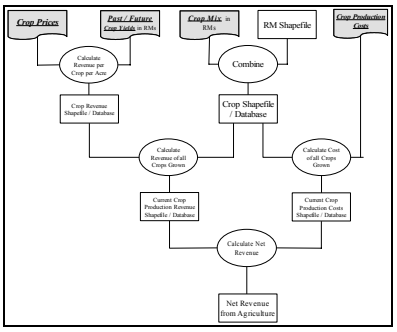
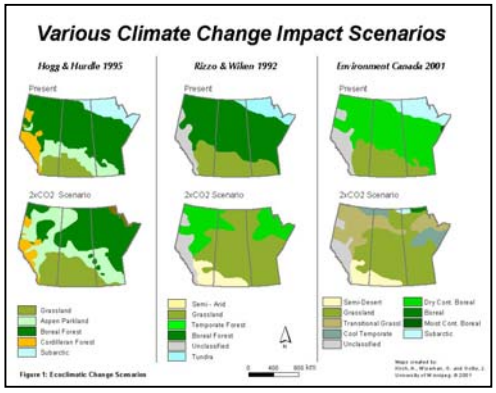
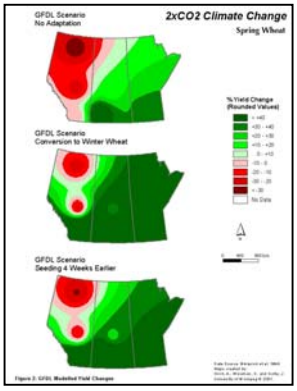
Socio-Economic Vulnerability of Prairie Communities to Climate Change

PARC Project No. 48







Final Report
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Executive Summary

Climate change is a phenomenon that is receiving increasing worldwide attention. While substantial research has been carried out on the potential effects of climate change in the Canadian Prairies at the regional, provincial, and individual farm levels, no studies have evaluated the socio-economic impacts of these changes at the community level. In addition, despite the increase in media attention, many people at the community level are still uninformed and confused about the potential biophysical and socio-economic impacts of climate change. The research presented in this report assessed the potential impacts of climate change on agriculture and forestry, and evaluated the detailed impacts on six rural municipalities in the Canadian prairies. The research project was designed as an evolutionary model, allowing for progressive improvements in functionality and sophistication. An initial model in the form of a software tool was developed and established: the Socio-Economic Analysis (SEA) model. The model is designed to examine the socio-economic impacts of climate change on agriculture and forestry in prairie communities and to aid these communities in determining the economic impacts of various adaptation strategies. It is flexible and interactive and can accommodate various standard or user-defined scenarios. The base data used in the SEA model includes biophysical data published by various authors, as well as economic and socio-economic data from various government agencies. The output from various iterations of the SEA model shows that climate change impacts on agriculture mostly depend on the chosen scenario, while all forestry scenarios agree that grassland and other vegetation types will extent northwards, thereby reducing the amount of boreal forest in the three Prairie provinces.

The main output from this research is an easy-to-use, transparent software model with the capabilities to analyse and display climate change impacts for individual Prairie communities. The individual objectives achieved in this study included:

- Development of a Socio-Economic Analysis (SEA) software program which examines the economic impacts of climate change on agriculture and forestry in the three prairie provinces at the rural municipality level and provides guidance in terms of the economic impacts of various adaptation strategies;

- Extensive consultations with partner Prairie communities in order to identify their needs for a climate change tool, such as the Socio-Economic Analysis (SEA) model, and the development of an extensive network of community partners for further model development;
- A thorough review of existing vulnerability and climate change models;
- Identification of socio-economic activities vulnerable to climate change;
- A determination of the most relevant and accessible socio-economic measures for use in the SEA;
- Collection of existing data on biophysical vulnerability to climate change in the Canadian Prairies;
- Assembly of relevant socio-economic data on a community level.

The modelling team hosted and attended workshops and meetings with RM representatives in order to identify the needs of the users. A literature review was carried out on the issues of climate change, vulnerability and adaptability with special regard to the Canadian Prairies. Socio-economic measures suitable for use in model development were reviewed. The review revealed that, geographically, agriculture and forestry were the most vulnerable activities in the Prairies. Published data on impacts of climate change on agriculture and forestry were collected into a database, as well as sector employment, which was the most readily accessible parameter to evaluate socio-economic impacts. The biophysical and socio-economic data was entered into Microsoft Excel and Access databases. The SEA model was designed based on the available data. The model completed to date is a core component that can be extended in the future. The next step will be to build other submodels, when the necessary funding is secured. The initial version of the model was developed for six test locations: in Manitoba the RMs of Stanley and Swan River; in Saskatchewan the RMs of Indian Head and North Battleford; and in Alberta the Counties of Stettler and Athabasca. The model was programmed using Visual Basic 6.0.

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1. Introduction

The potential impact of climate change on the Canadian Prairies will vary from region to region and among different economic sectors (Cohen et al. 1997; Watson et al. 1998). Our understanding of these potential impacts is limited by a number of critical uncertainties, including those inherent in economic and social models (Kates et al. 1985; Stabler et al. 1988). These uncertainties limit our ability to identify the full impacts of prescriptive adaptation measures (Watson et al. 1998). In almost all cases, the effects of climate change have been examined either from the perspective of their impact on specific sectors of the economy (Wheaton et al. 1992), or on a regional basis (Stabler et al. 1988; Mintzer 1993). However, research into the socio-economic impacts of climate change on individual Prairie communities have not been analyzed. This represents an important gap in the scale of spatial coverage.

In order to determine the potential effects of climate change on the social and economic fabric of a region, and to develop effective adaptation strategies, quantitative measures of both the degree of vulnerability as well as adaptability of a region, must be developed. This is a necessary first step for developing policies aimed at mitigating the social and economic dislocations that may result.

This study was designed specifically to address the vulnerability and adaptability of Prairie communities to climate change by means of a comprehensive model with standard and widely applicable data requirements.

2. Climate Change in the Canadian Prairies

Climate Change is a phenomenon that has been gaining more and more attention over the past decades. As a result, a large number of studies on the impacts of climate change have been conducted. This section reviews the available literature pertaining to the objectives of this project. Research has been carried out worldwide, however the following discussion is restricted to studies related to the Canadian Prairies.

The present climates of the 3 Prairie provinces are characteristically dry-continental, and range from cold-temperate in the south-west to sub-arctic along the shore of Hudson Bay. Gullet and Skinner (1992, in Herrington et al. 1997) divide the area into 2 main regions, the Prairie region with an average precipitation of 300-500mm, and the North-Western forest region, with 400 to 550mm average precipitation. Past climatic fluctuations can be classified into 3 phases over the past 100 years: a warming trend from the 1890s until the 1940s, a cooling trend from the 1940s to the 1970s and a warming trend from the 1980s until present (Herrington et al. 1997).

The impacts of climatic change are manifold. It affects the biophysical settings of individual areas and can result in a shift of existing biophysical zones (Parry and Carter 1988; Wheaton et al. 1987). In addition to focussing on shifting climate and biophysical zones, climate change impact can be assessed in terms of risk within biophysical zones or in terms of vulnerability at the spatial, economical or social margins (Parry and Carter 1988; Arthur et al. 1987).

Climate change trends have been modelled using various Global Circulation Models (GCMs). Model results used in publications pertaining to this study originated from the Geophysical Fluid Dynamics Laboratory (GFDL) Model, developed at Princeton University, the GISS model, developed by the Goddard Institute of Space Studies (NASA), the United Kingdom Meteorological Office Model (UKMO) and the Canadian Climate Centre General Circulation Model (CCC GCM) of Environment Canada. The models assessed the effect of twice the amount of CO_2 in the atmosphere, as compared to pre-industrial standards.

Wheaton et al. (1987) and Brklacich et al. (1994) employed GISS and GFDL, Rizzo and Wiken GISS. Hogg and Hurdle (1995) used CCC GCM results. Temperature increased considerably under all GCMs at all sites, with the largest increases appearing in winter (GISS) or spring (GFDL) (Wheaton et al. 1987; Brklacich et al. 1994a; Rizzo and Wiken 1992). Increments above normal were usually greater with the GISS- than the GFDL-based scenario, especially in winter (Wheaton et al. 1987). The temperature increase proposed by Wheaton et al. (1987) is 6-9° C, while Brklacich et al. (1994) proposed an increase of 3-6.5° C, and Rizzo and Wiken (1992) between 2 and 5° C. The discrepancy is related to the location and size of the study areas. For example Brklacich et al. (1994) restrict their analysis to the southern Canadian Prairies, while

Wheaton et al. (1987) extended their analysis to the Northwest Territories. The highest warming occurs at higher latitudes for all models (Rizzo and Wiken 1992). The CCC GCM results support the general trend of temperature increase. Hogg and Hurdle (1995) used an average increase of 4.2° C in mean daily maximum temperature and 4.9° C in mean daily minimum temperatures. Brklacich et al. (1994) used the United Kingdom Meteorological Office Model (UKMO) in addition to GISS and GFDL scenarios. UKMO scenario temperature results were higher than GISS and GFDL results, with the largest increases of 5-10° C (Brklacich et al. 1994a).

All GCMs predicted an increase in precipitation, which would offset the moisture stress resulting from the increased temperatures. However, historical periods of warmer weather did not coincide with increased precipitation. In order to accommodate for the uncertainty of elevated precipitation, most studies used two sets of GCMs: in the first run, temperature increases were calculated along with base-line precipitation, while in the second run, predicted (increased) precipitation was used.

2.1 Impacts of Climatic Change on Agriculture

Agriculture is vulnerable to climatic change due to its strong dependence on climatic conditions. Temperature stimulates plant growth through daily variations as well as through the length of the growing season. Increased temperature usually indicates higher growth rates although it may also increase evapotranspiration, water demand, and the risk of insect infestations (Herrington et al. 1997). Precipitation can be a limiting factor to plant growth due to either excess or lack of moisture. Droughts, especially severe ones such as those in the 1930s and 1980s, have the most obvious, drastic and immediate effects on agriculture (Herrington et al. 1997). Effects are usually exerted through changes in crop yields.

However, impacts on agriculture exceed the effects within agricultural zones due to the shifting of the boundaries of these zones. An increase of 1° C may move the boundary of a high-latitude cereal-growing region several hundred kilometres north under late 1980s technology and economic constraints (Parry and Carter 1988), assuming the soils are suitable.

Results from previous studies indicate the impact of climatic change on agriculture will vary regionally (Herrington et al. 1997; Arthur et al. 1987; Williams et al. 1988b; Shriner et al. 1998). The general trend indicates that agriculture in Manitoba will benefit from the predicted climatic changes, while it will suffer in Saskatchewan and Alberta (Arthur et al. 1987; Herrington et al. 1997). The following discusses analysis methods and results from previous studies that were of relevance to the SEA model development.

Brklacich et al. (1994a, 1994b) used GISS, GFDL and the United Kingdom Meteorological Office Model (UKMO) results with the CERES-Wheat model (after Godwin et al. 1989) to model spring wheat yields under alternative climate change scenarios (baseline data: 1951-1980 climate data, 1981-85 yield data) on 7 test locations throughout the Canadian Prairies. Adaptation strategies used in this study were earlier seeding and winter wheat conversion. The published results were incorporated into the SEA model. As explained in the "Data Input" section, the published yields were interpolated to obtain Prairie-wide yield change maps. The resulting maps are displayed in Appendix A (Figure 1 to 3). Figure 1 in Appendix A shows that a change in climate, as modelled by the GISS scenarios, would have a positive impact on spring wheat yields in most parts of the Prairies. Yields in southern Alberta and south-eastern Saskatchewan are expected to increase by more than 40%. The only area negatively affected by this scenario is the area around Ellerslie, Alberta. Adaptation through conversion to winter wheat was beneficial in all parts of the provinces. In areas where yields were modelled to increase without adaptive strategies, they increased further. Around Ellerslie, where GISS modelled yields decreased by 2%, they did not decrease as much with conversion to winter wheat. Adaptation through earlier seeding was beneficial in all areas except around Ellerslie where it would further decrease yields. However, caution must be exercised when interpreting the interpolated maps as they rely on very few data points.

Figure 2 in Appendix A displays the modelled effects of the GFDL climate change scenario on crop yields as published by Brklacich et al (1994). A GFDL climate would likely result in increased crop yields in the south-eastern part of the province, with the highest increases in south-western Saskatchewan. (The largest yield increase of 66% was modelled for Swift Current). Most of Alberta would be adversely affected, with the largest decrease in crop yields (-

35%) in the Fort Vermillion area. Earlier seeding and especially conversion to winter wheat would increase the positive effects and improve the negative effects.

