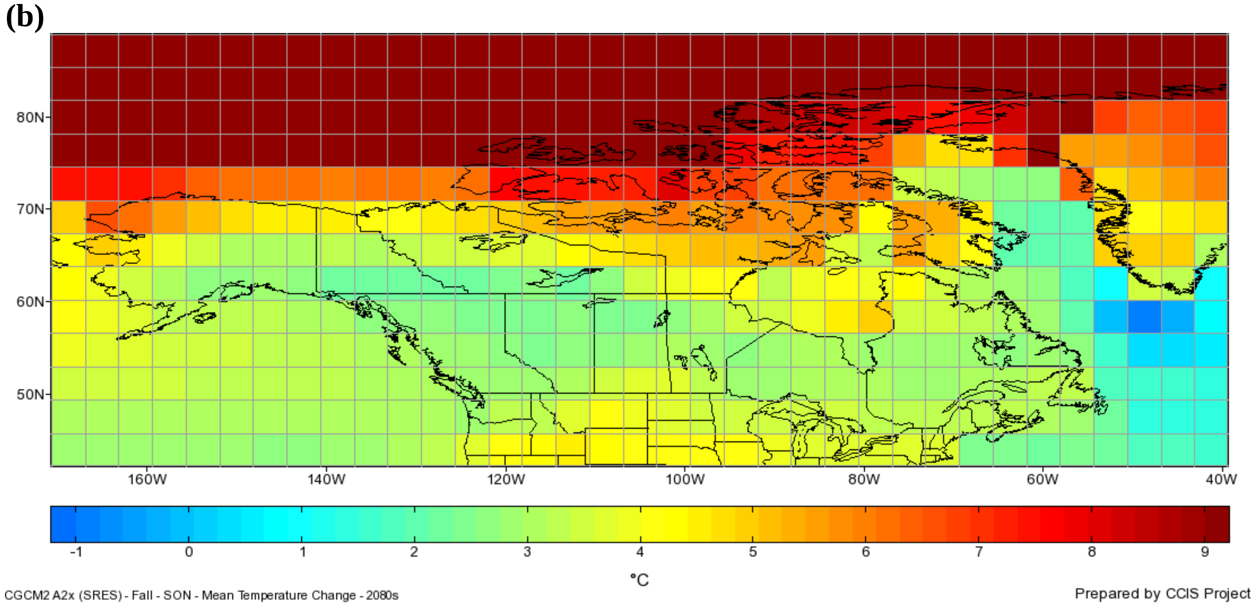


Figures 56a and 56b Seasonal Mean Temperature Changes for the 2080s from the CGCM2A2x Experiments (CICS 2005). Where (a) is winter and (b) is spring (CCIS 2005)

(a)

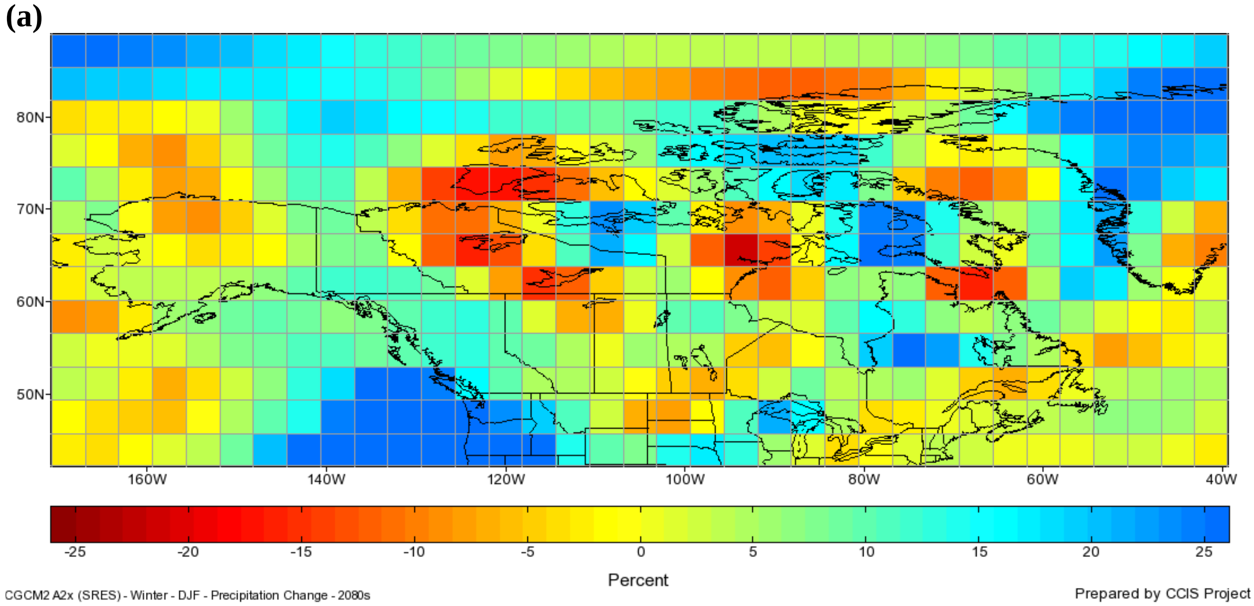


(b)

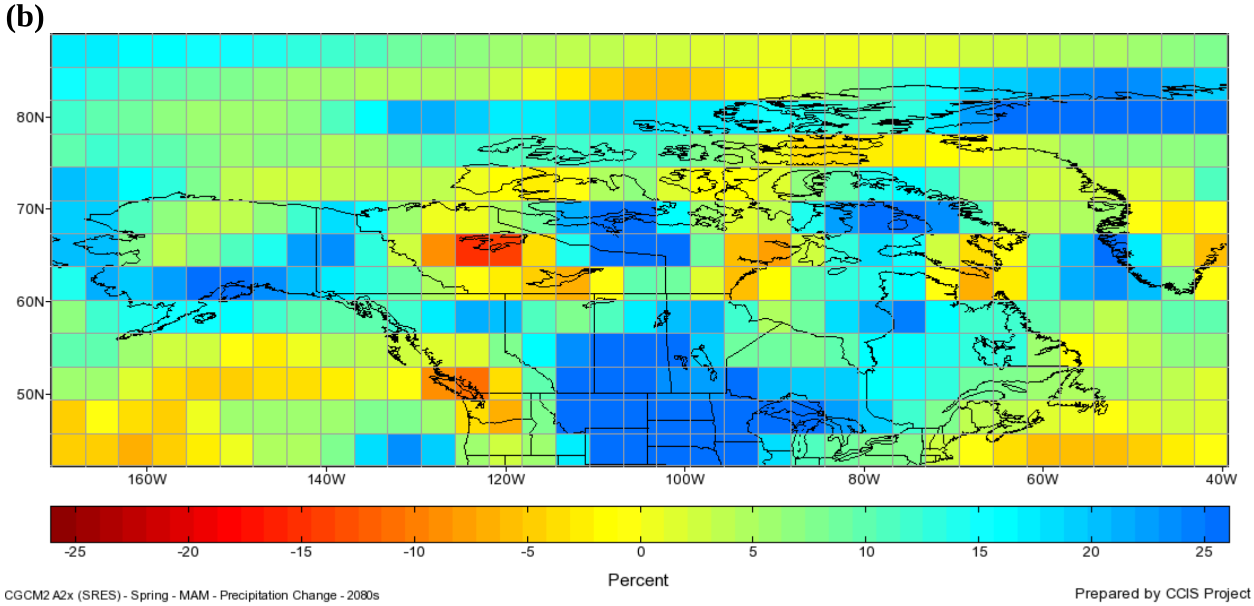


Figures 56c and 56d Seasonal Mean Temperature Changes for the 2080s from the CGCM2A2x Experiments (CICS 2005).   Where (c) summer and (d) is fall (CCIS 2005)

(a)

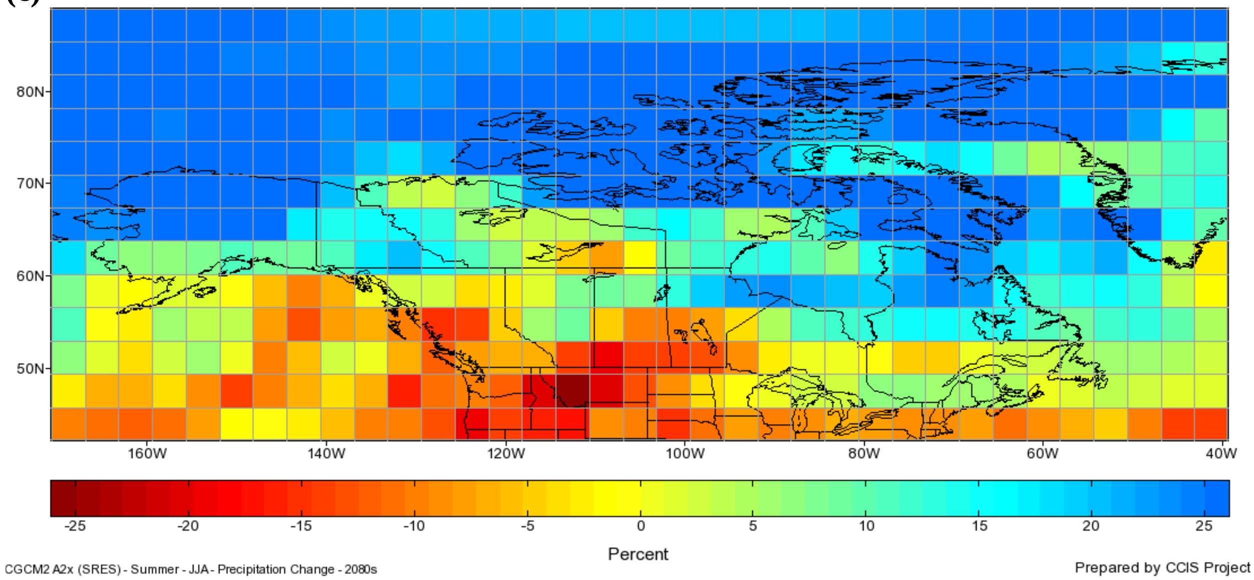


(b)

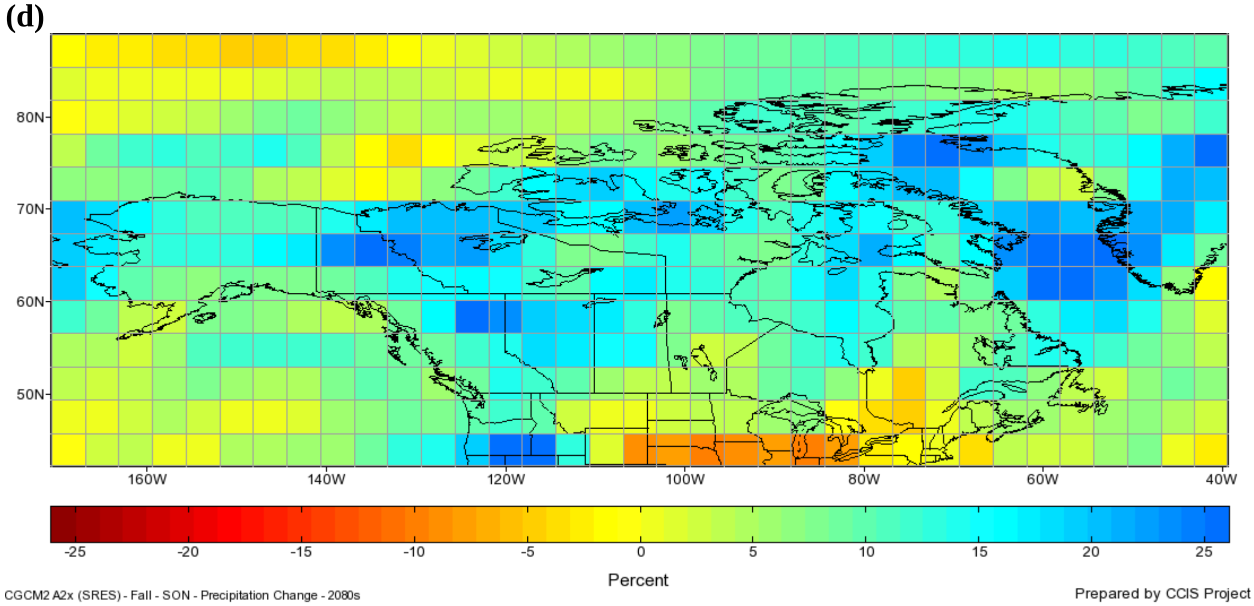


Figures 57a and 57b Seasonal Mean Precipitation Changes for the 2080s from the CGCM2A2x Experiments (CICS 2005). Where (a) is winter and (b) is spring (CCIS 2005)

(c)

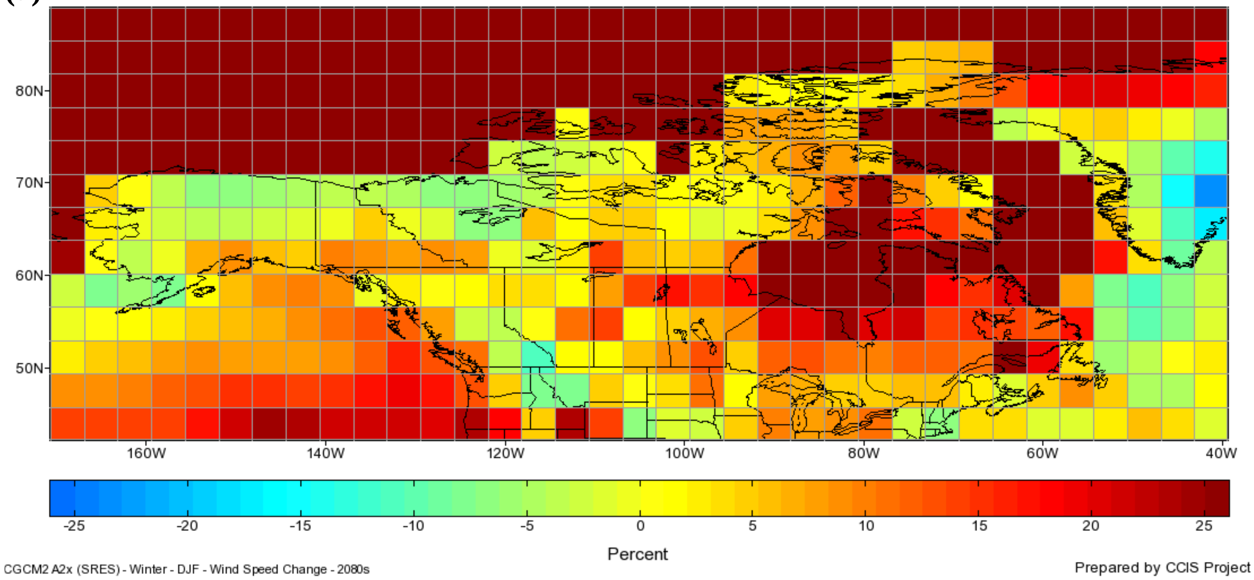


(d)

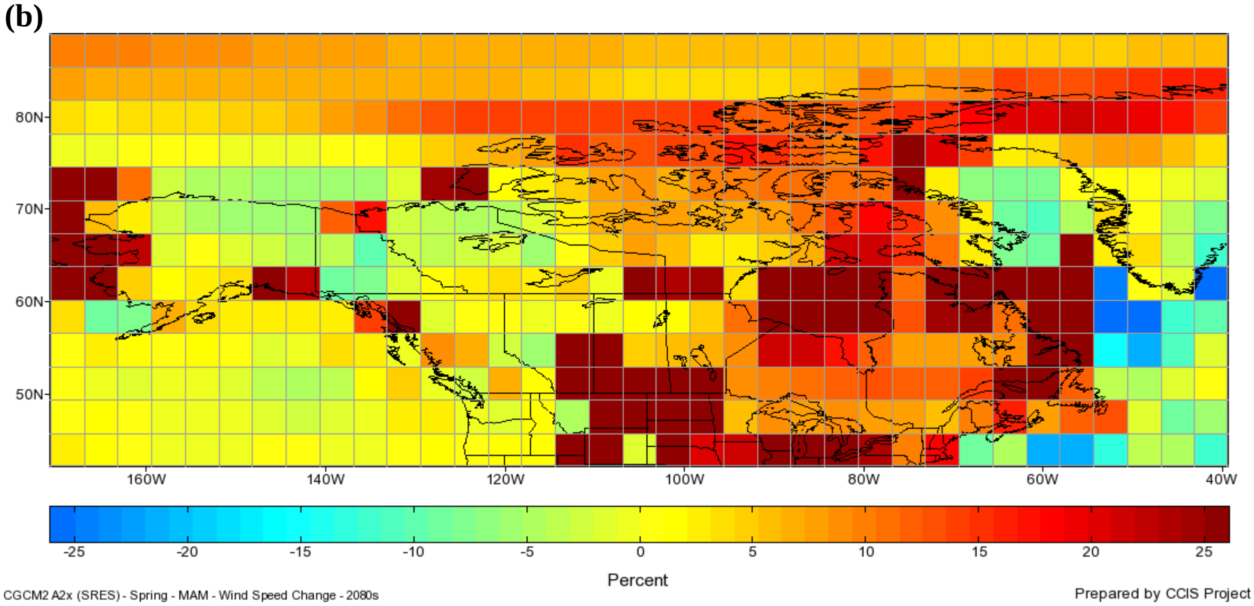


Figures 57c and 57d Seasonal Mean Precipitation Changes for the 2080s from the CGCM2A2x Experiments (CICS 2005). Where (c) is summer and (d) is fall (CCIS 2005)

(a)

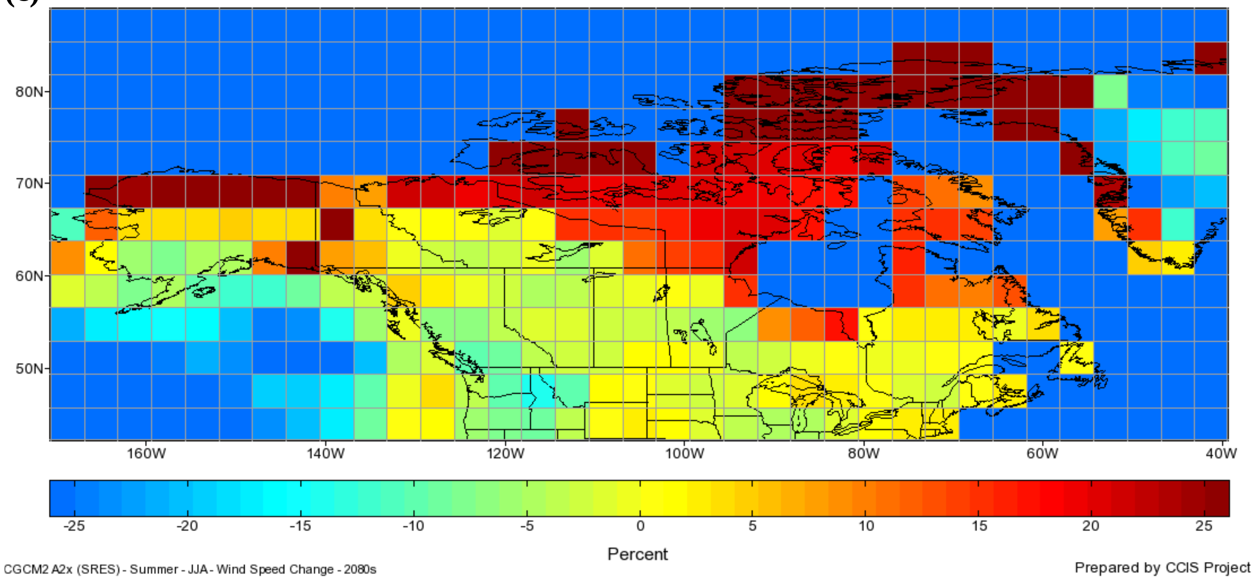


(b)

