Economic Impacts of Climate Change and Weather Extremes on Canadian Prairie Mixed Farms

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By

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ABSTRACT

Canadian Prairie agriculture, in general, is expected to benefit under climate change with increasing mean temperatures projected for the immediate future. However, a number of knowledge gaps still exist. Foremost among these is the measurement of the effects of extreme climate events in a given year as well as their long-term impact on the supply of agricultural products, and also the financial situation of farms. In addition, the economic impacts of climate change on livestock operations are relatively under-studied. In particular, knowledge of the impacts on Prairie beef cattle remains more guesswork than research-based evidence. This dissertation assesses the impact of changes in the normal climate as well as the impact of climate extremes by including projected inter-annual climate variability. The economic impact of these changes on crops, beef cattle activities and the viability of farms in mixed operation settings is measured. Correspondingly, this work presents alternative adaptation measures and their likely use in managing mixed farm operations for future extreme weather events. For the analysis, two study sites are selected: (1) the Oldman River Basin of Alberta, called Pincher Creek, and (2) the Swift Current Creek Basin of Saskatchewan, called Swift Current. This study is a part of a larger project entitled "Vulnerability and Adaptation to Climate Extremes in the Americas" and the study sites are intended to represent the project catchment areas in the provinces of Alberta and Saskatchewan.

I develop what I call a MF-CCE model (Mixed Farm model for the economic impact assessment of Climate Change and Extremes). The MF-CCE is a whole farm simulation model that integrates models of beef cattle production, crop production and climate changes into farm level economic decisions. Simulations are conducted over a 30-year period in each climate scenario: the first of these is a baseline climate scenario from 1971-2000, and I also simulate future climate change impacts for the 2041-2070 era. The modelled farms produce enough crops, hay and pasture to support the beef cattle feed demand. Pasture demand and supply are linked by specific pasture requirements and productivity. Beef herd feed grain demand and on-farm supply are linked by a linear programming optimization algorithm. Crop mix for the market is selected through the development of a multi-year linear programming problem that maximizes the present value of gross margins. Crop and hay productivity are estimated through the Food and Agriculture Organization's (FAO's) AquaCrop (version 3) modeling framework, while annual pasture

productivity is estimated using the Forage Calculator for Native Rangeland obtained from the Saskatchewan Research Council (SRC). The AquaCrop is a water-driven crop simulation model, termed a crop water productivity (WP) model which simulates the yield response of herbaceous crops to water availability and use. The model is believed to be superior in simulating crop yield in the conditions where water is a key limiting factor in crop production (FAO, 2011).

Summarizing the results of the simulation, prairie crop production is expected to benefit under the simulated climate change scenario. Increases in crop productivity generate about 60% higher profits in the Pincher Creek site and about 57% more for the Swift Current site. Due to increases in grain and hay productivity, more area is made available to produce grain for the market. This effectively doubles the crop net return at the Pincher Creek site and triples the crop return at the Swift Current site.

A consideration of future pasture response to the climate change scenario is important in estimating climate change consequences for live beef production as well as on the economic return of a mixed farm. If the pasture productivity decreases, as assumed under the regular pasture yield scenario in the study, appropriate adaptation is necessary for the farm to benefit from future climate change. Under this scenario, beef production activities in the future are projected to gain by 50% in Pincher Creek and 40% in Swift Current compared to the baseline scenario. If pasture productivity under the future scenario increases in a manner similar to crop yield increases, existing pastureland will be enough to maintain beef herds into the future. In turn, this strategy will mitigate the cost of beef herd adaptation during climate extremes, and instead gains from beef cattle production would be 35% higher in Swift Current and 6% higher in Pincher Creek relative to gains under regular pasture yield conditions.

At the farm level, with beef cattle and crop production combined, substantial gains are projected for both of the study sites. Farm net profit is estimated to increase by more than 35% at the Pincher Creek site and more than 140% at the Swift Current site under the future scenario. Income risk will also be lower in this scenario, as highlighted by a lower coefficient of variation of net farm profit. Farm financial indicators tracked in this study – farm cash flow, family cash flow, and farm net worth – all indicate that the farm’s financial position will be much better in the future climate scenario. At the Pincher Creek site, a few problematic liquidity events are forecasted

under the future climate scenario, but in light of significant improvements in other economic indicators, overall, this effect is negligible.

The appropriate choice of adaptation strategies for managing beef herds during extreme climate events plays an important role in determining the profitability of not only beef cattle activities, but also the financial position at the whole farm level. However, the choice of adaptations is contextual: the preference of adaptation strategy differs across activities, farms and period of study. For beef cattle activities, maintaining the beef herd without any compromise on herd size and implementing a regular feeding plan is preferred to other adaptation alternatives. At the whole farm level for the Pincher Creek site, culling the herd is preferred under the baseline scenario, while the purchasing feed option is preferred under the future climate scenario. At the Swift Current site, culling the herd is the preferred strategy under both scenarios.

Commodity prices and the cost of farm inputs profoundly affect the economic position of the farm under the future climate change scenario. If commodity prices and cost of production remain the same as under the baseline scenario, future farm net profit is estimated to be 50% higher for the Pincher Creek site and about 25% higher for the Swift Current site, compared to profits under projected future prices. This result implies that the pure effect of climate change could be much higher if costs and prices do not change.

Results of this dissertation indicate that average Prairie mixed farms, as represented by these study farms, remain economically viable under both the baseline and future scenarios. The results also suggest that the overall gain to these farms under a future climate change scenario would be positive. The potential severity of extreme climate events in the future, at least for the future scenario period simulated in this study, would not be significant enough to threaten the future economic viability of Prairie agriculture. However, the research also highlights the importance of policies that support farmers when they endure losses in years of extreme climate events. Further research on evaluating different Best Management Practices (BMPs) in dealing with droughts, for example, would be helpful in taking advantage of future climate change. Policy development to enhance the longer-term adaptive capacity of Prairie farmers, such as development of early warning systems for climate extremes, or the development of drought tolerant cultivars of crops and forages, would be most helpful in coping with climate extremes in the future.

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DEDICATION

Dedicated to

Three wonderful women in my life:

Mother, Kalpana Poudel

Wife, Anju Bohara Poudel

&

Daughter, Shelina Poudel

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Chapter 1 INTRODUCTION

1.1 Background

Scientific evidence and observations throughout the world make it clear that climate change,[1] especially the warming of climate system, is real (Solomon et al., 2007; Karl et al., 2009). Globally, the most pronounced climate change impacts to date include: rising sea levels, increasing temperature, increasing or decreasing precipitation depending on location, high variability in temperature and precipitation, and increasing frequency and severity of extreme climate events. The global average surface, land and water combined, temperature data show a warming of 0.85^0C (0.65 to 1.06^0C), over the period 1880 to 2012 (Stocker et al., 2013). In turn, globally averaged surface temperature is projected to increase more than the observed changes during the 20th century (Solomon et al., 2007). Mean global warming for 2081–2100, relative to 1986–2005, is predicted to be more than 2^0C (Solomon et al., 2007). This suggests that global warming is accelerating a situation that not only increases mean normal temperature but also the variability of temperature and precipitation. Recent global model simulation results indicate all land areas will warm more rapidly in the cold season than the observed global average, particularly those at northern hemisphere's high latitudes (Stocker et al., 2013). This implies that the Canadian Prairie[2] region will experience more warming than southern regions, especially in the winter. Mean annual warming in the northern hemisphere's high latitude regions is expected to exceed global mean warming. Similarly, the global average precipitation is projected to rise towards the year 2100 with notable increase in northern mid to high latitudes and in Antarctica, particularly during the winter and spring seasons (Solomon et al., 2007 and Stocker et al., 2013).

Climate is an important input in agricultural production and climate change will significantly affects world agricultural output as a result of altered weather variables. Changes in climate not only affect agricultural productivity but also the performance and maintenance of

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[1] "Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity" (Pachauri and Resinger, 2007).

[2] The Canadian Prairies comprise the provinces of Alberta, Saskatchewan, and Manitoba, as they are partially covered by prairie (grasslands) and they are also considered a northern extension of the great plains of North America (The Royal Canadian Geographic Society, 2014)

agriculture ecosystem as a whole. Agriculture productivity and performance is expected to increase at mid- to high latitudes, from small increases in local mean temperature and then decrease beyond that but the lower latitude regions are projected to suffer even from small increases in local temperature (Pachauri and Resinger, 2007). As a northern high latitude region, the Canadian Prairie, especially the far northern parts of the Prairies, is expected to become warmer with a higher minimum temperature, resulting in warmer summers in the future. In turn, these changes would lead to longer crop growing seasons and higher growing degree-days (GDD), and ultimately the expansion of crop and forage areas towards northern latitudes (Thorpe, 2011). Canadian Prairie agriculture is projected to benefit under the future climate change due to the easing of problems with lower temperatures (Kulshreshtha, 2011; Weber and Hauer, 2003). But the Canadian literature on climate change's impact on crop production varies from large negatives to large positives depending on the climate scenarios considered, methodologies used, and location of the study (Kulshreshtha et al., 2010). Overall, the effect of climate change on Prairie agriculture is predicted to be positive, understanding that the risk of drought and flooding also increases with climate change (Kulshreshtha and Wheaton, 2013). Researchers do agree that the Prairie climate patterns will significantly be altered in the future (Bonsal et al., 2013; Houghton et al., 2001; Barrow, 2009). Significant changes in climate may also change future Prairie agricultural practices and the farm financial situation.

1.2 Need for the study

Agriculture is perhaps the most researched industry in the context of climate change but uncertainties abound on its impact, both regionally and globally. These uncertainties are attributed to the methods and approach used in impact assessments, from the construction and selection of climate models to the selection of economic models in estimating likely economic impacts. Some of the considerations that bring uncertainties in these results include emission scenarios, agricultural enterprise/s or combination of enterprises, consideration of CO_2 fertilization effects on crops, selection of crop models, economic models used, consideration of extreme events, and assumptions for adaptations, amongst many others (Kulshreshtha and Wheaton, 2013).

The importance of Prairie agriculture in Canada cannot be understated since it occupies more than 80% of total agricultural land in Canada with about 50% of total Canadian farms operating in the Prairie region (Statistics Canada, 2012a; 2013a). Most of the past climate change impact studies on Prairie agriculture have concentrated on the crop sector, particularly on wheat production (e.g., Kumar and Haque, 1998; Mooney and Arthur, 1990; Bornn and Zidek, 2012). Prairie agriculture production systems continue to be diversified with the introduction of lentil, peas, oilseeds and beef cattle production activities. Beef cattle production is the largest source of farm cash income, with most beef cattle production concentrated in the Prairies especially in Alberta and Saskatchewan (Kulshreshtha, 2012). The contribution of the Alberta and Saskatchewan beef cattle industry in the total share of beef cattle production to Canadian farm cash income are 49% and 16%, respectively (Kulshreshtha, 2012). Also, increasing farm size as indicated by fewer farms with almost no change in total beef cattle inventory in recent years implies that beef cattle production is becoming more commercial (AAFC, 2014a). However, the study of livestock production under climate change, particularly beef cattle farms, is relatively limited (Kulshreshtha, 2011). Therefore, estimating climate change's impact on beef cattle farms would be a timely undertaking that would not only inform Prairie beef cattle producers about expected economic impacts, but could also help policy makers to formulate appropriate measures for the future.

The limited work that has been conducted on the impact of climate change on beef cattle farms has neglected the possible risk associated with one of the rapidly growing agriculture activities in the Prairies. Also beef cattle production is highly integrated with crop production activities. This is largely because crops and cattle activities often compete for the same resources such as lands and cash, and can also complement each other for some other resources. An increase in crop price may benefit grain farms but may also negatively affect cattle production due to increased feed cost. Crops and cattle may have different resilience to climate change and extremes. Therefore the effects of climate change on agricultural enterprises that are specialized in crop or livestock production may be different from the effects on mixed enterprises having both crop and cattle activities. Therefore, studies investigating individual enterprise's responses to climate change scenarios present only a partial picture of potential climate change impact (Kulshreshtha et al., 2010). Individual enterprises may incur losses due to climate change, but, for the industry as a whole, these losses may be offset by gains through different resilient mechanisms to climate change in agriculture.

While weather is beyond the immediate control of the humans, human activity may help minimize climate risks on agriculture, potentially making the system more resilient to changing climatic conditions. With respect to agriculture, Singh and Narayanan (2012) asserted that it would be ingenuous to consider typical dumb-farmer[3] assumptions whereby farmers do not react to the negative impacts of climate change on farm profit. A rational individual always adapt to changing condition to minimize negative impacts. Over time, humans have developed methods to adapt their farming practices to external and internal shocks. Kates et al. (2012) assert that these adaptations range from incremental to transformational[4] and can be understood as a part of development process. Producers may optimize input use, or change management strategies, such as switching over to more resilient agricultural practices, which could help agriculture adapt to a changing climate. These practices may minimize risk for the farmers and also take possible advantage of changing climate. Wall et al. (2004) suggested that consideration of adaptation is necessary in climate change impact assessment. Kulshreshtha and Wheaton (2013) also emphasized the necessity of considering producers' adaptive responses for climate change impact assessment in agriculture.

Considerations of future climate scenarios bring another uncertainty into climate change impact assessment. Global studies suggest that impact of climate change on Prairie agriculture would be positive but the Canadian studies show mixed results depending on regions and climate change consideration (Weber and Hauer, 2003). Kulshreshtha and Wheaton (2013) summarized these results and state that Prairie agriculture would benefit from global warming due to longer growing seasons and more heat units, but in fact none of the available climate change impact studies on Prairie agriculture have taken into account extreme weather events, or at least have not explicitly incorporated them in their analysis (Kulshreshtha and Wheaton, 2013).

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[3] The "dumb-farmer" assumption considers that an individual doesn't respond to or prepare for the climate change and continues to act as if nothing has happened (Smith et al., 1996).

[4] Incremental adaptation is a refinement of existing adaptation that reduces the losses or enhances the benefits of climate change. Transformational adaptation is collective adaptation that is explicitly planned and includes autonomous adaptation by individuals that can cumulate in transformative process, or action intended to address other problems that can become transformative adaptation (Kates et al., 2012).

1.3 Objectives

The primary goal of this dissertation is to assess the likely economic impact of climate change on a set of representative Prairie mixed farm businesses[5]. As discussed in Section 1.2, in this manner, this research addresses several of the research gaps identified in climate change impact assessment related to agriculture, namely: 1) the inclusion of future normal as well as extreme climate events; 2) the inclusion of farmer adaptation efforts over time, and; 3) the inclusion of beef cattle activities. Specifically, the dissertation sets out to fulfill the following research objectives:

- To measure the profitability and farm financial situation of Prairie mixed crop and beef cattle farms;
- To estimate the economic impact of climate change and extreme weather on crops, forages and beef cattle production activities;
- To estimate the effects of climate change and weather extremes on the economic viability of Prairie mixed farms; and,
- To evaluate selected adaptation alternatives to cope with climate change and weather extremes in managing mixed farms in the Canadian Prairie region.

1.4 Methods and Scope

In this research, I develop a Mixed Farm Model for the economic impact assessment of Climate Change and Extremes (MF-CCE) in order to address the issues identified in assessing potential climate change impacts in Canadian Prairie agriculture. In particular, two study farms, one located in the Swift Current region of Saskatchewan and the other located in the Pincher Creek region of Alberta are simulated using this approach comprising a whole farm simulation and scenario analysis.

The methodologies used here can be broadly divided into three categories: 1) development of a typical Prairie farm with description of farm level activities; 2) characterization of the farm

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[5] This study is a part of the project entitled "Vulnerability and Adaptation to Climate Extremes in Americas (VACEA)" which includes five countries: Alberta and Saskatchewan of Canada, Argentina, Brazil, Chile, and Columbia. The project is designed to understand the impacts of global climate change on regional climate variability and extremes, and resulting impacts on agricultural as well as indigenous communities (VACEA, 2011).

through inputs and outputs; and, 3) once calibrated, construction and simulation of the scenario. The farm construction approach has been used to develop what I refer to as a typical Prairie farm that performs all major agricultural activities attributable to the region. Specific information pertinent to mixed crop and beef cattle operations are obtained from Statistics Canada (2012b) and used to develop the land and livestock base of a mixed beef cattle-crop farm. Each farm is considered to produce major crops, namely spring wheat, barley, canola and maize along with the hay and pasture required to maintain a beef cattle operation. The beef cattle operation consists of three major activities: cow-calf, backgrounding and finishing activities. Besides normal climate scenarios, the impact of climate extremes is considered by including projected inter-annual climate variability in order to measure its impact on crop and beef cattle production. The base scenario I use in the simulation extends from 1971 to 2000 while the future scenario runs from 2041 to 2070.

In addition, a cattle herd simulation is performed to estimate the inputs required and output generated from beef cattle production activities. I assume that my simulated farms produce enough crops, hay and pasture to support beef cattle feed demand. Pasture production and resulting pastureland requirements are calculated by linking pasture demand and on-farm supply, both expressed in terms of Animal Unit Month (AUM) units. Beef herd crop demand and on-farm crop supply are linked through the solution of a cost minimizing linear programming algorithm. Crop mix is also conducted by solving a multi-period linear programming problem that maximizes the present value of farm gross margin. Within the simulation, crop and hay productivity are estimated using FAO's AquaCrop model framework, while pasture productivity is estimated by employing the Forage Calculator for Native Rangeland, as obtained from Saskatchewan Research Council (SRC). All the information is linked in a spreadsheet format to perform the whole farm simulation and scenario analysis.

1.5 Organization of the thesis

The thesis is organized into nine chapters. Chapter 2 presents a review of the literature related to observed and projected climate in the Prairies and the impacts of climate change on Prairie agriculture, and an overview of the methodologies used in climate change impact assessment. Theoretical considerations relevant to the interaction of climate and agriculture, as well as terminology applicable to climate change impact assessment in agriculture are presented in Chapter 3. Chapter 4 describes the general climate situation, as well as agriculture and typical beef cattle-crop farm characteristics of the study sites. Descriptions of the base simulation model and methodologies are outlined in Chapter 5. Description of the crop and pasture model, the input climate scenario and results of crops and forage yields models are presented in Chapter 6. Chapter 7 provides descriptions of study scenarios and farmer adaptation strategies for climate change and extreme. Chapter 8 discusses the overall results, including the base model and my scenario analysis. Summary of the work and policy recommendations are outlined in Chapter 9.

Chapter 2 LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature related to climate and agriculture in the Canadian Prairies and the methodologies used for climate change economic impact assessment in agriculture. A review of historical climatic patterns and climate forecast under future global climate change scenarios is presented in Section 2.2. This is followed by a review of the vulnerability of agriculture and livestock to climate events in the past and likely effects anticipated in the future in Section 2.3. These sections are followed by a detailed review in Section 2.4 of different methodological approaches which not only help articulate the available models and techniques in climate change impact assessment in agriculture but also provides a basis for the methodology developed in this study. As this study sets out to assess economic impacts on crop as well as beef cattle activities at the farm level, it pays a special attention to the farm level simulation models and their flexibility in incorporating livestock activity. As this study combines a mixed farm model to a farm simulation model, Section 2.5 reviews the literature related to the use of crop model, namely the AquaCrop model, in estimating crop production in the past. Section 2.6 summarizes the chapter with special focus on the likely impacts of climate change in the Canadian Prairies, and the available methodologies for a farm level climate impact assessment.

2.2 Climate in the Canadian Prairies

The Canadian Prairies are characterized by cold and temperate climate with dry and moisture-deficit conditions for most of the year. The winters are very cold and long while the summers are short and warm. The Prairies are the most drought prone region of North America, where droughts of varying intensities and durations have occurred for many centuries (Bonsal et al., 2013). In history, the 20th century is known for the period of severe droughts, especially the periods in 1920s and 1930s, which are known as the dust bowl years. Venema (2006) states that the severity of droughts varies across regions; regions experiencing higher inter-annual variability of temperature and precipitation are likely to experience severe droughts.

Historical climatic data of the Canadian Prairies has shown a warming trend with a significant increase in mean annual temperature since 1970s. An analysis of temperature records from 1895 for 12 stations of the Canadian Prairies shows an average increase of 1.6^{0}C (Sauchyn and Kulshreshtha, 2008). Spring shows the greatest warming with significant positive trends in January, March, April and June (Zhang et al., 2000; Gan, 1998). Climate projections for the Canadian Prairies are also similar to the observed trends as most of the studies project significant warming, no or little change in precipitation and increased frequency of extreme weather events in the future (e.g., Bonsal, et al., 2013; Houghton et al., 2001; Solomon et al., 2007)

Barrow (2009) estimated the effect of global climate change scenarios on climate indicators in Saskatchewan in terms of minimum, mean and maximum temperatures and precipitation, as well as for growing degree-day (GDD) and annual moisture index. These estimates were made for 2020s, 2050s and 2080s scenarios, each for forest and grassland regions. Results indicated that changes would range from no change to limited increases in mean annual precipitation and temperature in the forest region. Compared to forest regions, grassland regions are expected to experience larger decreases in precipitation and larger increases in temperature for all three scenarios. At the seasonal scale, wet and warm winters and springs, and dry summers and falls are projected. All the seasons are expected to have less precipitation, but, in the case of temperature change, winters are expected to see the largest increase in mean temperature (Barrow, 2009). Similar to Barrow's (2009) report, Thorpe (2011) predicted a substantial increase in temperatures but only small changes in annual precipitation and seasonal distribution of precipitation in the Prairie region.

Bonsal et al. (2013) assessed the variability, intensity and duration of past, present and future droughts in the Canadian Prairies using two standard drought indices, the Palmer Drought Severity Index (PDSI) and Standardized Precipitation Index (SPI). They used statistically downscaled climate variables from several Atmosphere–Ocean Global Climate Models with multiple emission scenarios. They showed that the twentieth century droughts were relatively mild compared to pre-settlement period droughts. With the anticipated warming during the course of the twenty-first century, future droughts in the Canadian Prairies are predicted to be severe and even worse than the ones in pre-settlement era (Bonsal et al., 2013).

PaiMazumdar et al. (2013) used the Canadian Regional Climate Model (CRCM) in studying changes in future drought characteristics in the Canadian Prairies. Their analysis of precipitation and drought patterns of the 1971-2000 and the 2041–2070 periods showed drier summers and wetter falls, winters and springs, suggesting summer droughts in the future (PaiMazumdar et al., 2013). The severity, frequency and duration of both short- and long-term droughts over the southern Prairies are projected to increase, with the largest increase in the longer term events of at least 10 months (PaiMazumdar et al., 2013). Table 2.1 presents possible changes in agro-climates of the Canadian Prairie regions and its implication in agriculture compared to base climate of the 1960-1991.