The negative impacts of climate change as determined by the UKMO model (Brklacich et al. 1994) are displayed in Figure 3 in Appendix A. Yields were modelled to decrease in most parts of the Prairies except southern Alberta and south-western Saskatchewan, where yields increased due to modelled yield increases in the Lethbridge and Swift Current regions (+17% and +19% respectively) (Brklacich et al. 1994). Conversion to winter wheat seems to be a very successful adaptive strategy, as areas with negative yield changes under the UKMO scenario produced positive changes for winter wheat. Earlier seeding had some positive effects in the south-western part of the Prairies, but also had adverse effects in central and northern Alberta.

Bootsma et al. (1984) used a crop growth model to simulate the possible effects of various climatic scenarios on potential net biomass and dry matter yields. Using seven locations across Canada as test points, the model (developed by F.A.O. (1978) and adapted by Stewart (1981)) was applied to crops such as corn, forage, potato, cereal and oilseed crops. The baseline data ("normal climate") consisted of long-term climate normals for the 1941-70 period. Two types of temperature and precipitation change scenarios were used: fixed GSL (growing season length), in which GSL is similar to the present climate and will not change, and variable GSL, where 1941-70 normals were adjusted while all other climate input data remained constant at the normals level. For both scenarios, expected yields were estimated for 22 combinations of temperature (+3 to –3˚C from normal) and precipitation (60% to 140% of normal). Growing season averages and bulk crop phenological characteristics were employed, while various crop growth stages and management variations (such as fertilizer and pesticide applications) were omitted. The numeric results for an increase of average annual temperatures by 1° C were published and used in this study.

Figures 4 and 5 in Appendix A show the results published by Bootsma et al. (1984) of a temperature increase of 1° C (fixed and variable GSL) interpolated over the area of the three Prairie provinces. The impact of the climate change scenario using fixed GSL on cereal, oilseeds, potatoes, forage and corn were negative throughout the region. The modelling results using

variable GSL were not as negative as for fixed GSL. However, yields decreased for all crops, except for cereal, and all regions. Cereal yields increased in northern Alberta, northern Saskatchewan and south-eastern Saskatchewan. There also is some increase in north-western Manitoba, an area that is currently not suitable for agriculture.

It should be noted that scenario results were based on only six point locations spread over a very large area. The modelled locations are also placed in regions that are very different from each other. For example, the environmental factors that determine crop growth vary greatly between the Okanogan Valley and the Prairie fringe. Therefore, it is questionable whether interpolation is an appropriate technique to create data between areas so different. The modelled yields between these points solely rely on mathematical averaging, neglecting environmental factors such as soil, surface, microclimate, etc. Once again, there may be locations where crop yield changes vary greatly from the modelled results.

In the 1980s, Louise Arthur developed one of the first studies on the socio-economic impacts of climatic variation in the Prairies. This research is documented in two reports encompassing three project phases: Arthur et al. (1986) and Arthur et al. (1987). This research approached the issue using several models. GISS and GFDL scenarios were applied using baseline conditions (1961-1985) to model a major, Prairie-wide drought, such as the one in 1961. They also modelled various climate change scenarios (see below) using a soil moisture model and yield models for the major crops and seedbeds (Arthur et al. 1987). The results of the impact on yields were calculated for the entire area of the 3 Prairie provinces for all major crops. The biophysical results from the yield model were then used to assess the economic impact for each of the 3 Prairie provinces.

In the case of Manitoba, Arthur et al. (1986, 1987) used an existing Linear Programming (LP) Model. The assessment for the other provinces was based on an extrapolation from the provincial yield effects, the economic impacts as simulated in Manitoba, and provincial Input-Output Models established by Kulsheshtra and Yap (1985) (Arthur et al. 1987). The LP Model relied on livestock populations, prices and cost data. It operated using the assumption that changes in the farm sectors' demands for inputs and in farm households' demands for consumer goods and

services will stimulate the regional and provincial economy (Arthur et al. 1987). The results published by Arthur et al. (1987) indicated that yield losses for some crops could be offset. This could be achieved by increasing the amount of crops that were not, or positively, affected by the prognosed climatic change or by adjusting cropping patterns across regions (from moisture deficient areas to less moisture deficient areas). These results showed that climatic change is much more likely to affect individual farmers than the provincial sector as a whole (Arthur et al. 1987). Despite its being somewhat dated, the yield data published in Arthur (1986 and 1987) was of use to the SEA model as the analysis included a range of crops not found in more recent studies. Therefore these publications served as our sole source of information for some crops, such as hay. The socio-economic analysis itself was not applicable to the SEA, as it targeted the province as a whole, rather than communities.

Climate change scenarios were modelled using two different mathematical models ("A" and "B") (Arthur et al. 1986). The two different models were run twice: the first run modelling only temperature change (precipitation remains at present levels). This produced scenarios "AT" and "BT". In the second run, temperature and precipitation changes were modelled, resulting in scenarios "ATP" and "BTP" (Arthur et al. 1986). In addition, the impacts of a major, Prairie-wide drought, such as the one in 1961 were simulated (Arthur et al. 1986). Arthur (1986) provided change scenarios for spring wheat, barley, oats, canola, flax and hay in Manitoba that were used in the SEA model. The maps established for the SEA project are displayed in Figures 6 to 10 in Appendix A.

Drought resulted in yield decreases for all crops in all regions, up to a decrease of -56% (tame hay). Canola proved to be the most drought-resistant crop, followed by wheat. Variations for crop yields between regions were slightly larger than for the other scenarios and ranged between 6% and 38%. This indicates that some areas will suffer more from droughts than others. Hay was the crop with the least range and resulted in large yield decreases throughout the studied area. Barley, oats and flax showed the largest variations in yield changes by region.

Arthur et al. (1987) published impacts on spring wheat yields (on stubble) in Manitoba. Baseline yields were the averages between 1977 and 1984 (Arthur et al. 1987). Climate change

simulations were improved and called “A2” and “B2”. Again yield changes were modelled with and without precipitation change, resulting in scenarios “A2T” (Scenario A2, temperature change only), “B2T” (Scenario B2, temperature change only), “A2TP” (Scenario A2, temperature and precipitation change and “B2TP” (Scenario B2, temperature and precipitation change). The results of the impact on yields were calculated for the entire area of the 3 Prairie provinces for all major crops. However, only the results for selected crops and crop districts were published. The publication included a statement that the complete results are available on request. Louise Arthur, now Louise Wilson, was contacted, and informed us that the results of this study have been lost.

For Manitoba yield changes for spring wheat on stubble were published for scenarios “A2T”, “B2T”, “A2TP” and “B2TP”. Figures 11 to 15 in Appendix A show the results for Manitoba in map form. Crop yield changes varied mostly under scenario “A2T”, from a decrease of –11% to an increase of +24% depending on the CRD. All other scenarios resulted in yield increases of up to +15% (scenario “A2TP”).

Arthur et al. (1987) published impacts on spring wheat (on fallow) and barley (on stubble) yields Saskatchewan. The general methods were discussed earlier in this chapter. For spring wheat scenarios “AT”, “BT”, “A2T” and “B2T” were available. For Barley scenarios “A2T”, “B2T”, “A2TP” and “B2TP” were available.

Figures 15 to 20 in Appendix A show the results for Saskatchewan. Yields for all scenarios vary greatly over the studied region. In the case of spring wheat, data values ranged from –7% (scenarios “AT” and “BT”) to +17% (scenario “B2T”). The more recent models created more optimistic scenarios despite the fact that they are restricted to temperature increases without precipitation increases. Barley yields increased on average for scenarios “B2T”, “A2TP” and “B2TP”. However, all scenarios produced negative yield changes in some parts of Saskatchewan. The northern part of Saskatchewan seemed to benefit the least and suffer the most from the modelled climate changes.

Arthur et al. (1987) modelled impacts of doubled CO_2 concentrations in the atmosphere on average spring wheat yields (on stubble) and barley yields (on stubble) in Alberta. Spring wheat yield changes were modelled with and without precipitation change, based on the old and new versions of climate change scenarios "A" and "B". However, only the following scenario results were published: "AT" (Scenario A, temperature change only), "A2T" (Scenario A2, temperature change only), "BT" (Scenario B, temperature change only) and "B2T" (Scenario B2, temperature change only). For barley the following results were published: "A2T" (Scenario A2, temperature change only), "B2T" (Scenario B2, temperature change only), "A2TP" (Scenario "A2", temperature and precipitation change) and "B2TP" (Scenario "B2", temperature and precipitation change).

The average results are similar for all scenarios with averages between –3% and +3 (See Figure 21 to 24 in Appendix A). Data values range between –6% ("BT") and +13% ("B2T"). The southern part of Alberta profited from all change scenarios, while the northern part was less negatively affected (all scenarios except for "B2T").

Mooney (1990) and Mooney and Arthur (1990) studied the impacts of climate change on agriculture in Manitoba using a 1987 run of GISS. Using seven regions in Manitoba, the model estimated the percent change in crop yields (barley, oats, canola, sunflower, silage corn, grain corn, soybean, potato and wheat) under a doubled carbon dioxide scenario. Crop yields were estimated using a biological weather crop-yield model developed by the FAO (FAO 1978) and modified by Stewart (1983). Baseline climate data consisted of thirty-year (1951-1980) Canadian climate normals (temperature and precipitation) from several weather stations. The published results were used in this study.

Crop yields were estimated using a biological weather crop-yield model developed by the FAO (FAO 1978) that was modified by Stewart (1983). Baseline climate data consisted of thirty-year (1951-1980) Canadian climate normals. Baseline yields were 1951-1980, and 10 year averages for wheat, barley, oats, canola, sunflower, grain corn, silage corn, soybean and potatoes. Published were the percent change in crop yields under a doubled carbon dioxide scenario in

Manitoba averaged over seven regions. The yield changes were incorporated into the SEA database (See "Data Input" section).

Figure 25 in Appendix A shows that the results calculated by Mooney (1990) were generally pessimistic with yield decreases for all crops except for silage corn, which showed yield increases in some regions (and potatoes in a very few regions). Wheat, oats, canola and sunflower yields decreased between -31% and -32% with variations over the studied area between 2% and 5%. Flax yields did not change anywhere under the doubled CO_2 concentrations. Potato yields showed the largest data range (from –8% to +1%).

Williams et al. (1987) and Williams et al. (1988) used GISS climate change scenarios (baseline data from 1980, model adjusted in relation to 1961-1979 and 1980) to estimate impacts on thermal and moisture parameters, potential biomass productivity, soil erosion by wind, and spring wheat yields in Saskatchewan. Spatial resolution was based on crop districts and soil zones. Economic impacts were assessed on the farm and provincial level. The result of $2xCO_2$ and precipitation under current conditions was pessimistic, predicting generally drier climates with occasional drought years, resulting in doubled wind erosion potential (Williams et al. 1988). Spring wheat production was expected to decrease to 25% of current production, resulting in considerable decreases in the individual farm and provincial economy. Even when increased precipitation was considered, spring wheat yields were expected to decline, causing substantial economic losses (Williams et al. 1988). As in the case of Arthur, the yield data statistics by CRD were useful despite the fact that the data is dated. The socio-economic analysis was, again, unsuitable for our model.

The yield change results published by Williams et al. (1988) were incorporated into the SEA database as scenarios "GISST" and "GISSTP": GISS GCM model results using temperature change with and without precipitation change (See "Data Input").

The result of $2xCO_2$ and precipitation under current conditions was bleak, predicting generally drier climates with occasional drought years, resulting in doubled wind erosion potential (Williams et al. 1988). The crop yield changes from Williams et al. (1988) varied greatly by

scenario and by region. The GISS1 (Temperature and precipitation change) scenario resulted in yield changes from –21% to +91% and the GISS2 (Temperature change, constant precipitation) scenario resulted in yield changes from –32% to +66% (Figures 26 and 27 in Appendix A). Eastern Saskatchewan was negatively affected under both scenarios. All RMs in western Saskatchewan profited from yield increases under GISS1 (temperature and precipitation). Under the GISS2 (temperature change only) scenario some areas in western Saskatchewan were negatively affected.