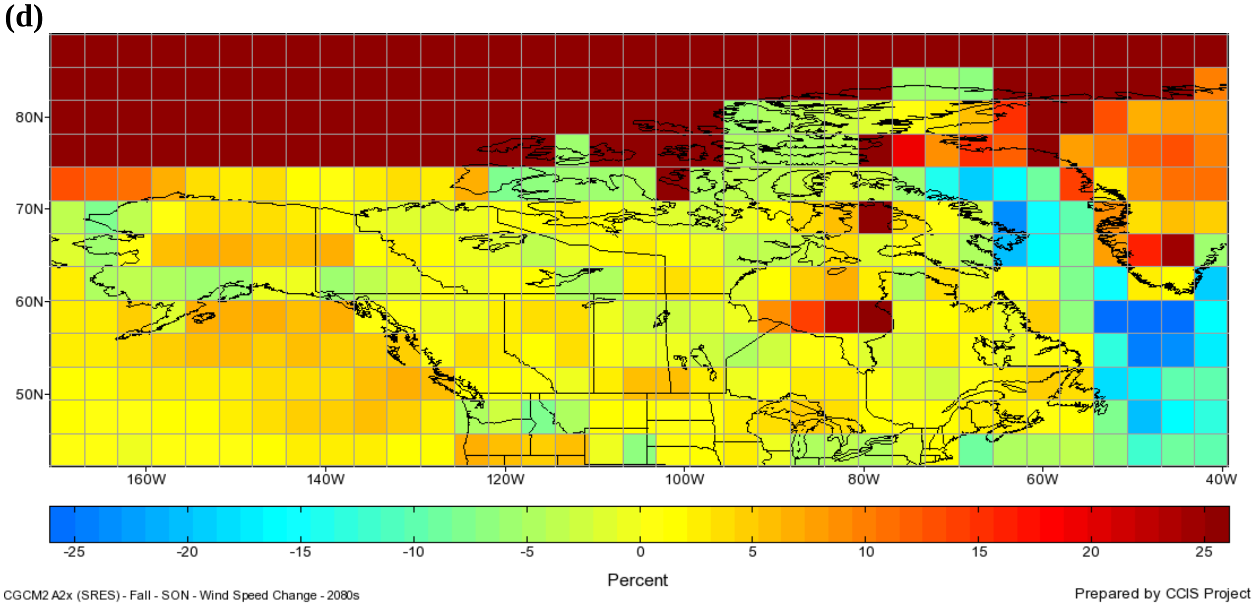


Figures 58a and 58b Seasonal Wind Speed Changes for the 2080s from the CGCM2A2x Experiments (CICS 2005). Where (a) is winter and (b) is spring (CCIS 2005)

(c)



(d)



Figures 58c and 58d Seasonal Wind Speed Changes for the 2080s from the CGCM2A2x Experiments (CICS 2005). Where (c) is summer and (d) is fall (CCIS 2005)

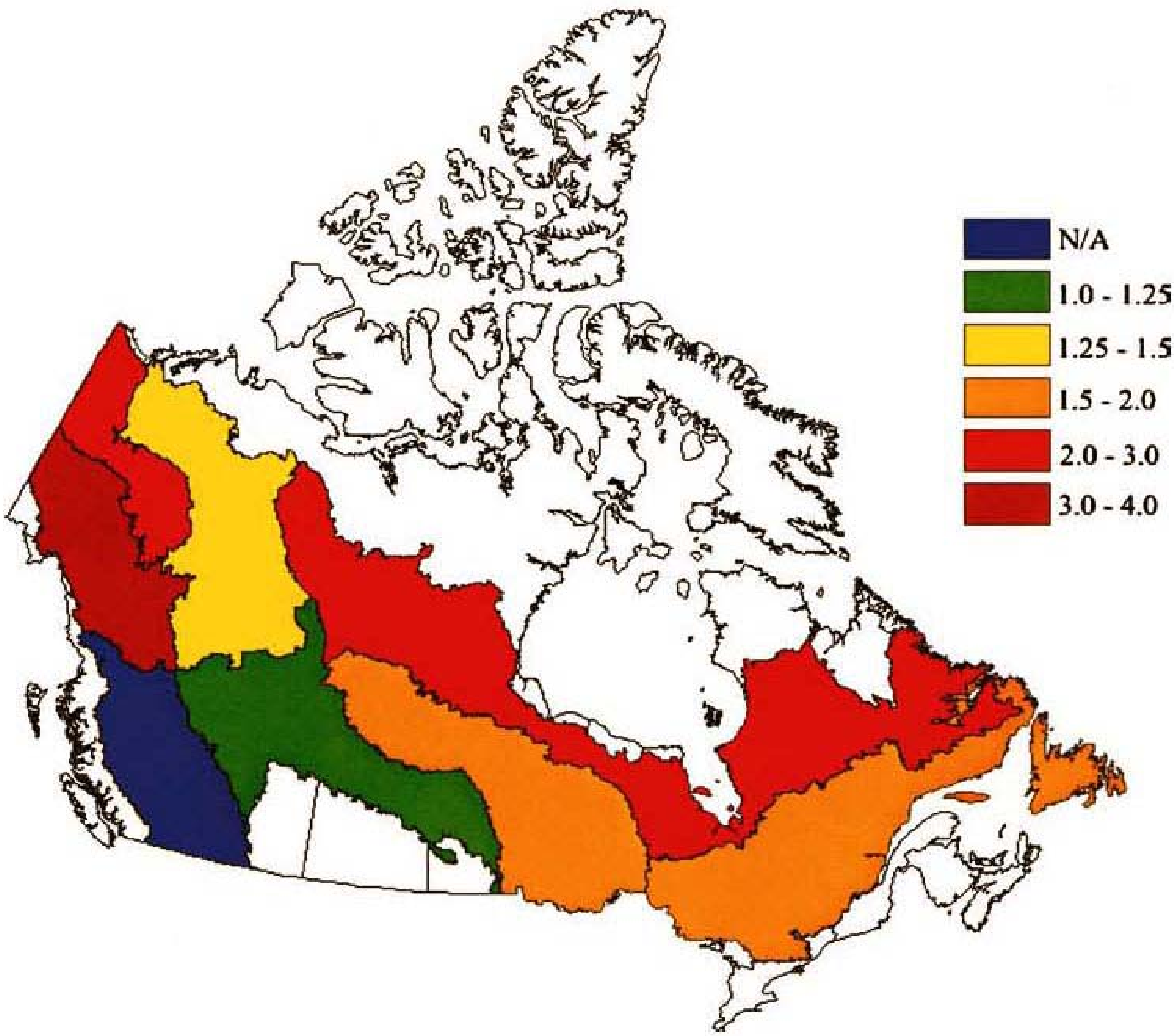


Figure 59 Increase in Area Burned for 2080-2100 using the Canadian GCM1 (Flannigan et al. 2005)

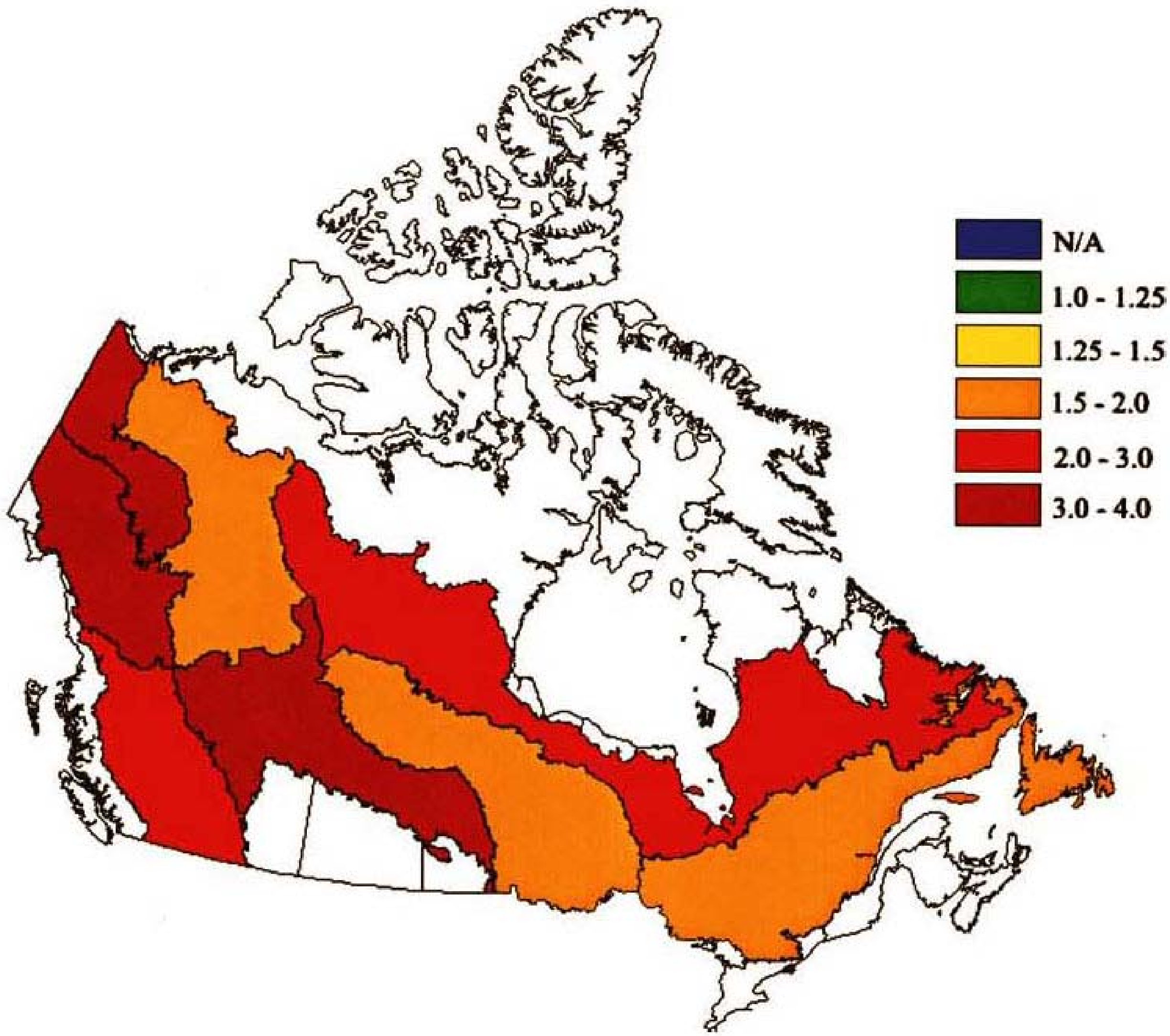


Figure 60 Increase in Area Burned for 2080-2099 using the UK Hadley GCM3 (Flannigan et al. 2005)

Table 1 Databases, Source and Period

Information Type	**Organization (Source)**	**Years**
Forest Fires	Fire Management and Forest Protection, Saskatchewan Environment Canadian Forest Service, Natural Resources Canada	1981-2003 1959-1999
Climate	Environment Canada, Fire Management and Forest Protection, Saskatchewan Environment	1981-2003
Population	Saskatchewan Health	1981-2003
Health	Saskatchewan Health	1980-2001
Evacuation	Department of Community Resources and Employment, Saskatchewan	1989-2003
Census	Statistics Canada	1996

Table 2 Population of the Four Northern Regional Health Authorities (1981-2003) (Data Source: Saskatchewan Health 2005)

	Total Population of all RHA	Total Population of RHA 9	Total Population of RHA 11	Total Population of RHA 12	Total Population of RHA 13
1981	101040	73943	14639	8192	4266
1982					
1983					
1984					
1985					
1986	102902	76716	15652	8969	1565
1987	104039	77184	15843	9009	2003
1988					
1989					
1990	104613	76609	16694	9221	2089
1991	103278	75078	16740	9398	2062
1992	104856	75890	17241	9566	2159
1993	105648	76000	17676	9755	2217
1994	105717	75558	18010	9953	2195
1995	107252	76494	18392	10120	2246
1996	108402	77151	18779	10173	2299
1997	108142	76288	19251	10364	2239
1998	110390	76869	20382	10757	2382
1999	111482	77867	20425	10846	2343
2000	110242	76655	20375	10931	2281
2001	111142	77064	20704	11092	2282
2002	111816	77215	21094	11147	2360
2003	111254	76759	20919	11269	2307

Table 3 Hospital Admissions by Regional Health Authority (Data Source: Saskatchewan Health 2005)

		Prince Albert (RHA 9)			Mamawetan Churchill River (RHA 11)			Keewatin Yatthé (RHA 12)			Athabasca (RHA 13)		
		Year	**Number of Hospital Admissions**	**Percent of Population**	**Year**	**Number of Hospital Admissions**	**Percent of Population**	**Year**	**Number of Hospital Admissions**	**Percent of Population**	**Year**	**Number of Hospital Admissions**	**Percent of Population**
Highest Admission Year	Group 1	1990	1629.93	2.1	1996	293	2.9	1994	275	2.8	1997	65	2.9
	Group 2	2001	26.58	0.03	2001	11	0.1	2000	8	0.1	1981, 1999, 2001	2	0.1
	Group 4	1989	1308.3	N/A	1995, 2000	153	0.8	1999	124	1.1	1981	37	0.9
Lowest Admission Year	Group 1	2001	523.09	0.7	2001	65.44	0.6	2001	55	0.5	2000	10	0.4
	Group 2	1982	3.69	N/A	1986	0	0.0	1980, 1981, 1982, 1985, 1988	0	0.0	1980, 1983,1988-1991, 1993-1995, 1998, 2000	0	0.0
	Group 4	1983	863.54	N/A	1980	59.64	N/A	1984	55	N/A	1993	6	0.3

N/A = Population totals are not available.

Table 4 Demographic and Evacuation Information for the Study Sites (Data Source: Saskatchewan Health 2005, Saskatchewan Department of Community Resources and Employment 2005, Saskatchewan Environment 2004)

Community	Population (1992)	Population (1995)	Evacuations (1995)		Associated Meteorology Station
			Dates evacuated	Number evacuated	
Pelican Narrows	215	144	June 15 -19	57	Pelican Narrows
Hall Lake	Not Available	Not Available	May 29 -June 4	163	Tracey
Stanley Mission	130	111	June 9 – June 20	593	La Ronge
Creighton	1922	1872		None	Creighton
Brabant Lake	Not Available	Not Available	June 26-July 6	39	Southend

Table 5 1995 Fires Located Near Communities (Data Source: Saskatchewan Environment 2005 and Saskatchewan Department of Community Resources and Employment 2005)

Fire Number	Fire District	Discovery Date	Extinguish Date	Fire Size (ha)	Longitude	Latitude	Community	Evacuation Dates
L504	Creighton	6/11	7/31	32,000	-102.23	54.86	Creighton	None
EG02	Dore Lake	5/31	6/27	2,300	-106.45	54.79	Hall Lake	May 29 – June 4
EG03	Dore Lake	5/31	6/27	20,000	-106.70	54.50	Hall Lake	May 29 – June 4
L218	La Ronge	5/31	8/08	58,500	-104.36	55.31	Stanley Mission	June 9 - 20
L220	La Ronge	5/31	8/08	92,000	-104.07	55.81	Stanley Mission	June 9 - 20
L818	Pelican Narrows	5/31	6/30	21,000	-102.76	55.14	Pelican Narrows	June 15-19
L828	Pelican Narrows	6/14	8/07	13,000	-103.40	55.39	Pelican Narrows	June 15-19
L409	Southend	6/18	7/22	10,700	-103.25	55.68	Brabant Lake	June 26 – July 6
L420	Southend	6/19	8/14	101,000	-103.95	56.19	Brabant Lake	June 26 – July 6

Table 6 Association of Number of Hospital Admissions and Area Burned in the Mamawetan Churchill River RHA for 1992 and 1995 (Calculated using SPSS 13.0)

		1995 Area Burned (ha)
1995 Admissions	Pearson Correlation	-0.148
	N	19
		1992 Area Burned (ha)
1992 Admissions	Pearson Correlation	-0.142
	N	17

			1995 Area Burned (ha)
Kendall's tau_b	1995 Admissions	Correlation Coefficient	-0.193
		N	19
Spearman's rho	1995 Admissions	Correlation Coefficient	-0.256
		N	19
			1992 Area Burned (ha)
Kendall's tau_b	1992 Admissions	Correlation Coefficient	-0.011
		N	17
Spearman's rho	1992 Admissions	Correlation Coefficient	0.002
		N	17

Table 7 Correlations of Hospital Admissions and Area Burned in the Saskatchewan's Regional Health Authorities 9, 11, 12 and 13 (Pearson Product Moment, Kendall tau b and Spearman's Rho, calculated using SPSS 13.0)

		Total Admissions	Standardized Hospital Admissions RHAs 9, 11, 12, 13	Standardized Hospital Admissions RHAs 11, 12, 13	Standardized Hospital Admissions RHAs 11, 12, 13 during Fire Season	Standardized Hospital Admissions RHAs 11, 12, 13 during Fire Season 1981 removed
Total Area Burned	Pearson Correlation	-0.035	-0.067	0.224	0.120	0.265
	N	21	15	15	14	13
Area Burned Greater than 200 ha	Pearson Correlation	-0.035	-0.066	0.225	0.121	0.265
	N	21	15	15	14	13
Area Burned 81, 95, 98 and 94 removed	Pearson Correlation	0.356	0.283	0.131	0.164	0.164
	N	17	11	11	10	10
Area Burned 81, 95, 98, 89, 93 and 94 removed	Pearson Correlation	-0.150	-0.048	-0.568	-0.516	-0.516
	N	15	10	10	9	9

			Total Admissions	Standardized Hospital Admissions RHAs 9, 11, 12, 13	Standardized Hospital Admissions RHAs 11, 12, 13	Standardized Hospital Admissions RHAs 11, 12, 13 during Fire Season	Standardized Hospital Admissions RHAs 11, 12, 13 during Fire Season 1981 removed
Kendall's tau_b	Total Area Burned	Correlation Coefficient	0.005	-0.067	0.048	0.033	0.154
		N	21	15	15	14	13
	Area Burned Greater than 200 ha	Correlation Coefficient	0.014	-0.048	0.067	0.055	0.179
		N	21	15	15	14	13
	Area Burned 81, 95, 98 and 94 removed	Correlation Coefficient	0.118	0.164	-0.164	-0.067	-0.067
		N	17	11	11	10	10
	Area Burned 81, 95, 98, 89, 93 and 94 removed	Correlation Coefficient	-0.105	0.067	-0.422	-0.333	-0.333
		N	15	10	10	9	9
Spearman's rho	Total Area Burned	Correlation Coefficient	0.027	-0.064	0.132	0.042	0.214
		N	21	15	15	14	13
	Area Burned Greater than 200 ha	Correlation Coefficient	0.032	-0.050	0.143	0.077	0.258
		N	21	15	15	14	13
	Area Burned 81, 95, 98 and 94 removed	Correlation Coefficient	0.179	0.227	-0.200	-0.030	-0.030
		N	17	11	11	10	10
	Area Burned 81, 95, 98, 89, 93 and 94 removed	Correlation Coefficient	-0.150	0.055	-0.600	-0.417	-0.417
		N	15	10	10	9	9

Table 8 Smoke Emissions Estimated by the Model FOFEM for the Case Study Fires in Northern Saskatchewan

Fire EG02 (Black spruce)	Total Emissions (tonnes)		
area of fire (ha): 2,300	Flaming	Smoldering	Total
PM_{10}	65	6,520	6,585
$PM_{2.5}$	54	5,523	5,578
CH_4	18	3,357	3,375
CO	139	73,613	73,752
CO_2	37,887	299,634	337,521
NO_X	67	0	67
SO_2	21	243	263
Fire L218 (Black spruce)			
area of fire (ha): 58,500	Flaming	Smoldering	Total
PM_{10}	1,642	165,841	167,483
$PM_{2.5}$	1,379	140,489	141,868
CH_4	460	85,383	85,843
CO	3,547	1,872,327	1,875,873
CO_2	963,650	7,621,126	8,584,776
NO_X	1,708	0	1,708
SO_2	525	6,174	6,699
Fire L828 (Black spruce)			
area of fire (ha): 13,000	Flaming	Smoldering	Total
PM_{10}	365	36,854	37,218
$PM_{2.5}$	307	31,220	31,526
CH_4	102	18,974	19,076
CO	788	416,073	416,861
CO_2	214,145	1,693,584	1,907,728
NO_X	379	0	379
SO_2	117	1,372	1,489
Fire L504 (Jack pine)			
area of fire (ha): 32,000	Flaming	Smoldering	Total
PM_{10}	1,150	48,681	49,831
$PM_{2.5}$	970	41,245	42,215
CH_4	287	25,041	25,329
CO	2,407	549,508	551,915
CO_2	659,445	2,236,724	2,896,169
NO_X	1,186	0	1,186
SO_2	359	1,832	2,192
Fire L818 (White spruce)			
area of fire (ha): 21,000	Flaming	Smoldering	Total
PM_{10}	1,650	29,401	31,051
$PM_{2.5}$	1,391	24,921	26,312
CH_4	424	15,137	15,561
CO	3,513	332,015	335,528
CO_2	956,011	1,351,449	2,307,461
NO_X	1,721	0	1,721
SO_2	542	1,108	1,650

Table 9 Future Climate Changes for Northern Saskatchewan for the 2080s from the CGCM2 A2x (Rounded values and changes from the 1961 to 1990 baseline) (Summarized from maps from CCIS 2005)

Season	**Temperature (°C) (Mean)**	**Precipitation (%)**	**Wind Speed (%)**	**Soil Moisture (Capacity fraction)**
Spring	5 to 9	10 to 25	0 to 25	-0.2 to 0
Summer	4	-8 to 5	-3 to 0	-0.2 to 0
Fall	2	10 to 15	-5 to 0	-0.2 to 0
Winter	7 to 9	-8 to 0	0 to 15	-0.2 to 0

Note: Spring is defined as March, April, May; summer is June, July, August; fall is September, October, November; and winter is December, January, and February.