Table 2.1 Future possible changes in agro-climates for the agricultural region of the Canadian Prairies, and examples of possible advantages and disadvantages for agriculture

Indices	**Changes (with respect to 1961-1990**	**Climate models and emission scenarios**	**Period and spatial pattern**	**Possible Advantages for agriculture?**	**Possible Disadvantages for agriculture?**
Thermal Indices					
Growing degree-days	25 to 40%	CSIROMk2b Bll, greater changes with the other models	2050s Greater changes in the north	More crop options; more crops per year; improved crop quality; shifts to earlier spring and later fall growth	Accelerated maturation rates and lower yields; increased insect activity; changed herbicide and pesticide efficacy; changing insects and diseases could be negative for human, plant, and livestock health
	42 to 45%	CGCM GA1	2050s for Lethbridge and Yorkton		
Heating degree-days	-23%	CGCM GA1	2050s for Lethbridge and Yorkton	Decreased heating costs	
Cooling degree-days	146 to 218%	CGCM GA1	2050s for Lethbridge and Yorkton		Increased ventilation needed for barns, increased cooling shelters, and air conditioning
Hot spells:20 y return period of maximum temperature	1 to 2°C increase from 2000	CGCM2 A2	2050	Better vacation weather?	Heat stress to plants and animals; increased transpiration rates can reduce yields; increased need for water for cooling and drinking
Cold spells: 20 y return period of minimum temperature	2 to >4°C increase from 2000	CGCM2 A2	2050	Decreased heat stress to animals	Increased pest and diseases Winterkill potential increases
Moisture Indices					
Soil moisture capacity (fraction), annual	>0 to <-0.2 Mostly drying	CGCM2 A2 ensemble mean	2050s Greatest decreases in south to southeast		Increased moisture stress to crops and decreased water availability
Palmer Drought Severity Index	Severe droughts twice as frequent	Goddard Institute for Space Studies*	Doubled CO_2	No flooding damages	Increased damages and losses from droughts; increased costs of adaptation, etc.

Moisture deficit; annual precipitation minus potential evapo-transpiration (P-PE)	-60 to -140 mm, i.e. increased deficit 0 to -75 mm -11 to 4 mm	GCM1 and HadCM3 CGCM1 GA CGCM1 GA1	2050s 2050s 2050s for Lethbridge and Yorkton	As for droughts As above Direction of change not clear	As for droughts As above Direction not clear
Aridity Index; ratio of annual precipitation and potential evapo-transpiration (P/PE)	Area of AI<0.65 increases by 50%	CGCM2 B2	2050s	As above	As above
Number of dry days: time between 2 consecutive rain days (=>1 mm)	Modest & insignificant changes	CGCM2 A2	2080-2100		
Number of rain days	Modest & insignificant changes	CGCM2 A2	2080-2100		
Precipitation extremes: 20 y return period of annual extremes	Increase of 5 to 10 mm and return period decreases by about a factor of 2	CGCM2 A2	2050		More flooding and erosion concerns; more difficult planning for extremes
Snow cover	Widespread reductions	CGCM2 IS92a	Next 50-100 years	Decreased snow plowing; Increased grazing season	Decreased quantity and quality of water supplies
Other Indices					
Wind speed, annual	<5 to >10%	CGCM2 A2 ensemble mean	2050s	Greater dispersion of air pollution	Greater soil erosion of exposed soils; damage to plants and animals
Wind erosion of soil	16% -15%	Manabe and Stouffer** Goddard Institute for Space Studies**	Doubled CO_2 Doubled CO_2	Direction of change is not clear	Direction of change is not clear
Incident solar radiation	<-2 to <-6 Wm^{-2}	CGCM2 A2 ensemble mean	2050s Greatest decreases in	Decreased radiation may partially offset heat stress	Reduced plant growth if thresholds are exceeded
Climate severity index	-3 to -9	CGCM1 IS92a	2050s Greatest improvements in AB and MB		Less severe climates for outside work; more suitable for animals
Carbon Dioxide	Various emission scenarios used, e.g., 1%y^{-1}	IS92a		Increased plant productivity, depending on other limits	Possible effects on quality of yield

* Per citation in Williams et al. (1988)

** Per citation in Williams and Wheaton (1988).

Source: Kulshreshtha and Wheaton (2013)

The findings of Price et al. (2011) also suggested the likelihood of increasing temperature, little or no significant changes in precipitation, increasing in water scarcity, and increasing frequency of droughts in the future. They derived finer scale future climate scenarios separately for Prairie semiarid and Prairie sub-humid regions.[6] Their findings revealed that in the Prairie semiarid region both the annual minimum and annual maximum temperatures would increase; however, the increase in minimum temperatures would be greater than the increase in maximum temperatures. Season-wise, winter warms the most with an increase in minimum temperature of up to 5.5^0C, and the maximum temperature increase is greater in the summer (Price et al., 2011). Their results projected a modest increase in precipitation in the range of 8% to 15% depending on emission scenarios and whether precipitation increase is evenly distributed through all the seasons. Further, Price et al. (2011) projected an increase in inter-annual variation of precipitation which implies the possibility of multi-year droughts. In sub-humid Prairies, temperature increases are similar in magnitude and pattern as in semiarid subzone and annual precipitation increase in the range of 5% to 12%. However, the distribution of precipitation is not even across all the seasons (Price et al., 2011). For instance, more precipitation increase in the spring and less in the other seasons, with little consistent increase in the summer, implies that the treed region of the Canadian Prairies is likely to experience increasing water scarcity in the future.

Existing literature suggests that climate change patterns in the Prairies indicate that climate change brings positive changes in many agro-climatic variables, such as lengthening of growing season, increasing frost free days and greater heat units. But an increase in the inter-annual variability of temperature and precipitation is also projected with the possibility of increasing severity, frequency and duration of droughts in the future.

2.3 Climate change impacts on the Canadian Prairie agriculture

The main effect of climate change is generally understood as an increasing temperature. For some Canadian regions, the increase in temperature could be beneficial as it results in production opportunities from the extended growing season and increase in available heat units

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[6] The semiarid region consists of largely treeless central Prairie grasslands, which extends south into the Great Plains region of the United States. The sub-humid region has significant tree cover and it borders the Rocky Mountains to the west, the boreal forest to the north, and the mixed-wood regions around Lake Winnipeg to the east (Price et al., 2011).

(Bootsma et al., 2005). The Prairies are a cold region in the high latitude of northern hemisphere, and effects of such warming are considered beneficial as they may present opportunities, such as expansion of growing season, increase in heat units, and milder and shorter winters. However, the positive effects of such warming can only be harnessed if the water requirements to compensate increased evapotranspiration and the needs of expanded agricultural activities are sufficiently met. Climate change has many other effects on agro-climatic indices as presented in Table 2.1. Bonsal et al. (2013) showed that the possibility of more severe droughts in the future may outweigh the benefit of warming alone. The studies investigating the impact of climate change on Prairie agricultural system are mixed - ranging from absolute loss to absolute benefit depending on assumptions made, climate scenarios used, methodologies used, and whether adaptations are incorporated or not (Kulshreshtha et al., 2010).

2.3.1 Climate change impacts on crop production

Global studies relating climate change and agriculture suggests that Canada will benefit from global warming (Weber and Hauer, 2003). However, results from Canadian studies suggest mixed results, depending on regions, crops and climate change considerations (Weber and Hauer, 2003; Kulshreshtha et al., 2010). Individual crop response to climate change scenarios varies across crops as different crops have different critical temperature ranges (Robertson et al., 2013). Brklacich et al. (1998) concluded that warmer frost free seasons under global warming scenarios will enhance crop physiological development and shorten the time between seeding and harvesting in Canada. This would result into a reduction in cereal yield by 34% in Western Canada and an increase of up to 66% in eastern Prairie regions. Bootsma et al. (2005) stated that corn yield will increase by 40-115% and soybean yield will increase by 21-50% while the barley yield will suffer in the future. An and Carew (2015) projected negligible impacts on canola and negative impacts on barley yield in the future. Chipanshi et al. (1999) showed that global warming will likely bring drier conditions and may negatively impact wheat yield. In case of only a temperature increase with no effect to slight increase in precipitation, the crop productivity may decrease in the future. Crop production in the Prairies is expected to benefit if both the temperature and precipitation increase under future climate change scenario (Carew et al., 2009). Saskatchewan canola yield is projected to decrease under global warming without a change in precipitation (Kutcher et al., 2010). Changes in the variability of climate have major impacts on crop yield. An increase in average temperature may be beneficial for future crop production, but an increase in variability will impact the crop production negatively, as shown by An and Carew (2015) and Cabas et al. (2010). However, the studies investigating individual crop responses to climate change scenarios present only a partial picture of the climate change impact (Kulshreshtha et al., 2010). Producers try to maximize their farm income by adapting to changing climatic conditions and by altering management practices and farm enterprise mix. Bringing such an adaptation processes into impact studies gives different estimates of climate change effects. Arthur and Abizadeh (1988) found that the yields of most of the existing crops in the Prairies would decline under global warming scenario, but the aggregate provincial sector could offset these losses by adapting more drought resistant crop varieties.

Robertson (2012) focused on the impacts of climate change, specifically the effect of changes of temperature and precipitation under future climate scenarios on the profitability and crop mix in the Canadian Prairies. Her study tested the hypotheses that climate change will increase the production of drought-tolerant crops; the heat tolerant crops will move farther north as temperatures increase; and the spatial distribution of crops depends on the distribution of rainfall patterns. Her results supported the hypotheses proposed in the study. She further suggested, that with small increases in greenhouse gas (GHG) emissions, farmers on the Prairies would see significant benefits by including some drought tolerant crops, such as winter wheat and barley, in their crop mix. However, with the large increase in the emissions, the profitability of production of the crops modeled decreases, and barley and winter wheat dominates Prairie crop production by the 2050s.

In his study on the vulnerability of grassland and land shifts under climate change, Thorpe (2011) observed that climate change will likely impact the Prairie ecozone significantly over the coming centuries. Vegetation zones were expected to shift northward with increasing grass in the existing treed region. Grassland production was estimated to decrease, but the size of this loss depends on climate scenarios: slight under the cooler scenarios to moderate under the warmer scenarios. The fertilizing effect of rising CO_2 concentrations could help to moderate production losses but the occurrence of drought in the future would cause major impacts on crop production and shifts in the vegetation zone (Thorpe, 2011).

IISD (1997) reviewed historic droughts and their impacts on Prairie agriculture, including livestock. The drought of 1987-88 severely impacted the Prairie crop sector resulting in a $4 billion export loss. The farmers were paid out over $1.3 billion in crop insurance and special drought assistance from the government across the Prairie Provinces. Even after that support, Manitoba showed net farm income losses of 50% with Saskatchewan showing a loss of 78%. In Canadian drought impact studies, Kulshreshtha and Marleau (2005) reported that Alberta crop producers lost $413 million in 2001 and $1.33 billion in 2002, whereas Saskatchewan's reduced crop production value amounted to $925 million in 2001 and $1.49 billion in 2002. Losses in farm cash receipts in 2001 and 2002 were recorded as $267 and $920 million respectively for Alberta, and $652 and $953 million respectively, for Saskatchewan (Kulshreshtha and Marleau, 2005).

The literature on climate change impacts on Prairie crop production is divided: the results vary from some negative to some positive productivity changes. Studies investigating farm and higher spatial levels estimated positive economic gain in the future, given that the producers would adapt to changing conditions. Most of the available studies also agree that adverse impacts may be generated due to the increased frequency of extreme events.

2.3.2 Climate change impacts on livestock production

Livestock production in the Canadian Prairies is a relatively unstudied area in terms of climate change effects. Some available studies from the Prairies and other regions of the world show mixed results depending on the context of assessment, methodologies used, and climate scenarios considered. The effects of climate change on livestock can be broadly categorized into two types: 1) direct effect of warming on livestock growth and productivity, and 2) through indirect impact on grassland and rangeland production. According to Rowlinson (2008), heat stress reduces the rate of animal feed intake and results in poor growth performance. Inadequate water and increased frequency of drought lead to loss of resources including grassland and rangeland. Kulshreshtha and Wheaton (2013) noted that conceptually the impacts of climate change on livestock should be negative because of the adverse impacts of climate change on forage and grain production, and on livestock productivity. Thornton et al. (2008) summarized different direct and indirect effects of climate change on livestock. Livestock would be directly affected through heat stress and heat-related mortality. The indirect effects on livestock would be through changes in grassland and rangeland productivity and also by changes in digestibility and palatability of pasture and forage crops.

Seo and McCarl (2011) investigated the effect of future climate scenarios on the livestock sector in Australia and found that livestock species are resilient to a hotter and more arid climate. They showed that both the number of livestock species owned and amount of revenue per farm increased significantly with the increasing temperature under all the climate scenarios considered, except for dairy cattle. Seo and McCarl (2011) found a similar result for the scenarios with the decrease in precipitation, implying that livestock producers can make positive profit under future hotter and drier conditions by proper management of livestock. An earlier study on impact of climate change on livestock by Seo and Mendelsohn (2007) showed that both the increasing temperature and rainfall negatively impact income and the number of beef cattle head. With higher temperatures, the number of beef cattle decreased while the number of dairy cattle, sheep and goats increased.

Belasco et al. (2015) estimated the direct impacts of climate extremes on livestock production. Their study related the weather shocks measured through Comprehensive Climate Index (CCI) to the production variables, such as the average daily gain (ADG), feed conversion ratio (FCR) and mortality rate (MR). They evaluated the loss associated with extreme weather events in the beef feedlot operations in the United States and derived producer willingness to pay to eliminate the risk. They further discussed a possibility of insurance products to cover the biological effects of extreme weather events on a beef cattle operation. They employed a non-linear regression to 20 years of panel data of 15,836 pens covering the period between 1980 and 1999. Specifically they examined the impact of animal exposure to hours of extreme hot and cold weather on the cattle’s performance by controlling other pen characteristics, such as gender, location, animal weight, and seasons of feedlot placement. Their results suggest that when the exposure to extreme weather increases, ADG of feedlot cattle decreases and the mortality increases. Impacts are more severe on young cattle while mature cattle are relatively less sensitive.

In the Canadian Prairies, few existing studies suggest that an increase in temperature and a slight increase in precipitation will have positive effects on livestock through increased production of forages and grain. Thorpe (2011) concluded that the future warming scenarios will shift the

Prairie ecozone northwards with the possibility of more rangeland in formerly forested areas, which opens up the possibility of expanding livestock activities in the northern part of the Prairies. Though future warming may impact the grain industry, it may also provide the possibility of expanding the livestock industry. However, in her study, Sykes (2008) concluded that, in the existing grassland area of the Prairies, the forage and beef cattle would not be significantly impacted, implying that beef production is somewhat resilient to climate change. However, the extreme weather events would likely significantly impact cattle production as in the past. According to IISD (1997) the 1987-1988 Canadian Prairie droughts severely affected the livestock sector because of the limited feed availability and lack of suitable pastureland due to drought conditions.

Knowledge on the direct impact of climate change on livestock in the Canadian Prairies is very limited (Kulshreshtha, 2011) and the impacts on livestock are mainly linked through the projected impacts on crop and forage productivity and quality (e.g., Sykes, 2008; Thorpe, 2011). Increases in both temperature and precipitation are believed to positively impact feed production. At the regional level, livestock production may benefit due to the expansion of forage area towards the north but the changes in productivity of forages and grain are major factors that determine farm level impacts.

2.4 Methodologies in estimating economic impact of climate change on agriculture

A variety of methodologies have been used to estimate the impact of climate change on agriculture. These methodologies range from crop specific bio-physical simulation approaches to estimate crop yield impact to a combination of different biophysical and economic approaches to estimate the economic impacts on farm, regional, national and global scale. Some of the most common approaches are reviewed in the following sub-sections.

2.4.1 Bio-physical simulation approach

Biophysical crop models are used to simulate crops' response to given input and management conditions by creating controlled dynamic plant growth processes. The models are computerized representations of crop's physiological process in the form of mathematical equations (Hoogenboom et al., 2004). These simulation models can be used in a variety of scenario analyses by altering the variable of interest. The need and characteristics of the crop models have been discussed by Whishler et al. (1986). Once the model is calibrated, the climate input can be altered to see the crop response against climate change. Crop-specific or generic models have been developed and widely used in the climate change impact assessment (Parry et al., 1998).

The use of bio-physical models to assess the direct impacts on livestock is rare; instead crop and pasture models are used to examine possible climate change impacts on forage, pasture and grain production (Baker and Vigilizzo, 1998). The livestock component is integrated into an economic decision model to see the likely impact of climate change on livestock.[7] Cohen et al. (2002) and Sykes (2008) used Grassgro Decision Support System (DSS) tools to estimate the future climate change impacts on forage production linked to livestock performance in Saskatchewan.

The crop models have been widely used to understand the effect of climate change on crop yield as the focus of such models is on the biological consequences of climate change on crops. For this reason, the crop models are usually combined with economic models to assess the economic impact on farm to regional and global level (Adams et al., 1995; Mooney and Arthur, 1990; Rosenzweig and Parry, 1997; Henseler et al., 2009). The outputs from biophysical models are fed into economic models to estimate the economic impacts of climate change at farm and higher spatial levels. Therefore, biophysical simulation models alone have limited scope in estimating economic impacts of climate change. This study combines biophysical models with economic models to estimate the economic impacts of climate change at farm level. The bio-physical model used in this study is discussed in Section 2.5.

2.4.2 Computable General Equilibrium (CGE) approach

Computable General Equilibrium (CGE) models estimate the impact of climate change on agriculture and relate the impacts to the other sectors of an economy. This technique is best suited

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[7] There have been a variety of livestock models available for the different purposes. These models are commonly called by their acronyms and used to analyze a variety of scenarios: the CCGRASS, CENTURY, GEM, and GRASS simulate the rangeland ecosystem; the *Hurley Pasture* model; the *ToppandDoyle* model and SPUR2 simulate rangeland livestock production; and the GRASSMAN and CLIMPACT combine different biophysical production models with economic decision models to estimate the economic consequences of climate change on livestock production and management (Parry et al., 1998).

for the macroeconomic assessment at regional, national or global levels. It allows the interaction among sectors and other global regions (Parry et al., 1998). The interaction among sectors in CGE approach allows estimating the indirect effects of climate change on non-agricultural sectors as well as on the economy of other global regions. CGE models were first developed by Darwin et al. (1995) to evaluate the effects of global climate change on world agriculture that links climate to land, water, production, trade and consumption of 13 commodities throughout the world. They combined CGE models with Geographical Information System (GIS) models, where GIS models estimated the impacts of climate on agriculture, and to identify economy-wide impact. Gebreegziabher et al. (2011) analyzed the economic impact of climate change on Ethiopian agriculture using a national CGE model, where effects on agriculture were measured initially by using the Ricardian model to estimate the current and future agricultural productions as a function of temperature and precipitation. Bosello et al. (2012) used a CGE modeling approach to estimate the economic impact of climate change on agriculture by employing partial equilibrium techniques to physically quantify the impact of climate change on agricultural productivity as well as on other non-agricultural sectors while linking them to recursive dynamic CGE models to measure the economy-wide impact of climate change in the EU regions. Ochuodho and Lantz (2013) used a CGE approach to estimate the impact of climate change on Canadian agriculture. Specifically, they used CGE models to compare the economic impacts of individual, additive, and simultaneous climate-induced changes on agriculture and forest sectors over the 2006-2051 periods (Ochuodho and Lantz, 2013).

In summary, CGE models can be used to simulate the impacts of climate change by introducing exogenous climate shocks derived in the equilibrium but such assessments are more suitable for the modeling of economy on a regional or national level. These models highly aggregate the sector in an economy and there are only few of them that are concentrated on global warming (Bosello and Zhang, 2005). Therefore, CGE model may not be a good choice for farm level assessments.

2.4.3 Econometric approach

Econometric approaches link climate to crop yield, farm profit or farmland values using simple linear models and complex structural models in an attempt to estimate the climate change impacts on agriculture. Econometric approach, which is widely used in the economic analysis of climate change impact on agriculture, can be grouped in two broad classes: the Ricardian land value approach and the production function approach.

The Ricardian land value approach relates the hedonic land values to climate variables and land attributes. The approach was first put forward by Mendelsohn et al. (1994) in order to assess the impact of climate on US agriculture by estimating the direct impact of climate on agriculture productivity measured through land rent. The approach is based on the "Ricardian land rent theory" which holds that in a competitive market, land value equals the present value of expected net revenues from land, which are derived from the most economically efficient use of land (Mendelsohn et al., 1994). Results are expressed in terms of net farm revenue that captures the farmers' adjustments in the changing climate. In other words, this approach implicitly assumes that the farmers automatically adjust to the changing climate, for instance, by altering input choices, production technologies and enterprise mixes for the economically efficient use of land (Parry et al., 1998). Reinsborough (2003) used the Ricardian model to establish the relationship between climate and land value in Canada. He used Canadian census division level data and regressed farm- land value for the climate, socioeconomic and geographical variables. Amiraslany (2010) also used the Ricardian model to estimate the economic impact of climate change on farm net revenue and farm land value in the Prairie regions of Canada. Maddison et al. (2007) examined the impacts of climate change on African agriculture to see how farmers in African countries have adapted to existing climatic conditions using a Ricardian land value model.

The other econometric method uses a production function approach, which relates agricultural production or profit to climate variables using panel or time series data. Cabas et al. (2010) employed stochastic production functions to estimate crop yield response to economic, site and climate variables in southwest Ontario, Canada. Chen et al. (2004) used a similar stochastic production function approach to estimate crop yield variance across the United States for the present and future projected climate. Poudel and Kotani (2013) deployed a stochastic production function model to estimate the impact of climatic variation on current crop yield and extrapolated the effect of projected future climate in Nepal utilizing district level average seasonal climate and crop yield data.

These econometric approaches are more common for aggregate regional level studies as the data required to estimate them are flexible, and climate, yield or profit data on aggregate level are readily available (Robertson, 2012). However, the application of this approach at a farm level is difficult due to the lack of farm-specific information over a long period of time. The production or profit function model can be developed as a simulation model by combining an agronomic crop simulation model, as shown by Brassard and Singh (2008). This approach assumes all the inputs except climate are fixed, implying farmers do not make any adaptive adjustment to climate change whatsoever (Reinsborough, 2003). The Ricardian models take into account cost and benefit of adaptation because farmers' adaptations are reflected in farm land value (Kurukulasuriya and Ajwad, 2007), though the model cannot explicitly explain what adaptations are done. The major demerit of the econometrics approach is that the model usually suffers from omitted variable bias and as a result, its robustness remains weak (Schlenker and Roberts, 2006).

2.4.4 Farm modeling approach

Farm modeling approaches can simulate the effect of climate change on farm income and economic decisions by changing climatic and non-climatic variables. This approach is often developed and used as a tool for rural planning and agricultural extension, being used to simulate the effect of changes in inputs on farm strategy (Parry et al., 1998). This approach requires farm specific data on farm processes and characteristics to simulate the farm situation. A modeled farm in this approach can be a single real farm, a hypothetical or representative farm with mean or median characteristics of the region, or an aggregate farm by aggregating individual farm data in the region of interest. The modeled farm generates farm income, land use, crop mix or other variables of interest. These outcomes may be varied by altering inputs or coefficients in the farm model. For example, changes in climate can be an input, and the farm-level response an output and income simulated therein (Parry et al., 1998). A farm modeling approach is flexible in the use of methodologies in that it can be a single technique or can be a mix of different techniques, such as biological simulation model for production component, simulation or mathematical programming model/s for economic behavior with the flexibility of incorporating many techniques in an integrated framework (Wijk et al., 2012). This flexibility in model building makes the farm model an appropriate method for the estimation of the climate change impact on the representative Prairie farms in this study. The most commonly used farm models are reviewed in the subsequent sub-sections.