The impact of climatic change on the viability of the wheat economy under a $2xCO_2$ climate in south-western Saskatchewan was examined by Delcourt and van Kooten (1995) using 7 sub-regions and the Canadian Climate Centre's second-generation general circulation model, CCCGCMII. The baseline data consisted of monthly precipitation and temperature data as well as annual spring wheat yields for the years spanning 1973 to 1990. Results of a multiple regression analysis of the effect of precipitation and temperature on spring wheat yields (on stubble and on fallow) were used to simulate changes in wheat yields due to climatic variation (Delcourt and van Kooten 1995). Year 2050 yields decreased with increased temperatures, especially with increased July temperatures, which reduced pollination and increased moisture loss. Increased annual precipitation was found to be beneficial (Delcourt and van Kooten 1995). As future temperature and precipitation patterns are expected to be very variable, crop production risk must be expected to increase (Delcourt and van Kooten 1995). Proposed adaptation strategies were summer fallow or irrigation (which induces high economic and social costs). Adaptation by means of tillage of fallow land resulted in land degradation while chemical fallow was found to be too expensive and pollution-prone (Delcourt and van Kooten 1995). Therefore the authors recommend a gradual withdrawal from grain agriculture in the study region (Delcourt and van Kooten 1995). Unfortunately the results could not be used in the preliminary model as the spatial extent was very limited.

Some of the published climate change scenarios, especially those assuming a drier climate, will require adaptive strategies in order to keep the agricultural sector viable. A common response to a lack of moisture is the use of irrigation. However, under the proposed climate scenarios, a general decrease in water availability is predicted. In the Prairies, where water is a limiting factor

in most regions under present conditions, this adaptation strategy may not be viable. Arthur et al. (1987) discussed this problem and chose not to use irrigation as an adaptation strategy in their study, given the low abundance of viable water supplies. Other adaptations to lower moisture regimes were offered through new drought-tolerant crops, the diversification into speciality crops (such as mustard seeds, dry peas or lentils), or the conversion to livestock production. The introduction of new crops is not assessed in the SEA model. Herrington et al. (1997) proposed that the seeding of spring wheat is an excellent adaptation strategy, as spring wheat will be positively affected by the predicted climates in the drier and moister part of the Prairies. However, other authors (e.g., Williams et al. 1988, Brklacich et al. 1994) recommend the seeding of winter wheat, which can take advantage of winter precipitation and whose winter survival rate will be higher due to warmer winters. Barley and canola are well adapted to the driest portions of the study area, while yields from winter wheat, oats and flax will decrease (Herrington et al. 1997). In more moist areas, the seeding of canola, barley and oats is expected to be preferable to summer fallow.

One of the proposed adaptations to climate change is the conversion of grain production to livestock production. Livestock production may benefit from reduced grain quality available at reduced grain prices (Wheaton and Wittrock 1992). Other advantages of livestock production may be its flexibility and its adaptability to various climates (Wheaton et al. 1992; Herrington et al. 1997). However, a limiting factor might be the demand for fresh water (Wheaton and Wittrock 1992). Longer-term adaptation could also include a shift to native species, such as buffalo and elk, or to exotic species such as emu (Herrington et al. 1997). Herrington et al. (1997) indicated the need for policies to adapt in order to allow for new techniques and products. Assessment will be more complex than that of the impact of standing agriculture, as the climatic impacts are less direct and easier to mitigate. In addition, there is less literature focussing on this aspect (Wheaton and Wittrock 1992).

As mentioned previously, the literature discussed in this section is not complete, as it is restricted to impact analysis in the three Prairie provinces. Studies in other regions have used various crop yield simulators whose outputs were used as inputs into I-O models or linear programming models to evaluate the effects of climate change on the farm, provincial or national level (e.g.

Kaiser et al., 1993). As none of the reviewed studies evaluated impacts at the RM level, the study team evaluated different of measures of vulnerability for use in the SEA model. The most suitable parameter for evaluation of climate change impacts due to changes in agriculture was the producer surplus, which could be used to determine RM net revenues from different crops with and without the effects of climate change (See "Methods").

2.2 Impact of Climatic Change on Forestry

Responses of forest ecosystems to climate change occur fairly slowly. For example, in the case of more favourable growth conditions, the adaptation process may take more than one generation of trees (Wheaton et al. 1987). The effects of climatic change are twofold: changes within forest ecosystems and changes in the location of forest ecosystem boundaries. Changes within the ecosystem will be the sum of the effects on individual species. Each species will react differently to changes in temperature, precipitation and CO_2 concentration with respect to growth rates, seedling mortality and health (Herrington et al. 1997; Rothman and Herbert 1997; Wheaton et al. 1987). The impact of climate change will also occur indirectly through changes in the frequency of forest fires, disease outbreaks, or insect infestations (Herrington et al. 1997; Rothman and Herbert 1997; Wheaton et al. 1987). The general consensus is that the probability of forest fires and pest infestations is most likely to increase due to increased temperatures (Wheaton et al. 1987). The present ecosystem boundaries are expected to shift north as a result of the above changes within forest ecosystems (Herrington et al. 1997; Wheaton et al. 1987). In general, forest growth is expected to be positively affected in Alberta and Saskatchewan and negatively in Manitoba (Herrington et al. 1997).

Hogg and Hurdle (1995) examined the effects of $2xCO_2$ concentration on the southern boreal forest based on changes in annual precipitation and temperature. The CCC General Circulation model scenario was applied to 1951-1980 climate normals of 254 weather stations in Western Canada. The results of a doubling of CO_2 concentrations in the atmosphere would include a 4.2° C increase in mean daily maximum temperature, a 4.9° C increase in daily minimum temperature and an 11% increase in precipitation (Hogg and Hurdle, 1995). Currently the southern boreal forest is restricted to areas where annual precipitation exceeds potential evapotransporation

(Hogg and Hurdle 1995). In drier areas where precipitation does not exceed evapotranspiration, aspen parkland is found (Hogg and Hurdle 1995). The results showed that climate changes as modelled under the CCCGCM would result in permanent losses of forest cover, as the 11% increase in precipitation would not balance the modelled increase in temperature (Hogg and Hurdle 1995). "Losses in productivity of aspen and other commercial species in the boreal forest would be greatly reduced" (Hogg and Hurdle 1995). The shifts in forest boundaries modelled by Hogg and Hurdle (1995) were made available to this study and imported into ArcView GIS and included in the SEA model (Figure 1 in Appendix B).

Rizzo and Wiken (1992) adjusted and applied the output from a 1981 2xCO_2 GISS GCM run to a climatically-based ecological classification based on the Holdridge life-zone model (Holdridge 1947 in Rizzo and Wiken 1992). The Ecoclimatic Provinces of Canada classification at a scale of 1:5 million, were used to generate global ecosystem-type maps (Rizzo and Wiken 1992). GCM outputs were applied to 1951-1980 climate normals of 8000 meteorological stations. The climate change results were classified using applied temperature-related functions of the Holdridge model to produce world vegetation maps under current and future climate conditions (Rizzo and Wiken 1992). The doubling of CO_2 suggested major changes to Canada's Ecosystems (Rizzo and Wiken 1992). The aerial extent of existing zones changed and new zones needed to be defined (Rizzo and Wiken 1992). The result most pertinent to this study was the large increase of the Grassland Ecoclimatic Province throughout mid-Canada. These data were imported into ArcView GIS and included in the SEA model (Figure 1 in Appendix B).

A third scenario included in the SEA model incorporated the results of an impact analysis published by Environment Canada (2001). The investigation was based on an ecological framework that expresses regional climate through the development of vegetation and soils. The impact of doubled CO_2 concentrations in the atmosphere was used to display how the location and quantity of existing ecosystems might change (Environment Canada 2001). Again, the published data were imported into ArcView GIS and included in the SEA model (Figure 1 in Appendix B).

Wheaton et al. (1987) employed different GISS and GFDL scenarios to assess the impact of climatic changes on various productivity parameters, namely growing degree days (GDD), index of agricultural potential (CA) and mean annual increment (MAI). They found all scenarios included an increase in growing degree-days (above 5° C) (Wheaton et al. 1987). This increase would result in a northward shift in current forest boundaries (GISS: 400-980 km; GFDL: 200-900 km), as they are a function of growing degree isolines: 600 GDD and 1,300GDD isolines coincide with the northern and southern boundary of the boreal forest respectively (Kauppi and Posch 1985 in Wheaton et al. 1987).

In addition to biophysical impacts of climate change, Wheaton et al. (1987) assessed potential impacts of improved forest growth in the Canadian boreal forest on the Canadian forestry sector. The assessment considered that Canada exports more than 50% of its timber to the United States (U.S. timber production was assumed to be unaffected by climate change). They concluded that an increase in the supply of Canada's timber due to climatic change causes the free trade price to drop and the quantity of traded timber to increase. The result was a net gain to the U.S. although it was not clear whether Canada would experience a net gain or loss from a change in the climatic conditions (Wheaton et al. 1987). Elasticity of supply and demand and the extent of the supply shift would need to be known in order to evaluate whether Canada's forestry sector would experience economic gains or losses through climate change. A further aspect of uncertainty is added because subsidies, taxes and restraints distort the economics of international trade (Wheaton et al. 1987).

Assessing the socio-economic impacts on a regional or communal basis is even more uncertain than the impacts on a national basis (Rothman and Herbert 1997). The communal effects will be in the form of harvest levels, recreational values, employment, government revenues and expenditures, community stability, etc. (Rothman and Herbert 1997). However, some of these effects depend on factors such as land use designation policies, fire and insect control policies, technology development and utilization, trade policies, and many other concurrent developments, not always directly related to climate. Therefore, "translating the biophysical changes on forests into socio-economic impacts is at its best a series of educated guesses" (Rothman and Herbert 1997, p. 228). The key impacts will be in the form of changes in fire and

pest suppression costs, annual allowable cut, optimal rotation, concurrent developments, stumpage rates, technology trends and labour force utilization (Rothman and Herbert 1997). Previous studies have examined how changes in allowable cuts may impact key economic indicators such as employment, earnings and government revenues. However, "applying current ratios of economic impacts per unit harvest to future levels of harvest can be quite misleading, given other changes in the industry" (Rothman and Herbert 1997, p. 239). While it is unclear what the exact effect of a changing climate on the communities will be, the impact is expected to be significant (Rothman and Herbert 1997).

Based on this loose and uncertain relationship between forest health and growth rates and communal health, as well as project resource and time constraints, impact analysis within the SEA model was limited to an assessment of shifting ecological boundaries and community dependency based on employment. Most forested land is crown land and the revenue produced (including stumpage fees) is reaped by the provincial government. Therefore, the only real benefit from forestry tied to a RM is employment. Woodlots, a type of private forestry based on the value of the property, are small in number and size in Manitoba, although significant in other provinces such as Alberta. Their impact on a RM is usually minimal. The fact that many woodlot owners/operators must assume a second job to supplement their income is proof of this.

3. Measures of Socio-Economic Impact

A range of socio-economic measures were evaluated for use in the SEA model. A brief discussion of these measures is merited.

Input-Output (I-O) models have been used to assess socio-economic impacts on the agricultural sector in various studies (e.g., Arthur et al. 1986, Arthur et al. 1987, Kaiser et al. 1993). I-O models exist for some of the Prairie provinces. However, the use of I-O models was not feasible for the SEA model, as it is targeted at the community rather than the provincial or regional level. Necessary adjustments to account for the more detailed scale would require community-specific analysis, which was beyond the scope of this study.

Use of changes in land and property values due to climate change was a second approach assessed for use in the SEA model. The value of land that is suitable for cultivation may be affected by such physical characteristics as drainage, topography, erosion, salinity and stoniness – some of which are influenced by climate. Use of property values would be an asset in socio-economic vulnerability assessment as they determine municipal income (personal communication with Dennis DePape, socio-economist with Intergroup, Dec. 2000). However, market values of arable farmlands are also influenced by supply, demand, proximity to the market, and the ability to grow specialized crops, which can outweigh the biophysical characteristics (personal communication with Jane Inouye, Manitoba Intergovernmental Affairs, Assessment Branch). This consideration made this measure unfeasible for the SEA model.

A number of measures are designed to estimate the impacts of shocks on the welfare of a community compared to the welfare of larger economic units, such as the province or the nation. Shocks can be exerted in the form of supply shocks (e.g., change in yield/productivity) or demand shocks (which usually result in a change in world prices for products). If welfare impacts to a community largely exceed the impacts on the larger unit, then the distribution of wealth will be altered (Fletcher et al. 1991). When modelling the impacts of shocks on community welfare, the process "should represent the actual conditions in the community as closely as possible, including inter-sectoral linkages" (Fletcher et al. 1991). The closest approximate is the use of a General Equilibrium Model (GE). However, GE models depend on a variety of assumptions and generalizations in order to be practical under realistic data and time constraints (Fletcher et al. 1991). Use of a GE in the framework of the SEA model would have resulted in an excessive number of assumptions and the requirement for complex algorithms. This was found to be inappropriate, as the goal of this project was to develop a user-friendly, transparent model.