APPENDIX A

Froese, D., 2005. Particulate Matter and Human Health: A Review of Literature. Background document for "Climate Changes, Wildfires and Respiratory Ailments in Northern Saskatchewan" CCAF Project

Particulate Matter and Human Health: A Review of Literature

Presented to Lynda Langford, Project Leader,
"Climate Changes, Wildfires and Respiratory Ailments in Northern Saskatchewan"
CCAF Project

Prepared by Derek Froese
July 22, 2005

Outline

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5. Effects of Natural Particulate Matter
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6. Conclusions

Abstract

Particulate matter (PM) and its associated health impacts have been studied extensively over the last 50 years. Research has demonstrated the biological effects of PM, primarily cardiovascular and respiratory effects; the effects of PM on populations, including associated morbidity and mortality rates, hospital admission rates and decreased pulmonary function; the health effects of PM on susceptible populations such as asthmatics and children; and the effects of PM on occupational groups such as forest firefighters. This review of literature focuses on both anthropogenic and natural sources of PM and their associated short- and long-term health effects. Both forms of PM (from industrial processes and smoke, in particular) have been shown to pose risk to human health even at relatively low ambient levels. The review provides information that may be useful for policy makers who must determine which levels of ambient particulate matter are acceptable and which groups in the population need to be protected.

1. Introduction

Extensive research has been conducted over the past few decades on the effects of particulate matter (PM) on the human body, on populations, and on susceptible groups. Although it has been known for a long time that exposure to extreme events of particulate air pollution can lead to severe health effects in populations, recent studies have shown that even low levels of ambient PM can have similar effects. This paper provides an extensive literature review that pertains to PM exposure and its associated health impacts. The literature demonstrates both the significance of long-term exposure to relatively low levels of particulate air pollution and of short-term exposure to high levels. The effects of both anthropogenic and natural sources of particulate matter are examined. Although PM causes a number of general, well-known health issues, research in this area helps to clarify the degree to which levels of particulate matter affect humans.

This review of literature is organized to first provide the reader with an understanding of PM, and second, to review studies on its health effects. In providing a background, the paper discusses the definition of PM, its composition and formation, the elements of its toxicity, the biological effects of particles on respiratory and cardiovascular function, and the ambient air quality standards that are in place in North America. The review goes on to look at a number of studies relating anthropogenic particulate air pollution to mortality and morbidity rates. While most of the studies on general populations focus on the effects of particulate air pollution on the elderly and those with pre-existing cardiopulmonary conditions, a number of studies focus solely on infants, children, and children with asthma. The review then highlights research work on the health effects caused by natural sources of particle pollution such as biomass smoke and dust. Studies focussing on the health impacts of the Indonesian fires of 1997 as well as recent forest fires in Canada, Australia, and the United States are reviewed. Finally, a brief look at the impacts of biomass smoke on firefighters is presented. Conclusions based on the chosen literature are drawn at the end.

2. Methodology

Literature was chosen for this review in order to provide a broad examination of the health implications of PM. Most studies chosen focussed on the effects of ambient PM on populations and susceptible groups. Of particular interest were the health effects of changes in ambient PM and exposure to PM as a result of industrial processes and forest fires, as these two elements pose the greatest risk to both urban, rural, and northern populations. Literature was selected primarily through the scanning of Internet and library resources. Searches were conducted in government websites for general material pertaining to the topic, including the websites of Environment Canada, the United States Environmental Protection Agency (USEPA), the United States Department of Agriculture: Forest Service, and the World Health Organization. Journal articles were obtained through searches on the University of Saskatchewan and the University of Regina library databases. Focus was paid to studies published after 1990 that examined the correlation between changes in ambient PM/exposure to PM and health effects. Of particular value on this topic was the Health Effects Institute (website: www.healtheffects.org), which is supported jointly by the USEPA and industry to provide research on the health effects of air pollution. The HEI website provided an avenue for exploring the most current research available on PM and health both within and outside of the organization.

3. Particulate Matter

3.1 Definition

Particulate Matter (PM) is solid matter or liquid droplets from smoke, dust, fly ash, or condensing vapours that can be suspended in the air for long periods of time. PM varies in composition and size, ranging from approximately 0.1 to 100 micrometers (µm) in diameter. Particles are generally defined according to their diameter (See Figure 1). Those particles that are 44 µm or less in diameter tend to remain in the air much longer than larger particles and are largely responsible for poor air quality. Particles less than 10 µm in size is called thoracic PM, or PM10. Particles less than 10 µm in diameter but larger than 2.5 µm are called coarse PM, or PM10-2.5. Particles smaller than 2.5 µm in diameter are called fine PM, or PM2.5, and those smaller than 0.1 µm are called ultrafine PM. Smaller particles, particularly those smaller than 10 µm, generally pose the greatest risk to human health, as their size allows them to penetrate much deeper into the lungs than larger particles. PM10 and PM2.5, also known as inhalable and respirable particulates respectively, are most commonly monitored to determine their effects on human health.

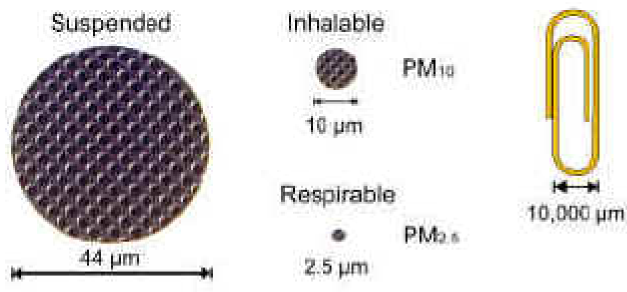

Figure 1. Particulate matter sizes (SLEA, 2000)

3.2 Sources and Composition

PM originates from both natural and human sources. Natural sources primarily produce coarse PM while human activities produce both coarse and fine ones. Coarse particles, including PM10 and larger particles, originate from sources such as farmland, construction sites, naturally exposed soil or sand, vegetation (in the form of pollen), and volcanic eruptions. Fine particles, or PM2.5, originate from human sources such as electrical power plants, motor vehicles, heating systems, industrial sources, and also natural sources such as forest fires and agricultural burning. Fine particles are also generated by reactions between industrially produced chemicals and chemicals that naturally exist in the atmosphere.

The composition of PM depends not only on its source, but also its process of formation. Primary particles are emitted directly into the atmosphere from a source such as exposed soil, and are generally coarse. These particles most often have a basic pH. Secondary particles are generally fine, and are formed through chemical reactions of precursor gases in the atmosphere. These gases, which are largely anthropogenic, include nitrogen oxides (NO_x), sulphur dioxide (SO_2), volatile organic compounds (VOCs), and ammonia (NH_3). Fine particles are most often acidic.

Fine PM is composed of a combination of organic and inorganic particles. PM2.5 collected in five urban locations across Canada in the 1990s were comprised of six major fractions: organic compounds and elemental or black carbon, inorganic compounds composed of sulphate, nitrate, and ammonium, and soil or crustal material, and metals. Most of the organic compounds collected, such as soil particles, were deemed primary. Most of the inorganic compounds were secondary particles formed from precursor gases as a result of human activity (Environment Canada 2001).

The composition of PM at any site depends on a number of factors, including location, season, and climate. Of the five locations examined in Canada, organic compounds comprised one third to half of the particle mass, depending on the location in Canada. Western Canada sites had a greater portion of organic particles than sites in Eastern Canada (Environment Canada 2001). In both the United States and Canada, nitrates tend to predominate in the west, while sulphates predominate in the east, largely due to more intensive industrial activities in the east (HEI 2002).

On a seasonal basis, data from Canadian sites revealed that 15% of total particulate emissions in summer resulted from natural sources consisting of lightning, forest fires, and emissions from soils (Environment Canada 2001). Since temperature has a varying influence on the formation of secondary particles, sulphate levels in PM are much higher in summer, while nitrate levels are much higher in winter. On a day-to-day basis, the PM composition can also vary considerably, depending on changing weather conditions.

3.3 Toxicity of Particles

The toxicity of particles generally depends on both the size and composition of the particulate matter. Studies have reported different findings on the associations between particle size and health effects. A study that conducted a time-series analysis of mortality in relation to different sizes of PM in southwestern Mexico City found that coarse particles had the strongest association with mortality (Castillejos et al. 2000). While a 10 $\mu g/m^3$ increase in PM2.5 was associated with a 1.83% increase in mean daily mortality, the equivalent increase in PM10-2.5 was associated with a 4.07% increase in mean daily mortality. However, other studies have reported the opposite. For example, Burnett et al. (2000) examined ambient air and mortality data from eight cities across Canada from 1986-1996. They found that fine particulate matter, PM2.5, was a stronger predictor of mortality than coarse matter, PM10-2.5. A study that examined the effects of particulate air pollution on the San Francisco Bay area also found that PM2.5, as well as NO3, had the highest correlations with mortality (Fairley 1999). These discrepancies between studies can been attributed to a number of factors, including the fact that the nature of PM varies with the region and the studies vary in the statistical methods and measurements of PM that they use (HEI 2002).

Research on the toxicity of PM based on composition is limited. The heterogeneous mix of chemicals that constitute PM makes it difficult to isolate the chemical agents that impact human health. Studies on mortality-pollution associations report different findings as to the specific causal agents of PM that contributes to death. For example, some studies attribute mortality effects to sulphur dioxide and sulphates, but not PM; while, others attribute these effects primarily to PM (Ostro 1993).

The literature does show that certain elements of PM are highly correlated with their levels and mortality. Goldberg et al. (2000), for instance, found that sulphate particles were consistently associated with elderly people who died of cardiovascular conditions, coronary artery diseases, and lung cancer in Montreal from 1984-1993. The study of eight Canadian cities took an even more in-depth look at the composition of fine PM and their associations (Burnett et al. 2000). Of the elements, sulphur showed the strongest association with PM2.5 (coefficient of 0.74). Lead, silicon, iron, potassium, zinc, magnesium, phosphorus, and selenium were modestly correlated (0.3-0.5). Based on one-day lag data, sulphate, zinc, nickel, and iron were the most significantly positively associated with mortality. The study also determined that size-fractionated particulate mass accounted for only 28% of the total effect of the urban pollution mix on mortality. Once additional constituents of PM were examined, such as elemental concentrations and sulphates, the risk attributable to particulate air pollution increased to 49%. Mass alone may therefore be a relatively crude indicator of the toxicity of particulate phase pollution in urban environments.

Research in the Utah Valley also suggests that metal concentrations in PM are significantly associated with morbidity and mortality (Ghio and Devlin 2001). When a local steel mill was shut down for 13 months, researchers observed decreases in elementary school absences, bronchitis and asthma admissions for pre-school-age children, total respiratory hospital admissions for pneumonia, pleurisy, bronchitis, and asthma, pulmonary function abnormalities, and mortality. In this particular study, volunteers were exposed to PM extract from filters collected while the mill was closed, while others were exposed to PM extract from filters collected while the steal mill was open. The second group, which was exposed to significantly higher levels of iron, copper, zinc, lead and nickel, had significant increases in both lung inflammation in contrast with the first group. In short, the composition of fine PM has shown to significantly contribute to toxicity.

3.4 Biological Effects

PM engages a number of bodily defences when inhaled. Particles larger than 5 μm in diameter deposit in the upper airways or larger lower airways of the lungs, and particles smaller than 5 μm are more likely to deposit in the smaller airways such as the bronchioles and alveoli. The body's defences against these particles include fluid secretions, such as mucus lining the airways, ciliated cells which trap the particles for removal through the nose and throat, receptors on nerve cells in airways that induce coughing, and epithelial cells that prevent material from entering between cells. If particles do penetrate these defences, then cells called macrophages (white blood cells in the lungs) and neutrophils (white blood cells in the bloodstream) attempt to destroy the foreign material. Lymphocytes, another type of white blood cell, become involved if these defences are overwhelmed. Proteins called cytokines also work to destroy the foreign particles as they are secreted into affected areas (HEI 2002).

These defence mechanisms result in an inflammatory response in the lungs, which can lead to a restriction of airways (bronchoconstriction) and an alteration in respiratory mechanics. The inflammatory response often damages epithelial cells and other cells in the airway, such as macrophages, thus reducing the body's defences to new foreign particles. Hence the inflammation may worsen the conditions of those already affected by respiratory infections, and may make them more susceptible to infections in the future (Empey et al. 1976; Ostro 1995).

Chronic airflow obstruction and decreased pulmonary function as a result of PM has been documented in a study comparing subjects from Mexico City who lived their entire lives in a high PM locale to subjects from a Vancouver region who lived in a low PM region (Churg et al. 2003). All subjects were never-smokers, had not worked in dusty occupations, had not cooked with biomass fuels, did not have any respiratory disease, and had lived in their location for more than 20 years. The mean three-year level of PM10 in Mexico was 66 $\mu g/m^3$, while the mean PM10 level average over ten years in Vancouver was $25 \mu g/m^3$. The autopsy lungs of subjects from Mexico were found to contain significantly greater particle loads, including aggregates of ultrafine particles that appeared to be ambient combustion products. Most significantly, the morphological changes seen in the lungs from Mexico City were deemed very similar to those found in cigarette smokers and in workers with high-level occupational exposure to many kinds of dusts.

PM has also been shown to aggravate the conditions of those with pre-existing cardiovascular disease. The biological processes of how they influence the cardiovascular system, however, are less well understood. What is known is that the inflammatory response in the lungs can cause a number of pulmonary effects throughout the body. Cytokines released in the lungs, for instance, are known to stimulate the liver to release molecules which increase the coagulability of the blood (its ability to clot). Increased coagulability can lead to acute episodes of cardiovascular disease in susceptible individuals (Goldberg et al. 2001). Nerve cells stimulated by particles can lead to changes in the nervous system's control of the pattern of breathing, the heart rate, and heart rate variability (HEI 2002). In animals, it has been shown that the inhalation of particles can increase the circulating levels of endothelins which are potent vasoconstrictors, agents that constrict blood vessels (Bouthillier et al. 1998). Elevated levels of endothelins have been reported in a number of conditions, including cardiovascular disease, asthma, and diabetes (Goldberg et al. 2001). Furthermore, studies show that the long-term consequences of sustained vascular inflammation can lead to increased atherosclerosis (the constriction of arteries) and cardiovascular death (Pope et al. 2002; Kunzli et al. 2005).

3.5 Ambient Air Quality Standards

In this review, a general understanding of ambient air quality standards for PM provides context for varying levels of PM that are documented in the literature. It is important to note, however, that these standards are not established solely to protect human health, as much lower levels of PM10 and PM2.5 have been documented to cause adverse health effects. Air quality standards are generally established to minimize risks to human health and the environment, while at the same time taking into account feasibility and costs of reducing pollutant emissions.

Within Canada, ambient air quality standards for total suspended particulate matter (TSP) vary from province to province. Within Saskatchewan, for example, the 24-hour average for TSP is 120 $\mu g/m^3$ (The Clean Air Act 1989), while in Alberta, it is 100 $\mu g/m^3$ (Environmental Protection and Enhancement Act 1992). The annual geometric mean for Saskatchewan is 70 $\mu g/m^3$, while in Alberta the value is 60 $\mu g/m^3$.

Both Canada and the United States have national standards in place for PM2.5, the measurement of greatest concern when it comes to health effects. The Canada-Wide Standards (CWS) for PM and Ozone, which was signed by the federal, provincial, and territorial governments except Quebec in June 2000, has set goals to reduce PM significantly by 2010. The CWS commit governments to reduce PM2.5 to a mean of 30 $\mu g/m^3$ over a 24-hour period (CCME 2000). In comparison, in the United States, National Ambient Air Quality Standards for PM2.5 have been set at a mean of 65 $\mu g/m^3$ over a 24-hour period and 15 $\mu g/m^3$ for the annual arithmetic mean. For PM10, the 24-hour average standard is 150$\mu g/m^3$ and the annual arithmetic mean value is 50 $\mu g/m^3$ (USEPA 2004).

4. Effects of Anthropogenic Particulate Matter

4.1 Effects on Populations

Extreme air pollution events, such as the London Fog of 1952, have demonstrated the lethal health effects of unabated particulate air pollution. Increased mortality rates and hospital admissions have been linked to particulate pollution in numerous studies since then. Most notably, research has shown that health effects are associated with particulate concentrations at much lower levels than those experienced in extreme air pollution events (Dockery and Pope 1994). Incremental increases in particulate concentrations correlate with increased mortality and hospitalization rates as reported in studies in the United States, Canada, and Europe.

Pope et al. (1993) examined the association between particulate air pollution and mortalities in six American cities over an extended period of about 15 years. The study surveyed 8111 individuals from the six cities annually. Over the course of time, 1401 of the 1430 individuals who had died were independently evaluated as to the cause of death. Ambient outdoor concentrations of total suspended particulate matter, sulphur dioxide, ozone, and suspended sulphates were measured in each community by air-monitoring stations throughout the same time period. The final results showed a positive correlation between fine and inhalable particles (particles with diameters less than 15 µm before 1984 and less than 10 µm starting in 1984) and mortality, even when controlling for other risk factors, such as age, sex, and tobacco use. In addition, mortality was more strongly associated with inhalable, fine, and sulphate particles than with total suspended particles, sulphur dioxide, nitrogen dioxide, or the acidity of the aerosol.

Based on the results from this study and many others, Dockery and Pope (1994) examined air particulate pollution and mortality associations for eight different cities of the United States over varying time periods throughout the 1970s and 1980s. Results from the review indicated a 0.7 to 1.6% increase in daily mortality for each 10 $\mu g/m^3$ increase in PM10 concentration. In a similar review of time-series and cross-sectional mortality studies, Ostro (1993) estimated a 0.96% increase in daily mortality per 10 $\mu g/m^3$ increase in PM10 concentration. The review also observed consistent lagged associations between particle exposure and increased mortality, suggesting that mortality effects of particle pollution may be lagged by several days.