2.4.4.1 Mathematical programming model

Some farm models are based on only a mathematical programming (MP) approach to optimize farm profit. In this type of model, climate is modeled as a stochastic factor based on the observed weather. The model assigns probability to the occurrence of different weather states and associated agricultural yield or profit. The MP model may make use of production models integrated with an optimization model. The methodologies used in such a model are a mix of different techniques, like process-based simulation or statistical methods for production component, and optimization approaches for whole farm economic decisions. Kingwell et al. (1992; 1993) developed a farm-level linear programming model based on discrete stochastic programming, known as Model of an Uncertain Dryland Agricultural System (MUDAS). This model can estimate changes in farm management practices under the assumptions of climate risk. The model incorporates a discrete stochastic representation of weather and tactical response of the farmers in the face of that risk. This approach considers the seasonal variation by considering number of discrete states of nature. Visage and Ghebretsadik (2005) developed a representative crop and livestock farm model using Mixed Integer Linear Programming to optimize the land use for crops, and number of livestock under different level of risk generated by weather variability. These types of models, which use mathematical programming, may provide the effect of climate risk based on observed data.

Table 2.2 lists the Canadian studies that combine crop productivity models with mathematical programming optimization models to estimate the economic impact of climate change on Canadian agriculture. Rivest (2007) used a farm model to estimate the climate change impacts on an average crop and dairy farms separately in Quebec and the rest of Canada. He used an econometric approach to estimate production component, which is linked to linear programming techniques to select profit-maximizing combinations of different farm activities. The impacts of climate change were modeled through yield effect on crops and pastures. Seyoum-Edjigu (2008) modeled a crop farm in Quebec, and the rest of Canada by using the Decision Support System for Agrotechnology Transfer (DSSAT) crop model. The DSSAT model was used to forecast crop yield, results of which were combined with the farm level linear programming techniques for the economic decisions. The base model was then simulated with the crop yield effect of future climate to see the changes in farm income and regional crop mix. Robertson (2012) modeled the impact of climate change on land use changes in Saskatchewan, Alberta and Manitoba. She combined the econometric techniques of yield forecasting with the spatial linear programming model to assess land use change and land shift in these provinces. Brklacich and Smit (1992) combined a crop productivity model with a linear programming model to simulate the farm income and land use change at a farm level and extended the analysis to the regional and province levels in Ontario.

Table 2.2 Studies using mathematical programming based farm models in Canada

Author (Year)	Methodologies	Sector/s considered	Climate change representation
Rivest (2007)	Statistical model of yield forecast incorporated into farm programming model.	Crop and dairy farm separately	Crop and pasture productivity changes
Seyoum- jigu (2008)	Crop model combined with farm programming techniques.	Crop only	Crop yield change
Robertson (2012)	Econometric model of crop climate association incorporated with spatial linear programming model.	Crop only	Crop yield change
Brklacich and Smit (1992)	Crop productivity model incorporated into linear programming model	Crop only	Crop yield change

Similar methodological approaches have been used in countries other than Canada to estimate the impact of climate change on agriculture. Some of these models integrate crop and livestock in a single farm setting. The climate change impacts of these models is incorporated through changes in the productivity of the crop by altering climatic inputs in a crop productivity model (Table 2.3). Kaiser et al. (1993) examined potential economic and agronomic impacts of climate change on a grain farm in Southern Minnesota. A farm level model was developed by combining climatic, agronomic, and economic processes to simulate the sensitivity of crop yields, crop mix, and farm revenue to climate change. The economic model included a farm level multi-stage sequential linear programming model where farmers' responses at any particular point of time depend on the previous decisions and climate state of nature. John et al. (2005) used a whole farm linear programming model with discrete stochastic specification to represent climate risk. They investigated the consequences of several climate scenarios on farm profit, crop mix and sheep herds in the context of dryland farming in Western Australia. The livestock component was linked through the availability of on-farm pasture. The results showed that the optimal farm plan contains fewer crops and is more pasture dominant but the overall livestock carrying capacity decreases and more supplementary grain feeding per head was required in comparison to normal climate scenario (John et al., 2005).

Table 2.3 Selected studies using mathematical programming based farm model, countries other than Canada

Author (Year)	Location	Methodologies	Sector/s considered	Climate change representation
John et al. (2005)	Australia	Crop simulation model incorporated into linear programming model	Crop and livestock	Crop yield change
Henseler et al. (2009)	Germany and Austria	Biophysical crop model combined with Positive Mathematical Programming (PMP) model	Crop and livestock	Crop yield change
Janssen et al. (2010)	European region	Combine biophysical model for the generation of technical coefficient on crop and livestock activities and PMP farm optimization techniques.	Crop and livestock	Crop yield change
Kaiser et al. (1993)	US	Agronomic simulation model linked to multi-stage mathematical programming model	Crop only	Crop yield change
Lehman and Finger (2012)	Switzerland	Crop model incorporated into economic simulation model	Crop only	Crop yield change

Henseler et al. (2009) used the ‘‘Agro-eConomic pRoduction model at rEgional level (ACRE)” to simulate farm income and regional agricultural land use in Germany and Austria. Production factors within each county were aggregated to create a ‘single farm’. The model characterized all possible processes and interactions in agricultural production. The model included the crop production, livestock production, and livestock feeding activities. The crop activities supply feed for livestock while animal manure is used as fertilizer in crop production.

The crop and grassland production activities were simulated through agro-climatic simulation model. The whole farm model was optimized via linear programming approach using Positive Mathematical Programming (PMP) calibration technique. Janssen et al. (2010) used the Farming System Simulation Model (FSSIM) that has two components: the Farming System Simulation Model-Agricultural Management (FSSIM-AM), which simulates the production component, and the Farming System Simulation Model-Mathematical Programming (FSSIM-MP), which simulates the economic component. These are then linked to Extrapolation and Aggregation Model (EXPAMOD) to scale up the findings at a regional level. The FSSIM-AM component consists of biological crop simulation model to link crop yield and weather, which were linked to the FSSIM-MP, which combined both crop and livestock components, and generated optimum crop mix and livestock size under both base and climate change scenarios. Livestock and crop activity were linked through the feed model that specified energy and protein requirements of livestock (Janssen et al., 2010).

Mathematical programming based farm models can simulate the climate change impacts at the farm level as discussed above. The main analytical component of these models is optimization and is best suited to optimize the resource allocation given the expected costs and revenues from the activities, such as land use change. In mixed farm settings with integrated crops, combined with forages, and cow-calf, backgrounding and finishing beef cattle operation, an optimization model may not be a good choice because of difficulty estimating per unit cost and return. Nonetheless, mathematical programming can be a tool in selecting crop choice and formulating the least cost ration for beef cattle combined with other tools and techniques necessary to develop a farm simulation model.

2.4.4.2 Farm simulation model

There is no clear marker between the MP based farm model and Farm Simulation model as the MP models are also the tools for integrated assessment of farming systems. For the purpose of this discussion, the models with more detailed description of process and interaction amongst farming components are illustrated as a farm simulation model. They are more detailed and flexible in model building and scenario analysis. Table 2.4 presents some of the studies that have used whole farm simulation model to assess mixed crop and livestock farms in Canada.

Table 2.4 Selected studies using integrated whole farm simulation model in Canada

Author (Year)	Methodologies		Sector/s considered
	Simulation	Optimization	
Kulshreshtha and Klein (1989), and Klein et al. (1989)	Crops, livestock and poultry mix-farm simulation for drought impact evaluation	No	Crop, beef cattle, hog, dairy and poultry integrated
Koeckhoven (2008)	Beef herd as well as whole farm simulation for economic analysis	No	Crop and beef cattle integrated
Beauchemin et al. (2010)	Beef herd as well as whole farm simulation	No	Crop and beef cattle integrated
Modongo (2014)	Whole farm simulation for economic analysis	No	Crop and beef cattle integrated

Kulshreshtha and Klein (1989) and Klein et al. (1989) developed an Agriculture Drought Impact Evaluation model (ADIEM) to evaluate the impacts of agricultural drought on typical mixed farms in Saskatchewan, Canada. The results were also extrapolated to the regional and national level. A yield-hydrology model was used to assess the impact of moisture stress on crops and forages and its impact on livestock on farms. Sets of farm business simulation models were used to evaluate farm financial positions. The farm level impacts were linked to the provincial level by employing input-output and employment models. The employment model linked the farm level impacts to provincial employment whereas the input-output model linked the impacts to non-agricultural industry and provincial GDP. Impacts on provincial level imports were also derived from the input-output model, which were then linked to the national economy.

Koeckhoven (2008) modelled a farm representative of a large mixed crop and livestock operation in the Lower Little Bow Watershed in southern Alberta using a farm simulation approach to assess the benefits and costs to a producer who follows riparian habitat and water preservation and conservation practices. The model specified all possible processes and interactions amongst farming resources and components in a mixed farm settings in conjunction with capital budgeting techniques. The methodology used in constructing this model was a whole farm simulation without optimization techniques (Koeckhoven, 2008).

Using a farm simulation approach, Beauchemin et al. (2009) modeled a mixed crop and beef cattle farm to estimate the whole-farm Greenhouse Gas (GHG) emissions from beef cattle production in Alberta. The Life Cycle Assessment (LCA) type framework was conducted for 8 years to fully capture beef herd dynamics and to estimate GHG emissions over the life cycle of breeding beef cow on a mixed farm. Beauchemin's (2008) study also simulated the given farm by specifying all the processes of a mixed farm to represent their biological and technical relationships. In this method, optimization techniques were not used.

In modelling a mixed crop and beef cattle farm in the Vulcan County, southern Alberta, Modongo (2014) developed a beef herd simulation model integrated with crop and forage activities to measure the impacts of adopting GHG mitigation practices on farm profitability. He adopted real world coefficients to simulate the processes and relations within the farm. Again, optimization techniques were not used in this method.

Similar whole farm simulation models have been used in other parts of the world to assess the impacts of biological, policy and economic scenarios on farm profitability. Some of the selected studies are shown in Table 2.5. Foran and Smith (1991) conducted a process-based simulation study to evaluate the impact of droughts on the financial return of cattle farms in Australia. They used a basic simulation model known as RANGEPACK Herd-Econ model. The model incorporates the RANGEPACK model that was developed for the management of extensive grazing properties and a Herd model called HerdEcon, developed for the economic dimension of the farm. Rainfall was the only climatic indicator that entered the simulation to represent the drought events. Based on the historic climate data, drought years were classified as average, good and dry years in this study.

Castelan-Ortega et al. (2003) modeled an integrated maize-cattle farm in Mexico using a simulation approach that combined a Ceres crop model, a dynamic hybrid CM model (Cow Model) and a multi-period mathematical programming model. This model was used to find the optimal combination of resources and technologies that would maximize farm income. The study included the whole farm process: the Ceres maize model simulated the maize yield under given climate and management conditions; the CM model simulated the herd dynamics under different feeding alternatives; and whole farm optimization model assessed the farmers' economic decision that maximizes whole farm income.

Parson et al. (2011) developed an integrated crop-livestock farm model in Mexico. The model integrated crops with livestock and dynamic linkages among crop, livestock, and socio-economic components. The modeling framework consisted of the integration of two biological simulation models: the Small Ruminant Nutrition System (SRNS) and the Agricultural Production Systems Simulator (APSIM). These models were linked with the socioeconomic components, the Vensim™ model, which included management, flock dynamics, sheep production, partitioning of nutrients, labor, and economic outcomes (Parson et al., 2011).

Table 2.5 Selected studies using integrated whole farm simulation model, countries other than Canada

Author (Year)	Location	Methodologies		Sector/s considered
		Simulation	Optimization	
Foran and Smith (1991)	Australia	Farm simulation using RANGEPACK Herd-Econ model	Yes	Livestock
Castelan-Ortega et al. (2003)	Mexico	Simulation models of both crop and livestock	Yes	Crop and livestock integrated
Parson et al. (2011)	Mexico	Representative Farm simulation-CropSyst crop model and Small Ruminant Nutrient System (SRNS) sheep growth model combined	No	Crop and sheep integrated
Thornton and Herrero (2001)	N.A.	Both crop and livestock integrated. This is a generic approach	Yes	Both crop and livestock

N.A. = Not available

Thornton and Herrero (2001) developed a generic framework for an integrated crop-livestock farm mode. They described the general framework where different components and the inter- and intra-relationships amongst components can be modeled. They also discussed the possibility of using different techniques to handle biological processes and economic decisions of a farm under consideration and scenario analysis for the simulation of a crop-livestock integrated farm.

Farm modeling approaches have been widely used in the simulation of agricultural systems for economic impact studies and scenario analysis as discussed above. These models, however, are specific to purpose and location, and are seldom used in the other studies. The simulation model can consist of different tools and techniques, which makes a particular modeling package fit for all situations not possible (Parson et al., 2011). Wijk et al. (2012) have also stated that a number of farm programming and simulation models for farm modeling and scenario analysis exist, but no single robust model can be applied everywhere. However, basic tools and techniques from available models can be adopted to develop a farm simulation model based on the aim and scope of a study. This study, therefore, follows a farm simulation approach and develops a farm simulation model, “Mixed Farm Model for the economic impact assessment of Climate Change and Extremes (MF-CCE),” to assess climate change impacts on mixed farm settings. The details on the MF-CCE are described in Chapter 5.

2.5 Use of FAO AquaCrop model to simulate crop production

As part of the whole farm simulation model, this study uses Food and Agriculture Organization’s (FAO’s) AquaCrop model (version 3) to estimate the production of various crops and hay. AquaCrop is a general model that can be used to simulate crop yield for a wide range of herbaceous crops, including forage, grain, fruit, oil, vegetables and root crops. The AquaCrop is a water-driven crop simulation model, termed a crop water productivity (WP) model which simulates the yield response of herbaceous crops to water availability and use. The model is believed to be superior in simulating crop yield in the conditions where water is a key limiting factor in crop production (FAO, 2011).

The model has been extensively used to simulate yield for different crops in different regions of the world with more application in the regions where water is a limiting factor in crop production. Some examples include: barley in water shortage condition in East Africa (Araya et al., 2010); wheat in deficit irrigation condition in Iran (Andarzian et al., 2011); winter wheat production in north China plain (Iqbal et al., 2014); winter wheat production in deficit irrigation condition in Iran (Salemi et al., 2011); (v) canola in a moisture stress condition in Australia (Zeleke et al., 2011); and, potato production in water deficit condition in Burkina Faso (Wellens et al., 2013). All of these studies revealed satisfactory performance of AquaCrop model in simulating crop productivity under water-deficit conditions. The model has also been parameterized and tested in North America with satisfactory results. Hasiao et al. (2009) and Heng et al. (2009) parameterized the model for maize crop in different regions including Texas and Florida. Their results revealed, with some limitations in extreme dry condition, the model produced fairly robust results. Mkhabela and Bullock (2012) used AquaCrop model to simulate wheat yield under moisture stress condition in the Canadian Prairies. They stated that AquaCrop can be a valuable tool for simulating both wheat grain yield and soil water content in the Canadian Prairies, particularly considering the fact that the model can be run with limited information.

2.6 Summary of the literature review

Climate of the Canadian Prairie region is dry and cold. Moisture deficit has frequently been an issue on Prairie agriculture in the past and is expected to be more frequent in the future. Studies investigating climate change patterns in the Prairies indicate that climate change could bring positive changes in many agro-climatic variables, such as lengthening of growing season by increasing frost-free days and overall heat units. These changes in climate are considered to be positive for crop and livestock production. However, frequent moisture deficits due to high variability of temperature and precipitation could be a major issue on Prairie agriculture, impacting crop and forage production in existing grassland.

A wide variety of methods have been used to examine the impacts of climate change on Prairie agriculture. Agronomic crop models and econometric models are the most commonly used techniques to simulate the biophysical production process. Models that evaluate the economic impacts tend to vary, depending on the objective and scope of the study. The econometric approach and farm programming approach, individually and in combinations, are widely used for the economic impact assessments at farm and regional level. Due to data limitations and model specification problem associated with econometric approach, integrated farm simulation models are preferred for the economic impact assessment at a farm level. The way a farm model is developed, however, is tailor-made to researchers' need and rarely used by others. Nonetheless, there are enough techniques used by these models which can be combined to develop a model of interest. Thus, using this review on projected climate impacts on Prairie agriculture and the available assessment tools, the following chapter reviews and identifies key considerations needed in climate change impact assessment in agriculture.

Chapter 3 CONCEPTUAL FRAMEWORK

3.1 Introduction

This chapter links the global climate change impacts projected in regional climate and agriculture of the Prairies (as reviewed in Chapter 2) with the building of appropriate methodology by highlighting the consideration needed for climate change impact assessment in agriculture. In Chapter 2, the Prairies' historical climatic patterns, projected future climate and its economic impact, and available methodologies for the impact assessments are reviewed. Building upon the various cases outlined in the review, this chapter develops a theoretical background outlining major elements and their interactions for the economic impact assessments of climate change in agriculture. This chapter begins with the descriptions of some terminologies commonly used in defining agricultural responses to climate change. This is followed by the concept of climate change impact assessment that compares farm profit before and after climate change. Climate change's impact on agricultural output and farm income are discussed thereafter. Major considerations in climate change adaptation decisions are also discussed in this chapter.

3.2 Sensitivity, adaptability, vulnerability and climate resilience in agriculture

This study uses a vulnerability approach for the impact assessment that considers both the sensitivity and adaptability of a system to climate change and extremes as shown in Figure 3.1.

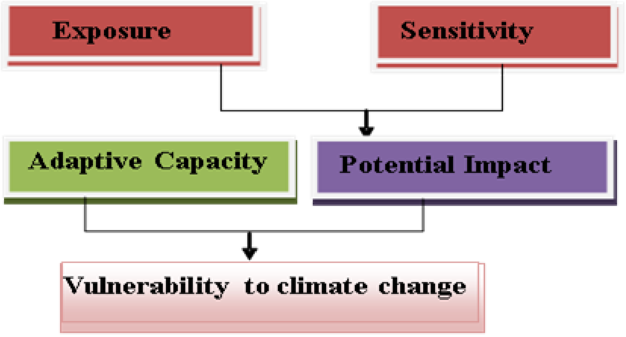


Figure 3.1 Vulnerability to climate change (Source: Stern, 2007)

Vulnerability is the function of potential impact that primarily depends on the sensitivity of a system and, adaptability as expressed in equation (3.1). Specifically, greater adaptability causes lower vulnerability. If there is no adaptability, let us say if A takes the value of 0, the farm will be highly vulnerable as it is exposed to climate change. Vulnerability decreases with the increasing value of adaptability and as the severity of exposure to climate change is muted.

$$V = f[I(E, S), A] \tag{3.1}$$

where, I is potential impact that comes from the exposure (E) and sensitivity (S) to climate change and A is the adaptability of a system to changed environment.

Houghton et al. (1995) define vulnerability as the extent to which a system is damaged. Therefore the vulnerability of a system depends not only on its sensitivity but also on its ability to adapt to a changing climate. Therefore, the vulnerability includes internal dimensions, such as "sensitivity" and "adaptive capacity", as well as an external dimension, the "exposure" of a system to climate change and variations. Some common terms used in defining climate change impact and vulnerability are presented in Table 3.1.

Table 3.1 Characteristics of a system related to climate change impacts and adaptations

Sensitivity	Degree to which a system is affected by or responsive to climate stimuli (note that sensitivity includes responsiveness to both problematic stimuli and beneficial stimuli)
Vulnerability	Degree to which a system is susceptible to injury, damage, or harm (one part — the problematic or detrimental part — of sensitivity)
Impact Potential	Degree to which a system is sensitive or susceptible to climate stimuli (essentially synonymous with sensitivity)
Resilience	Degree to which a system rebounds, recoups, or recovers from a stimulus
Resistance	Degree to which a system opposes or prevents an effect of a stimulus
Adaptive Capacity	The potential or capability of a system to adapt to (to alter to better suit) climatic stimuli or their effects or impacts
Adaptability	The ability, competency, or capacity of a system to adapt to (to alter to better suit) climatic stimuli (essentially synonymous with adaptive capacity)

Source: Smit et al. (2000)

Sensitivity is defined as the response of a system to climatic conditions, such as changes in the composition of an ecosystem due to the changes in climatic pattern, changes in the primary productivity in response to altered climate variable, and so forth (Houghton et al., 1995). Some examples include: crop yield response to changes in temperature or precipitation, changes in the productivity of livestock, occurrences of diseases and pests in crops and livestock in response to changing environment.

Adaptability, on the other hand, refers to capacity of an object or a system to withstand or adjust to changing conditions.

> *"Adaptability refers to the degree to which adjustments are possible in practices, processes or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in conditions" (Houghton et al., 1995).*

In the context of climate change, the very term adaptability refers to the ability of a system to adjust to or cope with the climatic stimuli. Adaptation, therefore, can be understood as any adjustment in response to climatic stimuli to moderate the damage or to seize the opportunities that come with the change. A key objective of adaptation is to reduce the vulnerability to climate change and extremes, thereby reducing negative effects, and enhancing the capacity to maximize any benefits (Stern, 2007).

A number of definitions of adaptation are available in climate change literature with the common elements being the adjustment to external stimuli; however, their scope varies when defining *what to adapt and who/how to adapt.* Burton (1992) defined adaptation as the process whereby people respond to reduce the negative effect on their health and wellbeing and take any opportunities provided by changing conditions. Thus, Burton defined it as primarily a human action. Smit (1993) focused on the notion of *what to adapt* to and defined adaptation as an act of adjustment that enhances the viability and reduces vulnerability to climate change and extremes. Smith et al. (1996) defined adaptation as an adjustment in behavior or economic structures that reduces the vulnerability of a society to climate change.

Some adaptation occurs autonomously as objects of impact (including humans) respond to external stimuli to better fit in the changing context. Changes in the biology or internal characteristics of a plant or an individual object or a system as a whole to better adapt to altered climate is an adjustment by an object itself. Another example of autonomous adaptation is the producers' changes to farm operations, like changes in timing of farm activities. Here humans help the agricultural system to adjust to climate change and extremes. Changes in sowing or planting dates to avoid unfavorable weather are such adaptations. Planned adaptations, on the other hand, are the major decisions, such as developing irrigation infrastructure to cope with drought and investing in researching drought tolerant crop varieties. Adaptation, therefore, requires correct information about climate change whether it is autonomous or planned. Factors that determine the adaptive capacities are economic wealth, infrastructure, institutions, information and knowledge, equity, and social capital (Stern, 2007).

Climate resilience is the short-term phenomenon to cope with climate shock. An example of this on a beef cattle farm is to have enough feed inventory for feeding beef cattle during the drought period, or enough feed purchasing capacity to manage feed shortages. Long-term adaptive capacities may be needed to cope with multi-year droughts by developing the drought tolerant forages and crops or by developing irrigation facilities. If the farm does not have the capacity to produce forage or manage feed in some other way during a multi-year drought, it may not be able to continue its operation at the same scale. Reduction in herd size or changes in farm activities could be viable options. According to Easterling (1996), a system with short-term resilience can adjust to changing climate conditions to maintain existing functionality, but long-term adaptive capacity is required to continually adapt to changing conditions for long term existence. Therefore, identifying the farming system's limits of adaptive capacity and factors that increase the short-term resilience are important in climate change impact assessments (Rivington et al., 2007).