A much more tractable approach is the use of sector dependency measures, such as the location quotient. Location quotients compare sector employment in a community to sector employment in the larger unit, such as the province or the nation. The higher the location quotient, the higher employment concentration in one sector, compared to the national level (Fletcher et al. 1991). This measure would have been appropriate to employ in the SEA based on simplicity and data

availability. However, they measure targets at the wrong output and the underlying assumptions in terms of market-wide consumption and production and sector aggregation were not appropriate for this study.

The Canadian Model Forest has produced a variety of studies that examined forest dependency of RMs in Canada. Reliance was based upon a variety of goods, such as lumber, pulp and paper, and logging (Canadian Model Forest 2000). The results of these studies show that a detailed socio-economic analysis of the community is warranted in order to produce relevant data that can be used in complex socio-economic analyses. These data would require detailed studies of the socio-economic systems within RMs, including interviews and questionnaires.

The simplest approach to evaluate sector dependency in a RM is to compare the number of people employed in a certain sector to the total labour force. While this approach has a number of limitations, it gives the SEA a means to assess sector dependency. This simple approach was taken due to the limitations of data availability and time/resource constraints. The underlying assumption is, of course, that people are not mobile: they work within the RM where they live.

4. Model Requirements Identified by RM/Community Representatives

One of the key requirements for success in developing relevant adaptation strategies is to engage municipalities in the research early and often. The participation of decision-makers and policymakers to ensure the benefits of this project are effectively utilized, cannot be overstated (Offutt 1993; Bernabo et al. 1993; MacIver 1998). The following activities helped the research team to gain an understanding of what is demanded of a climate change tool, such as the SEA.

1. *An all-day workshop entitled "Community Climate Change Workshop - Climate Change in Manitoba: the Impact on Communities" was hosted by the University of Winnipeg on August 28, 2000.*

This workshop was meant to function as a two-way street between researchers and municipal officials with the common objective of determining and discussing the impact of climate change on Prairie communities. Within this framework, the following objectives were established: 1) to understand the aspects of climate change most important to municipalities and municipal

officials; 2) to enlist the advice of municipal officials in designing tools that will help them understand the socio-economic impacts of climate change on their communities; and 3) to solicit the advice and views of municipal officials in developing strategies that will allow their communities to minimize the impacts, or maximize the benefits, arising from climate change. The workshop was attended by researchers from the University of Winnipeg (Geography Department, the Institute of Urban Studies), the Saskatchewan Research Council, Alberta Environmental Protection, AAFC, and the Prairie Farm Rehabilitation Administration (PFRA). The workshop was a success due to the attendance of representatives from local government agencies (Highways and Government Services, Intergovernmental Affairs, Provincial Planning Services Branch, Clean Environment Commission) as well as from local communities (City of Winnipeg - Daniel McIntyre Ward, Town of Morden, Town of Winkler, City of Selkirk, the RMs of Taché, East St. Paul and Springfield) (see Appendix C). The agenda (see Appendix D) consisted of a set of information sessions hosted by some of the researchers in the morning and a round table discussion between researchers and community representatives in the afternoon. While some of the information communicated by the researchers during the information session is included in subsequent sections and in the report produced by the PARC Community Workshop project team, key results from the round table discussion are provided here.

Aspects of climate important to municipalities and municipal officials:

- Weather is more important to farmers than climate
- Probability ratios: is a 1 in 50-year event to be expected more frequently?
- Temperature (spring temperatures at least as important as length of “winter” to get crops started)
- Precipitation (droughts, severity of events, such as flooding through heavy summer rainfalls, long-term trends)
- Natural disasters (hail, tornado, fire)
- Freeze-thaw cycles
- Windstorms

Designing **tools** that would be useful to help municipal officials understand the socio-economic impacts of climate change:

Weather forecasting tools:

- Drought forecasting: should high spring rainfall be retained?
- Need to treat concept of uncertainty: will *this year* be wet or dry?
- Predictions need to be tagged with confidence level, so farmer can decide, e.g., this year: El Nino year, so we have low confidence in what we predict
- Need to know what to design for, what are future trends, will frequency of 1:10 or a 1:20 events change? How will future climate and patterns affect the community?
- Risk management
  - Identify activities that are exposed to changing climate / weather patterns, then reduce risk of impact
  - Advise farmers what to do: if low summer precipitation is predicted, leaving fields in fallow may be an appropriate adaptation strategy, but farmer has to take chances otherwise might never get a crop
  - Degree to which communities depend on transportation and potential impacts from climate change
  - Answer questions such as "Would diversification through livestock production be a good idea?"

Strategies which will allow communities to minimise the impacts, or maximise the benefits, arising from climate change:

- Infrastructure adaptation:
  - Are present ditches sufficient?
  - Field drainage: Should drainage capacity be increased or decreased: if future trend to wetter climate: increase; if trend to drier climate: retain as much water as possible
  - Building resilience, building capacity – basement flooding

- Stormwater management plan / design
- Power shortages during windstorms

- Other community expenses due to:
  - Deterioration of roads - Pavement break-up due to greater frequency of freeze-thaw cycles
  - Salt/sand application
  - Snow removal, winter cleanup
  - Mowing roadsides
  - Pest control

- Community income losses
  - Outdoor pool
  - Ice rink – when to make ice?

Other findings:

- Farm families rely on insurance since there is an estimated 1:4 loss ratio (1 bad year in 4 good years) – this practise is not satisfactory to families
- Need for education on climate change
  - General education needed
  - Identify what information to distribute and to whom
  - How to prepare?
  - Education in sensible way: do not stress one point too strongly
  - How can effects be buffered?
  - Information needs to be designed for people in the street – probabilities need to be explained
- Business losses because infrastructure breaks down must be considered
- Adaptation depends on
  - How much money is available in community
  - What neighbouring communities have done (competition)

- Some regulations have adapted to climate (change)
  - Sump pump bylaw was enforced. Resulting problem: how to deal with groundwater that is now surface runoff? – new costs created by erosion!
  - Building code – insulation
- Cost of adaptation
  - Who has to bear it? – Federal financial incentives exist

While most of the identified needs require detailed community studies, the need for education on climate change became apparent during the discussions. RM citizens were uncertain and confused about the trend and extent of change that is to be expected. While some representatives showed a good understanding of how they could adapt to various scenarios, especially with regard to infrastructure, others were more uncertain about potential impacts and adaptation strategies, especially in the agricultural sector.

2. Meeting with the council members from the rural municipality of Stanley, Winnipeg, January 23, 2001.

The purpose of this meeting was to introduce the initial SEA model design to RM representatives and get feedback on its usefulness and needs. A survey was handed out which asked for feedback on how to improve the usefulness of the SEA model (See Appendix E). The collective response contained of several suggestions for our model: 1) the display of corn heat units, growing degree days, agricultural potential and frost-free days to the user; 2) the inclusion of annual precipitation levels, maximum temperatures, evaporation and soil moisture; and 3) the inclusion of the above parameters in monthly averages, with special emphasis on the spring, summer and fall months. Another suggestion included determining potential new crops for a given scenario. In addition, the council members posed two questions: Will they be more susceptible to extreme weather events and will they be more frequent and severe? Will there be a population shift to or from their area if warming occurs as predicted?

5. Methods

This study was designed as a 10-month work plan (June 1, 2000 - March 31, 2001). The SEA model relies on the partially integrated approach described by Parry and Carter (1988) where GCM output is used as an input to biophysical models, whose outputs are used in subsequent economic models (Parry and Carter 1988). The SEA model does not include active biophysical simulation capacities. Rather, it integrates crop simulation outputs from previous studies with a simple economic analysis. Thus a wide range of change scenarios could be used.

The SEA model largely benefits from the use of a GIS, which provided a means of spatial and non-spatial database management. The GIS also provided a platform for visual display of model results. Software used for the spatial and non-spatial data management were ESRI's ArcView (3.2) and ArcInfo (8.0) software, Microsoft Access 97 and Microsoft Excel 97. The model was programmed using Visual Basic 6.0.

An interactive submodule within the initial SEA model, which allows extensive user interaction, was developed for six test locations: in Manitoba, the RMs of Stanley and Swan River; in Saskatchewan, the RMs of Indian Head and North Battleford; and in Alberta, the Counties of Stettler and Athabasca.

We are planning further model development to eventually encompass all major economic activities present in the Prairies, but for the reasons discussed above, the current model is restricted to agriculture and forestry. Given the choice of sectors, the current model encompasses 2 submodels: an Agriculture Submodel, and a Forestry Submodel (see Figure 1). Economic sectors not included in the preliminary model will be easy to incorporate in the future by adding additional submodels.

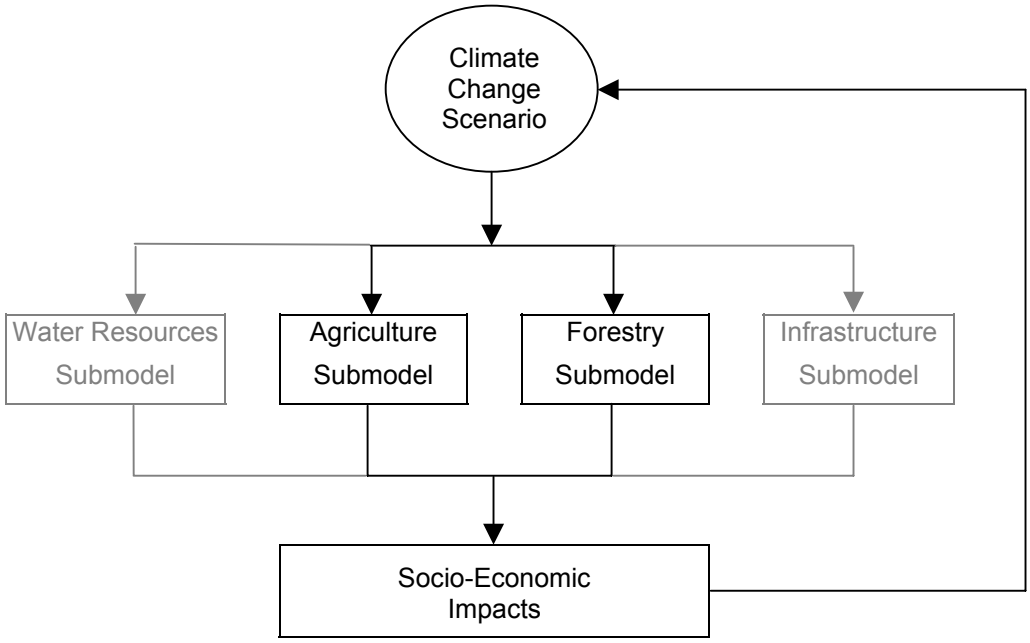

Figure 1: The SEA Model – Solid Submodels have been Realized, Gray-shaded Submodels will be Realized in the Future.

5.1 Evaluation of Socio-economic impacts

The scope of this study was to develop a transparent model that can be used throughout the Prairies with readily available and consistent data. This, and the scale of the approach, limited the choice of socio-economic measures but provided a number of benefits for widespread model adoption and use. As discussed above, a detailed evaluation of socio-economic impacts on a community basis would require a detailed study of the socio-economic fabric of and imports and exports in the community. However, it was felt that given the complete lack of community-level socio-economic models, the SEA model fills a crucial gap in the field of climate change.

The measure that was the most feasible for this study was a sectoral employment quotient for each community. Sector dependency can be assessed by dividing the labour force of each

industry by the total labour force of all industries. The result is percentages that reflect the economic dependency of the RM based on income sources. The effect of climatic change can then be interpreted given this economic make-up of the community. To date, the evaluation of socio-economic impacts is not fully included in the SEA. This is due to the fact that the study team was not able to obtain the correct employment data for all three provinces within the given time frame[1].

5.2 Evaluation of Impacts on Agriculture

Impacts of climate change on the agriculture sector in a RM were evaluated by calculating changes in producer surplus from various crops. Net revenue from agriculture in a RM was based on crop production costs, crop prices, acreage and crop yields. Yield changes published by various authors simulated changes in revenue from agriculture. The following section details the assessment of the net revenue changes in the SEA model.

Net Revenue for RM *i* from crop *j* before climate change (bNR_{ji}) is calculated using the following equation:

$$bNR_{ji} = (p_{jz} * y_{ji} * a_{ji}) - (c_{jz} * a_{ji})$$

Where:
p_{jz} = average price for crop *j* in province *z* [dollars / tonne]
y_{ji} = historic yield of crop *j* in RM *i* [tonnes / acre]
c_{jz} = average production cost for crop *j* in province *z* [dollars / acre]
a_{ji} = historic average acreage under crop *j* in RM *i* [acres]

Net Revenue for RM *i* from crop *j* after climate change (aNR_{ji}) is calculated using the following equation:

$$aNR_{ji} = (y_{ji} * r_{jis} + y_{ji}) * p_{jz} * a_{ji}) - (c_{jz} * a_{ji})$$

[1] Employment data for the RMs in Saskatchewan and Alberta was requested from Statistics Canada, but only data for Economic Regions was provided. The finalization of the socio-economic assessment is pending until the correct data is made available.