Since the Dockery and Pope study, other studies confirm the linear correlation between increases in ambient PM10 and increased mortality, albeit a weaker correlation. Unlike Dockery and Pope's review, which analyzed studies that used locations for unspecified reasons and a variety of statistical approaches, the Air Pollution and Health – A European Approach (APHEA) project used a standardized protocol for data management and analysis and published a complete report of its findings for all cities. Katsouyannie et al. (1997) used data from 12 different European cities, estimated a 0.6% increase in total nonaccidental mortality per 10 $\mu g/m^3$ increase in PM10. Supporting this lower estimate, an American study estimated a 0.5% increase in mortality per 10 $\mu g/m^3$ in the 90 largest American cities where daily average PM10 ranged from 15 to 53 $\mu g/m^3$ (Samet et. al. 2000). As in the European study, Samet et al. (2000) utilized a well-defined sampling frame and analyzed its data with uniform methods.

Along with an increase in mortalities, studies reveal an increase in hospital admissions for both respiratory and cardiovascular diseases as PM levels increase. A study examining particles and hospitalizations in Toronto from 1980-1994 found that increases of 10 μg/m^3 in PM10, PM2.5-10, and PM2.5 were associated with a 0.5, 0.77, and 0.75% increase in respiratory and cardiac hospital admissions, respectively (Burnett et al. 1999). The study controlled for gaseous co-pollutants, temporal trends in admission rates, and climatic factors. A quantitative review of 12 published studies found that for every 10 μg/m^3 increase in PM10 was an associated increase in hospital admission rates of 0.8% for congestive heart failure, 0.7% for ischemic heart disease, and 0.2% for cerebrovascular accidents (Morris 2001). It was further reported that the magnitude of the effect of PM10 on hospital admissions was highly variable and depended on the specific disease category being considered, the time lag used in the analysis, and the role of co-pollutants (Morris 2001).

Specific causes of death associated with particles have been identified in much of the literature. Mortalities associated with particles are most commonly linked with respiratory and cardiovascular diseases. In the study of the six American cities, Dockery and Pope (1994) determined that cardiovascular deaths, which accounted for 45% of all deaths in their review of studies, increased 1.4% for each 10 μg/m^3 increase in PM10, while respiratory deaths, which composed 2 to 8% of the total, increased 3.5% . In a review of data from 30 European cities in the APHEA-2 Project, both cardiovascular and respiratory deaths increased as PM10 concentrations increased (from 36 to 83 μg/m^3), with a slightly steeper increase in cardiovascular mortality (Samoli et al. 2005). In an examination of the association between ambient air quality and mortalities between 1984 and 1993 in Montreal, Quebec, Goldberg et al. (2001) found a greater increase in respiratory deaths than in cardiovascular deaths for a 100 μg/m^3 increase in total suspended particles (TSP) and in PM10. While daily mortalities for cardiovascular diseases increased 6.7 and 7.4%, daily mortalities for respiratory diseases increased 5.8 and 16.5%.

4.2 Effects on Asthmatics and Children

Most of the literature discussing the health impacts of particulate air pollution alludes to the impact of particles on susceptible groups, particularly the elderly and those with pre-existing cardiopulmonary diseases. It has been shown that morbidity and mortality effects apply primarily to the elderly with pre-existing diseases (Goldberg et al. 2000, 2001). Fewer studies have been conducted on other susceptible groups of the population such as asthmatic adults and asthmatic and healthy children.

Asthmatics have been selected in a number of studies to determine the health effects of extreme particulate air pollution events on susceptible portions of the population. However, some research suggests that asthmatic individuals do not react any more significantly than healthy individuals. Two different studies found that neither mild asthmatics nor healthy individuals showed significant physiological changes when exposed to elevated levels of particulates, even when exercising (Gong et al. 2003; Frampton et al. 2004). Ultrafine particles, which did not contain metals or organic compounds, had no significant effects on the airways of the more sensitive group. However, it was found that at the same inhaled concentration of particles about

50% more particles were deposited in the lungs of asthmatic people than in the healthy group (Frampton et al. 2004).

The effects of particulate matter on children's health has not been thoroughly documented, although numerous studies exist. Long-term ambient exposure to particles appears to have the greatest effect on children's health and lung development, while exposure to periodic high levels of particles has a less significant effect. Higher levels of particulate air pollution have also been found to impact infant mortality rates.

Gauderman et al. (2004) found that exposure to higher levels of ambient particulate air pollution affects lung development. They documented the respiratory health of 1759 children in southern California over eight years. Lung function was measured each year, starting at the average age of 10, using spirometric measures, including forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC). A survey was used, in addition, to determine health and background information on the children. Air pollution monitoring stations were positioned in each of the 12 communities examined to measure ozone, acid vapour, nitrogen dioxide, and particulate matter, including PM10 and PM2.5. Nitrogen dioxide, acid vapour, and particulate were significantly correlated with one another. The results showed a positive correlation existed between clinically low FEV_1 and levels of exposure to PM10 (correlation value of 0.02) and PM2.5 (correlation value of 0.002). By the age of 18, a deficit in lung function was observed in children who were exposed to the highest levels of PM over the eight years. The researchers suggest this could be a result of a reduction in the growth of alveoli or also changes in the airways as a result of inflammation, as occurs in bonchiolitis.

A study conducted in East Germany took a different perspective by examining the health of children as air quality improved over time (Frye 2003). Children from three communities in the East Germany region ages 11-14 years were surveyed and tested over six years as air quality improved throughout the 1990s. Both ambient levels of sulphur dioxide and TSP declined significantly. The annual mean of TSP in the three areas studied fell from a high of 79 to a low of 23 $\mu g/m^3$ from 1991-1998, and sulphur dioxide levels fell from a high of 113 to a low of 6 $\mu g/m^3$. Lung function tests were performed on 2,493 children throughout this time period. Although most of the observed effects were small and not statistically significant, all values for measuring lung function increased with decreases in TSP and sulphur dioxide levels over time. Overall, the adjusted percent change of the geometric means of FVC was 4.7% for a 50 $\mu g/m^3$ TSP decrease.

Infants appear to also be susceptible to high levels of ambient PM10. A study that combined infant mortality data and PM10 levels found that post-neonatal mortality rates correlated positively with increases in PM10 (Woodruff 1997). Post-neonatal mortality was defined as the death of an infant between one month and one year of age. PM10 levels were averaged for the infant's first two months of life, and categorized into three categories where low exposures involved PM10 level means of less than 28 $\mu g/m^3$, medium exposures involved PM10 levels between 28 to 40 $\mu g/m^3$, and high exposure involved PM10 levels greater than 40 $\mu g/m^3$. Approximately 4 million infants born between 1989 and 1991 in states that report relevant covariates were examined. The study's results indicated post-neonatal mortality rates were 3.1% among infants with low PM10 exposures, 3.5% among infants with medium PM10 exposures, and 3.7% among highly exposed infants. The strength of association between PM10 exposure and mortality decreased after control for demographic factors and maternal smoking during pregnancy. After adjustment for confounding variables, the risk of post-neonatal mortality from SIDS and respiratory causes was approximately 10% higher in infants in the high PM10 category than in those in the low PM10 category.

Questions arise as to whether children with respiratory illness are more susceptible to particulate air pollution. A unique study in the UK compared the health effects of normal and asthmatic children in two different inner city locations. Ward et al. (2002) recorded daily symptoms and tested lung function (peak expiratory flow or PEF) of 162 nine-year -olds over eight-week periods in the summer and winter. This data was analyzed along with daily pollutant levels, correcting for trends, weather, pollen, and autocorrelation. PM10, PM2.5, nitrogen oxides, sulphur dioxide, ozone, and carbon monoxide were some of the primary pollutants measured. PM10 exceeded 40 $\mu g/m^3$ on only four occasions in the winter weeks, and were associated with increased levels of nitrogen oxides and sulphur dioxide. The results showed statistically significant associations between pollutants and PEF or respiratory symptoms in both winter and summer. However, no consistent patterns emerged in any symptom or lung function when the entire panel of pollutants was considered. There were also no consistent responses in incident symptoms to PM10 or PM2.5. Most notably, children with atopy or a history of recent wheezing were no more susceptible to the short-term respiratory health effects of air pollutants than children without respiratory illnesses. However, this could be the result of asthmatics modifying their behaviour on high pollutant days, either by the use of bronchodilating drugs or by staying indoors and reducing activity.

Studies examining the effects of one-time air pollution episodes found similar results. In a study by Hoek and Brunekreef (1993), 112 children between the ages of 7 and 12 were examined in a non-industrial town in the Netherlands during a single air pollution episode. Respiratory symptoms were recorded by parents during the episode and pulmonary function testing took place at three-week intervals. Daily measurements of PM10 were also taken. During the air pollution episode, PM10 concentrations reached 174 $\mu g/m^3$ on one day, exceeding the US standard of 150 $\mu g/m^3$. The study found that after adjusting for ambient temperature, there was no association between the prevalence of acute respiratory symptoms and air pollution concentrations. The magnitude of response in pulmonary function to the air pollution episode was accordingly small. The group mean measurements used to test pulmonary function were slightly lower than on the baseline days during high-pollution episode days. The study's results were limited, however, by the fact that the number of test days were not sufficient to differentiate between pollutants, including sulphur dioxide, black smoke and PM10.

5. Effects of Natural Particulate Matter

5.1. Composition and General Health Effects

The health impacts of biomass smoke have been less extensively researched than those of particulate air pollution. A number of studies in recent years, however, have examined the effects of biomass smoke on populations. Literature has been produced on the health effects of wood smoke as well, which is useful to review, as the emissions are similar in composition. Studies that have been conducted on the effects of biomass smoke on forest firefighters also provide some indication of how smoke effects respiratory function in the short term.

The most notable cardiopulmonary problems resulting from biomass smoke include decline in lung function, decline in breathing rate, breathing discomfort, emphysema, asthma, allergies, bronchitis, angina, myocardial infarction and heart attack, and pneumonia (Fowler 2003). Little research has been completed on the carcinogenic effects of biomass smoke on populations, and available data do not indicate an increased risk even at very high levels of exposure (Brauer 1998). While biomass smoke is composed of some carcinogenic substances, its cancer risk is still much lower than that posed by motor vehicle exhaust (Lewis 1988).

Most of the pollutants produced by wildfires result from the incomplete combustion of organic material. The major pollutants from biomass smoke include inorganic gases such as carbon monoxide and nitrogen dioxide, hydrocarbons such as benzene, adlehydes such as formaldehyde, polycyclic aromatic hydrocarbons (PAHs) and particles. Ozone is a secondary product of nitrogen oxides and hydrocarbons that can be produced downwind of fires (Brauer 1998). PM is considered the most significant emission because of its volume and associated health problems (USEPA 1998). Ninety percent of this PM produced in wildfires is less than 10 microns in diameter (PM10) and 80 to 90% is less than 2.5 microns in diameter (PM2.5) (Ottmar 2001). Biomass smoke has a similar chemical make-up as particulate air pollution, but the exposure is generally at a much higher level and over a shorter period of time (Frankenburg et al. 2002). In addition, particles from biomass smoke are predominantly composed of organic and elemental carbon, while particles from industry, for example, would be predominantly inorganic in composition (Sastry 2000).

5.2 Effects on Populations

The forest fires of Indonesia in 1997 produced extreme episodes of air pollution as a result of biomass smoke and haze that affected many countries of southeast Asia. For some regions, the haze lasted for a number of months until monsoon rains extinguished the fires in November. Particulate concentrations in the most severely affected regions of Indonesia were estimated to be between 20 and 40 times the normal background concentration (Frankenburg et al. 2002). In Malaysia's capital, Kuala Lumpur, particulate levels exceeded the maximum USEPA recommended concentration for a 24-hour period of 150 $\mu g/m^3$ on numerous occasions (Sastry 2000). Researchers were able to use the data from health surveys as well as vital statistics records to determine the associated health impacts on the populations.

Frankenburg et al. (2002) utilized a health survey that was administered annually in Indonesia to determine general respiratory effects of the smoke haze. The Indonesia Life Survey (IFLS) is an on-going survey of individuals, households, communities, and facilities. Particulate data was obtained through the Aerosol Index reported by the NASA Total Ozone Monitoring System (TOMS). The aerosol indices in the regions of southern and western Kalimantan and southern Sumatra were between 3.0 and 4.0, which corresponds to total suspended particles levels of around 1000 $\mu g/m^3$. By matching TOMS and IFLS data and the physical locations, the study was able to capture each individual's condition of health during exposure to the smoke haze in terms of smoke inundation and duration of that exposure. IFLS looked at overall health by examining ability to perform strenuous functions, like carrying a heavy load. The results were stratified according to age groups.

Two approaches were used to control for other factors that could impact health. In the first approach, individual's results from 1997 were compared to another year, 1993, when there was no smoke haze. The comparison showed that one third more older women and one quarter more older men reported having difficulty carrying a heavy load in 1997 compared to 1993. The reasons for this could also have to do with the fact that the participants were four years older in 1997. The second approach compared groups exposed to the haze in 1997 to groups that were not exposed in the same year. Data from this analysis revealed that among older adults and prime age women, those in haze areas were 10 to 20%more likely to report difficulty carrying a heavy load, suggesting a hindering of respiratory function.

Overall, the study found that the elderly and women were the most susceptible to health effects from the haze. Older men and especially older women were the most affected by a heavier dose of exposure to the haze. For prime age women, the effect of exposure to haze was apparent only at high levels of dosage, while for prime age men, the effect of smoke haze did not vary with intensity. The study also found that among males, the effect of smoke on the ability to carry a heavy load dissipated over time (one month), while with females, the effect persisted for several months (Frankenburg et al. 2002). There was no explanation offered for this gender difference in effects.

A related study examined the effects of the haze in Malaysia using vital statistics records and daily measurements of PM10 in Kuala Lumpur to determine the mortality effects of severe air pollution episodes (Sastry 2000). The average PM10 level for 1996-1997 for Kuala Lumpur was 64.2 $\mu g/m^3$, which is higher than the 50 $\mu g/m^3$ recommended level established by the USEPA and considerably higher than the mean PM10 concentration of cities like Los Angeles (33 $\mu g/m^3$ in 1997). On 13 occasions in Malaysia's capital city, the 24-hour PM10 level exceeded 210 $\mu g/m^3$, the point at which the strongest mortality effects emerged. On high pollution days (exceeding 210 $\mu g/m^3$), an upward shift in mortality occurred for the elderly aged between 65 and 74. On the day after these high air pollution episodes, deaths due to non-traumatic causes (which excludes the effects of accidents and injury) increased by 70%. Due to the shortcomings in the quality of the coding of cause of death in Kuala Lumpur, the specific cause of death (i.e. due to respiratory or cardiovascular disease) could not be determined. Over the time period of 1994-1997, using low-visibility days as an indicator of high air pollution episodes, data revealed that the risk of non-traumatic infant mortality increased by 62% one day after these episodes. The risk of death for individuals aged 65-74 was twice as high on days following a smoke-haze episode (Sastry 2000).

Studies in the United States also reveal negative health effects on populations during smoke-haze episodes. Mott et al. (2002) assessed the health effects caused by the fifth largest fire in the United States on the population of Hoopa Valley National Indian Reservation in California in 1999. Medical visits and a survey revealed health impacts, while measurements of PM10 revealed the extent of the air pollution. The nearby fire burned from August 23 to November 3 in 1999, and on 15 days in that time the 24-hour concentration of PM10 exceeded 150 μg/m^3. On October 21 and 22, particulate concentrations exceeded 500 μg/m^3, USEPA's 24-hour hazardous level. During the year of the smoke episode, medical visits for respiratory problems increased 52% over the previous year. Weekly PM10 levels were also positively correlated with the weekly number of patients admitted to the medical facility with respiratory illness in 1999 (correlation of 0.74), while there was no such correlation in 1998. The survey of 289 residents, some of which had pre-existing respiratory and cardiovascular disease, revealed that more than 60% of respondents reported increased respiratory symptoms during the smoke. Even two weeks after the smoke cleared, more than 20% continued to report an increased frequency of respiratory symptoms. Respondents with pre-existing conditions (those who had previously been treated in the past year for coronary artery disease, asthma, chronic obstructive pulmonary disease, or other lung diseases) reported significantly more symptoms before, during, and after the smoke than others in the community.

Other studies have revealed similar correlations between elevated PM10 levels from biomass smoke and hospital admissions. During a series of California fires in 1987, PM10 concentrations as high as 237 μg/m^3 were recorded during the two and a half week period in six affected counties (Duclos et al. 1990). During this time, asthma and chronic obstructive disease visits increased by 30 and 40%, respectively. Individuals with congestive lung diseases such as emphysema and asthma were particularly affected.

A study in Darwin, Australia, revealed a correlation between PM10 concentrations as low as 20 μg/m^3 and asthma-related admissions (Johnston et al. 2002). A nearby bush fire was the primary source of PM, as Darwin has few industries that emit particles other than motor vehicles. The study found that increases in PM10 after reaching a level of 20 μg/m^3 had a positive linear correlation with increases in asthma-related admissions. However, only when PM10 concentrations were greater or equal to 40 μg/m^3 was there a statistically significant increase in the risk of asthma when compared with the baseline category of less than 10 μg/m^3. Past 40 μg/m^3, there was no significant increase in hospital admissions. An examination of lag time revealed that the number of hospital admissions was on average highest five days after a high-pollution episode, second on the high-pollution day itself, and third highest after a lag of one day.

Of the few studies on the health effects of crop residue burning, one study revealed a significant increase in respiratory symptoms among adults with pre-existing respiratory ailments (Long et al. 1998). The Lung Health Study surveyed 428 individuals in Winnipeg in 1992 during an extreme air pollution episode caused by nearby agricultural burning between September 25 and October 15. Air pollutant levels were measured continuously at two stations in Winnipeg. The 24-hour integrated concentration of PM10 increased from a range of 15 to 40 μg/m^3 between June and September to a range of 80 to 110 μg/m^3 during the air pollution episode. Similarly, the twenty-four-hour TSP varied between 20 and 80 μg/m^3 between June and September, but during the air pollution episode it varied between 80 to 200 μg/m^3. Moreover, the 1-hour maximum concentration of carbon monoxide was as high as 11 ppm, and nitrogen dioxide reached 11 parts per hundred million. VOC measurements, taken every sixth day for a 24-hour period, also increased considerably, reaching a maximum of 458.65 μg/m^3 on October 9, while the average annual concentration was 94.06 μg/m^3.

The individuals surveyed were between the age of 35 and 64, with slightly over half of them being smokers. More women than men reported symptoms relating to the air pollution episode, such as eye, nose, or throat irritation, increased coughing, wheezing, and shortness of breath. While 33% of women reported increased coughing, only 19% of men reported the same symptom. In addition, 42% of men reported they were not bothered at all by the pollution episode while this was true for 30% of women. Smokers were not affected to the same extent by the air pollution as non-smokers.

One study suggests that naturally occurring particles resulting from soil erosion may not have as severe health impacts on human populations as particles from industrial sources or from biomass smoke. An investigation into the association between emergency room visits for respiratory disorders and dust storms in the Tri-Cities area of Washington State found that the dust storms had minimal public health impact. The study area exuded minimal industrial activity and the particles were volcanic in origin (Hefflin et al. 1994). It was further reported that an increase of 100 $\mu g/m^3$ in PM10 resulted in a 3.5% increase in the number of emergency room visits for bronchitis, while there was no increase in emergency room visits for asthma (Hefflin et al. 1994).

5.3 Effects on Firefighters

While most of the literature examines the effects of biomass smoke on the general population or susceptible groups, studies that have examined the effects of PM on forest firefighters provide a different perspective (Betchley et al. 1997; WHO 1998; Reinhardt et al. 2000). Firefighters are physically fit young adults who normally do not suffer from pre-existing health conditions, but are exposed to high concentrations of biomass smoke in their everyday work. Despite their top physical condition, their health has been shown to be compromised in a number of ways. Smoke exposure among forest firefighters has been associated with acute irritation, shortness of breath, headaches, dizziness, and nausea (Reinhardt et al. 2000). Given the top physical condition of firefighters, the health impacts of smoke on general populations would be expected to be just as significant at equivalent or lower levels of exposure (WHO 1998).