3.3 Measuring effect of climate change on agriculture

Agriculture is perhaps the most researched area of climate change impact assessment at present (Singh and Narayanan, 2013). However, the climate change impact assessment framework for agriculture is highly specific and localized depending on the context in which the assessment is being done. Nonetheless, the basis for the modeling framework should be the same since climate science and climate change mechanisms are widely understood as common across the globe. Hope (2005) [as cited by Stern (2007)] presents the simple unidirectional framework showing drivers of climate change and their impact on agriculture (Figure 3.2). Many biophysical, economic, and human components come to play a decisive role between climate and agriculture. Climate change caused by the radiative forcing of GHGs, can alter different climate variables important to agriculture. Changes in those agro-climatic variables directly impact agricultural production potential, leading to changes in agricultural cost and returns.

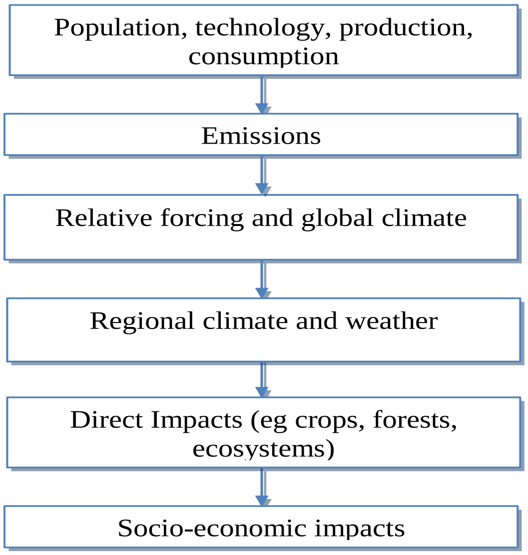
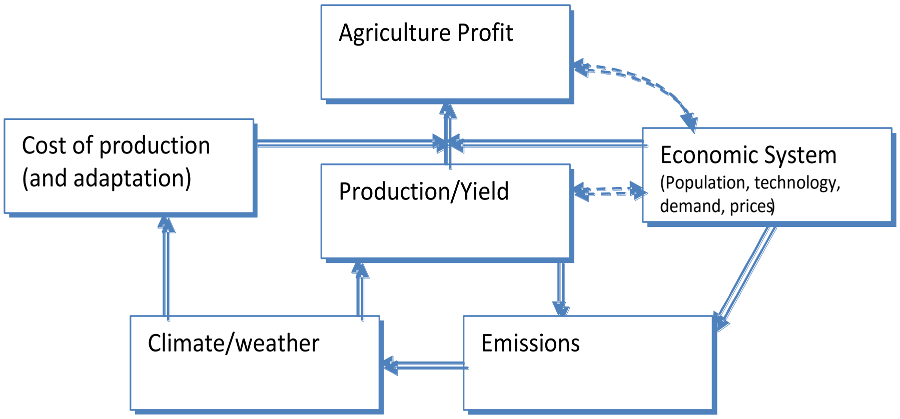


Figure 3.2 Unidirectional figure of modeling climate change from emission to impact on agriculture (Source: Hope, 2005 adopted from Stern, 2007)

Due to the changes in crop biology, agricultural practices may change. Therefore, the changes in economic components and human actions are of great importance in adjusting agriculture to climate change and should be considered in impact assessments. Moreover, market factors, combined with climate change induced bio-physical impacts, have an impact on producers' profits and adaptation responses. The market factor, generally termed as price effect or indirect effect, arises from fluctuations in demand and supply that influence the commodity price, thereby changing the farm profit and the subsequent production plan. A simple theoretical framework and its components used in this study are given in Figure 3.3. The solid lines show the direct interaction of agriculture and climate. The dotted line shows the indirect market effects. Climate change directly impacts agricultural output and cost of production (COP) through adaptation, both of which directly influence the agricultural profit. Indirectly, climate change also impacts economic systems. For instance, price changes through changes in supply, which then affect farm profits, and influences producers' investment on technology. Also the choice of technology and agricultural production contributes to the level of emissions and, thus, climate change. However, this study focuses only on direct effects of climate change, including adaptation, and no indirect interactions with economic system (such as price effect of climate change) are considered.



Note: The solid lines show the direct interaction of agriculture and climate. The dotted lines show the indirect market effects.

Figure 3.3 Modeling diagram of agriculture and climate interaction

An economic framework for assessing the impacts of climate change at a farm level can be developed by measuring the changes in producer's utility before and after climate change. Fankhauser et al. (1997) and Heal and Kristrom (2002) proposed a utility framework of measuring climate change damage at individual level, and willingness to pay to avoid future climate change.

Let us assume that every year a producer maximizes their utility by selecting an appropriate agricultural practice (*A*) relevant to the prevailing climate. Equation (3.2) represents the producer's utility function, where utility is a function of farm profit. Farm profit, π is determined by the producer's choice of an agricultural practice, A (or an adaptation) through an appropriate allocation of farm resources, X.

$$Max\ U\ (\pi) = [P, Q(Z, A\ (X)) - C(Q, W, Z, A)] \tag{3.2}$$

s. t., $X_A \leq X$.

where, $X_A \leq X$ says that the resources required to undertake a practice adaptable to climate (X_A) should be less than the farm's total resources (*X*). Here, *P* is the vector of commodity prices, *Q* is the vector of commodities produced on the farm, *Z* is the prevalent climate, and *A* is the vector of agricultural practices, *C* is the total cost of production, and *W* is the vector of input prices.

After climate changes (from Z to Z_1), the producer maximizes utility by changing agricultural practices from A to A_1 through optimum allocation of resources. The producer's objective function after climate change can be represented by equation (3.3).

$$Max\ U\ (\pi_1^A) = [P, Q(Z_1, A_1\ (X)) - C(Q, W, Z_1, A_1)]$$

(3.3)

s. t., $X_A \leq X$.

Hence, net impact of climate change (I_{net}) will be the difference between maximized utility before and after climate change, as shown in equation (3.4).

$$I_{net} = U(\pi) - U(\pi_1^A) \tag{3.4}$$

On the other hand, the conventional approach of climate change impact assessment that assumes the dumb-farmer assumption usually overestimates the damage. This approach does not take account of producers' rationality in adjusting agricultural practices. The utility after climate change without change in agricultural practices can be represented by equation (3.5).

$$U(\pi_1) = [P, Q\{Z_1, A\ (X)\} - C(Q, W, Z_1, A)] \tag{3.5}$$

Hence the impact of climate change without adaptation, also called gross impact (I_{gross}) will be the difference between utility before climate change, and utility after climate change without adaptation as shown in equation (3.6).

$$I_{gross} = U(\pi) - U(\pi_1) \tag{3.6}$$

Conceptually adaptation is practiced to minimize the negative impact of climate change and to harness its possible benefits. Gross Impact of climate change is measured as the climate change damage (or gain) without any adaptation. Net Impact is measured as the climate change damage (or gain) after taking into account the cost of adaptation. The damage from climate change would be more if adaptation is not adopted as shown in equation (3.7). Stern (2007) has suggested that even after considering the cost of adaptation, the benefit would be much higher, if adaptation is practiced as shown in equation (3.9).

$$I_{gross} \geq I_{net} \tag{3.7}$$

Combining (3.4), (3.6) and (3.7) yields;

$$U(\pi) - U(\pi_1) \geq U(\pi) - U(\pi_1^A) \tag{3.8}$$

Rearranging (3.8);

$$U(\pi_1^A) \geq U(\pi_1) \tag{3.9}$$

These concepts are considered in building methodology to estimate the impact of climate change in this study.

3.4 Climate change, agricultural output and farm income

It is necessary to consider the interactions between climate, agricultural production, human actions and market in measuring climate change's impact on agriculture. These interactions can be presented in generic profit equation as described by Singh and Narayanan (2013) and shown in equation (3.10).

$$\pi = P(Q) * Q(z) - C(Q(z)) \tag{3.10}$$

where, Q is output produced, C is total cost of production, z is climatic factors, and P is commodity output price.

Differentiating equation (3.10) with respect to z yields;

$$\frac{d\pi}{dz} = Q\left(\frac{dP}{dQ} * \frac{dQ(z)}{dz}\right) + P\left(\frac{dQ(z)}{dz}\right) - \frac{dc}{dQ} * \frac{dQ(z)}{dz} \tag{3.11}$$

Equation (3.11) can be re-written as:

$$\frac{d\pi}{dz} = [Q\left(\frac{dP}{dQ}\right) + (P - \frac{dc}{dQ})] * \frac{dQ(z)}{dz} \tag{3.12}$$

Equation (3.12) shows that changes in profit due to change in climate can be grouped into two sources. The first source is the price effect that arises due to changes in output supply under climate change. The second one is the difference between marginal revenue (P) and marginal cost under climate change. Here, quantity produced is a function of productivity (Y) and scale of agricultural operations (L), as shown in equation (3.13).

$$Q(z) = Y(z) * L(z) \tag{3.13}$$

Differentiating equation (3.13) with respect to z becomes;

$$\frac{dQ(z)}{dz} = L\left(\frac{dY}{dz}\right) + Y(\frac{dL}{dz}) \tag{3.14}$$

Combining equations (3.12) and (3.14) produces the equation (3.15) that represents the interaction of climate, agriculture, market and resulting profit.

$$\frac{d\pi}{dz} = \left[Q\left(\frac{dp}{dQ}\right) + \left(P - \frac{dc}{dQ}\right)\right]\left[L\left(\frac{dY}{dz}\right) + Y\left(\frac{dL}{dz}\right)\right] \tag{3.15}$$

The first term of the equation (3.15) presents the marginal contribution of output price changes that occur due to the impacts of climate change on supply of agricultural commodities. However, this effect arises only in the short run (Singh and Narayanan, 2013). In the long run, due to the differences in climate across the globe, the short supply commodity can be produced elsewhere and the price effect vanishes (Deschenes and Greenstone, 2007). Moreover, producers can make land use changes to select commodities that are more suitable to the existing climate, hence, any price effect arising from over-supply also vanishes. The term ($P - \frac{dc}{dQ}$) is the marginal condition of profit maximization and its long-term impact is zero. For the marginal profit due to changes in climate to be zero, there needs to be perfect adaptation against climate change. The price, P, multiplied with the right hand side parenthesis in equation (3.15) yields the value of changes in scale of production and in productivity under climate change situations, respectively, and ($\frac{dc}{dQ}$) multiplied with right hand side term in right hand parenthesis is the cost associated with climate change. Since price, P, is assumed to be constant, the major factors influencing agricultural profit in climate change condition identified by equation (3.15) are changes in productivity (Y), changes in scale of operations (L) and changes in cost due to climate change (C). The major factors identified in this sections are incorporated in climate change impact assessment in this study. Assumptions on price effect under climate change are discussed in Chapter 5, Section 5.5.2.

Productivity change under climate change and extremes are discussed in Chapter 6, Section 6.2 and 6.3.

3.5 Climate change investment and adaptation decisions

Heal and Kristrom (2002) calculated the total damage before and after climate change as the maximum investment worth to avoid climate change. Their approach is shown in equation (3.16).

$$\sum_{t=1}^{C} \delta^{t-1} [U(\pi)\text{-}\ U(\pi_1)] = \sum_{t=C+1}^{T} \delta^{t-1}\ [U(\pi)\text{-}\sum_j U(\pi_1)] \tag{3.16}$$

where, $U\ (\pi)$ is utility without climate change, and $U(\pi_1)$ is utility after climate change; δ is discount factor; C is the year that climate change is expected to occur; and $\sum_j U(\pi_1)$ is utility for the year j after climate change. They assumed that utility under climate change will decrease by some amount, Ω, from the utility without climate change as shown in equation (3.17).

$$U(\pi_1) = U(\pi) - \Omega \tag{3.17}$$

Combining equations (3.16) and (3.17) results into equation (3.18).

$$\sum_{t=1}^{C} \delta^{t-1} [U(\pi)\text{-}\ (U(\pi) - \Omega)] = \sum_{t=C+1}^{T} \delta^{t-1}\ [U(\pi)\text{-}\ \sum_j U(\pi_1)\ ] \tag{3.18}$$

The left hand side of the equation (3.18) is loss of utility in incurring cost Ω from now to time period C when change in climate is realized, discounted back at present value. Loss each year is $[U(\pi)\text{-}\ (U(\pi) - \Omega)]$. The right hand side is the sum of expected utility loss each year from the year of climate change C to a future distant year T, discounted at present value. The expected loss each year is $[U(\pi)\text{-}\ \sum_j U(\pi_1)\ ]$. The sum on right hand side is the benefit of avoiding climate change, therefore; the maximum investment to avoid climate change is the value of Ω at which both sides are equal.

This study, however, is more concerned with adaptation decisions assuming climate change will happen with certainty. Measuring impact with and without adaptation under climate change scenarios is more appropriate in making short term coping as well as long term adaptation strategies. With such considerations, an appropriate estimation of adaptation investment can be done by comparing the loss of utility with and without adaptation assuming climate change and its impact as well as the role of adaptation is known with certainty.

Yearly gains in utility by employing adaptation alternatives, A_i $(i = 1 \dots 3)$ over no adaptation is shown in equation (3.19) where, π_1^{Ai} is the profit after climate change by employing available adaptation strategies, A_i.

$$Invest = [U(\pi_1^{Ai}) \text{-} U(\pi_1)] \tag{3.19}$$

Equation (3.16) shows the maximum amount a producer is willing to invest in coping with climate change in a year ($Invest$). Assuming the producer continues farming until year T, the maximum amount a producer is willing to invest in adaptations at present for his/her entire farming period would be the sum of yearly net benefit from adaptations discounted back at present ($Invest_T$) as shown in equation (3.20).

$$Invest_T = \sum_{t=1}^{T} \delta^{t-1} [U(\pi_1^{Ai}) \text{-} U(\pi_1)] \tag{3.20}$$

The relationship between total climate change damage and benefit of adaptations in minimizing climate change damage can be represented by Figure 3.4. Climate change damage can be minimized through appropriate adaptations; however, the residual damage is still possible. Therefore, the total climate change cost is the residual impact plus the cost of adaptations, while net benefit is the benefit of adaptations after considering the cost of adaptations. This approach has been followed in calculating net benefit of different adaptation alternatives in this study.

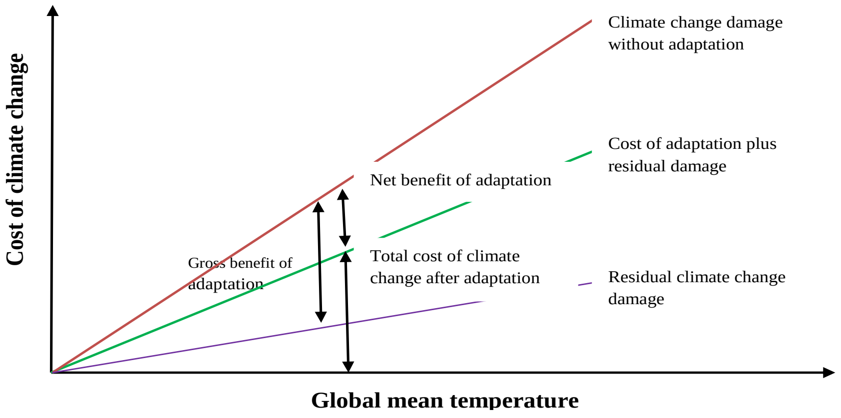


Figure 3.4 : Role of adaptation in minimizing climate change impact (Source: Stern, 2007)

3.6 Summary of the conceptual framework

Impact of climate change on agriculture depends on the potential effects of, and adaptive capacity to, climate change and extremes. Many biophysical and economic components come to play a decisive role between the climate change and agriculture. Biophysical characteristics of climate and agriculture determine the potential impact while economic factors, such as markets and the producer's management decisions, influence the adaptive capacity and adaptation options to climate change. Three important effects of climate change are very critical in impact assessment: agricultural productivity response, changes in scale of operation, and changes in costs of production. Adaptation to climate change are also essential in impact assessment as it may help minimize negative effects while creating positive opportunity and thus influencing the productivity response of agriculture and scale of production. Adaptation, however, may also increase the costs of production. Therefore, information on potential impact, adaptive capacity, cost of adaptations, and the net impact are very important in making informed decision to climate change adaptation.

Chapter 4 STUDY SITES

4.1 Introduction

This study is based on two study farms, one located at Swift Current, Saskatchewan and the other at Pincher Creek, Alberta. This chapter is devoted to highlighting the major biological, physical, and weather characteristics and the farming compositions of these areas. Details on the location of the areas, soil types, major plant compositions, weather patterns, long-term climate information, average farm size, and major agricultural activities are also highlighted in this chapter. Information regarding the regional differences of nature and farming activities is important to understand how climate change would impact agriculture and farming across farms and regions.

4.2 Location of the study sites

The VACEA study sites in Canada are the Oldman River Basin (ORB), Alberta, and Swift Current Creek Watershed (SCCW), Saskatchewan. The Oldman River Basin is located in southern Alberta and the northern United States with a drainage area of 27,500 km^2 whereas Swift Current Creek Watershed is located in southern Saskatchewan with a drainage area of 5,592 km^2 (Wittrock, 2012). Within these boundaries, specific locations for this study were selected: Saskatchewan Census Division 8, Swift Current and Alberta Census Division 3, Pincher Creek. These locations are the closest regions where the study farms are located. The ORB and the SCCW boundaries are shown in Figure 4.1 and maps showing the Statistics Canada census division boundaries are presented in Figures 4.2 and 4.3.

The ORB is located in the southwest corner of Alberta. Annual mean precipitation varies from only 400 mm in eastern parts to 2,200 mm in the wet parts of the Rocky Mountains. About 40% of precipitation falls as snow. Seasonal average temperature variations range from less than -30°C in winter to over 30°C in summer. The SCCW is located in southwest Saskatchewan. Mean annual precipitation is about 400 mm. Similar to ORB, the seasonal temperature variations in SCCW also ranges from 30°C in the summer to -30°C in the winter (Kienzle, 2013).

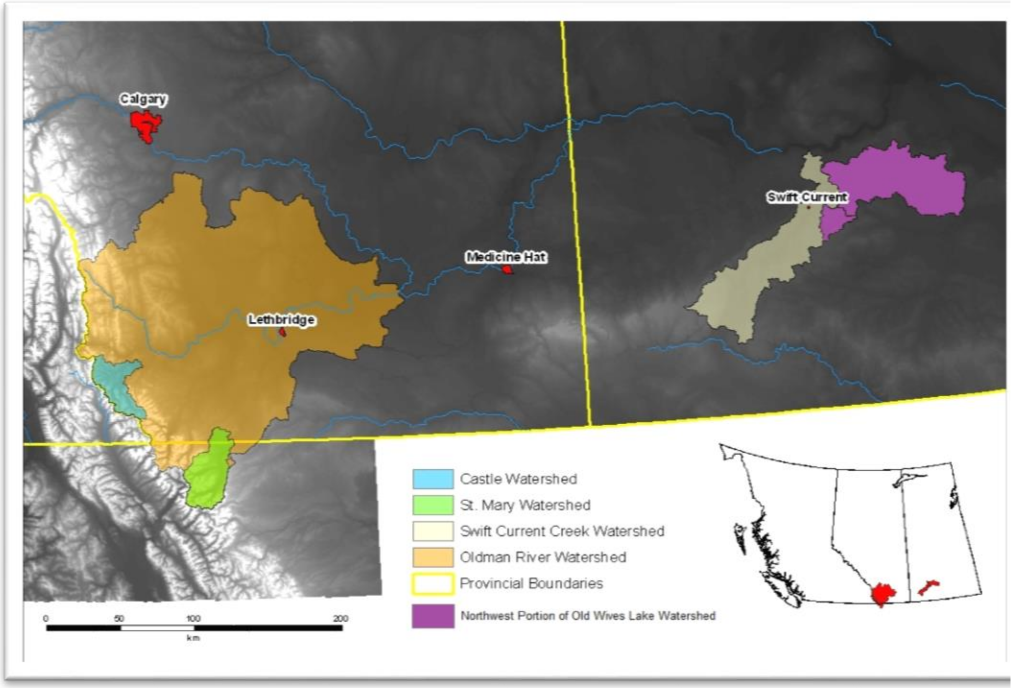
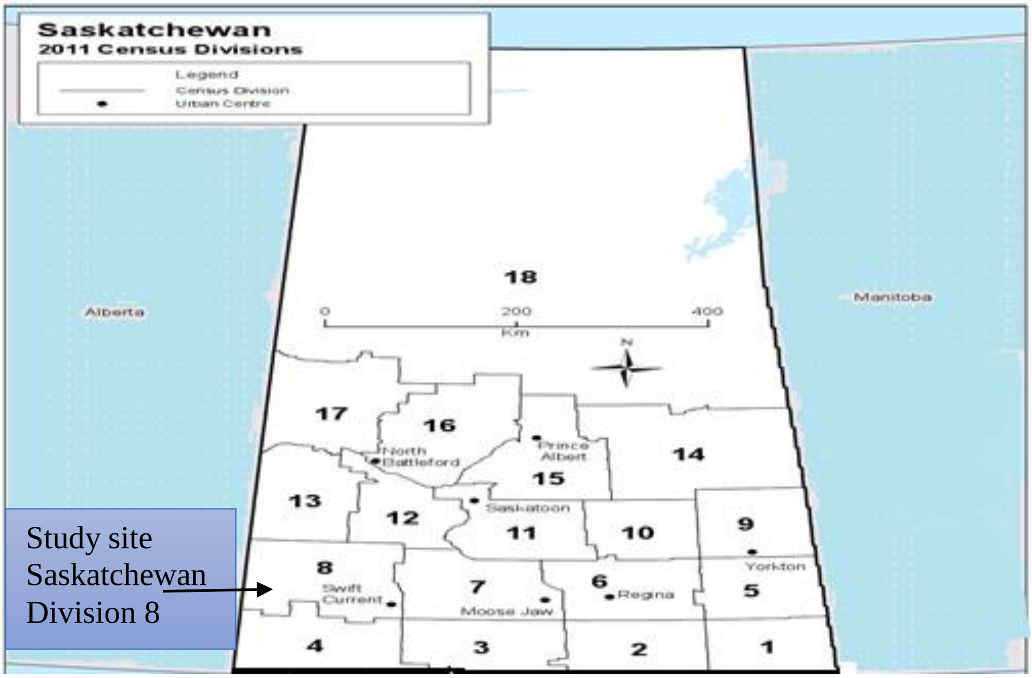


Figure 4.1 Study Area showing the Oldman River Basin and the Swift Current Creek Watershed (Source: Kienzle, 2011).



Study site Saskatchewan Division 8

Figure 4.2 Saskatchewan 2011 census divisions (Source: Statistics Canada, 2011)

Figure 4.3 Alberta 2011 census divisions (Source: Statistics Canada, 2011)

Based on 1961-1990 recorded climate, the ORB has warmer winter temperatures with 4°C higher January average temperature than in the SCCW, whereas hotter summer temperatures were observed in the SCCW with a July daily average 1.5°C higher than the ORB. Some places in the ORB receive almost double the annual average precipitation than some places in the SCCW. Taking the average of all the stations for the period of 1961-1990, the ORB receives 43 mm more rainfall and almost 60 cm more snowfall than the SCCW on an annual basis (Wittrock, 2012).