Where:
p_{jz} = average price for crop *j* in province *z* [dollars / tonne]
y_{ji} = historic yield of crop *j* in RM *i* [tonnes / acre]
r_{jis} = change in yield for crop *j* in RM *i* under scenario *s* [%]
c_{jz} = average production cost for crop *j* in province *z* [dollars / acre]
a_{ji} = historic average acreage under crop *j* in RM *i* [acres]

The net revenue effect of Climate Change (EC_{ji}) on the RM income from agriculture was then assessed by calculating the difference in net revenue before and after climate change:

$$EC_{ji} = aNR_{ji} - bNR_{ji}$$

The above steps calculated the effects of climate change scenarios for individual crops. In order to assess the combined effect of each scenario on all crops, the net revenues before and after climate change and the revenue effects were summed for all assessed crops in the RM.

5.3 Evaluation of Impacts on Forestry

As detailed earlier, the assessment of socio-economic impacts of changes in forestry due to climate change contains a number of uncertainties. The effects are indirect in nature and affected by global supply and demand elasticities. For the SEA development, the vulnerability analysis largely relied on the location of individual communities in relation to existing and modelled ecozone boundaries, as published by various authors.

In order to evaluate the locations, all published climate change scenario maps were imported into the GIS. Each historic and scenario map was overlaid with the RM maps in order to carry out the following analysis: First it was established in which ecozone the RM is currently located. Then it was established in which modelled ecozone the RM is located after climate change. The results in map format show whether or not the ecosystem around the RM is subject to change and how the distance between the RM and the forest boundaries will change.

6. Operational Aspects of the Model

The SEA model will eventually have 2 versions: an interactive and an automated version. When entering into the software program, the user will be given the option to use either. However, the initial SEA model is restricted to an interactive mode.

After start-up, the SEA presents the user with an interface in which the submodel, the RM and the climate change scenario are chosen. The initial SEA includes an agriculture and a forestry submodel. Once the choices are made, the model will move either into the agriculture or the forestry submodel. Operation of the submodels is described in the following section. Upon leaving either submodel the user is made aware of whether or not the other submodel has been used. Both submodels give the option to view the final results, whether or not both submodels have been used.

6.1 The Agriculture Submodel

When starting, the agriculture submodel automatically displays the default input data from the database (historic crop yields, crop mix, crop yield changes, crop production costs and crop prices) that can be used to calculate net revenue from each crop. The user also has the choice to change each data value and calculate the net revenues based on these user-identified data.

For example, if wheat yields are predicted to increase and canola yields predicted to decrease under a changed climate, it is financially viable to assign more acreage of land to wheat than to canola. The user can change acreage input in order to achieve the optimum crop mix based on net revenues. The user can also change crop prices and production costs to evaluate potential impacts of local and world market fluctuations. The RM decision-maker, may, for example, know that canola is of much higher local demand than wheat. Thus, the user can adjust the suggested crop mix in favour of canola and let the model evaluate the economic impact of this. The model also displays sector dependency in pie chart format and the default yield changes can be viewed in map format at the click of a button.

6.2 The Forestry Submodel

The Forestry Submodel is not as flexible and interactive as the Agriculture Submodel due to the different nature of this sector. The reaction of forests to climate change will occur at a much slower pace than agricultural crops and the effects will be much more indirect that those from agriculture, especially when considering that the SEA evaluates impacts on an RM basis.

This is reflected in the submodel by the fact that the user can only choose which climatic change scenario to use from the list. The model automatically informs the user in which ecozone the RM is currently located as well as whether and how this was modelled to change under the chosen CO_2 scenario. Maps can be viewed which show ecozone distribution before and after $2xCO_2$ climate change impacts have taken place. The model also displays economic sector dependency in pie chart format and the ecozone changes can be viewed in map format at the click of a button.

7. Data Used in the Model

A variety of data is used in the SEA model. However, as the model covers three provinces, data was not equally available at the appropriate scale in all places. Caution had to be exercised when comparing variables between provinces because of differing terminology. Where data could not be found, comparable figures were used. All economic data was adjusted for inflation. The list of data and its source is shown below.

7.1 Employment Data

The evaluation of socio-economic vulnerability will be based on sector dependency in terms of employment for each rural municipality or county as soon as the appropriate data is made available. Employment statistics from the 1996 Census of Population (Statistics Canada) were obtained for the RMs of Swan River and Stanley in Manitoba. Employment data from the RMs of Indian Head and North Battleford in Saskatchewan, and the counties of Stettler and Athabasca in Alberta is by Labour Force (15 years and over) estimates by industries, 1996 annual averages

per Economic Region (Statistics Canada 1996). (Note: Employment data by RM for Saskatchewan and Alberta is absent, but will be incorporated when available.)

In the case of Manitoba, all employment statistics were readily available by rural municipality from Manitoba Intergovernmental Affairs (2001). (The original source is from the 1996 Census of Population from Statistics Canada.) The employment data was provided using the following categories: labour force by industry, total labour force (15 years and over) by industry divisions, dominant industry division, all industries, agricultural and related services, fishing and trapping industries, logging and forestry industries, mining (including milling) quarrying and oil well industries, manufacturing industries, construction industries, and transportation and storage. In the Manitoba examples, the dominant industry was given, as was the percent base for industry activities or services, which represented the percent of employment in a particular activity in relation to the overall employment in all industries.

In the case of the RMs/counties of Saskatchewan and Alberta, the employment statistics were provided for Economic Regions rather than RMs. Figure 1 in Appendix F displays the employment statistics available for the 6 test RMs. In Saskatchewan and Alberta, the employment statistics were subdivided into categories and sub-categories. The categories were all industries, goods-producing sector, service-producing sector and unclassified. Under the goods-producing sector, the subcategories were agriculture, forestry/logging, fishing/hunting/trapping, mining/oil/gas extraction, utilities, construction, and manufacturing. Under the heading service-producing sector, the subcategories were trade, and transportation and warehousing.

7.2 Crop Price Data

The crop prices are one of the variables used in the model to determine net revenue from agricultural production in a particular RM. Crop prices vary from year to year as they greatly depend on world market elasticities in supply and demand. This makes crop price prediction extremely difficult and unreliable. Due to this, the SEA model is restricted to historic crop prices as published in the most recent provincial Agriculture Statistics Yearbooks (Manitoba

Agriculture and Food 1999, Saskatchewan Agriculture and Food 1999 and Alberta Agriculture, Food and Rural Development 1999). The values were averaged for the years from 1995-1999. The user can interactively change the crop price input to adjust for the inaccuracies generated by using historic averages.

In the case of Manitoba, provincial farm value prices (freight, handling and other marketing charges are deducted) or price per bushel (the total farm value divided by the amount of production in bushels) were averaged from 1995-1999 (Manitoba Agriculture and Food 1999). Where necessary, conversions from dollars per bushel to dollars per tonne were made (Manitoba Agriculture and Food 1999, pp. 203). Values were averaged for the following crops: wheat, oats, barley, all rye, mixed grains, grain corn, oilseeds, canola, flaxseed, sunflower seed, buckwheat, canary seed, dry beans, dry peas, fababeans, lentils, mustard seed, sugar beets, fodder corn, tame hay, horticultural crops and forage seeds, potatoes (Manitoba Agriculture and Food 1999, pp.85-129).

For RMs in Saskatchewan, the model uses provincial farm/crop price averages from 1995/96-1998/99 in dollars per tonne (equal to total farm value in dollars divided by production in tonnes) (Saskatchewan Agriculture and Food 1999). Annual data for the following crops was averaged: winter wheat, spring wheat, durum, oats, barley, rye, flax, canola, hay, mustard, sunflowers, lentils, peas and canary seed (Saskatchewan Agriculture and Food 1999).

In the case of Alberta, average crop prices were calculated for 1995/96-1998/99 for all wheat, oats, barley, flaxseed, canola, and all rye (Alberta Agriculture, Food and Rural Development 1999). The derived values were annual provincial averages given in dollars per bushel. Data values were converted into dollars per tonne.

7.3 Crop Production and Operating Cost Data

The crop production and operating costs are used in the SEA model to determine net revenue from agricultural production in a particular RM. While crop production costs and operating costs may seem similar, there are significant differences. Total crop production costs are operating

costs plus fixed (or capital) costs plus labour costs, while operating expenses include the following: property taxes, cash rent, share rent, cash wages, room & board, interest, repairs to buildings and fences, electricity, telephone, heating fuel, machinery fuel, machinery repairs and other, business insurance, custom work, stabilization premiums, crop and hail insurance, fertilizer, pesticides, commercial seed, twine/wire/containers, commercial feed, livestock and poultry purchases, A.I. and veterinary fees, legal and accounting fees, and others (Manitoba Agriculture and Food 1999).

Crop production costs vary from year to year. They depend on variables of the land (i.e., fertility of the soils) but also on world market prices (i.e., fuel or fertilizer). The SEA model is restricted to using historic crop production costs, averaged for the years from 1995-1999, as found in the most recent provincial Agricultural Yearbook of Manitoba (Manitoba Agriculture and Food 1999). The user can interactively adjust the cost inputs.

In the case of crop production costs for Manitoba, the model uses provincial historical operating costs of crop production for each crop (normal costs, excluding any abnormal pre-harvest spraying) in dollars/acre (Manitoba Agriculture and Food 1999). Values were averaged from 1995/96-1998/99 for the following crops: all wheat, oats, barley, rye, flax, canola, mixed grain, grain corn, tame hay, fodder corn, buckwheat, canary seed, dry peas, fababeans, lentils, mustard seed, soybeans, sunflower seed, triticale, and beans (Manitoba Agriculture and Food 1999, pp.150).

No comparable data on crop production costs (by crop type) was available at the RM level in Saskatchewan or Alberta. For example, the 1996 Census of Agriculture has total crop expenses for each RM/county in both provinces (in dollars). However, since the values are by RM and not by crop type, this data was not utilized. The other option for Alberta was to use farm operating expenses (per reporting farm) as stated in the 1996 Census of Agriculture (Statistics Canada). However, to make the model equally applicable across the Prairies, the Manitoba figures, as described above, were used. (Note: The crop production costs for spring wheat in the RMs was substituted using the Manitoba crop production costs for all wheat.) It is acknowledged that the use of the Manitoba figures does introduce some error. Due to the data limitations, this error had

to be tolerated. The user is given the option to adjust the figures interactively to reduce the error in the future.

7.4 Historic Crop Yield Data

Crop yield is the parameter that varies with climate in the SEA analysis. The SEA model uses historic (1995-1999) yield averages (specific to each RM) to calculate historic average net revenues. Historic crop yields for the three provinces were acquired from a variety of sources. Yields from 1995 to 1999 for each RM in Manitoba were derived in tonnes per acre from the Manitoba Management Plus website (Manitoba Agriculture, Manitoba Crop Insurance Corp. and Manitoba Rural Adaptation Council, 2000). In the cases where a number of varieties existed for a crop (such as wheat) all yields from all varieties were averaged to calculate an overall crop yield.

The Manitoba yield data does include some imprecision as it was obtained from the Manitoba Management Plus website (Manitoba Agriculture, Manitoba Crop Insurance Corp. and Manitoba Rural Adaptation Council, 2000), as this data excludes information from non-insured producers. Incidentally, the data on the website generally included 80-90% of the seeded/harvested area, but this could vary from crop to crop. Data, therefore, may not include all farmers, or all yields.

Historic (1995-1999) yields in bushels per acre for each county in Saskatchewan were derived from Statistics Canada (1996) for the following crops: barley, canola, durum, fall rye, flax, tame hay, lentils, mustard, oats, peas, spring rye, fall rye, sunflowers, winter wheat, spring wheat, and canary seed. The data was averaged and converted into tonnes per acre.

In the case of Alberta, provincial historic (1995-1999) yields in bushels per acre of major crops were derived from Statistics Canada (1996). Historic yields were converted into tonnes per acre and averaged for the following crops: all wheat, winter wheat, spring wheat, durum wheat, oats, barley, flaxseed, canola, all rye, fall rye, spring rye, grain corn, and dry peas.

In some cases, it was necessary to average crop yields for particular categories, like cereal, forage and oilseeds. Unfortunately, Bootsma et al (1984), who used these categories, did not specify which crops were included in each category. Therefore the assessment had to rely on commonly used classifications. Furthermore, the crops included in these kinds of categories vary between provinces, countries and users. For example, one jurisdiction may include alfalfa, alfalfa mixtures, sweet grass and sweet clover forage in the acreage representative of forage, while another might only include alfalfa and alfalfa mixtures. Therefore, the resulting assessment of yield change impacts will not be directly comparable.