A study examining full-time and seasonal forest firefighters in Salem, Oregon, found significant declines in pulmonary function after managing several prescribed burns (Betchley et al. 1997). Both cross-shift and cross-season data were collected from 76 and 96 individuals who were predominantly white and male with a mean age of 36 years. Cross-shift data was collected immediately before, during (when possible) and immediately after the prescribed burns. In the cross-shift analysis, all respiratory symptoms except for cough increased from pre-shift to mid-shift, and also to post-shift. However, the increase was not statistically significant. Spirometric results, which measure overall lung function (forced vital capacity, forced expiratory volume in one second, and forced expiratory flow), showed a significant decrease in lung function. Cross-season data was collected early in the season in March 1992 and then in November and early December of 1992, on average 77.7 days after the last occupational smoke exposure. These data showed a significant (greater than 5%) increase in respiratory symptoms for cough and phlegm, while wheeze and chronic bronchitis only increased slightly. Again, spirometric results indicated a significant decrease in most measurements that were used to determine lung function.

Slaughter et. al. (2004) conducted a similar study, focussing on the difference between pre-shift and post-shift (a time difference of approximately 8 hours) lung measurements in 76 firefighters fighting prescribed burns in the U.S. in the fall and spring of 1992 and 1993. Spirometric results again showed a significant decrease in all lung function measures from pre- to post-shift, even when exclusions for allergies, re-existing lung conditions, smoking status, or recent colds were made. However, according to smoke exposure data, lung function associated with higher concentrations of PM (at 4000 $\mu g/m^3$), was no worse than lung function associated with low concentrations of PM (at 51 $\mu g/m^3$). There did not appear to be a threshold value above which pollution exposure was particularly harmful. The researchers suggest the relatively small decline in lung function could, in part, reflect the "healthy worker effect," as wildland firefighters are generally very fit and accustomed to high levels of exertion. But it could also indicate that the threshold for pulmonary function effects of fine PM is low, in the range of 30-110 $\mu g/m^3$.

6. Conclusions

The health effects of particulate matter (PM) have been well documented throughout the world. PM, both in the form of air pollution and biomass smoke, poses significant risk to populations. Previous studies have shown that mortality rates, hospital admissions, and decreased lung function are all positively correlated with increases in both PM10 and PM2.5. Even at PM levels below established ambient air quality standards, significant portions of the population remain at risk.

The biological effects of particles on the human body are now better understood than half a century ago, when particulate air pollution became a significant issue. Exposure to PM causes an inflammatory response in the lungs, which in the long-term can lead to chronic airflow obstruction and airway remodelling. PM has also been associated with increased coagulability of the blood and the constriction of blood vessels. However, it is still unclear as to which components of PM contribute the most to its toxicity. Both size and composition play a role, although it has been suggested in the literature that the composition plays a bigger role than size. Metal and sulphate concentrations, for example, have shown to be significant contributors to particulate toxicity.

The health effects of PM from anthropogenic sources have been the most extensively studied. Studies in the United States, Canada, and Europe all indicate that incremental increases in PM10 are linearly correlated with increases in mortality rates and hospital admissions. Most studies indicate that the most susceptible groups involve the elderly, particularly those with pre-existing cardiopulmonary diseases. But inhibited lung development among children and increased mortality rates among infants have also been shown to be associated with elevated levels of suspended particulates. Interestingly, some studies suggest that asthmatics may not be as susceptible to short-term air pollution episodes as once thought. In these studies, short-term exposure to high levels of particulates resulted in few respiratory symptoms in both healthy and asthmatic children and adults.

While particles from biomass smoke may differ in composition from those emitted from anthropogenic sources, they have similar effects on populations. Typically, exposure to biomass smoke is more intense (at a greater concentration of particles) but over a shorter period of time. Those with pre-existing cardiopulmonary conditions have been shown to be the most susceptible to PM in biomass smoke. Even at PM10 levels of 40 $\mu g/m^3$, for example, significant increases in asthma-related admissions have been reported. It is clear that all portions of a population may be susceptible to some degree, as even some of the most fit and healthy portions of the population, such as forest firefighters, suffer health consequences from exposure.

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Ware, J.H. 1981. "Assessment of the health effects of atmospheric sulphur oxides and particulate matter: evidence from observational studies." Environmental Health Perspectives 41: 255-76.

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APPENDIX B

Case Study Methods and Rationale

Methods to deal with confounding factors were discussed in the Feasibility Report (Warnock et al. 2003: 15). As discussed, several other factors, besides wildfire smoke and other emissions, are associated with cardio-respiratory ailments. These include factors such as cigarette smoking, age, socio-economic level and indoor air quality. The purpose of the case study approach is to assess the level of influence of the confounding factors on cardio-respiratory ailments as compared with possible wildfire emissions effects.

Fire seasons with low fire amounts were presented as possible useful controls for comparison with very active fire seasons (Warnock et al. 2003). This section provides the criteria for case studies selection and applies them to select case-control studies.

Selection criteria for the case study years (and therefore areas) are:

- The high and low fire years should be close in time so that the confounding variables for cardio-respiratory health would be similar.
- The low fire year should occur prior to the high fire year so that there are fewer lag effects of the smoke. Preferably, the low fire year should be the last year in a sequence of low fire years.

The case control study years were selected by applying these criteria to the annual graphs (area burned, evacuation information Figures 9 and 21). 1995 had a large area burned and high evacuations as compared with 1992 which had a low area burned and low evacuation. 1995 has the second highest burned area in the period of record. 1981 has the highest area burned, but is not suitable as it is at the start of the record. Other advantages of using 1992 are that it is relatively close in time to 1995 and is preceded by two years of relatively low area burned.

The location of burned areas for 1992 and 1995 are plotted on Figures B1 and B2. There were a small number of large fires in 1992 and most of these fires were on the northwest and far northern portion of Saskatchewan. Only seven large fires (greater than or equal to 200 hectares) were in the Mamawetan Churchill River Regional Health Authority with a total burn area of almost 9,000 ha. These fires were discovered during mid June to mid August. None of these fires were close to communities and no evacuations were due to these fires. The largest fire was in the Wollaston District with more than 4200 ha burned.

During the active high fire year of 1995, 50 large fires (greater than 200 hectares) were recorded in the Mamawetan Churchill River RHA with the total burn area of nearly 645,000 ha. These fires were discovered from the end of May through to mid July. The latest the large fires were extinguished was August 29, 2005. The largest fire (101,000 ha) located in the Southend district, was discovered June 19 and was extinguished on October 14, 2005.

Many of the 1995 fires were in proximity of many communities located in the Mamawetan Churchill River RHA. This resulted in several of the communities being evacuated including Montreal Lake (three fires in the district), Timber Bay (three fires in the district), Hall Lake (IR 217) (two fires in the district), Pinehouse (three fires in the district), Stanley Mission (eight fires in the district), Brabant Lake (14 fires in the district), Sandy Bay (ten fires in the district), Pelican Narrows (six fires in the district) and Wollaston Lake (three fires in the district) (Figure B3).

Several seasonal climate stations are located within the Mamawetan Churchill River RHA. These include Besnard Lake, Cumberland House, Candle Lake, Creighton, Little Bear Lake, La Ronge, Pelican Narrows, Southend, Tracey and Waskesiu. The completeness of these station records is variable (Figure 25).

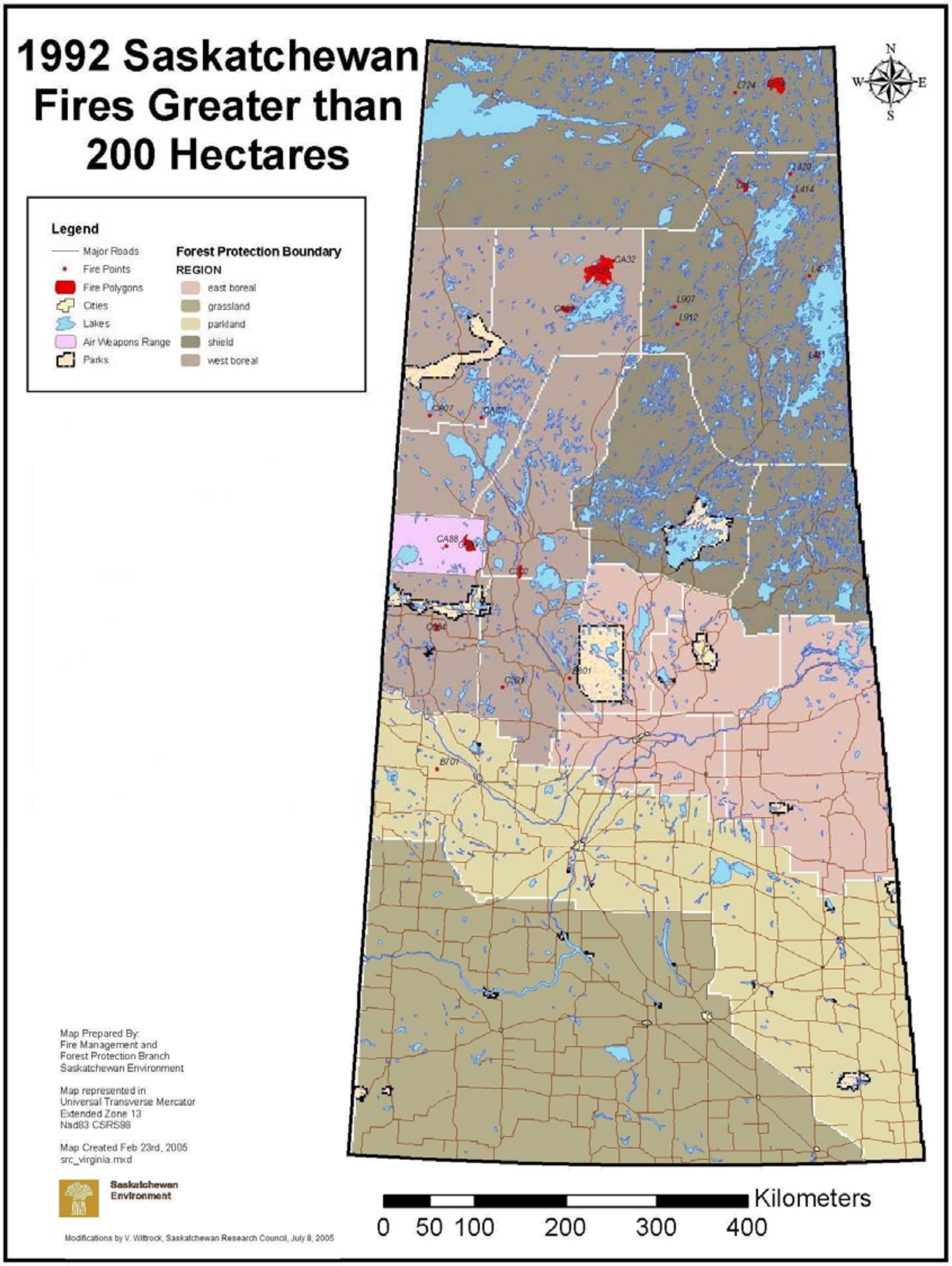


Figure B1 1992 Saskatchewan Large Fires (≥ 200 ha) (Data Source: Saskatchewan Environment 2005)

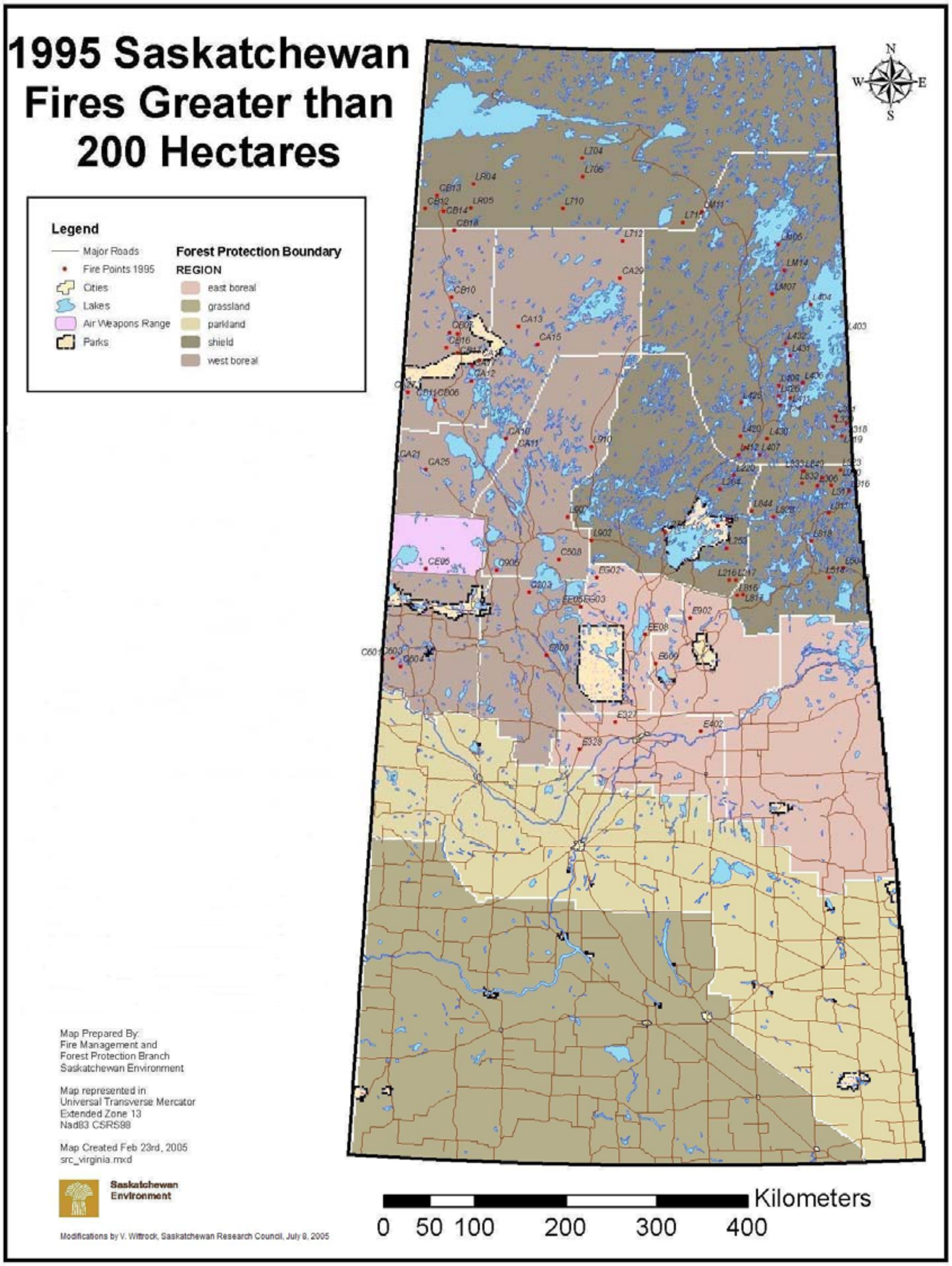


Figure B2 1995 Saskatchewan Large Fires (≥ 200 ha) (Data Source: Saskatchewan Environment 2005)

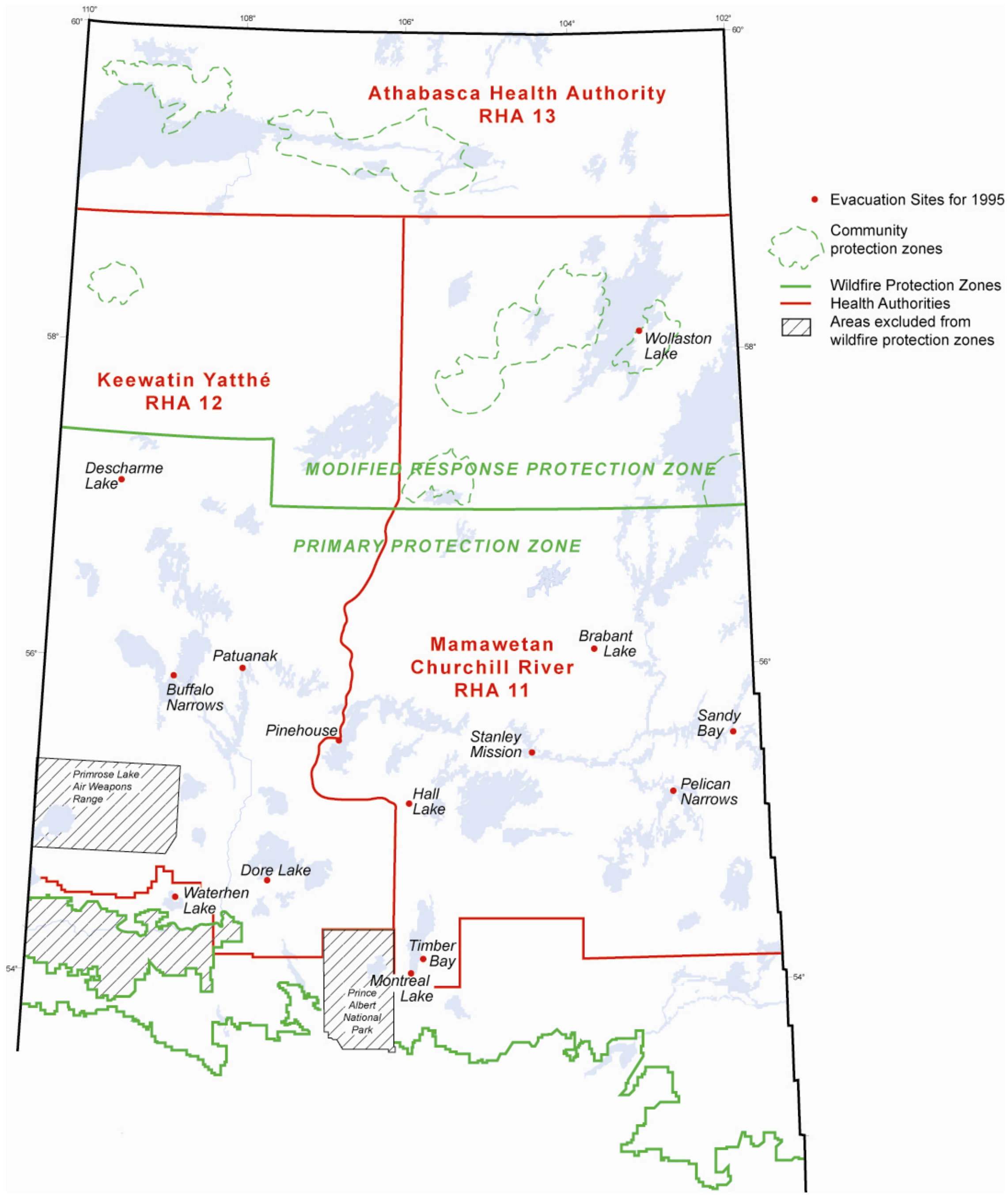


Figure B3 Communities Evacuated in 1995 (Data Source: Saskatchewan Department of Community Resources and Employment 2005)

APPENDIX C

Newsletter (April 2004)

Progress Report – Climate Changes, Wildfires and Respiratory Ailments in Northern Saskatchewan.

PROGRESS REPORT

Climate Changes, Wildfires and Respiratory Ailments in Northern Saskatchewan

Climate Changes, Wildfires and Respiratory Ailments in Northern Saskatchewan Project Approved!

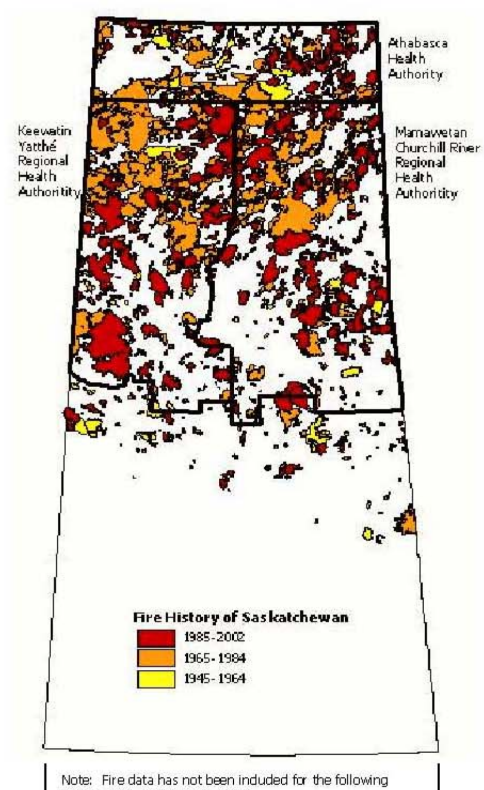
We are pleased to announce that our *Climate Changes, Wildfires and Respiratory Ailments in Northern Saskatchewan* project (Climate Change Action Fund Project No. A573) has been recently approved for completion by Natural Resources Canada.