The climate of both the study sites, however, varies across places. In addition, there are high inter-annual variations with the occurrence of many episodes of climate extremes in both locations. The extreme low winter temperature of -45.6°C was measured on January 23rd, 1943, at Beaver Mines on the western part of ORB, and the high temperature of 20.6°C was observed on January 30, 1931 in High River. Also a low July temperature of 0°C has been recorded in the ORB in some years. An extreme high summer temperature of 42.8°C was recorded in the ORB region at Fort McLeod in 1877 (Wittrock, 2012). In the SCCW region, the extreme maximum temperature of 43.3°C was recorded on August 5, 1961 at Maple Creek (Wittrock, 2012). The lowest extreme temperature in SCCW is similar to, but not as low as, those in the ORB. A major similarity of both the study sites, however, is that they are located within the Palliser Triangle, a drought-prone region of the Canadian Prairies (Wittrock, 2012). Table 4.1 presents the top ten driest years and Table 4.2 presents the top ten wet events calculated based on Standardized Precipitation Index (SPI) in the ORB and the SCCW. The SPI12 is the SPI for 12 months for the September to August period.

Table 4.1 Top ten driest years in the study sites as measured by SPI12*

Year	Oldman River Basin	Year	Swift Current Creek Watershed
1904	-3.2	1937	-2.4
1910	-3.1	1929	-2.4
1988	-2.4	1961	-2.3
1961	-2.4	1984	-2.2
1919	-2.3	1988	-2.1
2001	-2.2	1936	-2.1
1905	-2.2	1949	-2.0
2000	-2.1	1919	-2.0
1949	-2.0	1914	-1.9
1931	-1.9	1945	-1.8

*The SPI12 is the SPI for 12 months for the September to August period

Source: Wittrock (2012)

Table 4.2 Top ten wet years in the study sites as measured by SPI12*

Year	Oldman River Basin	Year	Swift Current Creek Watershed
1951	3.0	2004	2.1
1927	2.5	1965	2.0
1986	2.5	1927	1.9
1987	2.4	1974	1.8
1978	2.4	1991	1.8
1948	2.3	1916	1.8
1902	2.2	1966	1.7
1993	2.2	1907	1.7
2005	2.1	1954	1.7
1947	2.1	2002	1.6

*The SPI12 is the SPI for 12 months for the September to August period

Source: Wittrock (2012)

4.3 Ecoregion and rangeland communities in the study sites

Ecoregions are broad geographical zones that are primarily determined by climate, as plant communities and their productivities differ across climatic regions. Therefore, soil zones and ecoregions reflect the climate of the area (Thorpe, 2007). A warmer and drier climate prevails in the Swift Current site. A major soil type of the Swift Current site is classified as brown soil and the ecoregion of the area is Prairie ecozone dominated by mixed prairie grassland. The major vegetation types of mixed grassland in the Swift Current site are wheatgrass and needle grass. The climatic moisture index range of the mixed grassland is -325 to -225/mm. The sustainable stocking rate, which measures the supply of forages in terms of Animal Unit Month (AUM/acre) of mixed grassland, is 0.38 AUM/acre (Thorpe, 2007).

The main soil type of the Pincher Creek site is black thin soil with foothill rough fescue as dominant vegetation type with mix of columbian needle grass, and wheatgrass. The relatively flat areas of the foothills fescue are largely devoted to crop agriculture and upland areas are dominated by native vegetation and are used for livestock grazing. The sustainable stocking rate for the Pincher Creek site is 0.58 AUM/acre (Adams et al., 2003).

4.4 Agricultural activities

SCCW represents predominantly rainfed (i.e., dryland) agriculture. Major agriculture production (grains, pulses, forage, and cattle) is dependent on spring and summer rain. The ORB gets water from the eastern slopes of the Rocky Mountains and agricultural production relies heavily on irrigation. Therefore, agricultural production in ORB is also affected by fluctuating water levels (VACEA, 2012).

In 2011, a total of 1,717 farms were reported in the Pincher Creek Division 3 of Alberta. Only 34% of the farms were pure crop farms without any livestock operations, whereas the remaining 66% farms had livestock with 62% of the farms with beef cattle activities. For the Swift Current site, the situation is exactly opposite to that of the Pincher Creek site: 66% farms are pure crop farms without any livestock activities. Out of 2,354 farms in the Swift Current site in 2011, 765 farms were beef cattle farms with majority of farms being in cow-calf operation. The distribution of major farm types in the study sites is shown in Figures 4.4 and 4.5.

In 2011, the total area under crops in the Swift Current site is more than that in the Pincher Creek site. Recent (2011) census shows that the Swift Current site is a heavily crop-practicing region compared to the Pincher Creek site. The land use of the study sites is given in Table 4.3.

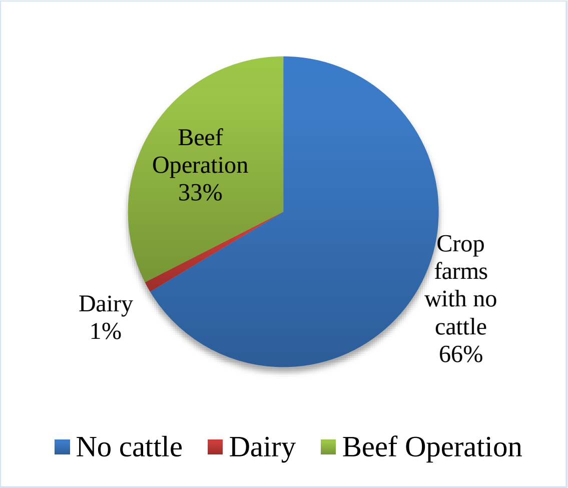


Figure 4.4 Major farm types in the Swift Current study site in 2011 (Source: Statistics Canada, 2011 and Larson, 2013)

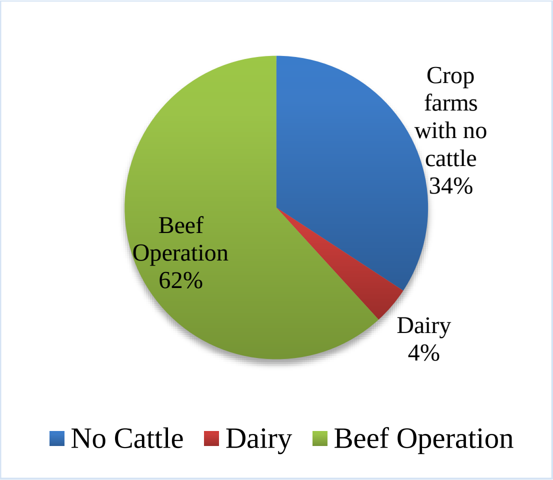


Figure 4.5 Major farm types in the Pincher Creek study site in 2011 (Source: Statistics Canada, 2011 and Larson, 2013)

Table 4.3 Land use in the Pincher Creek and Swift Current study sites in 2011

Land Use	Swift Current Division 8		Pincher Creek Division 3	
	Area in acres	Percentage of total land use	Area in acres	Percentage of total land use
Land in crops	2,838,381	52	1,104,531	40
Summerfallow	735,628	14	22,210	1
Tame or seeded pasture	371,576	7	344,747	12
Native pasture	1,255,246	24	1,201,411	43
Christmas tree, woodland and wetlands	51,130	1	45,719	2
All other Land	80,827	2	50,814	2
Total land use	5,332,788	100	2,769,432	100

Source: Statistics Canada (2011)

Popular crop choices in 2011 in the Swift Current site include spring and durum wheat, barley, canola, field peas, lentils and forage crops. In the Pincher Creek site spring wheat, barley, canola and forage are among the dominant crop activities. The crop activities seem to have expanded in recent years (2006-2011) in the Swift Current site. Total crop area in the Swift Current site has almost doubled since 2006 while the total crop area of the province of Saskatchewan as a whole remains almost unchanged. In the Pincher Creek site, the scenario is just opposite: as total crop area in 2011 has decreased slightly as compared to 2006, while the provincial total has slightly increased. The provincial total and the study sites[8] total land in crops are presented in Table 4.4.

Table 4.4 Major crop activities in the Pincher Creek and Swift Current study sites in 2006 and 2011 census years

	Swift Current Div. 8 (Area in acre)		Saskatchewan (Area in acre)		Pincher Creek, Div. 3 (Area in acre)		Alberta (Area in acre)	
Crop/ Census Year	2011	2006	2011	2006	2011	2006	2011	2006
Spring wheat	375,357	483,818	7,991,553	9,574,964	231,509	247,416	5,971,359	5,768,705
Durum wheat	937,972	829,725	3,701,481	3,224,609	22,033	30,131	536,018	570,771
Winter wheat	11,233	11,775	228,632	236,762	37,654	24,497	196,326	128,152
Oat	19,815	38,319	1,720,863	2,316,791	18,324	31,432	891,580	1,269,229
Barley	112,553	150,544	2,331,386	3,522,510	333,234	422,576	3,610,111	4,094,689
Corn for grain	X	-	11,251	4,251	-	X	17,148	4,326
Corn for Silage	X	1,037	26,786	16,583	465	X	95,861	70,411
Canola	327,589	106,751	9,778,799	5,977,272	182,030	72,490	6,071,744	4,068,511
Soybean	216	X	28,798	5,507			3,957,772	2,970,449
Flaxseed	17,549	27,367	812,437	1,544,879	X	952	69,743	60,372
Dry field peas	200,636	220,957	1,647,548	2,430,461	24,494	X	706,726	587,263
Chickpea	5,767	52,133	86,477	278,170	X	-	12,538	40,749
Lentil	428,873	187,070	2,476,791	1,275,770	608	-	97,775	10,825
Alfalfa	165,000	140,893	3,585,496	3,934,428	185,767	181,082	3,657,114	3,935,022
Other forage crops	44,726	47,780	1,001,444	1,217,673	44,956	67,469	1,466,557	2,060,967
Total	1,190,356	676,200	35,431,753	35,562,636	231,331	248,551	27,360,383	25,642,447

Source: Statistics Canada (2011)

Unlike the crop activities, the beef cattle production activities in the Pincher Creek site seem to be relatively higher than in the Swift Current site in both 2006 and 2011 census years. The

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[8] As discussed in section 4.2, within the SCCW and ORB, the specific locations of this study are Swift Current Division 8 and Pincher Creek Division 3, respectively. Therefore, study sites from this point forward refers to Swift Current Division 8 and Pincher Creek Division 3. In short they are called Swift Current site and Pincher Creek site only.

number of beef cattle is almost double and the number of feedlot animals is almost five times higher than the Swift Current site in both the census years, as shown in Table 4.5. One common characteristic in both sites, however, is that beef cattle activities seem to be the popular choice as evident from the higher-per-farm average in the project sites in comparison to provincial average in the most recent two census years. In 2011, the Pincher Creek site's per-farm average was 118 beef cows while the provincial average was 82 beef cows. For the same year, the Swift Current site's per-farm average was 92 beef cows while provincial average was 80 beef cows. Furthermore, these averages are higher in 2011 than in 2006. Figure 4.6 shows the number of beef cattle head[9] in the 2006 and the 2011 census years in the project sites, provinces and Canada wide total. Total beef inventory in 2011 decreased from 2006 in both study sites as well as in the two provinces. These results imply that despite decreasing total beef cattle inventory, the average size of beef cattle production in the study sites has increased in recent years.

Table 4.5 Beef cattle activities in the Pincher Creek and Swift Current study sites in 2006 and 2011 census years

Animal type		Swift Current (Division 8)		Saskatchewan		Pincher Creek (Division 3)		Alberta	
		2011	2006	2006	2006	2011	2006	2011	2006
Steer for slaughter	# farms	254	370	5,154	7,375	430	495	7,387	9,975
	# animal	8,423	13,047	172,074	207,251	53,057	55,847	819,409	974,559
	Average (#/farm)	33	35	33	28	123	113	111	98
Heifers for slaughter	# of farms	159	206	3,646	4,903	286	326	4,910	6,090
	# animal	7,519	9,777	113,992	149,875	54,864	43,623	684,470	805,829
	Average (#/farm)	47	47	31	31	192	134	139	132
Beef cows	# of farms	721	983	14,074	19,738	953	1,166	18,618	25,665
	# animal	66,624	81,692	1,124,149	1,444,640	112,027	123,338	1,530,391	2,035,841
	Average (#/farm)	92	83	80	73	118	106	82	79

Source: Statistics Canada (2011)

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[9] The beef head calculation includes steers and heifers for slaughter, replacement heifers and beef cows only.

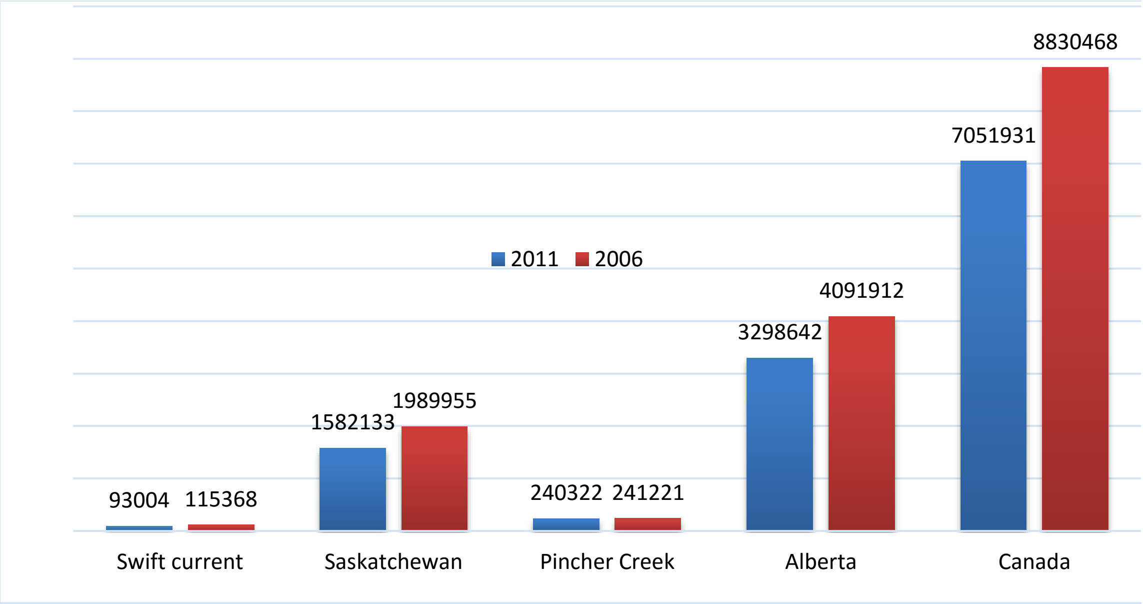

Figure 4.6 Number of beef cattle in selected regions in 2006 and 2011 (Source: Statistics Canada, 2011)

Statistics Canada (2013a) reports the distribution of farms by gross receipts. Annual gross farm receipts vary widely, from less than $10,000 to over $2,000,000 per annum in the study sites. Table 4.6 provides a distribution of gross farm receipts. Except for the year 2011 in the Pincher Creek, the majority of farms located in both study sites have recorded annual gross receipts in between $100,000 to $249,999 per annum.

Table 4.6 Percent farm distribution by farm gross receipt in the Pincher Creek and Swift Current study sites in 2011

Farm gross receipt	**Pincher Creek**		**Swift Current**	
	2006	2011	2006	2011
Under $10,000	14	16	7	6
$10,000 to $24,999	16	18	12	11
$25,000 to $49,999	14	14	15	12
$50,000 to $99,999	15	15	21	16
$100,000 to $249,999	22	16	29	28
$250,000 to $499,999	10	10	11	15
$500,000 to $999,999	4	6	3	8
$1,000,000 to $1,999,999	2	2	1	3
$2,000,000 and over	3	3	1	1

Source: Statistics Canada (2011)

4.5 Summary of the study sites

The Swift Current site is located in the Prairie mixed grassland ecoregion whereas the Pincher Creek site is located in the foothill fescue natural sub-region. A major soil type of the Swift Current site is classified as brown soil and the major vegetation types are wheatgrass and needle grass. The main soil type of the Pincher Creek site is black thin soil and the dominant vegetation type is foothill rough fescue mixed with columbian needle grass and wheatgrass. Temperatures of both the sites range between -30°C in winter and 30°C in the summer with extremes more than 40°C in summer and less than -40°C in the winter observed in some years. Regarding precipitation, the Swift Current site is a drier region with less average annual precipitation. In both the study sites, a substantial part of the precipitation falls as snow in the winter. Both the study sites are located within the Palliser Triangle, a drought-prone region of the Canadian Prairies.

Beef cattle activity is more common in the Pincher Creek site in comparison to the Swift Current site. Recent census data shows that the Swift Current site is a heavily crop-practicing region compared to the Pincher Creek site as indicated by both the number of farms and the total land use. Nonetheless, beef cattle activity is growing in both sites with more upward trends observed in recent years.

The bio-physical and farm characteristics of the study sites reviewed in this chapter are linked to the following chapters which develops “study farms” representing the two study sites. Thus, it builds on the discussion from this chapter in developing the farms and farm simulation models by detailing the biophysical and economic characteristics of different farm activities.

Chapter 5 STUDY METHODOLOGY

5.1 Introduction

A review of the general response of crops, livestock and other agricultural activities to climate change, including the knowledge gaps in climate change impact assessments, has been presented in Chapter 2. The review also consists of an assessment of models, methodologies and approaches used to assess individual agricultural enterprises or their combination at different spatial levels. Chapter 3 has developed a theoretical framework for an economic impact assessment of climate change in agriculture. Drawing upon the discussion of existing methodological approaches as well as the theoretical framework, a whole farm simulation model, MF-CCE (Mixed Farm model for the economic impact assessment of Climate Change and Extremes), has been developed in this study. This chapter describes different economic and biological components as well as the structure of the MF-CCE model.

5.2 Study farm construction

The first and foremost step in a simulation process is to identify the economic entity to be simulated with possible details of its characteristics. Simulation in this study begins with the identification and characterization of mixed beef cattle-crop farms in both the study sites. A farm construct approach has been followed to synthesize the study farms representing the characteristics of mixed farms in the study sites. Averaging regional information to obtain an average scale of operation in the study sites was a crucial step in study farm construction. In addition, some adjustments are made to validate the average information to the real farms in the region. Therefore, the "study farms" simulated in this study can be termed synthetic farms, which are close enough to represent an average farm in the study sites.

As guided by the objectives of this study, the study farms are made up of mixed beef cattle-crop farm with cow-calf, backgrounding and finishing beef cattle operations combined with production of forages and crops. Therefore, average information related only to farms that perform aforementioned activities is used to develop the beef herd base and land base of the study farms. The process and information used in detailing the farm characteristics and herd performances are provided in Section 5.4.

The data on mixed beef cattle-crop farms specific to the study sites are obtained from Statistics Canada (2012b)[10] and are used to construct the study farms. The land base of the farms is equated to average land base of the mixed farm in the two sites. For the livestock base, each animal type found in the mixed farm, such as beef cattle, backgrounding, and finishing animals, are averaged. The beef herd base at the start of the simulation is shown in Table 5.1.

Table 5.1 Beef herd base of the study farms

Beef cattle type	Pincher Creek Division 8 (Number)	Swift Current Division 8 (Number)	Remarks
Beef cow	100	86	Two calving including just born calves.
Heifer for herd replacement	16	12	Age of 12 months
Calves	88	74	Calves are of 0 age
Steer finishing	42	11	Age of 12 months
Heifer finishing	55	10	Age of 12 months
Service bulls	6	4	Mature service bull with 2 services already
Total	307	197	

Crop portfolio of the farms includes major crops grown in the study sites. Land base and major crop activities are given in the Table 5.2.

Table 5.2 Crop and forages activities of the farms

Activity	Pincher Creek Division 8 (Acres)	Swift Current Division 8 (Acres)
Crops and hay	686	1075
Pasture	1700	1500
Crop activities	Spring wheat, barley, canola and maize in 400 acres	Spring wheat, barley, canola and maize in 825 acres
Hay activity	Mixed alfalfa and grass hay in 286 acres	Mixed alfalfa and grass hay in 250 acres
Pasture activity	Mixed native pasture	Mixed native pasture

Statistics Canada (2011) reported the beef herd production in following categories: cow, bull, herd replacement heifer, calves under one year age, and heifer and steer one year and above. Based on the available information and for simplicity at the start of simulation period, all the

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[10] The data were made available to the author by Kathy Larson of the Western Beef Development Center.

heifers and steers one year of age and above are assumed to be the age of 12 months and are ready to go into a finishing lot. Similarly, all the calves under one year are assumed as just-born calves of 0 age. Hence, the cows are assumed to have completed two calving and bulls have provided two services before the start of the simulation.

In terms of relative farm size, both the farms simulated here are smaller farms. Using Statistics Canada's (2013a) crop farm categorization based on crop acres, the farm simulated in this study falls in the category of 760-1119 farm size and represents 12.3% of total Saskatchewan farms. In case of Pincher Creek, the farm simulated in this study falls in the 560-759 acre farm size category and represents 8% of the total farms in Alberta.

5.3 Overview of models and methodology

As noted above, the study develops a whole farm simulation model called MF-CCE to simulate the mixed crop and beef cattle production activities and to assess their response to climate change and extremes. The model integrates the sub-models of beef cattle, crops and climate to the model of economic decisions in an excel spreadsheet format. An overview of the model is presented in Figure 5.1. The MF-CCE contains five sub-models as shown in the boxes with bold outline: agronomic crop model, pasture yield model, beef cattle herd simulation model, crop mix linear programming model and least cost feed model. Boxes with dotted outlines indicate scenario inputs and scenario outputs.

Under a given climate scenario, the crop model estimates the productivity of crops as well as hay and crop biomass for silage making. The pasture model estimates the native pasture productivity under a given climate scenario.[11] The impacts of climate change and extremes in this study are estimated through the impacts on crops and forage productivity. The impacts on beef cattle production are linked through the impacts on crops and forages, which are linked to feed availability for beef cattle. As discussed in Chapter 2, climate change, especially global warming, is also believed to have direct effects on livestock productivity performances, such as changes in feed conversion ratio and the increases in the incidence of livestock diseases (Rowlinson, 2008). Climate change also affects livestock productivity through the impacts on forage quality (Sykes,

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[11] Detailed methodologies and results of crop and pasture models are described in chapter 6.

2008). However, these direct effects on beef cattle are not modelled in this study largely due to the unavailability of adequate information.