For the SEA model, cereals included total wheat, oats, barley and total. Forage included alfalfa and alfalfa mixtures and oilseeds included canola and flaxseed. However, since only data for canola was available in Athabasca and Stettler, it was used to represent oilseeds. In the case of Manitoba, canola and flaxseed are integrated to represent oilseeds. Potatoes posed another problem, as numbers were available for non-irrigated and irrigated potatoes – the authors did not specify which were used in their studies, so the numbers were averaged.

7.5 Crop Yield Change Scenarios

Crop yield changes are used in the SEA model to evaluate the impact of climate change on RM net revenues from agriculture. Published climate change yield model results were used in the SEA. Publications that included yields for all three Prairie provinces were Brklacich et al. (1994b) and Bootsma et al. (1984). Yield changes for Manitoba were derived from Arthur et al. (1986), Arthur et al. (1987) and Mooney (1990). Yield change model results for Saskatchewan were published by Arthur et al. (1987) and Williams et al. (1988) and for Alberta by Arthur et al. (1987). All yield changes were converted into percent changes. Details regarding the methods and results of these publications are discussed in the sections entitled “Impacts of Climate Change in the Prairies” and “Results”.

For the SEA model, the results in percent published by Brklacich et al (1994b) for Winnipeg, Dauphin, Prince Albert, Swift Current, Lethbridge, Ellerslie and Fort Vermillion were entered

into a point database (see Table 1). To provide prairie-wide coverage, the data from these points was interpolated using the Inverse Distance Weighted (IDW) method, using all neighbours. The continuous maps were then overlaid with the RMs and the average yield change within each of the 6 test-RMs was calculated. The resulting yield change scenarios were called:

"GFDL Scenario - No Adaptation"

"GFDL Scenario - Seeding Four Weeks Earlier"

"GFDL Scenario - Conversion to Winter Wheat"

"GISS Scenario - No Adaptation"

"GISS Scenario - Seeding Four Weeks Earlier"

"GISS Scenario - Conversion to Winter Wheat"

"UKMO Scenario - No Adaptation"

"UKMO Scenario - Seeding Four Weeks Earlier"

"UKMO Scenario - Conversion to Winter Wheat"

Table1: Yield Changes in % Using Various Climate Change Models and Adaptation Strategies (Conversion to Winter Wheat and Seeding 4 Weeks Earlier).

Scenario:	GISS			GFDL			UKMO		
Location:	No Adaptation	Winter Wheat	Earlier Seeding	No Adaptation	Winter Wheat	Earlier Seeding	No Adaptation	Winter Wheat	Earlier Seeding
Winnipeg	10	39	22	40	62	56	-40	13	-15
Lethbridge	40	200	92	-7	145	90	17	139	68
Fort Vermillion	6	22	6	-35	-25	-31	-31	-42	-42
Ellerslie	-2	-1	-10	-26	-23	-20	-25	-39	-41
Swift Current	50	132	75	66	167	117	19	48	24
Prince Albert	14	23	12	13	35	27	-26	-25	-25
Dauphin	2	21	5	31	49	41	-32	2	-28

Source: Adapted from Brklacich et al. (1994b).

For the SEA model, the impacts of a temperature increase of 1° C and fixed and variable GSL on corn, forage, potato, cereal and oilseed crop yields published by Bootsma et al. (1984) were used.

Results were published in percent for Southern Saskatchewan, Okanogan Valley, Prairie fringe, Southern Ontario, Northern Ontario and Peace River. The points were digitized on-screen, based on a map in the publication. The estimated dry matter yields were then converted into a percentage for each scenario and entered into the point database (Table 2 and 3). To gain data for the extent of the Prairie provinces, the data from these points was interpolated using the Inverse Distance Weighted (IDW) method using all neighbours. The positional accuracy resulting from this procedure is known to be low.

Table 2: Yield Changes in % Under a Temperature Increase of 1° C with Fixed Growing Season Length.

Scenario:	Fixed Growing Season Length				
Location:	Cereal	Oilseeds	Potatoes	Forage	Corn
S Saskatchewan	-18	-19	-14	-16	ng
Okanagan Valley	-14	-24	-18	-13	-20
Prairie fringe	-16	-16	-14	-10	ng
Southern Ontario	-8	-9	-10	-2	-4
Peace River	-11	-10	-10	-4	ng
Northern Ontario	0	0	0	0	ng

ng = not grown
Source: Adapted from Bootsma et al. (1984).

Table 3: Yield Changes in % Under a Temperature Increase of 1° C with Variable Growing Season Length.

Scenario:	Variable Growing Season Length				
Location:	Cereal	Oilseeds	Potatoes	Forage	Corn
S Saskatchewan	6	-13	-3	-11	ng
Okanagan Valley	-18	-24	-13	-13	-20
Prairie fringe	4	-12	-5	-10	ng
Southern Ontario	-8	-9	-9	-2	-6
Peace River	14	-6	4	-7	ng
Northern Ontario	13	8	12	-3	ng

ng = not grown
Source: Adapted from Bootsma et al. (1984).

The Prairie-wide continuous maps were then overlaid with the RMs and the average yield change within each of the 6 test-RMs was calculated. The resulting yield change scenarios were called:

"Temperature Increase of One Degree, Variable GSL"

"Temperature Increase of One Degree, Fixed GSL"

Arthur et al. (1986) and Arthur et al. (1987) published a number of crop yield change scenario results for different crops (wheat, barley, oats, canola, flax and hay in Manitoba, wheat and barley in Saskatchewan and wheat in Alberta). The results were published on the Crop Reporting District (CRD) level. The published results were incorporated into the database in the following way: the percent change from the base yield was calculated for all crops, scenarios and CRDs; the percent changes were then entered into the RM database; all RMs that belong into one CRD were assigned the percentage for the CRD. The resulting yield change scenarios were called (For explanation of the scenarios see the section entitled “Impact of Climate Change on Agriculture”):

"A1 Scenario - Temperature Increase Only"

"A1 Scenario - Temperature and Precip. Increase"

"A2 Scenario - Temperature Increase Only"

"A2 Scenario - Temperature and Precip. Increase"

"B1 Scenario - Temperature Increase"

"B2 Scenario - Temperature Increase"

"B2 Scenario - Temperature and Precip. Increase"

Mooney (1990) calculated yield changes based on GISS GCM outputs for wheat, barley, oats, canola, sunflower, grain corn, silage corn, soybean and potatoes. The model estimated the percent change in crop yields under a doubled carbon dioxide scenario in Manitoba in seven

regions. The percent changes were entered into the RM database based on the location of the RMs within the seven regions. The scenario was called "GISS - FAO Scenario".

Williams et al. (1988) published spring wheat changes by crop district in kilogram per hectare using two GISS climate change scenarios: temperature change only and temperature and precipitation change. For data entry into the SEA model, the percent change was calculated. The scenarios are called "GISS1 Scenario - Temperature and Precip. Increase" and "GISS2 Scenario - Temperature Increase".

7.6 Crop Mix

The crop mix tells the user how many acres of a crop in a particular RM were farmed. It also tells the user whether or not a particular crop was grown between 1995 and 1999 in that RM. The acreage for each crop in each of the 6 test-RMs was obtained from the 1996 Census of Agriculture (Statistics Canada 1996).

As discussed before, some crops posed problems to the data integration, as some authors did not define crop classifications. The acreage for these crops was gathered using the same classifications as discussed under “Historic crop yields”.

If a crop did not appear in a particular RM, our assumption was that it was either not grown, not reported, or the acreage was too small to report. As mentioned above, the data from Manitoba Agriculture, Manitoba Crop Insurance Corporation and Manitoba Rural Adaptation Council (2001) only included the insured 80-90% of the seeded/harvested area.

8.0 Model Capabilities and Limitations

Although the SEA model has a number of strengths, such as the important spatial gap which the model addresses, as well as its education and decision-support roles, it does have limitations. The current SEA model uses a simplified approach to evaluating socio-economic vulnerability based

on sector dependence and modelled biophysical impacts. Evaluating the biophysical impacts of climate change was based on various yield change scenarios for the agricultural sector and various modelled ecozone boundary shifts in the forestry sector. Some limitations are inherent in both the modelling approach and input data.

The limitations inherent to the modelling approach are, in part, due to the general nature of using models to represent "real world" phenomena. Every model reduces inherently complex natural systems to a limited number of variables. Socio-economic impacts are second and third order impacts, which additionally increases the amount of uncertainty. In the case of the current model, vulnerability is based on sector dependence (sector employment). It is acknowledged that this is an extremely limited approach, which does not acknowledge a large number of issues affecting socio-economic health of a community. For example, the full implications of losing the boreal forest ecosystem in an area could not be included. Neither the existence value nor the economic value of carbon sequestration by the boreal forest was taken into consideration. The assessment of these factors was beyond the scope of this study and the implications of the model output are left to the user.

The use of employment statistics also introduces some modelling uncertainties. Often, a person's place of residence and place of work is not within the same community. This is expected to affect the results of the agricultural submodel to a lesser extent than the results of the forestry submodel. This is especially so in Manitoba, where farmers tend to live on or very close to the farmed land. However, the closer a RM to a major employment centre, the higher the number of people who commute to work. The vulnerability of the employment centre will then affect the vulnerability in the RM under review. This interconnectedness is not currently accounted for in the SEA model. The user is limited to viewing sector-dependence displayed in pie charts without an interpretation of the effects of climate change. As soon as appropriate data can be acquired, a more complete and robust socio-economic interpretation will be possible.

As the purpose of this project was to develop a model for the three Prairie provinces for different economic sectors, data from various sources had to be used. By having to obtain data from both public and private sectors, the difference in variables, terminology, geographical and temporal

scale was unavoidable (see "Data Input"). In the case of crop production costs, the terminology used in the three provinces was different enough to prohibit the use of figures from Saskatchewan or Alberta. The provincial averages from Manitoba used for the other provinces introduce an uncertainty of unknown magnitude.

Incomplete data sets add to the error of the SEA model results. For example, the Manitoba Management Plus website (Manitoba Agriculture, Manitoba Crop Insurance Corporation and Manitoba Rural Adaptation Council 2001) from which the Manitoba yield data was obtained, generally included only 80-90% of the seeded/harvested area, as it does not include the acreage from non-insured producers.

The SEA model integrates yield and forestry model results from various authors. All limitations and assumptions from these studies were transferred to the SEA. For example, some studies evaluated the effects of doubling of CO_2 concentrations in the atmosphere. However, CO_2 is not the only active agent that is accumulating in the atmosphere. Other agents, such as aerosols and methane, are increasing as well. These will also affect the climate. Most of the used publications that were available for the development of the agriculture submodel were dated and relied on outdated GCMs. A larger number of publications were evaluated, but could not be used (See section entitled "Impacts of Climate Change on the Prairies"). The use of results from more recent publications would have been desirable, as GCMs have been improved significantly since the 1980s. The newer versions do, for example, take increasing concentrations of other substances in the atmosphere into consideration.

The methods and assumptions underlying the data published by various authors and the data used in the SEA model are not coherent. Thus, comparisons between the two are restricted. For example, crop yield studies were carried out using different crop varieties and seedbeds; some publications used spring wheat yields or barley yields on stubble, others on fallow. The error was accounted for to some extent by using changes in percent rather than absolute values. However, the modelled crop yield changes in percent were then applied to 1995-1999 average crop yields to model changes in the SEA model in order to assess net revenue changes. As the average yield changes were originally calculated for older datasets, this introduced some temporal error. In

addition to the temporal aspect another error was introduced: seedbeds and varieties averaged from 1995 to1999 differ from those used in the original studies (See "Data Input"). The study team decided that this error must be accepted as varieties change continuously due to technological development. It must be noted that the SEA provides a tool that can be used to visualize certain trends that may occur due to a doubling of CO_2 concentrations in the atmosphere or an increase of annual average temperature by 1° C. The values displayed in the output represent only a limited range of possible scenarios.

In addition to the temporal error, spatial errors, inherent to GIS and mapping approaches need to be considered. Some of the published yield changes were published by administrative region, such as Crop Reporting District. It must, of course be acknowledged that yields vary within these administrative boundaries, depending on biophysical parameters, such as soil. Also, yield change rates (and ecosystem boundaries used in the Forestry Submodel) will occur gradually in a continuous fashion, rather than in a classified, discontinuous way. Continuous change is simulated in the cases where point data was interpolated over the area of the three Prairie provinces. The modelled yields between these points rely solely on mathematical averaging, thus neglecting environmental factors such as soil, surface, microclimate, etc. Indeed there may be locations where crop yield changes vary greatly from the modelled results. It was not possible to verify the accuracy of the interpolation, as there were very few test sites available in either case.