The overall study area is the Northern Administrative District, which is comparable to the northern regional health authorities of Keewatin Yatthé, Mamawetan Churchill River and the Athabasca Health Authority (roughly equivalent to the Canadian Census Saskatchewan Division No. 18) and roughly the northern half of the province of Saskatchewan. (See adjacent map.)

Project Purpose and Objectives

The purpose of the project is to examine the relationship between wildfire conditions and respiratory ailments in northern Saskatchewan and to estimate possible impacts of climate change on wildfires and respiratory ailments so as to assist in the identification of adaptation options. A respiratory ailment in this study is defined as a hospital admission for any sudden (acute) or prolonged (chronic) cardio-respiratory condition that could be aggravated by inhalation of smoke. The project objectives include the following:

1. To describe the trends and variations in hospitalizations for selected cardio-respiratory conditions, fire/fuel and meteorological conditions associated with significant wildfires in northern Saskatchewan over a 25-year period.
2. To examine the relationship between fuel types and smoke characteristics, then assess the relationship between wildfires and respiratory health for the significant wildfires.
3. To provide preliminary estimates of possible respiratory health concerns for northern communities for a range of climate change, fuel type, smoke, and wildfire scenarios.
4. To explore adaptation options and formulate recommendations.



Note: Fire data has not been included for the following years: 1951, 1954, 1962, 1965.
Fires that have occurred after August 22, 2002 have also not been included.
Fire Data Source: Saskatchewan Environment

Project Newsletter # 1 1 April 2004

Climate Change Impacts and Adaptation

Progress to Date and Future Directions

To date we have completed a feasibility study for Natural Resources Canada. We will have collected all key forest fire, human health, climate/weather and census databases by March 31, and will complete converting databases to a common format before June 30, 2004.

Next, we will determine communities with a high, medium and low wildfire frequencies, by determining the number of nearby fires during 5, 10, and 20 year time periods, by June 30, 2004.

Epidemiological analyses of cardio-respiratory ailments and time series correlations of forest fires and smoke dispersion patterns with spatial and temporal distribution of cardio-respiratory ailments will be completed by December 31, 2004. From these analyses, more detailed community case studies will be determined and analyzed.

A next step is to describe future fire conditions based on future climate scenarios from Global Climate Models developed by the Canadian Climate Scenarios Impact Project. Team members will then use the above relationships, linking climate with fire, and fire with respiratory health, in a model to be developed to estimate the possible nature of future cardio-respiratory health risks in the study area under several climate change scenarios.

The final phase of the project is the interpretation and discussion of outcomes and development of adaptation options and recommendations with stakeholders through plain language summaries and workshops by September 30, 2005.

The target completion date for this project (final report) is December 31, 2005.

Meet Our Team

- Lynda Langford
  Project Team Leader
  Saskatchewan Environment
  Regina, SK.
- Elaine Wheaton
  Senior Climatologist
  Saskatchewan Research Council
  Saskatoon, SK.
- Dr. Mark Johnston
  Senior Forest Ecologist
  Saskatchewan Research Council
  Saskatoon SK.
- Virginia Wittrock
  Climatologist
  Saskatchewan Research Council
  Saskatoon, SK.
- Dr. William Osei
  Provincial Epidemiologist
  Saskatchewan Health
  Regina, SK.
- Dr. James Irvine
  Chief Medical Officer
  Mamawetan Churchill River and Keewatin Yatthé Regional Health Authorities and the Athabasca Health Authority
  La Ronge, SK.
- Tom Laxdal
  Forest Fire Ecologist
  Saskatchewan Environment
  Prince Albert, SK.
- Robert Warnock
  Consultant Ecologist and Project Coordinator
  Regina, SK.

Contact Us!

We look forward to keeping you informed about our project.

- Lynda Langford, Project Team Leader
  Phone: 306-787-6868
  E-mail: llangford@serm.gov.sk.ca
- Elaine Wheaton
  Phone: 306-933-8179
  E-mail: wheaton@src.sk.ca or
- Rob Warnock
  Phone: 306-787-6748
  E-mail: rwarnock@serm.gov.sk.ca

Please feel free to contact us. We would love to hear from you!

Project Newsletter # 1 2 April 2004

Climate Change Impacts and Adaptation

APPENDIX D

Presentations made to Fire Control Section of Saskatchewan Environment
November 28, 2005

Appendix D1 Langford, L., Climate Changes, Wildfires and Respiratory Ailments in Northern Saskatchewan: Introduction. Saskatchewan Research Council, Saskatoon, Saskatchewan SRC Publication No. 11667-4D05.

Climate Changes, Wildfires and Respiratory Ailments in Northern Saskatchewan Introduction

Lynda Langford
Saskatchewan Environment

Project Team: Lynda Langford, Elaine Wheaton,
James Irvine, Mark Johnston, Tom Laxdal, William Osei, Virginia Wittrock
November 28, 2005
Presentation given to Fire Control Section, Saskatchewan Environment
Prince Albert, Saskatchewan

SRC Publication No. 11667-4D05

PURPOSE

- **Examine relationships** between wildfire conditions and respiratory health in Northern Saskatchewan.
- **Estimate possible impacts** of climate changes on these relationships to assist in the **identification of adaptation options**.

OBJECTIVES

- **Describe** the respiratory health, fire/fuel and meteorological **conditions associated** with significant wildfires in Northern Saskatchewan.
- **Examine** the **relationship** between fuel types and smoke characteristics, then **assess** the **relationship** between wildfires and respiratory health for the significant wildfires.
- **Provide** preliminary **estimates** of possible respiratory health concerns for northern communities for a **range** of climate change, fuel type, and wildfire **scenarios**.
- **Explore** adaptation **options** and **formulate recommendations**.

Appendix D2 Wittrock, V and E. Wheaton Relationships: Climate, Fire and Respiratory Health. Saskatchewan Research Council, Saskatoon, Saskatchewan. SRC Publication No. 11667-1D05.

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Relationships: Climate, Fire and Respiratory Health

V. Wittrock and E. Wheaton
Saskatchewan Research Council
Project Team: Lynda Langford, Elaine Wheaton, James Irvine, Mark Johnston, Tom Laxdal, William Osei, Virginia Wittrock

Presentation to the Saskatchewan Environment Forest Fire Managers
November 28, 2005
Prince Albert

SRC Publication No: 11667-1D05

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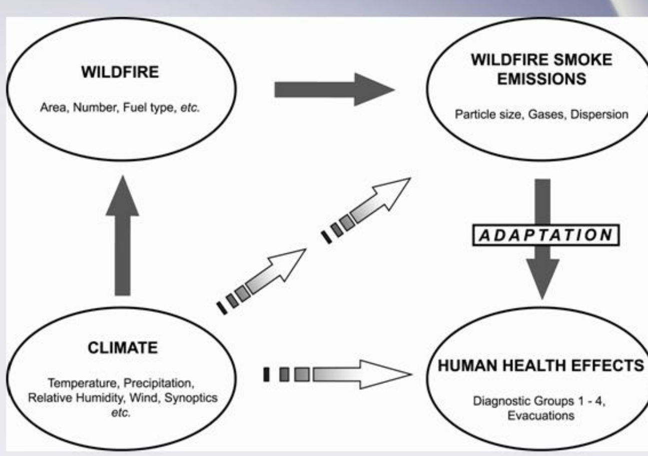
OUTLINE

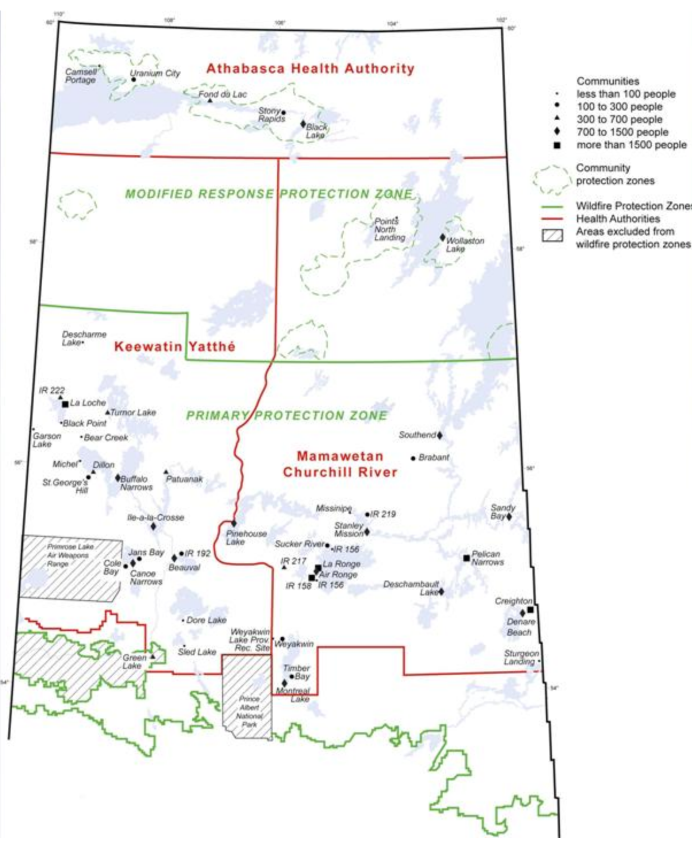
- Climate and Area Burned
- Hospital Admissions and Area Burned
- Case Study



METHODOLOGY

- Assess linkages between wildfires and occurrences of respiratory ailments.
  - **Graph** the yearly and weekly **time series** of the variables.
  - **Describe** and **compare** the time series.
  - **Determine** the overall **trends** of key variables.
  - Create **scatter-grams** of variables to assess the nature of the relationships.
  - Undertake **correlation analysis**.
  - Create **maps**.
  - Make **recommendations** for future analysis.

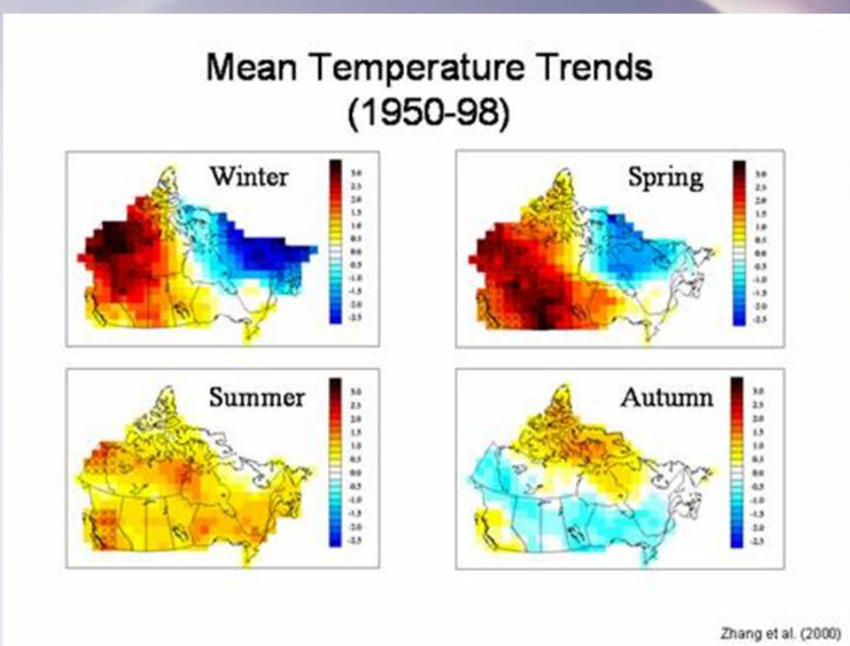
STUDY AREA

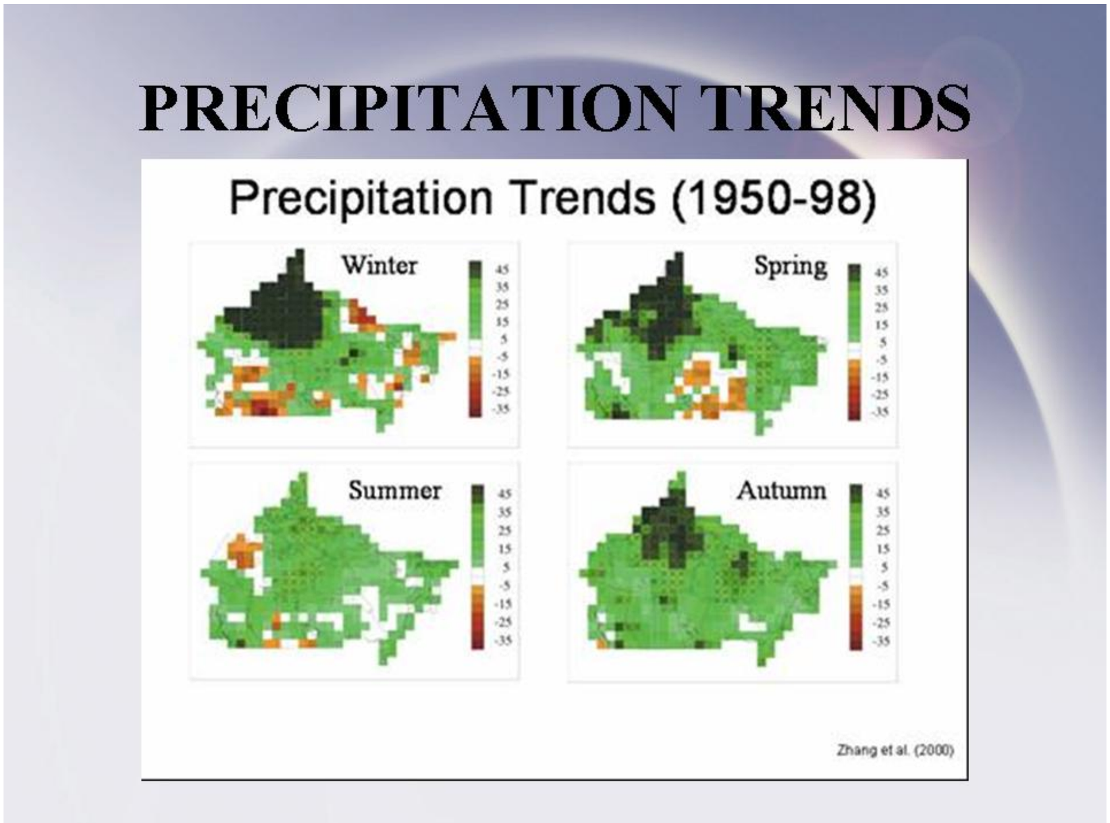


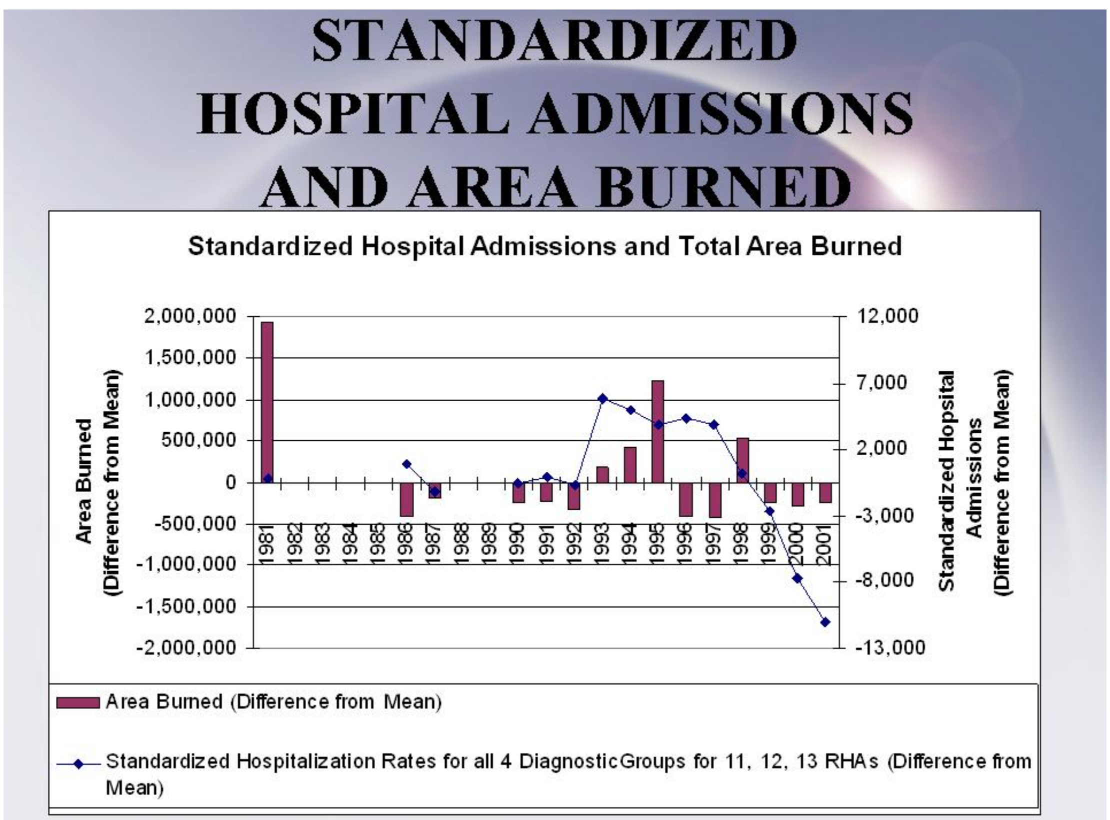
CLIMATE AND FIRE

- Forest **drought** has a **strong relationship** to **area burned**.
- **Drought** conditions **influence** the **fuel moisture content** (Clark 1991; Harrington and Flannigan 1993).
- Extended **dry spells provide** dry fuel plus suitable conditions for **fire ignition** (Harrington and Flannigan 1993).