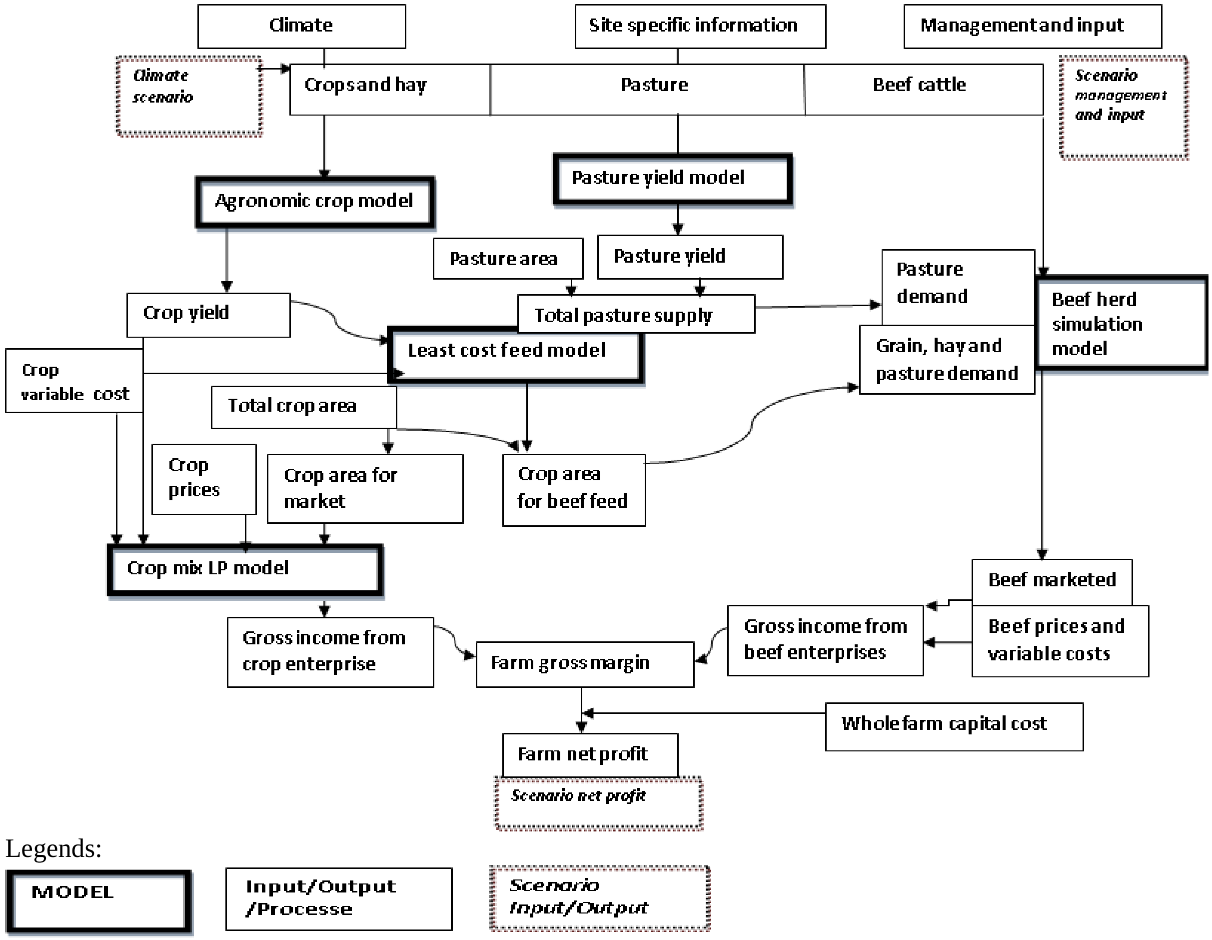

Figure 5.1 An overview of the MF-CCE simulation model

A beef herd simulation model[12] is developed to simulate beef cattle production activities in terms of input required and output produced. The beef cattle activities include three beef cattle operations: cow-calf, backgrounding and finishing activities. The farm produces calves, which pass through backgrounding and finishing phases on the same farm, and finished animals are sold to the market. Superior calves are kept for on-farm herd replacement. Pasture, hay, silage and feed grain demand of the herd are supplied by on-farm production activities. Pasture demand and supply are linked by Animal Unit Month (AUM) on the farm. The feed grain and silage demand of the

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[12] Beef herd simulation model is described in section 5.4.1

beef herd and on-farm supply are linked through a linear programming algorithm. The farm is assumed to have established alfalfa hay to meet the hay demand for the herd. The major revenue items for the farm are the sale of beef cattle, crops and surplus hay. The annual choice of crop production for the market sale is determined by formulating a multi-year linear programming problem by maximizing present value of yearly gross revenue. All these biological and economic components are linked to perform whole farm simulation under baseline and future climate scenarios. Timeline and dynamic linkage of the farm components are shown in Figure 5.2.

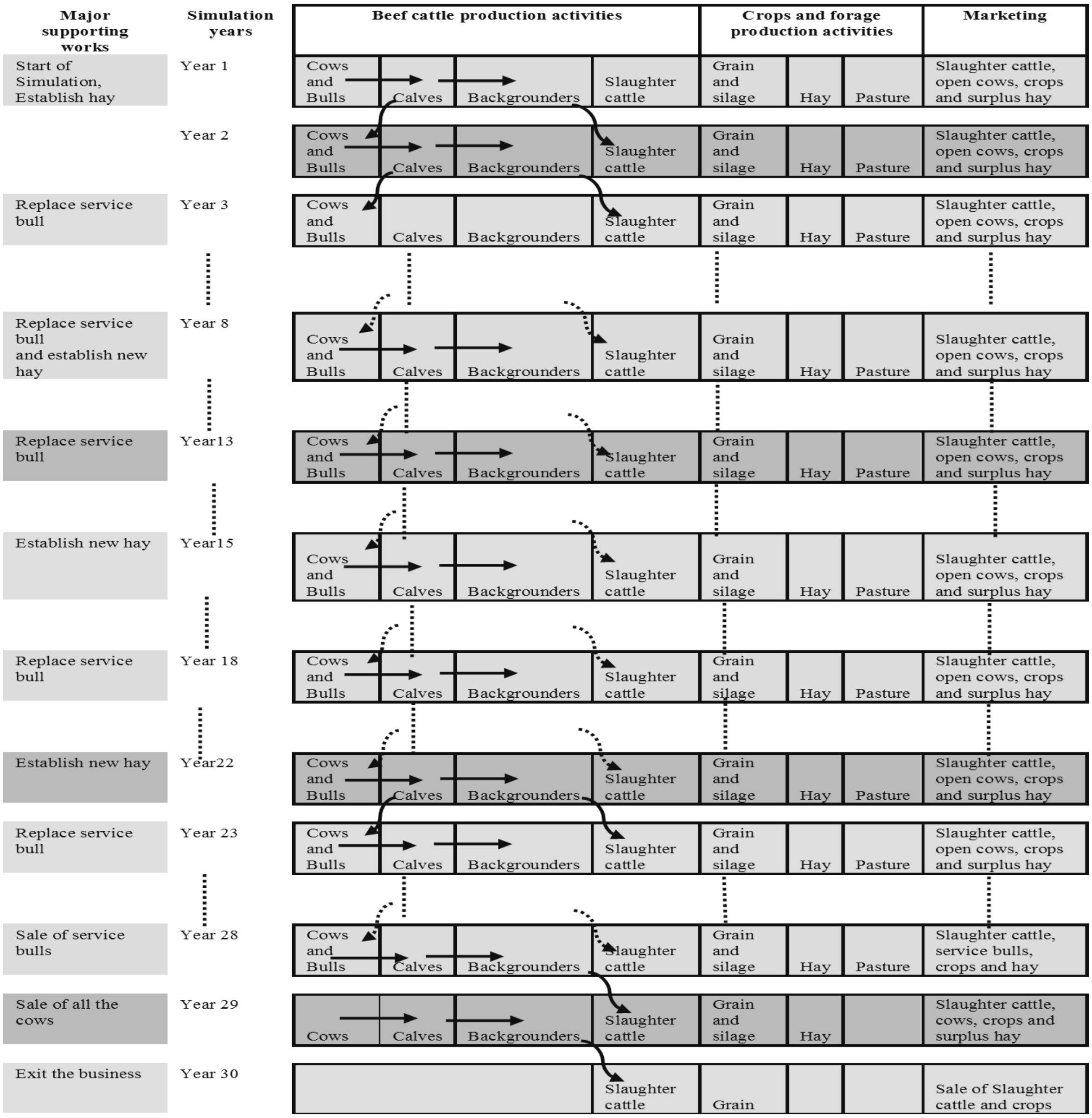

Figure 5.2 Dynamic linkages of farm components over the simulation years

The MF-CCE model has been simulated over a period of 30 years from 1971 to 2000 for the baseline scenario, and from 2041 to 2070 for the future scenario[13]. The crops and silage, hay and pasture areas are fixed throughout the 30 year simulation period. Any crop area available is first used to produce the feed grain and silage demand of the herd, and the remaining area is used to produce grain for the market. The crop activities include the major crops grown in the study sites. Throughout the simulation period of 30 years, crops, hay and pasture areas are held constant. Hay and pasture areas are set to match their demand and supply in an average climate year. Pasture is a native mixed pasture that was already established at the beginning of the simulation period. Hay is established as alfalfa and mixed grass hay. The farm would keep an extra inventory of 40% of yearly total hay and grain feed demand for any unforeseen reasons, such as droughts, or any plant diseases affecting feed production (Schoney, 2014). The producer determines which grain and silage to feed to livestock by preparing a least cost solution to supply grain and silage requirements[14] of the herd. The remaining crop area, after meeting feed demand of the herd, is allocated to grow crop for the market. Extreme climate events, therefore, would affect the supply of hay and pasture, and as a result, farmers are assumed to buy feed to maintain the beef herd or adopt other alternatives to reduce the herd's hay and pasture demands when the feed inventory is not enough.[15] Surplus hay, silage, and grain (other than inventory) are sold during current year and any remaining inventory is sold the following year.

The model is simulated in a yearly time steps, where the results of all the models are entered on yearly basis for the whole farm economic analysis. Sub-models may run differently than the whole simulation model. For example the beef herd simulation model runs in a monthly time step.

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[13] Results of one scenario represent one simulation cycle that spans 30 years. However, it should be noted that there are 30 yearly outputs in one simulation run, and economic results, for example, farm profits are expressed in terms of present value of 30 annual observations. Average values of the results as well as their variations are also reported.

[14] Total nutritional requirement of the herd is supplied through pasture, hay, grain and silage depending on animal type and feeding plan. Ratio of feed stuffs in total nutritional requirement by animal type are given in Section 5.4.1.3.

[15] The assumption of maintaining herd size with regular feeding plan applies to only the reference adaptation case of both the baseline and future scenario. Herd size is maintained but the amount of feed given to the herd is reduced under early weaning and the limited feeding strategy while herd size varies depending on pasture availability under the cull herd strategy. For the purpose of comparison of different adaptation alternatives, a producer cannot combine two strategies at a time. Details on beef cattle herd adaptation strategies are discussed in Section 7.2.2.

Feed required as well as calves' weight gain are estimated on a monthly basis. Costs associated with all the production activities and revenue generated from sale of outputs are calculated yearly. Economic information, including costs of production and prices for both baseline as well as future scenarios are estimated using time series autoregressive model and *Monte Carlo* simulations[16]. All the information is linked in an excel spreadsheet format for the whole farm simulation and scenario analysis. The base model of MF-CCE simulation consists of more than 100 excel worksheets with 15 excel sheets vertically layered and more than 85 sheets linked horizontally to produce final economic outputs.

5.4 Whole farm linkages and model operationalization

The simulation began with the given initial conditions: beef herd numbers, crop area, pasture area and capital complements. The capital investments, including all farm assets, are valued at prevailing market price at the start of the simulation year: 1971 for baseline and 2041 for the future period. As described in Section 5.2, the farm by nature is a small mixed farm that performs cow-calf as well as feedlot operations and produces crops, silage and hay. Major farm activities are described hereunder.

5.4.1 Beef herd simulation model

The beef herd simulation in this study starts with beef cows and newborn calves (calves of 0 year of age), one year old steers and heifers in finishing lot, and replacement heifers and service bulls of one year of age. The ages of the beef herd are identified from the data of mixed farms of the project sites (Statistics Canada, 2012b). The simulation is done for a period of 30 years under the baseline and future scenario using excel spreadsheets.

In the model, calving is done in late February to early March. The weaning is done at the seventh month (at the end of September). The weaned calves enter the backgrounding lot in October until February (for five months). The backgrounding animals enter the finishing lot in March and finished animals are sold for slaughtering in June. The total length of a calf prepared for market is 16 months from birth. Three months after calving, cows come into heat and

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[16] Descriptions on the processes and results of economic information estimation are given in Section 5.5.

conception takes place in between mid-May and mid-June. Pregnancy tests are done within three months of conception and open cows (starting old age) are culled. After the calving season in the 28th year, the cows are kept until the weaning of calves is completed (Beauchemin et al., 2010; Modongo, 2014; and Koeckhoven, 2008).

5.4.1.1 Herd performance assumptions

To run the simulation, the real world coefficients on beef cattle performance indicators (such as number of calving, age at first calving, conception rate, mortality rate, daily weight gain and so on) are required. Beef cattle characteristics and performances vary with beef breeds, climate, management and inputs (AARD, 2014a; Bailey, 1991; Bailey and Moore, 1980; Tanida et al., 1988; Rogers et al., 1985). Therefore, instead of focusing on any single breed, an average performance in Canadian Prairies is used. Key assumptions on herd performances are adopted from Beauchemin et al. (2010), Modongo (2014), and Koeckhoven (2008) and are presented in Table 5.3.

Table 5.3 Assumptions on beef herd performance coefficients for beef herd simulation

Particulars	Value
Conception rate	88%
Yearly herd replacement rate	12%
Calving rate	98%
Weaning rate	95%
Death loss in backgrounding	2%
Death loss in finishing	2%
Gender ratio	1:1

Source: Beauchemin et al. (2010); Modongo (2014); Koeckhoven (2008).

5.4.1.2 Cull cows and herd replacement plan

In the MF-CCE model, replacement heifers are produced on the farm. Every year replacement heifers equal to number of culled cows are kept for herd replacement. Open cows are culled in August and sold at the prevailing market price. It is assumed that producer selects superior female calves for herd replacement to maintain the same herd size every year. The remaining calves are sent to the backgrounding lot. Therefore, the model assumes that the diseased, old and open cows are replaced every year and herd retains only productive cows throughout the simulation. Similar to replacement heifers, service bulls are also replaced after five services.

Assuming that the bulls have provided two services before the start of the simulation, they are replaced after the 3rd, 8th, 13th, 18th, 23rd years of simulation. After the servicing in the 28th year, the bulls are sold without replacement. It is also assumed that superior male calves are retained as service bulls and remaining calves are sent to the backgrounding lot.

5.4.1.3 Feeding requirement and feed plan

In general, beef cows are sent to pasture from April/May until October/November and then put on winter feeding until March/April, depending on the weather. According to Larson (2011), on a cow-calf farm, there are 120 days of winter feeding in Saskatchewan. In the winter, cows are generally fed with hay supplemented with salt and minerals (SMA, 2010). Beauchemin et al. (2010) assumed that cows are pastured until October and then fed good quality hay for the remaining winter. MAFRI (2013a) reports that typical backgrounding operation on Prairies would be feeding 500 lbs calves to gain 1.75 to 2.75 lbs per day for an approximately 100-200 days to produce a feeder cattle with 800-900 lbs[17] body weight. MAFRI (2010) in its feedlot finishing guideline observes selling weight of finished animals at 1,400 lbs and average daily gain of 3.25 lbs per day. Beauchemin et al. (2010) assumed 2.2 lbs ADG per day weight gain for backgrounders until they weight 771 lbs, and a 3.20 lbs per day weight gain for finished cattle for 170 days, with the final selling weight of 1,315 lbs. Average daily gains vary with the expected finishing weight and the length of feeding. In this study, assumptions on expected finishing weight, length of feeding and average daily weight gain are derived from Beauchemin et al. (2010), MAFRI (2010), Larson (2011), and Modongo (2014), and are as shown in Table 5.4.

The beef cattle feeding plan for this study is taken from Beauchemin et al. (2010). Throughout the simulation, newborn calves are fed with cow's milk and good quality hay until the age of two months and then they continue on cow's milk supplemented by summer grazing until weaning in September (at the end of seven months). Breeding cows and bulls are completely dependent on grazing from May until October for a period of 184 days and then fed with hay supplemented with salt and minerals until April (for 181 days). Backgrounders are placed on a high forage diet comprising of 60% hay and 40% grain for 151 days which results in 2.5 lbs of

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[17] This is an approximate estimate from MAFRI (2013a). The exact calculations of feeding 500 lbs calves to gain 1.75-2.75 lbs per day for 100-200 days results the beef cattle body weight in the range of 675-1055 lbs.

weight gain per day and finishing cattle are placed on high grain diet with 80% grain and 20% silage, which results in 3 lbs of weight gain per day. Additional details on the feeding plan of the beef herd are given in table A.1 in Appendix A.

Table 5.4 Assumptions on desired weight and average daily weight gain

Particulars	Value
Calves weight at birth (lbs)	88
Weight at weaning (lbs)	558
ADG from birth until weaning (lbs)	2.2
Weight-in at backgrounding (lbs)	558
Weight-out at backgrounding (lbs)	936
ADG backgrounding (lbs/day)	2.5
Weight in at finishing (lbs)	936
Weight out at finishing (lbs)	1302
ADG finishing (lbs/day)	3
Mature bull weight (lbs)	1686
ADG mature bull (lbs/day)	0
Growing bull ADG (lbs/day)	2.5
Mature cow weight (lbs)	1302
ADG mature cow (lbs/day)	0
Replacement heifer ADG (lbs/day)	2.5

Source: Beauchemin et al. (2010); MAFRI (2010); Larson (2011); and Modongo (2014)

Daily nutritional requirement of livestock depends on the ADG, expected finishing weight, body weight, and age of the livestock. Nutritional recommendations by NRC (2000) and Parish and Rhinehart (2009) are adopted in this study. Given the desired weight, age in month, and daily weight gain, nutritional requirement (in terms of dry matter, energy and crude protein) of different type of beef animal in the herd are calculated separately and are matched with the nutritional content of the feed stuffs as per the feeding plan. The separate estimation of nutritional requirements was needed as the feeding plan, average daily gain, and feeding length vary with the animal type in the herd. For example, the daily nutritional requirements of a backgrounding animal vary with age and weight. The total nutritional requirement per animal for a backgrounding period is multiplied by the total number of backgrounding animals to get the total nutritional requirement for one backgrounding period. Then total nutritional requirement of backgrounding animals is calculated based on feeding of 60% forages and 40% grain.

Pasturing demand and supply: Cows and bulls are the two animal types that go on grazing in summer. Pasture demand is calculated based on dry matter (DM) requirements of the cows and bulls in the herd. The DM matter requirement of a 1,300 lbs beef cattle ranges from 25-29 lbs per day depending on stages of gestations and lactations (Parish and Rhinehart, 2009). According to AARD (1998), on average a 1,000 lbs beef cow requires 26 lbs of DM a day, which is called an Animal Unit Equivalent (AUE). The weight of a cow and of a bull is divided by 1,000 to get AUE per animal. A mature cow in this simulation is measured at 1.3 AUE (1,300 lbs) and a mature bull at 1.686 AUE (1,686 lbs). Then total pasture requirement of the grazing animal for the entire grazing period, expressed in terms of Animal Unit Month (AUM), is calculated as shown in equations (5.1) to (5.3).

$$AUM_{cow} = 1.3 * Number\ of\ cow * Months\ in\ grazing \tag{5.1}$$

$$AUM_{bull} = 1.686 * Number\ of\ bull * Months\ in\ grazing \tag{5.2}$$

$$Total\ AUM = AUM_{cow} + AUM_{bull} \tag{5.3}$$

Pasture supply, also expressed in terms of AUM/acre, from a given pastureland was calculated to match the pasture demand. This resulted in the total pastureland required to meet the grazing needs of the beef herd. Pasture demand and the resulting pastureland requirement is calculated for the average herd size under the reference case of the baseline scenario. A number of factors come into play while calculating pasture supply (AUM/acre) from a given pastureland. Consideration of the carrying capacity (CC) of the pastureland is important as ecologically sustainable stocking rate (ESSR) represents the maximum number of AUMs that can be placed without negatively affecting rangeland health (Adams et al., 2003). At the current average production level, ESSR of Pincher Creek is estimated at 0.58 AUM/acre and that of Swift Current at 0.38 AUM/acre.

The ESSR, expressed per unit of land, is multiplied by area to get the total AUMs supply from a given land. Pasture supply depends on the pasture productivity. Any changes in pasture productivity[18] may change the ESSR of the pastureland. Therefore, yearly productivity of pasture

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[18] Details on the pasture productivity estimate for both the baseline period and future period are described in Chapter 6.

should be converted in terms of yearly AUM/acre to match with the yearly pasture demand of the herd. Adams et al. (2003) described the major assumptions involving steps needed to calculate the sustainable stocking rate of pastureland for the given productivity, as outlined below:

Assumption 1: Ecologically sustainable grazing levels are set between 25% and 50% of total herbage production and the remaining amount is allocated for the maintenance of ecological functions (Adams et al., 2003).

Assumption 2: One AUM requires 455 kg of forages.

Then Ecologically Sustainable Stocking Rate (ESSR) is calculated as in equation (5.4);

$$ESSR\ (\frac{AUM}{acre}) = \frac{\text{Yield}\left(\frac{\text{kg}}{\text{acre}}\right)*\text{Utilization rate}}{455\ \text{kg/AUM}} \tag{5.4}$$

For the average pasture productivity of the 1960 to 1991 period, the choice of 35% utilization rate resulted into the observed ESSR for both the study sites. Therefore, 35% utilization rate and yearly pasture yield as in equation (5.5) are used to calculate yearly pasture supply for the both the study periods.

$$ESSR\ (\frac{AUM}{acre}) = \frac{Yield\left(\frac{kg}{acre}\right)*35\%)}{455\ kg/AUM} \tag{5.5}$$

The total pastureland required to meet the pasture demand of the herd is then calculated by dividing the total pasture demand (AUM) by the pasture supply measured as ESSR-AUM per acre, as shown in equation (5.6).

$$Pastureland\ required\ (acre) = \frac{AUM\ Demand}{ESSR\ (\frac{AUM}{acre})} \tag{5.6}$$

Hay demand and supply: Total hay demand of the herd is the amount required for cows and bulls, backgrounding animals and herd replacement cattle (bulls and heifers). Hay demand is calculated to fulfill the daily DM requirement of an animal. Cows and bulls depend on only hay for winter feeding from November to April. The DM required per day for different animal types (depending on weight, age and ADG) are adopted from Parish and Rhinehart (2009).

It is assumed that weight of a mature cow and bulls are not subject to change. Therefore the recommended DM per day, which depends on their weight, gestations and lactation period, is multiplied by number of days (181) and number of animals to get the total DM required throughout the winter feeding period. Equations (5.7) to (5.9) shows the process of hay DM calculations.

$$Hay\ DM_{Cow+Bull}(lbs) = 181 * [\ (DM/day * Cows) + (DM/day * Bulls)] \tag{5.7}$$

where, $Hay\ DM_{Cow+Bull}$ is the total DM need of cows and bulls from hay and, "*Cows*" and "*Bulls*" are the number of cows and bulls on the farm, respectively.