The output from the SEA model must not be regarded as a prognosis of what will happen once CO_2 concentrations have doubled or once the annual average temperature has increased by 1° C. Rather, the output reflects a trend of what *could* happen. In no way can the outputs be regarded as a prognosis of what will actually happen.

9. Model Output Results

The results are divided into three sections. The first discusses some of the findings regarding yield changes. This is followed by a description of the SEA output from the Agriculture and the Forestry submodels using the default values.

9.1 Agriculture Yield Changes – Historic versus Modelled

Climate change affects the agricultural sector dominantly through changes in crop yields. The SEA model relies on crop yield changes published by various authors to calculate net revenue changes in a RM. During the data input phase all published yield changes were converted into percent changes. These percent changes reflect the change in yield due to the used climate change scenario. As all baseline scenarios used data from the 1980s or older, it was assumed that some of the modelled yield trends could be identified when comparing the baseline data used by the author and the 1995-1999 average yields. In order to verify this, the various authors' baseline yields were compared to the SEA baseline yields (1995-99) by calculating the percent change between the historic baselines and the 1995-99 baselines. The comparison showed a large positive trend with large yield increases between the (pre-) 1980's and the 1990's. While the scenario yield changes varied between positive and negative changes, the historic – 1990's yield changes showed a clear trend to increased yields. In fact, the historic yield increases exceed the positive yield changes from the "best case" climate change models.

For example, Arthur et al. (1986) used 1961-1984 crop yield averages as baseline yields in their analysis. Comparing these baselines to 1995-1999 averages showed that wheat yields had increased by +3% in Stanley and by +0.3% in Swan River. The average of the yield change scenarios was an increase in wheat yields in both RMs by +17% under a climate with doubled CO_2 concentrations. The "best case" modelled by Arthur et al. 1986 was a yield increase by +7% in Stanley and +10% in Swan River ("Scenario A – Temperature and Precipitation Increase"). While the yield changes described in this example follow the same, positive, trend, most climate change scenarios resulted in negative crop yield changes – the opposite of the realized yield increase between the historic baselines and the 1995-99 averages. For example, Arthur et al. (1986) modelled average yield decreases for oats (-10% in Stanley, -23% in Swan River), barley (-5% in Stanley, -13% in Swan River) and flax (-1% in Stanley and Swan River) due to a doubling of CO_2. However, yields have increased for all three crops between the baseline years of 1961-84 and those of 1995-99. Oat yields have increased by +50% in Stanley and +38% in Swan River, barley yields have increased by +31% in Stanley and +27% in Swan River, and flax

yields have increased by +24% in Stanley and +18% in Swan River. While the individual numbers vary, the fact that yields have been increasing by a large extent is true for all crops and all provinces.

A factor other than climate change is probably affecting crop yields. The discrepancy between modelled and historic yield changes can mainly be attributed to technical improvements in agriculture and changes in agricultural practices. Pesticides and fertilizers have been improved and precision farming approaches have revolutionized many farm operations. Most important, however, is the availability of new, enhanced crop varieties that produce higher yields than older varieties. The success of farm modernization could erroneously lead to the conclusion that the modern farmer is not dependent on weather and climate anymore. However, while crop yields are obviously strongly influenced by technological developments, the effects of weather and therefore climate change can not be neglected. For example, if climate change was not taking place, oat yields in Stanley might have increased by even more than by +50% as there would not have been less negative impacts (-10% yield decrease under doubled CO_2 concentrations). Weather (and climate) is universally acknowledged as the most important factor affecting crop yields.

9.2 Agriculture Submodel – Default Settings

Agriculture is vulnerable to climatic change due to its strong dependence on climatic conditions. Most direct impacts of climatic change will occur through changing crop yields. The following discussion pertains to the changes in net revenues as modelled by the SEA for each of the 6 test-RMs using default values. The yield and net revenue changes are directly related due to the calculation of the net revenues (see "Methods").

Results from the SEA analysis using default values[2] for individual scenarios and individual crops are displayed in Appendix G. The impacts on yields by scenario are displayed in Appendix H.

[2] When using the SEA model the user can interactively change the output by, e.g., designating more acres to crops with more positive yield changes and less acres to climate change sensitive crops, or adjust costs, prices and yields.

The following discusses SEA model results for each crop in each RM. It must be kept in mind that the SEA analysis relies on previous studies and therefore the number of scenarios varies by crop and by province. Wheat yields were extracted from 4 different authors, who used a total of 18 scenarios. Sunflower and soybean yields were only examined by one author, who used a single scenario for Manitoba. All publications but one modelled changes due to doubled CO_2 concentrations in the atmosphere. Only Bootsma et al. (1984) modelled changes due to a 1° C temperature increase. Arthur et al. (1986) modelled a drought scenario. These results, which rely on inherently different climatic conditions, are included in the charts, but discussed separately. The following discusses the impacts incurred by average yield change, neglecting seedbeds and varieties.

9.2.1 Manitoba

Yield changes due to a doubling of CO_2 in the atmosphere in Manitoba were available for wheat, barley, oats, canola, flax, corn, potatoes, soybean, sunflowers and tame hay. Scenarios for an increase in annual atmospheric temperature by 1° C were available for corn, oilseed, potatoes and cereal. All of these crops have been grown in the RM of Stanley between 1995 and 1999, while corn, potatoes, soybeans and sunflowers were not grown[3] in Swan River.

In Stanley, average yields for all crops increased slightly (less than +1%) after averaging the results from all $2xCO_2$ scenarios. The very low yield increase translated into a low negative change (–2%) in net revenue from agriculture for the RM. All scenarios using a 1° C increase in temperature combined showed an average decrease in crop yields by -20%, which translated into a decrease in RM net revenues from agriculture of -10%. The drought scenario resulted in an average decrease in crop yields by –80% and a net revenue decrease of –34%.

In Swan River the $2xCO_2$ scenarios showed no change in average crop yields (-0.1%). However, the scenarios using a 1° C change in temperature resulted in an average crop yield loss by –11%, which caused Swan River's net revenue from agriculture to decrease by –34%. Yield decreased

to a lesser extent than in Stanley under the drought scenarios (-39%), but the loss in net revenues was much greater (-131%) due to the different acreage distribution.

In Stanley the crop that showed the highest sensitivity to the used climate change scenarios (2xCO_2 and 1° C increase in average temperature) in terms of net revenue change, was sunflowers, followed by oilseeds, corn, potatoes, oats, barley and canola, flax and soybean (see discussion below). Positive RM net revenue changes using the past average acreage, costs and prices were calculated for wheat and tame hay.

In Swan River only 5 crops were used in the default analysis, as the other ones were not grown. In order of decreasing susceptibility to a doubling of CO_2 concentration (none of the crops modelled by the 1° C change scenarios was grown), the analysed crops were oats, canola, barley, flax and wheat. When comparing the crops that were grown in both Stanley and Swan River, the order of susceptibility was the same.

The largest number of published yield change scenarios was available for wheat. This resulted in a large range of modelled yield changes (105% in Stanley, 230% in Swan River)[4]. On average the yield results were optimistic (+17% average increase in net revenues from wheat in Stanley and Swan River). The median was +3% and the mode +8% in Stanley. The median was +9% in Swan River (no number occurred more than once). The best case scenario was the "GFDL Scenario - Conversion to Winter Wheat" in both RMs (change in net revenues from wheat by +127% in Stanley and +148% in Swan River). The scenario that resulted in the next best case was the "A1 Scenario - Temperature and Precip. Increase", which modelled a net revenue increase by +19% in Stanley and +20% in Swan River. The worst case resulted in a change in net revenues from wheat by -87% in Stanley ("GISS - FAO Scenario"). While this scenario lead to a large decrease in agricultural net revenues in Swan River, the worst case scenario here was

[3] The acreage published was 0. This means that no farmers have insured these crops.
[4] Had all crops been modelled using the same scenarios, yield ranges could have been used as a measure of variability and therefore vulnerability. However, the previous studies used for the SEA model covered different crops, different varieties, different seedbeds, etc. This must be taken into account when interpreting the yield (and therefore net revenue) results.

"UKMO Scenario - Seeding Four Weeks Earlier" which resulted in RM-wide net revenue losses of –82% from wheat.

Sunflower net revenue averages displayed the largest modelled decrease (–208%), followed by corn (-43%) and potatoes (-20%) in Stanley (none of these crops were grown in Swan River). However, yield change for these crops originated from only one scenario: "GISS - FAO Scenario", a scenario that resulted in the most pessimistic changes for most crops.

RM agricultural net revenues from oats were modelled to decrease by an average of –19% and –24% in Stanley and Swan River respectively. The medians were slightly higher with -10% and –18%. The best case scenario was "A1 Scenario - Temperature and Precip. Increase" with +15% / +27%, the worst case –70% / -95% ("GISS - FAO Scenario") in Stanley / Swan River. Changes in RM net revenues from oats varied by +81% / +122%.

The average net revenue change from canola and barley was –13% in Stanley and –17% / -16% in Swan River. Net revenue changes ranged between 82% and 94% in the case of canola and 60% and 94% in the case of barley. The best case scenarios for both crops in both RMs was "A1 Scenario - Temperature and Precip. Increase" (and "B1 Scenario - Temperature and Precip. Increase" for barley). The worst case scenario in all cases was "GISS - FAO Scenario".

Modelled flax yields varied by 40% in Stanley (and 60% in Swan River). The average RM net revenue change was –2% (-3%) with a median of 0% and a mode of +14% (+21%) in Stanley (Swan River). The best case scenarios were "A1 Scenario - Temperature and Precip. Increase" and "B1 Scenario - Temperature and Precip. Increase" with +14% (+21%), the worst case "B1 Scenario - Temperature Increase" with –26% (-38%). This was the only crop where the "GISS - FAO Scenario" was not the worst case scenario.

Soybean yields and net revenues for Stanley remained constant. The only scenario available was "GISS - FAO Scenario".

Tame hay RM net revenue changes varied by 76% in Stanley (82% in Swan River). The average was +23% (+18%) in Stanley (Swan River). The median was higher in both RMs with +26% (+20%), as was the mode +60% (+56%). This crop showed the most positive reaction to climate change with strong positive yield changes and weaker negative changes: the best case scenarios were "A1 Scenario - Temperature and Precip. Increase" and "B1 Scenario - Temperature and Precip. Increase" with an increase in net revenue by 60% (56%), the worst case was "B1 Scenario - Temperature and Precip. Increase" with a decrease of -16% (-26%). Of course, it must be noted that tame hay was the only crop in Manitoba that was not analysed by Mooney (1990), whose "GISS - FAO Scenario" resulted in generally pessimistic yield changes.

In terms of drought vulnerability 6 crops were examined by Arthur et al. (1986). As in the 2xCO_2 scenarios, the crops in Stanley and Swan River showed close similarities. In both cases net revenues from barley decreased the most: -128% in Stanley and –189% in Swan River. Second was flax with –123% / 176%, third oats, then canola, then tame hay. Unfortunately there was no yield change published for tame hay in Swan River. Wheat was the least susceptible crop in both RMs with net revenue changes of –8% and –10% in Stanley and Swan River respectively. The above discussion, of course, assumes that crop prices and costs remain constant, which is unlikely in a drought year.

Yields from the baselines published in the various studies were compared to 1995-99 averages. The results showed that yields have generally increased drastically. This is mostly due to technical development and the use of new and better varieties. However, the impact due to climate change can not be neglected.

9.2.2 Saskatchewan

Yield changes due to a doubling of CO_2 in the atmosphere in Saskatchewan were available only for wheat and barley. Scenarios for an increase in annual temperature by 1° C were available for

corn, oilseed, potatoes and cereal. Corn, forage and potatoes were not grown in either North Battleford or Indian Head[5].

On average the $2xCO_2$ scenarios lead to an increase in average wheat and barley yields in both Indian Head and North Battleford: +11% in Indian Head and +12% in North Battleford. The resulting net revenue changes for the RMs from agriculture increased by +43% and +72% respectively.

As in Manitoba, the results from the scenarios that modelled an increase in average annual temperature of 1° C were much more pessimistic: average yields decreased by –12% in both RMs, considering all crops that were modelled. Considering only cereal and oilseeds yields decreased on average by –11% in Indian Head and –10% in North Battleford. This translated into net revenue changes of –47% and –32% respectively.

On average, Indian Head was less vulnerable to climate change as the scenarios resulted in higher positive and lower negative changes than in North Battleford.