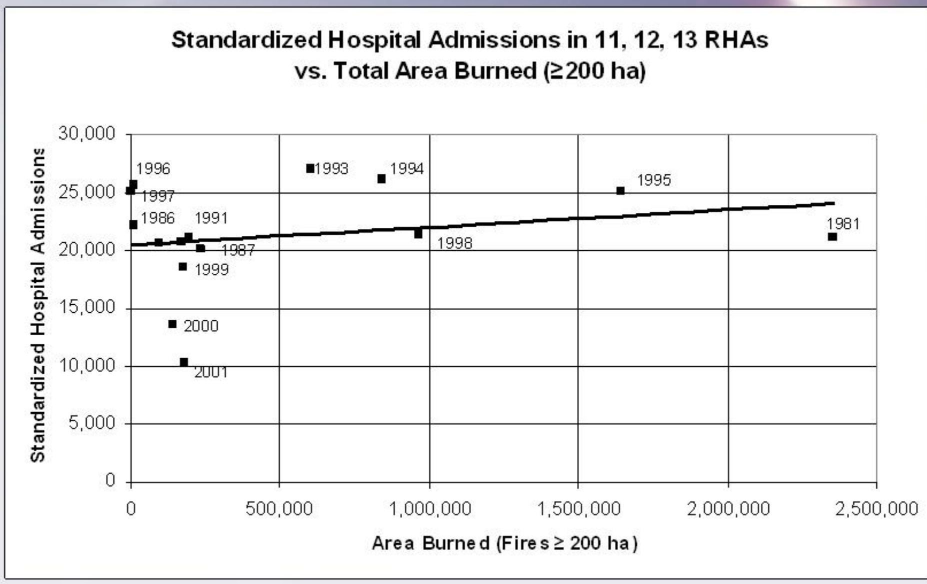
TEMPERATURE TRENDS




PRECIPITATION TRENDS
Precipitation Trends (1950-98)
Winter
Spring
Summer
Autumn
45
35
25
15
5
-5
-15
-25
-35
Zhang et al. (2000)


STANDARDIZED
HOSPITAL ADMISSIONS
AND AREA BURNED
Standardized Hospital Admissions and Total Area Burned
Area Burned
(Difference from Mean)
2,000,000
1,500,000
1,000,000
500,000
0
-500,000
-1,000,000
-1,500,000
-2,000,000
12,000
7,000
2,000
-3,000
-8,000
-13,000
Standardized Hopsital
Admissions
(Difference from Mean)
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Area Burned (Difference from Mean)
Standardized Hospitalization Rates for all 4 DiagnosticGroups for 11, 12, 13 RHAs (Difference from Mean)

HOSPITAL ADMISSIONS AND AREA BURNED

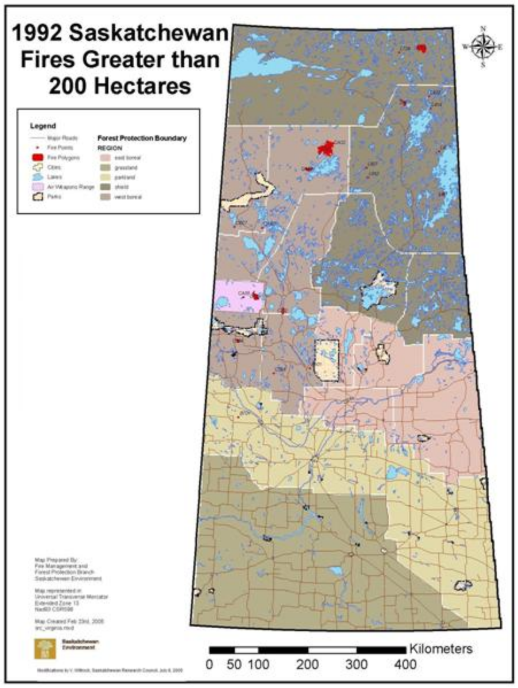


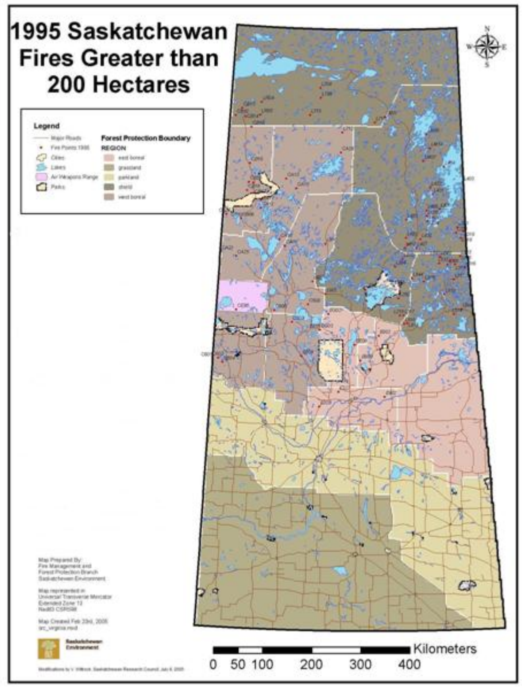
r = 0.225 (Pearson Product Moment Correlation)

CASE STUDY

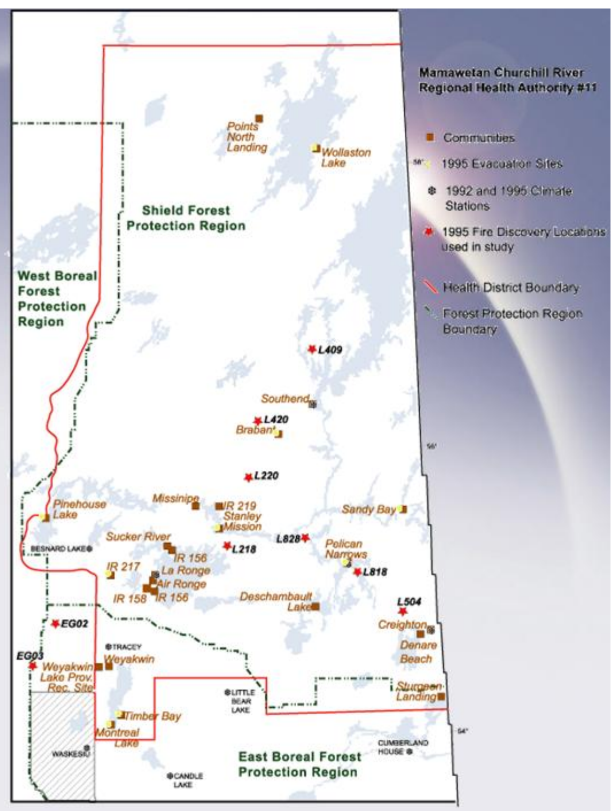
- Assess the level of influence of the confounding factors on cardio-respiratory ailments as compared to the possible wildfire emissions effects.
- Case study selection criteria:
  - High and low fire years should be close in time
  - Low fire year should occur prior to high fire year

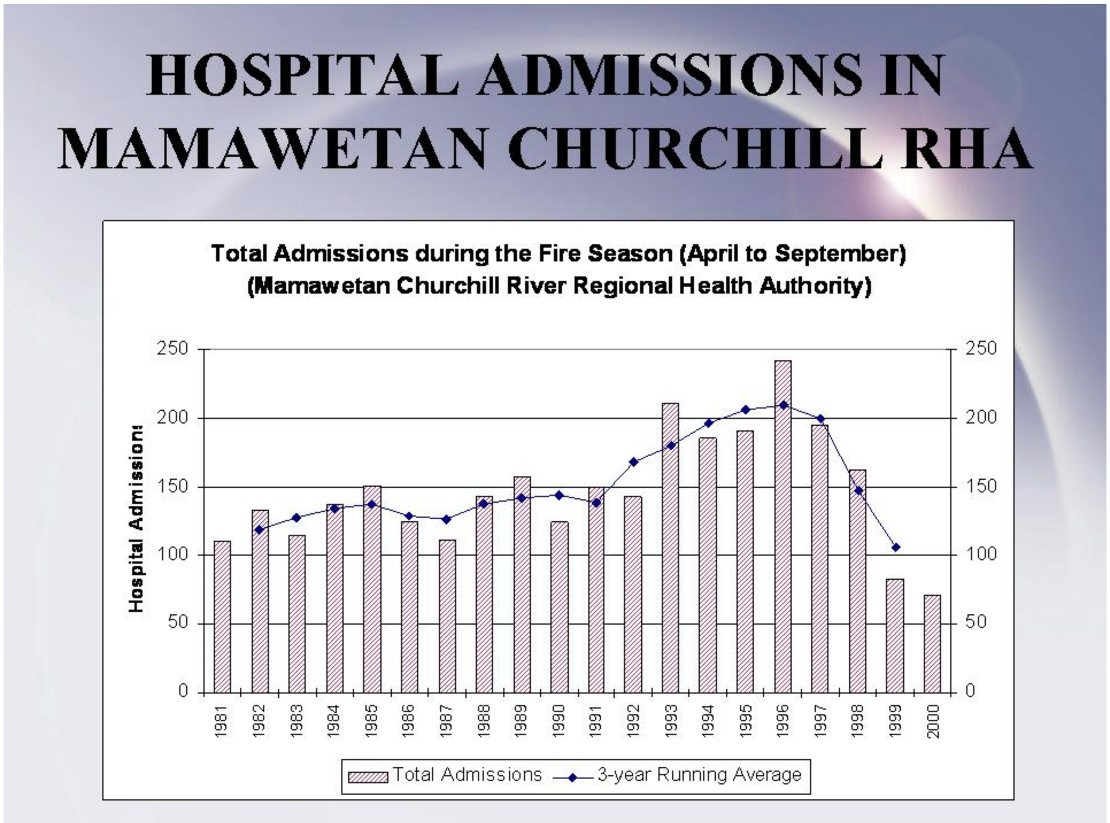
FIRE LOCATIONS (1992 and 1995)

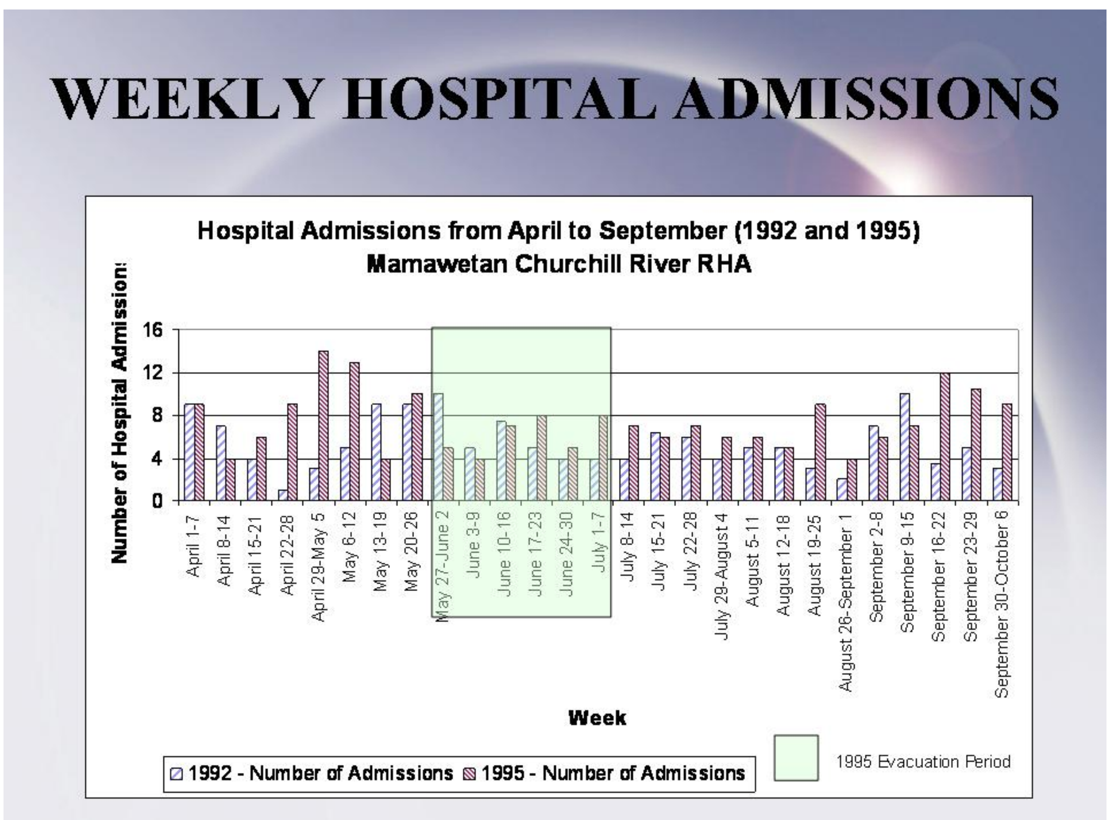




Mamawetan Churchill Regional Health Authority

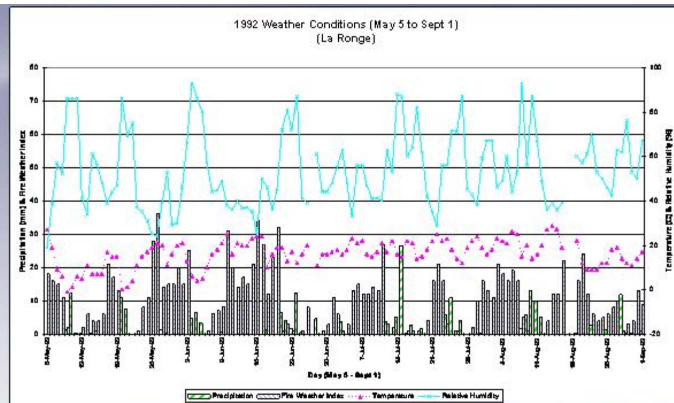


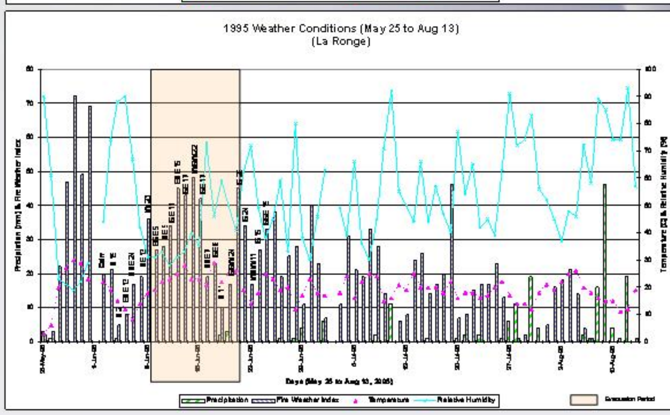

HOSPITAL ADMISSIONS IN MAMAWETAN CHURCHILL RHA
Total Admissions during the Fire Season (April to September)
(Mamawetan Churchill River Regional Health Authority)
Hospital Admissions
250
200
150
100
50
0
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Total Admissions
3-year Running Average


WEEKLY HOSPITAL ADMISSIONS
Hospital Admissions from April to September (1992 and 1995)
Mamawetan Churchill River RHA
Number of Hospital Admissions
16
12
8
4
0
April 1-7
April 8-14
April 15-21
April 22-28
April 29-May 5
May 6-12
May 13-19
May 20-26
May 27-June 2
June 3-9
June 10-16
June 17-23
June 24-30
July 1-7
July 8-14
July 15-21
July 22-28
July 29-August 4
August 5-11
August 12-18
August 19-25
August 26-September 1
September 2-8
September 9-15
September 16-22
September 23-29
September 30-October 6
Week
1992 - Number of Admissions
1995 - Number of Admissions
1995 Evacuation Period

Daily weather for the 1992 and 1995 fire season

- 1992 – low FWI (high 37)
- 1995 – high FWI (high 72)
- 1992 – numerous rainfall events with moderate amounts
- 1995 – few rainfall events with low amount





OBSERVATIONS

- Case study suggests that wildfire smoke is not an overwhelming influence on the hospital admissions for the two case study years.
- Why?
  - Communities were evacuated
  - Mamawetan has a historically high number of hospitalization rates compared to the rest of the province (Osei and Virag 1999)
  - Admissions have many causes
  - Data and methodologies require further sophistication
  - Other observations?

Appendix D3 Johnston, M. Modelling Smoke Emissions. Saskatchewan Research Council, Saskatoon, Saskatchewan. SRC Publication No. 11667-3D05.

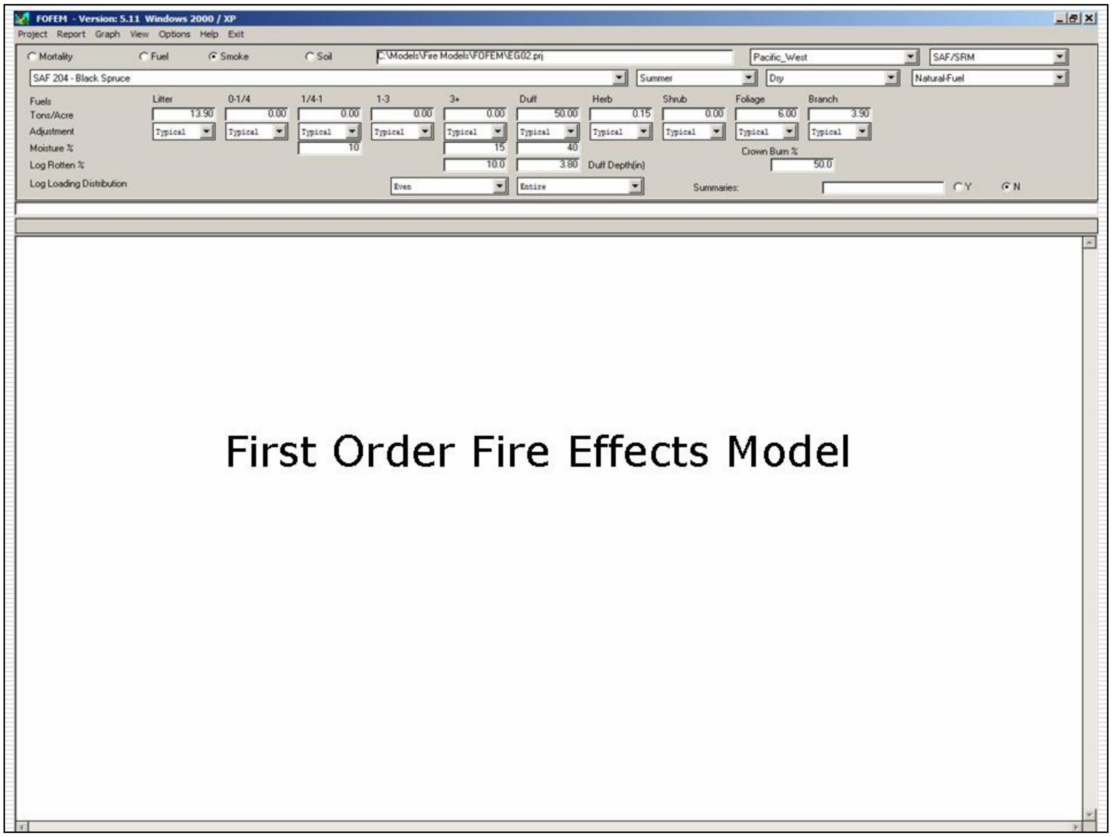
Modelling Smoke Emissions

Mark Johnston
Saskatchewan Research Council
28 November, 2005

SRC Publication No. 11667-3D05

General Approach

- Obtained location of fires
- Overlaid on forest inventory
- Determined majority forest type ID within 1 km of fire location
- Converted that to SAF Cover Type
- Used Cover Type in FOFEM with default values



Example of Smoke Model Output

Fire EG02

area of fire (ha) 2,300

Total Emissions (tonnes)

	Flaming	Smoldering	Total
PM_{10}	65	6,520	6,585
$PM_{2.5}$	54	5,523	5,578
CH_4	18	3,357	3,375
CO	139	73,613	73,752
CO_2	37,887	299,634	337,521
NO_X	67	0	67
SO_2	21	243	263

Appendix D4 Wheaton, E. Future Possible Climates and Forest Fires of Northern Saskatchewan. Saskatchewan Research Council, Saskatoon, Saskatchewan. SRC Publication No. 11667-2D05.