The weight of backgrounding animals and herd replacement cattle change during the feeding period, resulting in different daily nutritional requirements. To account for this change, average monthly weight and corresponding nutritional requirements have been used. The feeding period for backgrounder animals is 151 days and that for herd replacement cattle is 212 days.

$$HayDM_{b+rep}(lbs) = [\ (DM/day * 151 * backgrounder) + (DM/day * 212 * replacer)] \tag{5.8}$$

where, $Hay\ DM_{b+rep}$ is the total DM need of backgrounders and herd replacement cattle and, "*backgrounders*" and "*replacer*" are the number of backgrounders and replacement cattle on the farm, respectively.

Backgrounder and herd replacement cattle depend on hay for 60% of their DM need and 40% on grain; therefore total DM from hay needed to fulfill is;

$$Total\ Hay\ Dry\ matter = Hay\ DM_{Cow+Bull} + 0.6 * (Hay\ DM_{b+rep}) \tag{5.9}$$

Hay produced on the farm is mixed alfalfa and grass hay. Hay is established at the first year of simulation and is maintained and harvested until the end of the 7th production year. This simulation adopted a 7-year mixed alfalfa grass hay production rotation as suggested by MAFRI (2015). New establishment is done at the beginning of every 8th year. Thus, over the 30-year simulation period, four establishments of hay are done.

As in hay demand, hay supply is also needed to be estimated on a DM basis. The use of DM of alfalfa in western Canada has been on average 87% (Yaremcio, 2013). Therefore, the total hay required to account for the moisture content is calculated by using equation (5.10).

$$Total\ hay\ demand\ (lbs) = Total\ DM\ demand(lbs) * \frac{100}{87} \quad (5.10)$$

According to SMA (2010), the winter feeding loss can range in between 5-25%. Koeckhoven (2008) accounted for a feeding loss of 16%. In this study a 15% feeding loss was added in calculating final hay demand as shown in equation (5.11)

$$Total\ hay\ demand = \left[Total\ DM\ demand * \frac{100}{87}\right] * \frac{100}{(85)} \quad (5.11)$$

Feed grain and silage demand and supply: Feed grain and silage demand of the herd has been calculated to satisfy the nutritional requirements. Backgrounders, and herd replacement cattle need 40% grain and 60% forages in their diet while finishing cattle need 80% grain and 20% silage in their diet. Total grain demand includes the grain needed to meet 40% diet of backgrounders and herd replacement cattle, and 80% diet of finishing cattle. Similarly, total silage demand consists of the silage needed to satisfy the 20% of diet of the finishing cattle.

The DM, energy and crude protein needs of each animal type per day have been adopted from NRC (2000). Changing nutritional requirement of the animal with age and weight has been accounted for by taking an average monthly weight and corresponding nutritional requirements. Least cost feed mix linear programming (LP) has been formulated to estimate the feed grain and silage requirements of the herd given the nutritional content of crops grown on farm. This is done with the aim of minimizing total feed production cost[19] as suggested by Visagie and Ghebretsadik (2005). This analysis is repeated each year as the number of animals and their resulting nutritional requirements are not the same across years during the simulation period. Two separate LPs have been formulated to account for different grain and forage ratios in diet: one for backgrounding and herd replacement cattle, and another one for finishing cattle.

Total nutritional requirements for backgrounding and herd replacement cattle for a year are calculated in terms of DM, energy and protein. To estimate the total grain demand of backgrounding and herd replacement cattle, 40% of their total nutritional need has been taken as

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[19] Feed production cost ($/lb) has been calculated by dividing cost of production ($/acre) by total production (lbs/acre).

minimum nutrient needed to be satisfied from grain. The general LP structure of the backgrounding and herd replacement cattle feed mix problem is described in equations (5.12) to (5.16).

$$Minimize\ C = \sum_{i=1}^{n} FG_i * VC_i \tag{5.12}$$

$Subject\ to$;.

$$DM_r \ \leq DM_s; \tag{5.13}$$

$$E_r \leq E_s; \tag{5.14}$$

$$CP_r \ \leq CP_s;\text{ and} \tag{5.15}$$

$$FG_i \geq 0; \tag{5.16}$$

where, C is total feed production cost; FG_i is ith type of feed grain produced on farm (i = 1..n); VC_i is variable cost of production of the ith feed grains (i = 1..n); DM_r, E_r and CP_r are the dry matter, energy and crude protein requirement of the herd, respectively; DMs, E_s and CP_s are the dry matter, energy and crude protein supply from the feed mix.

The total yearly nutritional requirements for finishing cattle have been calculated in terms of DM, energy, and protein. The nutritional requirement for finishing cattle should be met by feeding 80% grain and 20% silage. Therefore, in formulating the LP for the finishing cattle feed mix problem, one additional constraint is added to specify that 80% of total nutrient should come from grain crops and rest 20% should come from silages. The general LP structure of finishing cattle feed mix problem is described in equations (5.17) to (5.22).

$$Minimize\ C = \sum_{i=1}^{n} FG_i * VC_i + \sum_{i=1}^{n} S_i * VC_i. \tag{5.17}$$

$Subject\ to$;.

$$DM_r \ \leq DM_s; \tag{5.18}$$

$$E_r \ \leq E_s; \tag{5.19}$$

$$CP_r \ \leq CP_s; \tag{5.20}$$

$$FG_i = 4 * (S_i)\text{; and} \tag{5.21}$$

$$FG_i \geq 0. \tag{5.22}$$

where, S_i is ith type of silage grown on farm (i = 1…n), and FG_i is $4*(S_i)$ limits the proportion of feed grain and silage to 80% and 20% respectively.

In the study, the FAO's AquaCrop model[20] is used to estimate grain, hay and crop biomass production. Annual silage yield for the baseline and future periods simulated in this study is not available. Silage is made by fermenting and acidification of green herbage that may be different from the total biomass of the crops (AAF, 2013; SMA, 2014). There have been studies estimating silage yield from the grain yield for some crops. Some examples include relating corn silage with corn yield in the United States by Rankin (ND), University of Illinois (2006), and Bates (ND). Therefore, an average 9-year silage yield for the period of 2002 to 2010 obtained from AAF (2013) is considered as an average silage yield for baseline period for both the study sites. A percentage change in baseline and future biomass estimates of respective crops from AquaCrop model has been applied to the average baseline silage yield to estimate average future silage yield. Yearly variation in biomass yield estimated by the AquaCrop model is then applied to the estimated average future silage yield to generate yearly values.

5.4.1.4 Feed inventory

Total feeding requirements of the beef herd are met by on-farm production in normal years. Estimation of total DM, energy, and corresponding feed amounts required are presented in Section 5.4.1.3. Besides the winter feeding requirement of cow-calf animals and the feedlot feed requirement for one feedlot cycle, producers keep some extra feed for any unforeseen reasons, like extreme climate events (drought or flooding) or plant disease related events that may lower the farm feed production and supply. Given the fixed area under hay and pasture, any changes in yield will significantly impact on-farm feed supply. In cases of lower yields, producers will have to buy feed from markets where the supply might also be limited due to similar yields in the region. Therefore, keeping extra feed is important to maintain the herd size and good financial health in

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[20] Calibration of AquaCrop model and crops and hay yield estimate results are described in Chapter 6.

the event of feed shortages. For this reason, the farmers' area allocation for forages constitutes the area required to feed in normal years as well as the area required to produce extra feed inventory. Schoney (2014) suggested that keeping at least 40% extra feed is a common practice in the Canadian Prairies. Therefore, yearly hay and feed grain production was set at 140% of the yearly requirements. Any excess grain and hay inventory is sold at market price in the following year. Due to the immobile nature of pasture forages, no such sales have been applied for surplus pasture.

5.4.2 Crop production activities

Crop activities include the production of feed grain, hay, and silage to meet the demands of beef cattle and the allocation of any remaining crop area into most profitable crop mix for the market. The level of such activities in each simulation period is accomplished by formulating a Multi-year Linear Programming (MLP) model for the entire simulation period with the constraints of yearly area available and area needed to feed the herd. Given the crop yield, market price of the crops, and their respective variable COP, the present value (PV) of future yearly gross margin flows are maximized. Every year the farmer has a choice of growing four major crops: spring wheat, feed barley, canola, and maize. The MLP is a non-stochastic model where model parameters are assumed to be known with certainty. Parameters like cost and price have been estimated using a time series model (please see Section 5.5) whereas crop yield estimations have been obtained from FAO's AquaCrop model simulation. The structure of the MLP model of crop mix is described in equations (5.23) to (5.28).

$$Maximize\ PV\ of\ Gross\ Margin = \sum_{t}^{m}[\frac{\{\sum_{i=1}^{n}(P_i * Y_i) - VC_i\}^t}{(1+r)^t}] \tag{5.23}$$

This can be written as: $Maximize\ PV\ of\ Gross\ Margin = \sum_{t=1}^{m}[\frac{\{\sum_{i=1}^{n} X_i\}^t}{(1+r)^t}]$ (5.24)

$Subject\ to;.$

$$\sum_{i=1}^{n} a_j \leq A, \forall\, m; \tag{5.25}$$

$$FG_{as} \geq FG_{ad}, \forall\, m; \tag{5.26}$$

$S_{as} \geq S_{ad}, \forall\, m$; and, (5.27)

$$X_i \ldots \ldots . . n \geq 0. \tag{5.28}$$

where, i = 1…n, are the number of crop choices; t is year of gross margin flow; m is length of simulation or total years of gross margin flow; $X_i = (P_i * Y_i) - VC_i$ is gross margin per acre of i^{th} crop activity; P_i is price of i^{th} crop; Y_i is yield per acre of i^{th} crop; VC_i is variable COP ($/acre) of i^{th} crop; r is discount rate; FG_{as} and FG_{ad} are area allocation and area demand for feed grain; S_{as} and S_{ad} are area allocation and area demand for silage.

5.5 Whole farm budgeting

The COP and price information for this simulation have been estimated by using benchmark costs of production available from SMA (2013); AARD (2013) and MAFRI (2010; 2012a; 2013a; 2013b and 2013c), and provincial level commodity prices. The details on the COP and price estimation as well as the description of economic analysis employed to assess the farm profitability and liquidity positions are discussed hereunder.

5.5.1 Cost of production and price information

Historical commodity prices for 1971 to 2000 are used to forecast the annual price for the baseline simulation period of 1971-2000 and the future simulation period of 2041-2070. Any missing price information is estimated by using Farm Product Price Index (FPPI). COP for the 2002-2007 period has been used to estimate the 1971-2000 period information using Farm Input Price Index (FIPI). These COP and commodity prices are forecasted for the 1971 to 2070 periods using time series autoregressive models and *Monte Carlo* simulations. The process involved in constructing the 1971-2000 series is discussed in Section 5.5.1.1, and the methods involved in forecasting them for the baseline and future scenario periods are discussed in Section 5.5.1.2. Section 5.5.1.3 presents the capital cost estimate for the baseline and future scenario periods.

5.5.1.1 Reference cost and price series

The COP for all the crops and beef cattle operations as well as respective price information are required to estimate farm financial situation. Finding historic commodity prices for the crops and beef cattle, as well as site specific yearly costs of production of individual crops and beef cattle operation for the two study sites for the baseline period of 1971-2000 is a challenging task. Most of the COP data for crops released by the provincial government's statistics division are available for only the post-2000 period. Similarly, the COP of beef cattle is not available every year even after 2000. For the pre-1950 period, prices for some commodities are provided by Statistics Canada, but price information for beef cattle included in this simulation are available only for post-1990 periods in both the Statistics Canada and Provincial government databases.

All the available commodity prices for Saskatchewan are obtained from Government of Saskatchewan (2014), Statistics Canada (2014a), and SAF (2000). These sources provide the crop prices from 1952 to 2000. Similar to Saskatchewan, historical commodity prices for Alberta are obtained from AARD (2014b). Beef cattle prices are available only for post-1992 period. Hence, beef cattle prices for both the Alberta and Saskatchewan for 1971 to 1991 periods are estimated by using FPPI of respective commodities obtained from Government of Saskatchewan (2014) and Statistics Canada (2013a, 2014a) to create reference price series for the period 1971-2000.

Complete and item-wise segregated yearly COPs for all the crops and beef cattle production included in this simulation are available only for post-2002 period. Therefore, 2002-2007 detailed yearly COPs are constructed by using the yearly COPs available from several sources (SMA, 2013; Paynne, 2013; Wood, 2013; AARD, 2013, and MAFRI, 2010; 2012a; 2013a; 2013b and 2013c). The COP for various crops for brown soil zones, which is obtained from SMA (2013), is used for the Swift Current site. The COP for black soil zones obtained from AARD (2013) is used for the Pincher Creek site. However, the COP of maize was not available from these two sources. As a substitute, this COP estimate was obtained from Arnott (2014).

The above sources provide an estimate of both the variable costs as well as capital costs. Since, this study simulates the whole farm having both crop and beef cattle enterprises, inclusion of capital cost of individual enterprises may overestimate the COP. Therefore, the capital costs reported in the above sources are excluded to produce variable cost estimates. The capital costs for this study are estimated separately for the whole farm based on its own capital items and their values.

Similar to the capital cost, operating interest in this study is based on the operating expenses of the farm. The operating interest estimate reported in the above sources is excluded. In this study, the operating interest for the individual activity is calculated based on operating expenses incurred.

The AARD (2013) and MAFRI (2010, 2012a, 2013a, 2013b and 2013c) COP estimates included the total labor cost in variable cost estimates but SMA (2013) included only paid labor. To maintain consistency, cost of unpaid labor estimate for specific crops for a specific year reported by AARD (2013) has been used as proxy for unpaid labor to estimate the total labor cost for the Swift Current site.

For the variable COP of cow-calf operation, the study relied on the Western Beef Development Centre's (WBDC's) annual survey for the years 2005 and 2010 (Larson, 2013). For the feedlot animals' variable COP, AARD (2004) data are used. Highmoor (2005) reported a medicine cost of 8.62/animal and yardage cost of 0.46/day/feedlot animal. The AARD (2004) reported $0.48/day/feedlot animal of veterinary services, medicine, and yardage cost for backgrounding cattle. Assuming that the yardage cost does not vary across backgrounding, finishing and herd replacement cattle, a yardage cost of $0.48/day/animal is used. Veterinary services and medicine, labor, and yardage costs (excluding capital depreciation) are taken from these sources for the entire beef herd. The feeding cost, depreciation, capital, and operating interests are estimated in this study.

Variable cost items included in crop and beef cattle COPs are listed in Tables B.1 and B.2 in Appendix B. After creating complete COPs for crop and beef cattle for both the project sites for the 2002-2007 period, 1971-2000 reference COP series are estimated by using Farm Input Price Index (FIPI)[21] obtained from the Government of Saskatchewan (2014) and Statistics Canada (2014b). The FIPI has a base year of 1992, which necessitated creating 1992 COPs from the available post-2000 COPs. To get the best estimate, 2002 to 2007 individual and average COPs were used to create the 1992 value and then to estimate the 1971-2007 series. The estimates that produced lowest mean difference in observed and forecasted COPs for 2002-2007 period are selected as best estimates to be used in forecasting COPs for the baseline and future scenario simulations. Those selected are contrasted in bold in Tables 5.5 and 5.6. The difference in observed average COP and estimated COPs is about 10% in a majority of the cases and more than 20% in a

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[21] Farm Input Price Index for crop (FIPI-crop) is used to estimate 1971-2000 reference variable cost of production (COPs) for all the crops, and FIPI for livestock (FIPI-livestock) is used to estimate the reference COPs for all the livestock activities. Hence, similar time series properties are expected amongst all the crop variable COPs. Similar time series properties are also expected amongst all the beef cattle variable COPs.

few cases. However, the difference between the ones that were observed and the ones that were selected for this simulation is less than 5%.

Table 5.5 Mean difference of 2002-2007 observed average cost of production and forecasted cost of production for Pincher Creek study site

COP Series	Spring wheat ($/ha)	Canola ($/ha)	Feed barley ($/ha)	Maize ($/ha)	Alfalfa hay ($/ton)	Grain Silage ($/ton)	Cow Calf ($/head)	Breeding Bull ($/head)
2002-2007 observed average minus 2002-2007 estimated average COP	13.81	13.81	8.00	19.05	**-0.15**	16.43	**3.64**	**2.86**
2002-2007 observed average minus 2002 estimated COP	-31.99	-19.06	8.33	**1.63**	-7.86	-25.0	-5.31	-9.77
2002-2007 observed average minus 2003 estimated COP	-19.41	-22.87	-11.96	-10.35	-2.23	-13.2	20.04	19.24
2002-2007 observed average minus 2004 estimated COP	**-2.62**	9.28	4.72	2.09	6.30	19.90	19.06	33.95
2002-2007 observed average minus 2005 estimated COP	40.12	11.73	21.49	5.70	-3.34	**1.71**	-24.88	-23.16
2002-2007 observed average minus 2006 estimated COP	4.86	11.93	**0.05**	15.50	2.87	8.75	4.44	4.75
2002-2007 observed average minus 2007 estimated COP	-18.43	**-7.74**	-11.33	-11.39	0.71	-2.68	-9.98	-18.38

Table 5.6 Mean difference of 2002-2007 observed cost of production and forecasted cost of production for Swift Current study site

COP Series	Spring wheat ($/ha)	Canola ($/ha)	Feed barley ($/ha)	Maize ($/ha)	Alfalfa hay ($/ton)	Grain Silage ($/ton)	Cow-calf ($/head)	Breeding Bull ($/head)
2002-2007 observed average minus 2002-2007 estimated average COP	9.38	13.81	5.98	19.05	**-0.15**	16.43	**3.64**	**2.86**
2002-2007 observed average minus 2002 estimated COP	**-2.21**	-19.06	**0.09**	**1.63**	-7.86	-25.07	-5.31	-9.77
2002-2007 observed average minus 2003 estimated COP	-9.95	-22.87	-10.57	-10.35	-2.23	-13.26	20.04	19.24
2002-2007 observed average minus 2004 estimated COP	-3.63	9.28	-0.80	2.09	6.30	19.90	19.06	33.95
2002-2007 observed average minus 2005 estimated COP	8.01	11.73	6.45	5.70	-3.34	**1.71**	-24.88	-23.16
2002-2007 observed average minus 2006 estimated COP	11.36	11.93	7.53	15.50	2.87	8.75	4.44	4.75
2002-2007 observed average minus 2007 estimated COP	-4.78	**-7.74**	-2.03	-11.39	0.71	-2.68	-9.98	-18.38

5.5.1.2 Price and cost of production forecast

Price and COPs for the baseline scenario of 1971 to 2000 and the future scenario of 2041 to 2070 have been forecasted using time series auto-regressive models using 1971-2000 reference series. This was preceded by a test for stationarity. Graphs and plot of Auto Correlation Function (ACF)[22] showed that most of the cost and price series are non-stationary. These results were confirmed by performing the Augmented Dickey Fuller (ADF) unit root test. All the COPs series are non-stationary. The results of the ADF unit root test are presented in Tables C.1 and C.2 in Appendix C.

Further econometric tests and forecasts are conducted for two alternative series: series at first difference and original series. This is done to compare the test results as well as their forecasting performance in order to select the best model. A Partial Auto Correlation (PAC)[23] test has been conducted to identify the number of significant lags for both series. For the original COP series, only the first lag was significant while for most of the differenced series every third lag was significant. For the price series, the first lag was significant for the original series while for the differenced series mostly the third and sometimes second and fourth lags were significant. Lags 10, 15 and 16 were also significant for some of the price series at first difference. The results of the PAC test are given in Tables C.3 and C.4 in Appendix C.

The PAC test identified the significant lag order at 5% type 1 error[24] level. In some cases, however, inclusion of only those lags identified by the PAC test was not sufficient and resulted in poor forecasting performance. Therefore, an alternative way of choosing the lag order is done by checking the number of significant lags by starting with a long lag, testing the statistical significance of the coefficient at the longest lag, and shortening the lag by one period until the lag

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[22] The ACF measures how a series is correlated with itself at different lags. It also tells how much correlation exists between neighboring data points in a time series. If the ACF values either cut off or decrease fairly quickly, then the time series is considered stationary. On the other hand, if the ACF values decrease slowly, then the series is considered non-stationary (Pindyck and Rubinfeld, 1998).

[23] The PAC is helpful in identifying the possible order for an auto-regressive term. The partial auto correlation function (PACF) can be interpreted as a regression of the series against its past lags. The PACF can be interpreted as the contribution of a change in that particular lag, holding other variables constant. Both the ACF and PACF function are estimated using Eviews-8 statistical software.

[24] A type I error is the probability of rejecting null hypothesis when it is true. The probability is the level of significance of the test of hypothesis.

becomes non-significant. The process is the called "trailing lag" method (Pindyck and Rubinfeld, 1998). Other criteria like Adjusted R-Square, lower Akaiko Information Criteria (AIC) and F-value of the model are also used in determining the model. Detailed model representation for all the cost and price series are shown in Tables D.1 and D.2 in Appendix D.

After identifying the appropriate models for the original series and first differencing, the forecasting performance of both the models is tested. A forecast of the difference series is created using equation (5.29).

$$Forecast Y_t = Y_{t-1} + Forecast\ (\Delta Y_t) \tag{5.29}$$

The model for original series produces better forecasts for both the study sites as observed and forecasted series move closely for all the years. Forecasted series from the model at differencing produced significantly lower, with some negative, values. Therefore, non-stationary issues are not considered and the results from the original series without first differencing are selected as followed by Koeckhoven (2008) and Cortus (2005).

A *Monte Carlo* simulation of the selected model has been conducted for the maximum likelihood estimation of the coefficients. For this "fully specified parametric model", this study followed the simulation process of Davidson and McKinnon (2004), as outlined in Adkins and Gade (2012). Identification of fully specified regression function was the first requirement for the simulation process. Then the experiment could be conducted by choosing the probability distribution of error term combined with estimated values of β coefficients and generated or real values of *Xs*. Then the predicted value of *Y* is regressed with *Xs* for a large number of times. This study followed the process with estimated values of β coefficients and real values of *Xs* and estimated variance with the assumption of normal distribution. The simulation was carried out for 1,000 iterations.

To capture possible random variation in cost and price, the forecasted values were allowed to move within observed standard deviation using random number generator. Figures 5.3 and 5.4 compare the observed wheat price with forecasted price from the model with original series and after first differencing for Saskatchewan and Alberta respectively. Some key statistics for the yearly cost and price forecasts are shown in Tables E.1, E.2 and E.3 in Appendix E. Relative to baseline scenario, average commodity price change for the future scenario simulation period ranges from small negative to +40% while COP is projected to increase by more than 200% for some of the commodities.