As in Manitoba, wheat yields and revenues were more positively affected than those of barley under a $2xCO_2$ climate. Average net revenues from wheat increased substantially by +50% in Indian Head and +88% in North Battleford. The medians, however, were lower with +26% and +83%. Also, the scenarios resulted in a wide range of results: net revenue changes ranged from –128% to +331% in Indian Head and from –30% to +279% in North Battleford. The scenario that resulted in the most optimistic change was "GISS Scenario – Conversion to Winter Wheat" in both RMs. Net revenues from wheat increased by +205% and +279% in Indian Head and North Battleford respectively. The worst case scenario for Indian Head originated from called "GISS1 Scenario - Temperature and Precip. Increase" which translated into a net revenue decrease of –128% from wheat in Indian Head. In North Battleford the same scenario resulted in large net revenue increases (+83%). The worst case scenario here was "UKMO Scenario – No Adaptation": -30% change in net revenues from wheat.

[5] The acreage published was 0. This means that no farmers have insured these crops.

While the "A1 Scenario - Temperature and Precip. Increase" and "B1 Scenario - Temperature and Precip. Increase" scenarios did not result in best case scenarios for wheat, their results clearly showed a positive trend – just as they did in Manitoba.

All available barley scenarios resulted in positive net revenue changes in Indian Head, with "A2 Scenario - Temperature and Precip. Increase" being the highest (+19%). In North Battleford all scenarios resulted in negative changes with "B2 Scenario - Temperature Increase" and "B2 Scenario - Temperature and Precip. Increase" resulting in the best case results with net revenue decreases of –6%.

The trends from the 1° C temperature change scenarios was coherent in both RMs. Oilseeds were negatively affected in all cases with greatest losses in Indian Head. Cereal benefited from the higher temperatures given a longer growing season. Largest increases in net revenue changes were calculated in North Battleford with +17%.

9.2.3 Alberta

Yield changes due to a doubling of CO_2 in the atmosphere in Alberta were available only for wheat. Scenarios for an increase in annual atmospheric temperature by 1° C were available for corn, oilseed, potatoes and cereal. Corn, forage and potatoes were not grown in either Athabasca or Stettler[6].

While the $2xCO_2$ scenarios lead to a slight increase in average wheat yields in Stettler (+5% with a mode of –8%), the impact in Athabasca was negative on average (-2%) but positive using the median (9%). The range in net revenue change was large for both RMs: 145% in Stettler and 128% in Athabasca. The best case scenario in both RMs was "GISS Scenario Conversion to Winter Wheat", which resulted in an increase in net revenues from wheat by +99% in Stettler and by +56% in Athabasca. The worst case scenario was "UKMO Scenario - Seeding Four

[6] The acreage published was 0. This means that no farmers have insured these crops.

Weeks Earlier" with a net revenue decrease of –46% due to wheat yield decreases in Stettler and –73% in Athabasca.

As in Manitoba, the results from the scenarios that modelled an increase in average annual temperature of 1° C were much more pessimistic than those from the 2xCO_2 scenarios: Average yields decreased by –12% in Stettler and –10% in Athabasca considering all crops that were modelled. Considering only the crops that are actually grown, cereal and oilseeds, yields decreased on average by –11% in Stettler and –8% in Athabasca. This translated into net revenue changes of –31% and –23% respectively. Oilseed yields decreased under both temperature increase scenarios (fixed and variable growing season length), while cereal yields increased in both RMs under a 1° C temperature increase and variable growing season length.

9.3 Agriculture Submodel – Using Adjusted Inputs

The following gives an example of how the SEA model input can be adjusted to evaluate adaptation strategies for agriculture. This example uses the "B2 – Temperature Increase" Scenario in North Battleford. The historic net revenue in the RM from agriculture is $4.9 million annually. Using the default values, the RM net revenue from agriculture with the impact of climate change is $5.5 million. This means that the RM would benefit from doubling CO_2 concentrations with a net revenue increase of $0.5 million. The increase in revenue is due to an increase in wheat yields by +7%. However, barley yields decreased by –2%, thereby inhibiting the benefits. In order to minimize the negative effect of barley yield decreases, the acreage of barley was decreased by 20,000 acres and the land was assigned to wheat. The impact of these changes was a further increase in net revenues to $5.7 million. This shows that the user-defined adjustments increased the RM net revenue from agriculture by $100,000.

9.4 Forestry Submodel

Table 4 shows the results of modelled impacts of doubled CO_2 concentrations on ecoclimatic zones in the 6 test RMs. The results of these three studies are also compared in Figure 1 in

Appendix B. When comparing the results it is important to recognize that the three scenarios used different classification and modelling methods. However, the three scenarios commonly display an increase of grassland area in the Canadian Prairies. This expansion of the grassland area northward will replace forest ecosystems in North Battleford, Swan River, Stettler and Athabasca. Stanley, in the south, is least affected under these scenarios.

The change in ecosystems from forest to grassland could have major impacts in North Battleford, Swan River, Stettler and Athabasca if employers that rely on the forest as a resource base move out of the area. However, as Figure 1 in Appendix F shows, employment in the forest industry, as classified by Statistics Canada, is highest in the economic region in which North Battleford lies. Even here it is no more than 2% of the labour force aged 15 years and older.

Table 4: Vegetation Zones.

Scenario Classification	**Hogg & Hurdle 1995**		**Rizzo & Wiken 1992**		**Environment Canada 2001**	
Location	**Historic**	**Modelled**	**Historic**	**Modelled**	**Historic**	**Modelled**
Swan River	Boreal Forest	Aspen Parkland	Boreal Forest	Grassland	Dry Cont. Boreal	Grassland
Stanley	Aspen Parkland	Grassland	Grassland	Nc	Grassland	nc
Indian Head	Aspen Parkland	Grassland	Grassland	Nc	Grassland	nc
North Battleford	Aspen Parkland	Grassland	Boreal Forest	Grassland	Border of Boreal Forest / Grassland	Grassland
Stettler	Aspen Parkland (Grassland)	Grassland	Grassland	Semi-Desert (Grassland)	Grassland	Semi – Desert (Grassland)
Athabasca	Boreal Forest	Aspen Parkland	Boreal Forest	Temperate Forest (Grassland)	Dry Cont. Boreal	Grassland

nc = no change
( ) = minor occurrence within RM

10. Summary and Conclusion

The initial SEA model was developed as a tool that allows the user to evaluate potential socio-economic effects of climate change due to its impacts on agriculture and forestry. The SEA model successfully combines the available results from research on the effects of climate change from the past 20 years. As the model was developed for people living in Prairie communities, it provides a tool that makes research results available beyond the academic realm, to people who will be affected by the changing climate.

A lot of research has been carried out regarding climate change in the Canadian Prairies and combining these results into one tool posed a major challenge. Effects on agriculture and on forestry were treated separately in two submodels. The Agriculture Submodel translates yield changes as published by a number of authors into net revenue changes for a RM. In order to make previous yield research results comparable, the data published by the various authors had to be reconciled. In the case of agriculture, previously modelled yield changes were transferred into percent changes, which were then used on the same baseline data. The yield changes were then used to calculate economic changes in terms of net revenue using crop prices, crop production costs and acreage. While this process produced usable results, it also contains inherent uncertainties and assumptions. Due to these, the SEA should be regarded as a tool that shows **potential or possible** trends due to climate change.

Comparing the SEA Agriculture Submodel output for different crops and different RMs displayed a clear trend: economic impacts due to climate change were very dependent on the particular climate change scenario chosen for the analysis. Some crops, such as tame hay or wheat, exerted more positive changes in yield and net revenue and lower variability under the given scenarios than others, such as barley. However, changes due to the use of different scenarios surpassed the amount of change due to the kind of crop. The combined results from various authors were very incoherent. Overall, the extent of negative changes was much larger than the extent of the positive changes, which dragged the average change for the RMs down.

Assuming that the incoherence of the published results reflects crop yield variation, the results also allow the conclusion that risks will increase in the future.

Unfortunately researchers used different crops and different crop varieties, which made a comparison of potential impacts on individual crops difficult. More recent studies covering a larger variety of crops would be needed to improve the picture of potential changes due to a doubling of CO_2 concentrations, or a generally warmer climate. Without this, interpretation of potential socio-economic effects based on biophysical changes is incomplete.

Model outputs in terms of net revenue changes assume a fixed commodity price, and it is well known that agricultural commodity prices are extremely volatile. Therefore the SEA model emphasizes yields and allows users to vary crop prices. A comparison between baseline yields used by various authors and 1995-1999 yield averages showed that yields have generally increased quite dramatically for each crop. This is partly due to the availability of improved crop varieties and the fact that static crop prices and production costs were used. While this shows that climate change is only one factor influencing crop yields, it must be regarded as one that may, and can, reduce revenues from agriculture. Future price and cost trends depend on such a large number of parameters that the study team decided an attempt at prediction at this stage in model development was not warranted. In addition, a farmer's choice of which crop to grow will not only be influenced by market prices and costs. Additional factors include existing infrastructure (a shift from, for example, grain production to livestock production must be a long-term decision) and local demand (e.g., demand for fodder for livestock production) (Arthur et al. 1987). In addition to these economic factors, the choice of commodity will be influenced by the biophysical settings, such as soil productivity and climate. By giving the user a choice of using some default values that reflect historic averages, or adjusting these values to assess the effects of different user-invented scenarios, the model can serve as a very useful decision-support tool for assessing the potential economic impacts of climate change as well as for assessing the potential economic implications of various adaptation strategies.

In the case of forestry, the model combines results from different research groups modelling boundaries of ecosystems in North America. While each group used a different classification

system, the results were surprisingly coherent in comparison to the results for agriculture. The dominant theme was that the area covered by grassland will extent northwards at the expense of the boreal forest. This will have impacts on communities that are currently located in the boreal forest. The socio-economic impacts will be most severe in communities whose economies rely on the natural resources of the boreal forest. However, employment and therefore dependency on the logging and forestry sector was low in all of the 6 test RMs.

The current SEA model provides some useful, but limited, adaptation strategy evaluation capacities. (Some previous authors used adaptation strategies in their models and published the results of conversion to winter wheat or earlier seeding (Brklacich et al. 1994), and these results were incorporated into the SEA). Also, the SEA provides the user the option to change the acreage distribution. Thereby the impacts increasing the amount of land under a certain crop versus another crop can be evaluated.

Overall, this project was able to provide a tool that can be used by local decision-makers to evaluate potential effects of climate change as modelled by researchers. While the model has a number of limitations, which are largely due to the unavailability of better data, the SEA provides a lot of flexibility for the user to evaluate the effects of scenarios. This can be done by using default values or by adjusting any of the input parameters.

11. Recommendations and Future Work

In the future it would be desirable to improve and refine the existing submodels as more and better data become available. It would also be desirable to carry out a risk analysis, in order to provide the SEA model user with some measure of output confidence. While some feed-back has been provided by RM representatives on the general model design, it would be beneficial to demonstrate the model to, and work with, potential users in order to get additional feed-back. Input from RM representatives would be invaluable in order to ensure greater user-friendliness and adoption of the program.

In terms of future development of other capabilities and submodels, some of the additional desirable operating parameters identified by RM representatives during the consultation process should be included in the model. In order to improve the Agriculture Submodel, the team would have liked to include some GCM outputs in the model. For example, average precipitation, average monthly minimum and maximum temperatures, etc. would be very useful to farmers to evaluate various future crop potentials.

RM representatives have clearly defined the need for a climate change tool targeted at infrastructure. An important task would be to determine the types of infrastructure most sensitive to different climate change scenarios. The results derived from these conclusions/calculations would be best demonstrated using RM financial plans. Reductions or increases in expenditures (in dollars) could be estimated and imported into the financial plan spreadsheet. The end result would show how much money would be lost or gained as a result of climate change impacts. For example, it would be advantageous to illustrate how a general increase in snowfall (i.e., 10%) during the winter months (as predicted by some general circulation models) would impact the budget for snow and ice removal. These scenarios would have spin-off or secondary effects, including the way in which municipalities operate and their ability to provide and maintain services in relation to budgetary constraints. In turn, local retail expenditure would also be affected.

Another issue that has been brought up by RM representatives is the availability of water for irrigation. Information on this important aspect would allow the extension of the Agriculture Submodel to include the evaluation of irrigation as a potential adaptation strategy. This evaluation, however, can not be carried out until more research has been done on the potential impacts of climate change on water resources. Results from such research would also be necessary in order to evaluate the potential impacts of climate change on the energy sector. The effect of climate change on Manitoba's water resources for the purpose of hydro-electricity would be one area of great interest to study.

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