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Future Possible Climates and Forest Fires of Northern Saskatchewan

E. Wheaton, Saskatchewan Research Council
Project Team: L. Langford, J. Irvine, M. Johnston, T. Laxdal, W. Osei, E. Wheaton, V. Wittrock
Prince Albert Climate, Fires, and Health Workshop
28 November 2005

SRC Publication No. 11667-2D05

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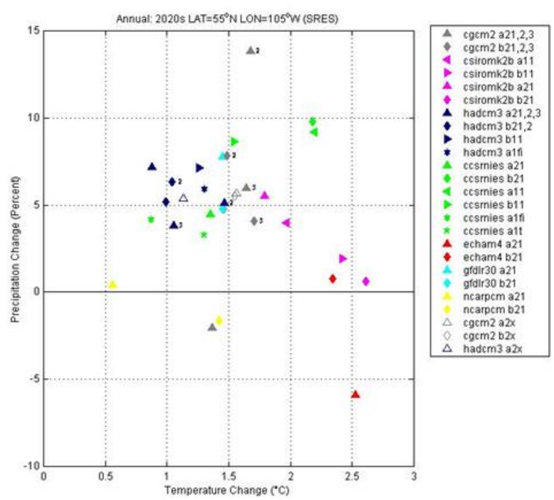
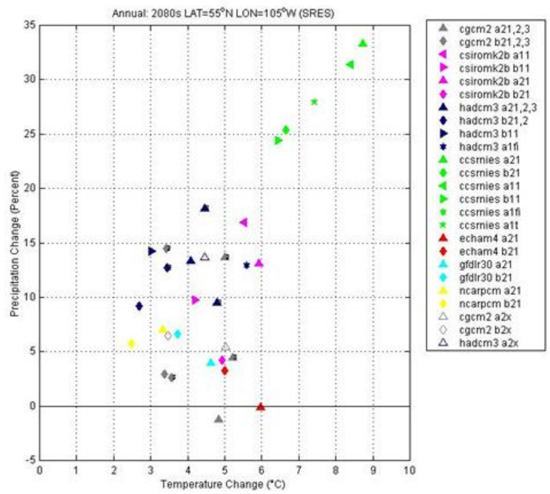
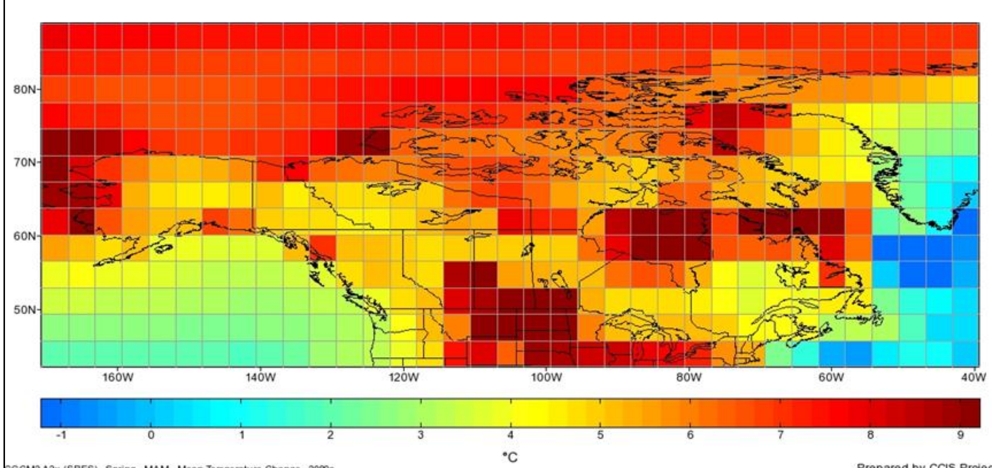
Mean Temperature and Precipitation 2020s (annual changes; grid-point centered near La Ronge)



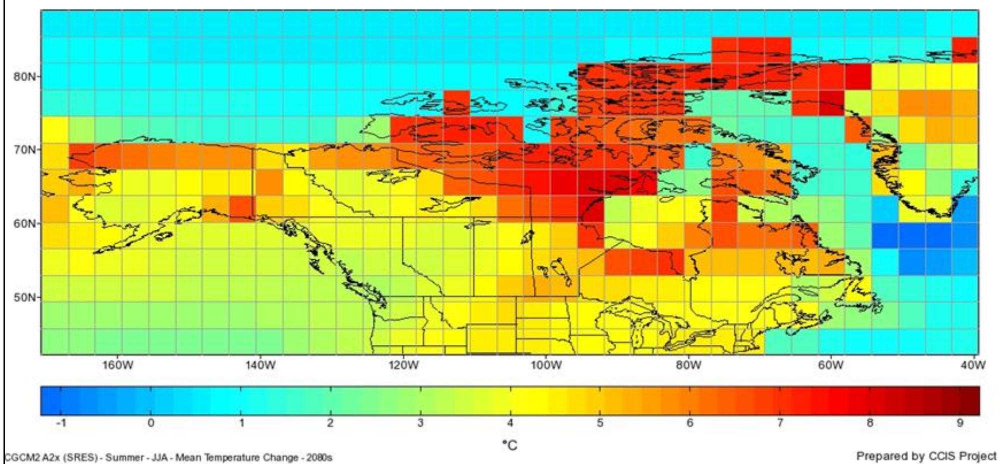
Scatter-plot for the 2080s



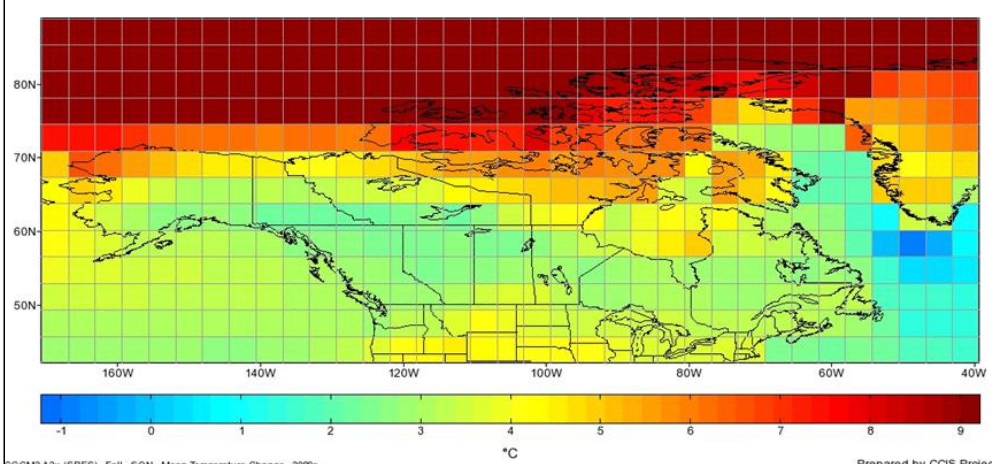
Spring Mean Temperature Change 2080s

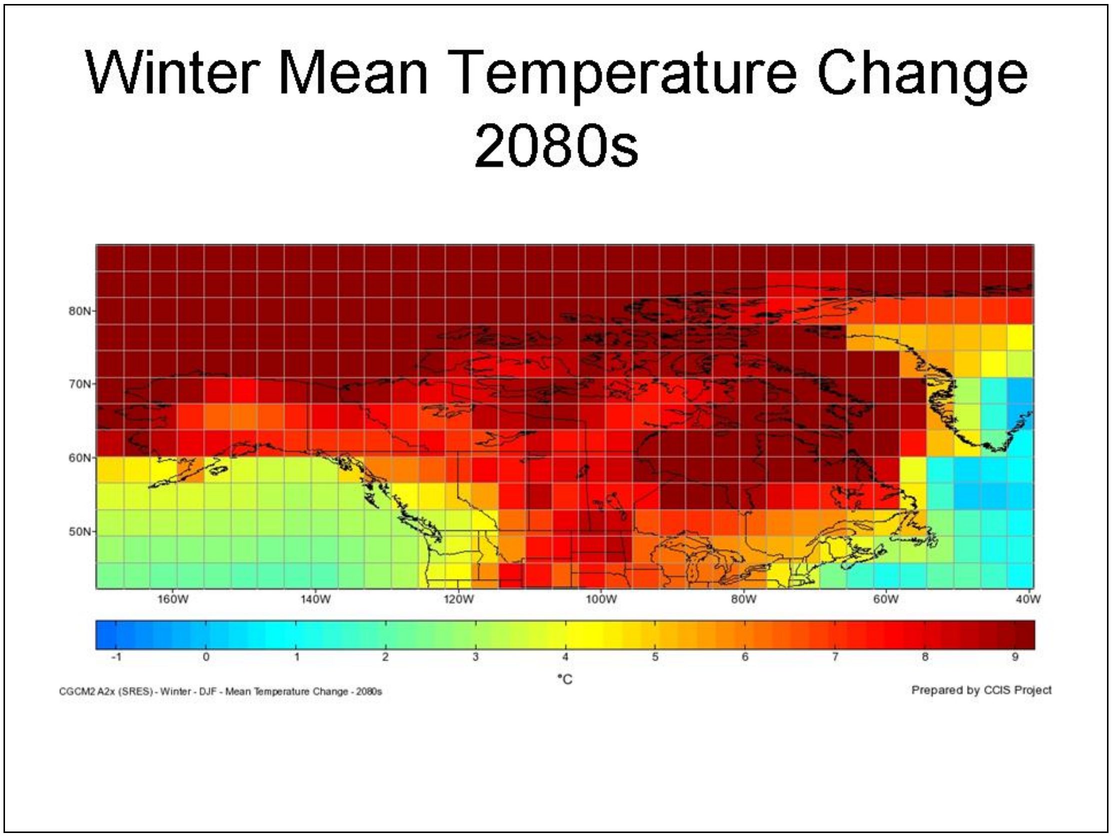


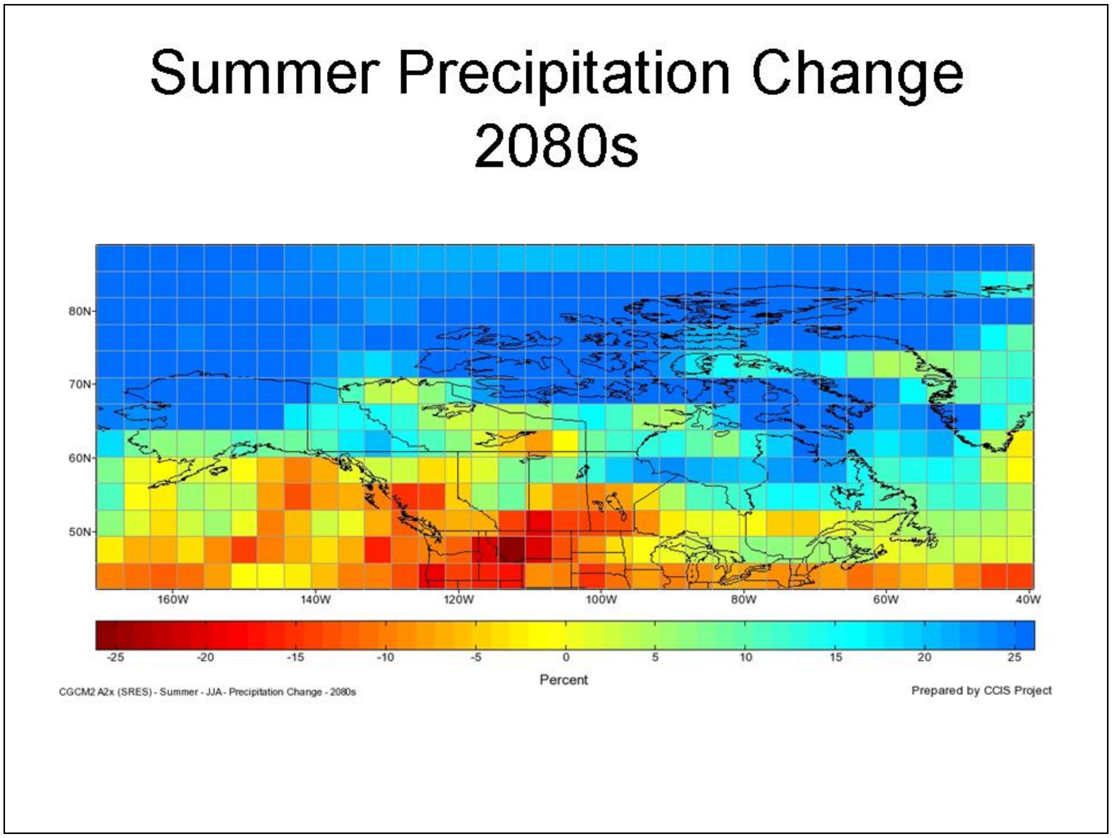
Summer Mean Temperature Change 2080s



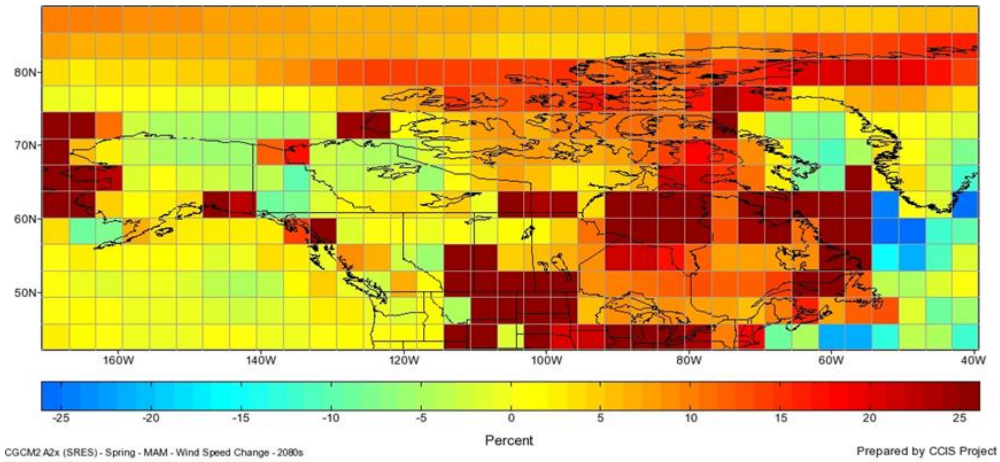
Fall Mean Temperature Change 2080s




Winter Mean Temperature Change
2080s
80N
70N
60N
50N
160W
140W
120W
100W
80W
60W
40W
-1
0
1
2
3
4
5
6
7
8
9
°C
CGCM2 A2x (SRES) - Winter - DJF - Mean Temperature Change - 2080s
Prepared by CCIS Project


Summer Precipitation Change
2080s
80N
70N
60N
50N
160W
140W
120W
100W
80W
60W
40W
-25
-20
-15
-10
-5
0
5
10
15
20
25
Percent
CGCM2 A2x (SRES) - Summer - JJA - Precipitation Change - 2080s
Prepared by CCIS Project

Wind Speed Change 2080s



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Future Possible Forest Fire Characteristics of Northern Saskatchewan

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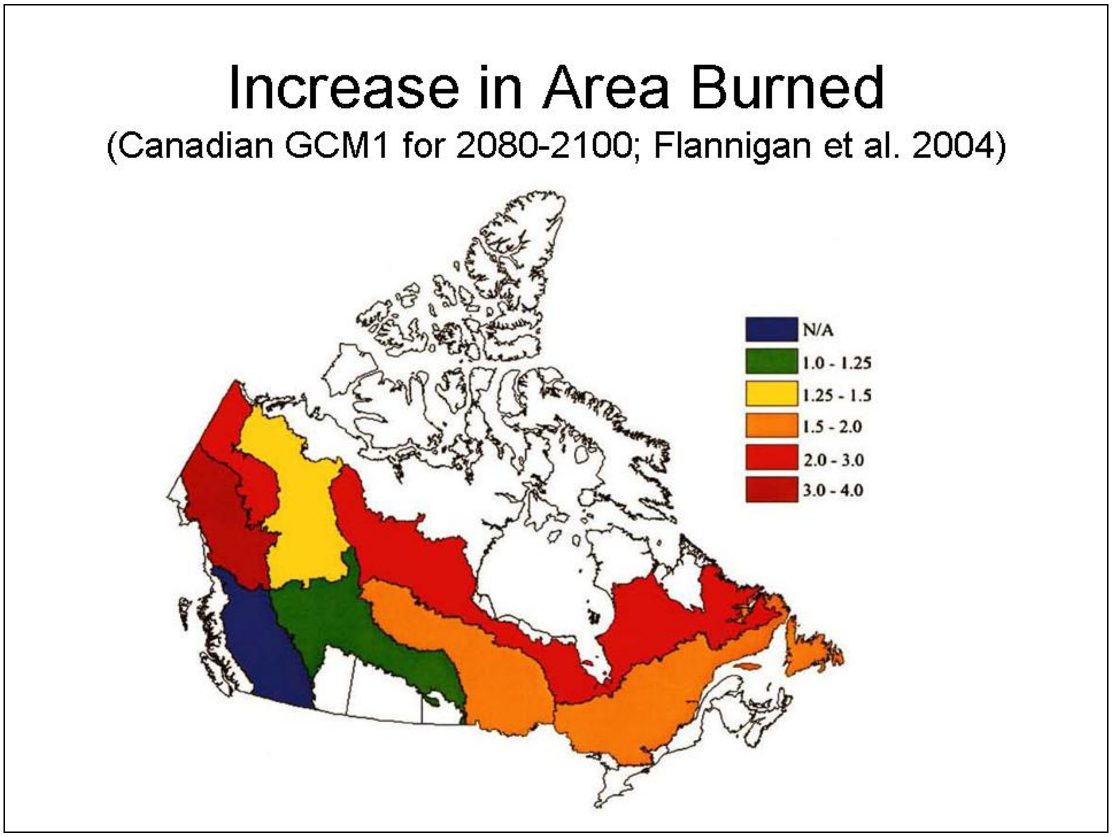
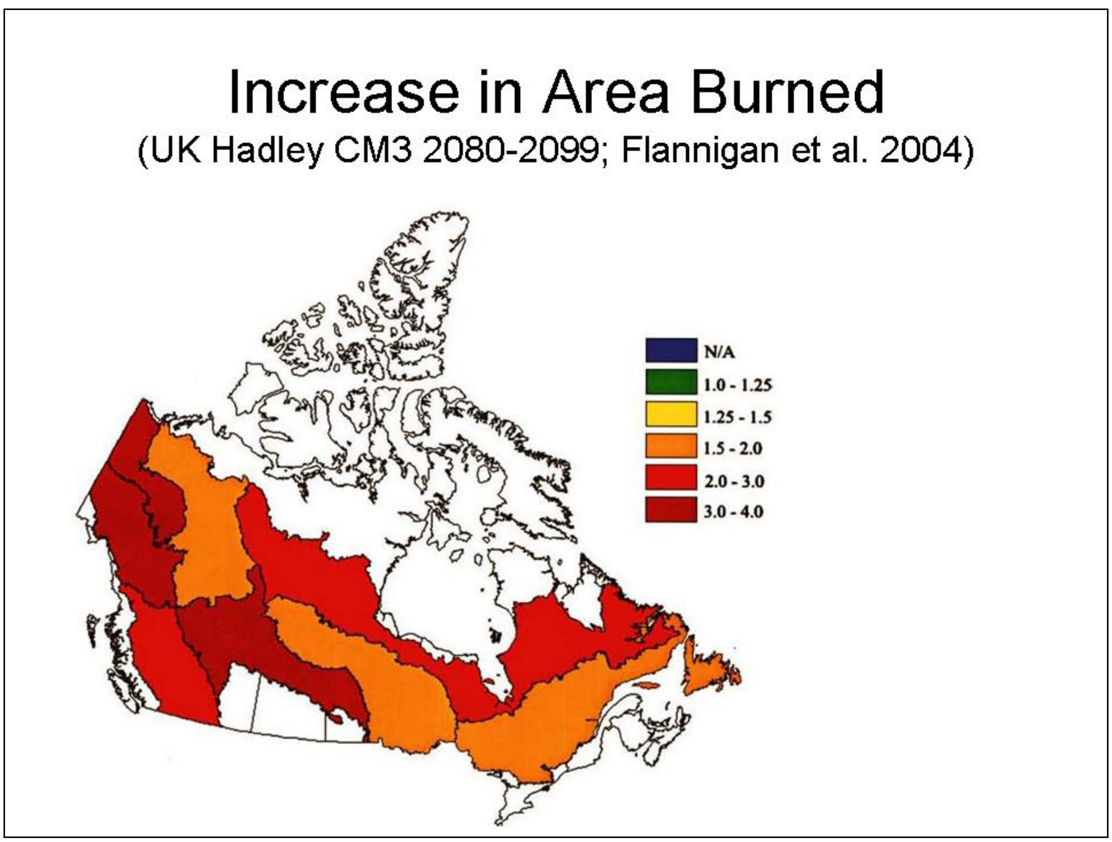

Increase in Area Burned
(Canadian GCM1 for 2080-2100; Flannigan et al. 2004)
N/A
1.0 - 1.25
1.25 - 1.5
1.5 - 2.0
2.0 - 3.0
3.0 - 4.0


Increase in Area Burned
(UK Hadley CM3 2080-2099; Flannigan et al. 2004)
N/A
1.0 - 1.25
1.25 - 1.5
1.5 - 2.0
2.0 - 3.0
3.0 - 4.0

Other Changing Factors Affecting Fire Include:

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- Increasing forest fire season length
- Changes in ignition (lightning and human activity)
- Changes in vegetation
- Changes in fire management
- And others

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Discussion?

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- Forest fire area, intensity, and season length will likely increase
- Spring wind speeds may increase
- Risk of fire and smoke damage will increase
- How will changing vegetation patterns affect future fires?
- How will risk to communities change?
- What are the implications for adaptive management?

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