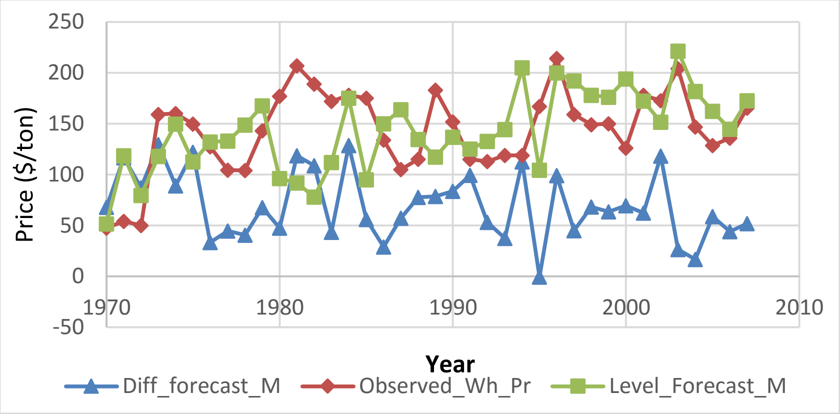

Figure 5.3 Saskatchewan Spring wheat price forecast, original series against model at differencing, and observed values

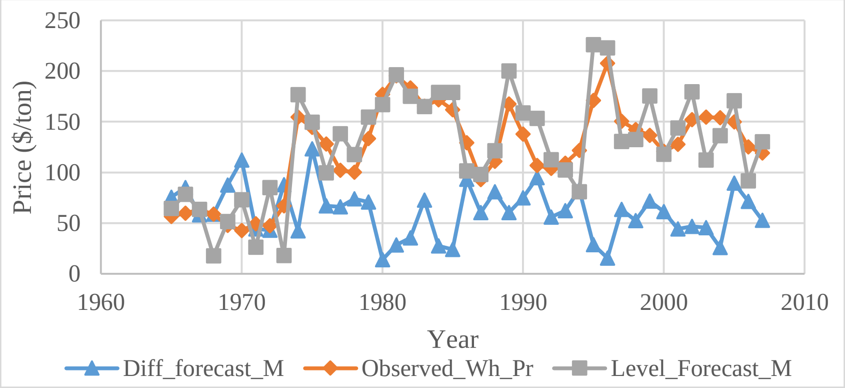

Figure 5.4 Alberta Spring wheat price forecast, original series against model at differencing, and observed values

5.5.1.3 Fixed assets estimation

Major items in the capital cost include buildings and feeding structures, machinery and equipment, and herd purchases. Herd purchase costs are calculated based on price of animals at the start of the simulation year. To calculate other capital costs, various capital items for the given size of the farm were needed. Several alternative ways of building farm capitals were explored.

The first alternative was to take capital costs that are available in various crop and beef cattle COP separately and add them together. However, the capital cost estimate that was derived in this manner was thought to overestimate farm level capital cost, as the same machinery and equipment can be used for both crops and beef cattle operations in a mixed farm.

The second alternative was to use the capital value estimate of Statistics Canada (2012a). This source provides yearly provincial capital values, capital (land and buildings) per acre farm by province, as well as the average land, building and machinery estimates based on North American Agricultural Industrial Classifications. That information provided the total value for land and buildings, breeding stock and other long-term assets as a single number. However, inclusion of land value in the assets poses difficulty in estimating the realistic value of farm profit, as changes in land value can mask the farm financial performance (The issues associated with the inclusion of land in farm profit estimation are discussed in Section 5.5.3.5).

A third alternative was to construct building and machinery base and monetize them using market price. The study farms are small mixed farms with different crops, hay, pasture, cow-calf, and backgrounding and finishing operations. On a mixed farm, the same machinery can be spread out into different activities resulting in the efficient use of capital assets. However, given the variety of production activities, the farms would also require a variety of machinery, equipment, and buildings. Given the small size of the farms, the inclusion of new capital items may severely impair the farms’ financial performances. Moreover, this type of estimation of the capital base may require many assumptions about the type of machinery to be purchased. For example, an assumption would have to be made about the place of purchase and the manufacturer.

After examining the limitations of the options discussed above, this study opted for estimating capital cost close to that of a similar sized farm in the study sites. To that end, a survey of the capital base of Prairie mixed farms for 2002-2014 has been obtained from Larson (2014). To estimate the capital cost for the study farms, a farm having cow-calves and feeder cattle operations and is of similar herd size is selected from the 2003 data base. Therefore, the study farms use the value of capital items already in use. The selected surveyed farm had 104 cow-calf units, 212 backgrounding cattle and 164 finishing cattle which seemed to have slightly bigger capacity of backgrounding and finishing lot than the study farms. Therefore, it is assumed that the study farms use only 2/3rd of the capital items. The list of capital items and their values are given in Table F.1 in Appendix F.

The capital values at 2003 are adjusted by historical capital replacement index obtained from the Government of Saskatchewan (2014) and the Statistics Canada (2014b) to estimate capital value for the 1981 to 2007 period. This was done separately for buildings and structures, and for machinery and equipment. The indices are only available after 1981. Available data for these series are used to forecast capital values for 1981 and 2041 a using similar time series approach as discussed in Section 5.5.1.2. The forecasted 1981 values are used as capital value at the start of the baseline period, 1971. The capital value estimates for 2041 are used as the capital cost at the start of the future simulation period. The result of the PAC test and time series models for forecasting capital cost are given in Tables F.2, F.3 and F.4 in Appendix F. Within sample capital value forecasts from selected models are given in Figures 5.5 and 5.6.

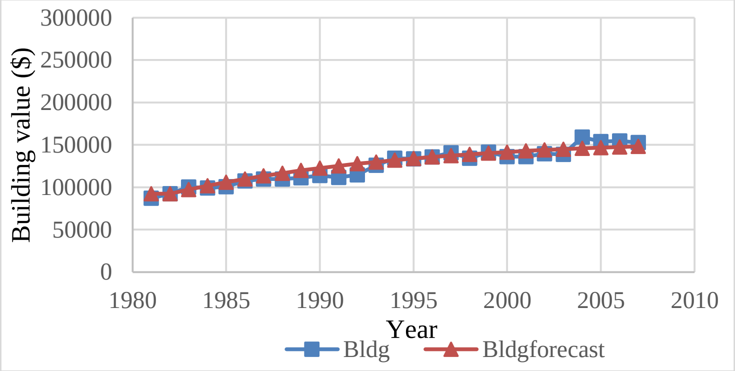

Figure 5.5 Within sample comparison of observed against forecasted building value, 1981-2007

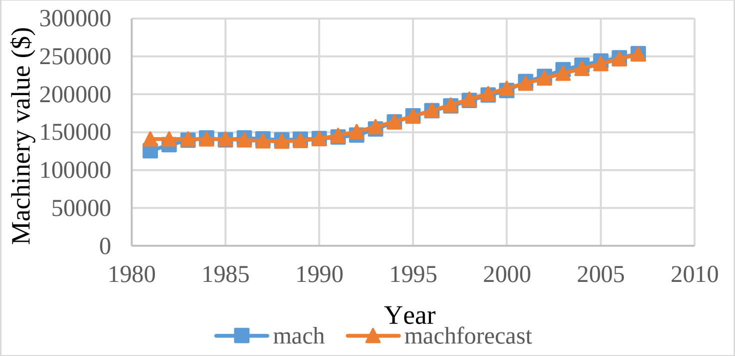

Figure 5.6 Within sample comparison of observed against forecasted machinery value, 1981-2007

The major annual cost items related to capital are the capital depreciation, capital interest, and repair and maintenance cost (Molenhuis, 2001). In SMA's (2013) and AARD's (2013) reporting of cost estimate of an enterprise report capital depreciation, capital interest was listed as a fixed cost whereas repairs and maintenance as a variable cost. MAFRI (2012b) lists four major capital costs of equipment ownership: equipment value, financing, depreciation, and repairs and maintenance. The equipment value is included at the first year of simulation for the value of similar sized farm as described above. Based on the value of capital items at the start of the simulation year, yearly capital costs are calculated as shown below:

Capital depreciation and replacement: Depreciation is an estimate of the loss of value of a machine (or a building) over time and is usually a function of asset's wear and tear occurred due to its use (Molenhuis, 2001). Machinery depreciation is usually calculated as straight line annual depreciation as shown in equation (5.30) by subtracting the trade-in or the salvage value of the machine from the original cost and dividing it by the number of years between purchase and trade-in (Molenhuis, 2001; MAFRI, 2012b). The trade-in value is the salvage value estimated at the time of trade-in or the end of use year (MAFRI, 2012b).

$$Annual\ Depreciation\ for\ new\ machinery = \frac{New\ Price - Salvage\ Value}{Years\ of\ use} \tag{5.30}$$

In this study, depreciation is included as an estimate of yearly capital cost. As noted earlier this study uses the value of capital items already in use in a similar sized farm and, annual depreciation estimates are done following the recommendation of Molenhuis (2001) for used machinery as given in equation (5.31).

$$Annual\ Depreciation\ for\ used\ machinery = \frac{Value\ at\ purchase - Salvage\ Value}{Expected\ life\ on\ farm} \tag{5.31}$$

MAFRI (2012b) and MAFRI (2013a) for beef cattle feedlot finishing cost assume 20 years of useful life and 10% salvage value on buildings. This results in a constant 4.5% depreciation rate. For equipment, a 10 years useful life and 20% salvage value has been used, which resulted in a constant 8% depreciation rate. Koeckhoven (2008) applied 8% depreciation to equipment. Unterschultz and Mumey (1996) applied 7-9% depreciation depending on machinery type. This study assumes that the farmer continues to use machinery for 15 years by spending on constant repairs and maintenance every year with zero salvage value at the end. Following Molenhuis's (2001) formula and assuming zero salvage value at the end of 15 years, a constant 6.66% depreciation has been applied annually for machinery and equipment. With the expected life of 30 years and zero salvage value at the end, 3.33% depreciation has been applied for the buildings.

Capital repair and maintenance: In the Farm Machinery Custom and Rental Rate Guide, MAFRI (2012b) provides an estimate of annual and full life repairs and maintenance cost of machinery and equipment. These estimates, however, require several assumptions related to machinery type, value, use hours and other details, which were not available for the present study. Estimating repairs and maintenance of used capital items is not as common as for new items. Therefore, different sources for estimating these repair costs are investigated. MAFRI's (2012b) guide reported repair and maintenance costs in the range of 1.2% to 4.5% of the investment cost. MAFRI (2013a) applied 2.2% of investment of the investment cost for building repairs. Likewise, SMA (2013) applied 2% of building investment on building repairs. Therefore, in this study a constant 2.1% of investment has been applied for repairs of both buildings and machinery.

Interest on operating and fixed capital: Operating interest is the interest on the variable expenses incurred on the farm. The SMA (2013) in the crop planning guide in Saskatchewan applied 4.2% of interest on crop variable expenses for six months. Highmoor (2005), in estimating beef cattle backgrounding cost estimate, applied 6.5% operating interest while MAFRI (2012b) applied 5.5% interest on variable expenses for beef cattle feedlot finishing operation. An examination of historical Bank of Canada (2014) short-term interest revealed that interest rates were around 5% prior to 1970 which have increased to an average annual interest of around 10% after 1970 to 2000, and decreased to an average of 5% after 2000. There is no specific trend in historical interest, and as such, they are highly unpredictable. A constant rate of 5.5% has been applied on operating expenses of crops for 6 months and 12 months for beef cattle for the baseline as well as future scenarios in both study sites.

Molenhuis (2001) observed that the fixed capital interest rate should be similar to the rates of return for money, such as the T-Bill rate or Guaranteed Investment Certificate (GIC) rate. It is applied on an average value of capital item over its life. The value of capital item in current year is calculated by adding purchase value and salvage value and divided by two to reflect the changes in capital loan over time. The total interest on capital assets is calculated by multiplying average capital value by the interest rate, as shown in equation (5.32).

$$Capital\ Interest = \left(\frac{Value\ at\ purchase + Salvage\ Value}{2}\right) * \ Interest\ rate \tag{5.32}$$

Historical GIC rate and the Canadian Government 10-year bond rate show a similar historical trend as observed for interest rates. For example the 1970-2000 was a very high interest period with more than 10% rate of return in some years. The rate before and after that period has been lower. It was around 5% for 1950s and 1960s and was in the range of 2-4% for post-2000 period (Bank of Canada, 2014).

The SMA (2013) applied a 3% investment rate on building and a 3.25% investment rate on machinery. MAFRI (2013b) applied a 2.5% investment rate on all the capital items. As investment rates are highly unpredictable and variable, an accurate projection for the future scenarios is very challenging. Therefore, a constant 5% investment rate has been applied for both the baseline and future scenarios.

5.5.2 Consideration of price effect of climate change and extremes

In the literature, it has been argued that climate change has impacts on future global production of agricultural commodities that could affect global supply. Other than economic factors, weather comes into play in estimating future input and output prices. Economists have tried to build complex global future demand and supply equations by adding a regional model that takes into account changes in local and regional supply under climate change in the future (Fischer et al., 1994 and 2005). Reilly et al. (1994) estimated that commodity prices could range from some negative to almost 600% of the base period (1990) prices, depending on scenarios and adaptations considered. Fischer et al. (2005) suggested that as the global supply would not change much in the future, the global price change would be a small positive, up to 20% relative to the base period of 1990. Some others, Deschênes and Greenstone (2007) for example, argue that the price effect of climate change would vanish in the long run. Recent assessments of climate change impact on commodity prices, specific to Canadian situation, is not available. Therefore, the price effect of climate change is not considered in this study.

Besides the impacts of climate change on long-term future prices, the effects of climate extremes are believed to have short-term effects on prices due to reduced supply. Quiggin (2012) noted that food prices, especially for fresh products, like fruits and vegetables, increased significantly during the 2005-2007 Australian drought. Food prices increased by 4.4% in the 2002-2003 droughts and by 12% in the 2005-2007 droughts. For grains, the situation was different. Most grains, meat and dairy products are part of integrated global markets, so the local prices are more influenced by the global price than by the local conditions (Quiggin, 2012). Major agricultural producers like Australia, Canada, the US, and China may influence global prices; thus, the effect of droughts in one country can be neutralized by supplies from other countries with no noticeable effect on prices (Quiggin, 2012). However, if a drought coincides with demand side pressure, the net result can be a sharp rise in prices. Quiggin (2012) indicated that the other factor contributing to higher food prices in Australia during the 2005-2007 droughts was demand side pressure including competition from biofuels productions, increased demand from major Asian markets, regulatory changes in Europe and Argentina, and rising global oil prices. Schreier and Pang (2014) studied the effects of climate events in major agricultural producing regions and global price index. They correlated some changes in the global price index during major drought events in major global supplying regions. They concluded that analysis to disentangle the drought effect is complicated because other factors, like changes in energy price, also significantly impact global food price. Therefore, this analysis assumes that the grain and beef cattle prices follow the global phenomenon and that there is no significant impact of local droughts on commodity prices.

The Canadian Prairie cattle feed market is influenced by local demand and supply. A trend analysis of the local Canadian droughts events on local feed prices shows that both the tame hay and feed barley prices increased during major drought events (Table 5.7). Percentage change in feed price during drought years from its last five year average price is shown in Table 5.7. Feed barley price rose by more than 35% and hay price rose by more than 50% during the 2002 droughts in both Alberta and Saskatchewan.

In this study all feeds, including grains and hay, are produced on-farm; therefore the feed price effect of extreme climate events on the beef cattle enterprise would be very minimal. However, such events in this study would lower the amount of grain sold. A producer purchases feed grain only if the farm-grown feed is not enough to meet the pasture deficit in summer, and purchases hay if reduced hay yield creates inadequate hay inventory for winter feeding. To reflect the impact of extreme events, feed prices estimated in Section 5.5 were adjusted by the average of the price changes during six major drought years. The average price change for six major drought years from their last five years average are 12% and 13% for feed barley prices for Swift Current and Pincher Creek, respectively and 22% for hay prices for both sites.

Table 5.7 Change in feed price during drought events from the last five-year average in Alberta and Saskatchewan.

Major Canadian Prairie drought years	SK feed barley price change	AB feed barley price change	SK hay price change	AB hay price change
1988	-1%	-5%	13%	-18%
1989	25%	17%	-11%	-12%
2001	4%	8%	9%	20%
2002	35%	36%	58%	54%
2009	7%	15%	66%	44%
2010	3%	4%	-1%	45%
Average	12%	13%	22%	22%

Source: Statistics Canada (2013b); Larsen (2015); Saskatchewan Forage Council (2004; 2005; 2006; 2007; 2008; 2009; 2010)

5.5.3 Economic indicators

The farm's overall economic position was evaluated using both the profitability and liquidity measures. The profitability measures, such as gross margin and net profit, are calculated annually and discounted at the present value to evaluate the overall profit situation for the entire simulation period. An annual cash flow has been calculated and evaluated to assess the liquidity position of the farm during the simulation period. Additionally, net worth analysis has also been performed to evaluate the overall financial health and economic vulnerability of the farm. These indicators are discussed from Section 5.5.3.1 to 5.5.3.5.

5.5.3.1 Farm gross margin

Farm gross margin is the sum of gross margins from crop and beef cattle enterprise minus capital interest, and repair and maintenance cost. Building and machinery repair and maintenance cost is generally reported in enterprise gross margin; however, for whole farm budgeting, applying it to the whole farm gross margin is easier than pro-rating the cost to different enterprises. Therefore repair and maintenance cost is applied at the end of whole farm gross margin calculation as formulated in equation (5.33).

$$Gross\ Margin\ (GM) = GM_b + GM_c + GM_h - IRC_{bme} \tag{5.33}$$

where, GM_b is the Gross margin from beef cattle; GM_c is the Gross margin from crop; GM_h is the GM from sale of surplus hay; and IRC_{bme} is the total repair and maintenance cost related to building, machinery and equipment..

The gross margin from beef cattle (GM_{b}) is the gross return from beef cattle sold minus all the variable cash costs related to feeding, veterinary services, medicines, labor, yardages and operating interest. The gross return from beef cattle enterprise consists of value of sales of finished cattle as well as sales of cull cows and bulls as shown in equation (5.34).

$$GM_b = \left[(P_b * N_b) + (P_C * N_C) - (\textstyle\sum_i^n FG_i * C_i) - \left(P * C_p\right) - (H * C_h) - (S * C_s) - VL - I_b\right] \tag{5.34}$$

where, P_b is the price of beef cattle (\$/cwt); N_b is the number of beef cattle sold; P_c is the price of culled cattle sold (\$/cwt); N_c is the number of culled cattle sold; FG_i is the amount of grain fed to beef cattle (i = 1…n); C_i is the cost of production of feedgrain (\$/lb); C_p is the cost of pasture maintenance (\$/acre); H is the hay area of the farm (acre); C_h is the cost of hay production (\$/acre); S is the area under silage (acre); C_s is the cost of silage production (\$/acre); VL is the total veterinary services, medicine, yardage, and labor cost for beef cattle enterprise; and I_b is the interest on operating expenses for beef cattle enterprise.

The gross margin from crop (GM_C) consists of the gross return from crop sold minus variable COP and operating interest on crop production cost as shown in equation (5.35).

$$GM_C = [\textstyle\sum_j^n\{(P_i * Y_i) - VC_i - I_c\} * Acre] \tag{5.35}$$

where, P_i is the price of i^{th} crop (i = 1…n); Y_i is the yield of i^{th} crop; VC_i is the variable cost of production of i^{th} crop (\$/acre); and I_c is the interest on operating expenses of crop production activities.

Yearly gross margin flows for beef activities and crop activities, as well as for the whole farm level, are expressed as present value (PV), as shown in equation (5.36). Single value obtained by discounting the gross margin for the entire simulation period can be compared across the study scenarios. As the gross margin is the only economic indicator calculated at the beef and crop activity level, present value at baseline and future scenarios can be compared to understand the impact of climate change at each activity level as well as the whole farm level..

$$Present\ Value\ of\ Gross\ Margin\ (PV_k) = \sum_{t=1}^{n} \frac{GM_{k,t}}{(1+r)^t} \tag{5.36}$$

where, t is the number of periods from 1…n; r is the discount rate; and k is the type of activities namely crop, beef and whole farm.

To estimate the present value, one needs the yearly cash flow and discount rate. Choosing the discount rate is a critical factor as its choice can change the profit situation of a business. A slight change in discount rate will have a considerable effect on the final output. At the same time, the discount rate should reflect the market interest rate of borrowing as well as the rate of return on equity (ROE) (Damodaran, 2005). Saskatchewan's mix farms with 50% crop and 50% beef operations have an average ROE of 7% (Statistics Canada, 2015). The interest rate on AFSC's farm loans ranges between 5% and 6% (AFSC, 2005; 2006; 2007; 2008; 2009 and 2010). Therefore, to reflect both the ROE and the interest rate, in this study a constant discount rate of 6% has been used.

5.5.3.2 Farm net profit

Yearly farm net profit is calculated by using equation (5.37) where the total farm capital costs including depreciations are subtracted from the farm gross margin.

$$Net\ Profit\ (NP) = Gross\ Margin\ (GM) - Capital\ Cost \tag{5.37}$$

$$Capital\ Cost = FC_{me} + FC_{bs} + FC_h \tag{5.38}$$

where, FC_{me} is the yearly depreciation cost of machinery and equipment ($); FC_{bs} is the yearly depreciation of building and structures ($); FC_h is the cost of herd purchase ($).

To examine the net farm financial position for the overall simulation period, present value (PV) is calculated for the flow of annual net profit for the entire simulation period using equation (5.39). Similar to the present value of gross margin calculation, the annual net profit has been calculated first for each year, then converted into present value.

$$PV\ of\ Net\ Profit = \sum_{t=1}^{n} \frac{NPt}{(1+r)^t} \tag{5.39}$$

where, t is the number of periods from 1…n; r is the discount rate.

5.5.3.3 Farm cash flow

The cash flow statement evaluates the liquidity position of the farm. It identifies the flow of cash in and out of the farm during the given accounting period. Yearly cash flow budget can be used to see its surplus/deficit status to understand a farm's financial vulnerability. Cash inflow in the current year includes the net profit of the farm from previous year that was available to use in the current year's farming operation, the return from sales in the current year, any loans taken to purchase capital items or to meet operating expenses, and any revenue generated from the sale of capital items. Cash outflows include capital purchases in the current year and crop and beef cattle variable costs of production including interest, capital repayment charges, capital repair and maintenance cost, and capital interest cost. The cash flow calculation is represented by equation (5.40).

$$Cashflow = (NC_{t-1} + GM_{b,t} + GM_{c,t} + B_t + CS_t) - (CP_t + IRC_{bme} + FC_{me}) \qquad (5.40),$$

where, NC_{t-1} is the net cash carried from last year; $GM_{b,t}$ is the gross margin from beef activities in the current year; $GM_{c,t}$ is the gross margin from crop activities in the current year; B_t is the amount of borrowings in the current year; CS_t is the income from capital sales in the current year; CP_t is the capital purchases in the current year; IRC_{bme} is the capital interest and repair and maintenance cost in the current year, and FC_{me} is the cost of capital depreciation in the current year.

5.5.3.4 Family cash flow

For the family cash flow, the average provincial current household expenditure is subtracted to the already calculated farm level cash flow. To do this, provincial average household expenditures are obtained from Statistics Canada (2014a). These are available only after the 1997 period. Therefore a reference series of 1971-2000 is estimated from available post-1997 values using the provincial consumer price index obtained from Statistics Canada (2014c and 2014d). Using a similar approach[25] used for forecasting COP and prices, the provincial household expenditure is forecasted for the periods of 1971 to 2000 and 2041 to 2070 from the reference series of the 1971-2000 period. Results of time series tests and the selected models are given in Tables G.1 and G.2 in Appendix G. Observed and within sample forecasts of current family expenditures are shown in Figures 5.7 and 5.8.

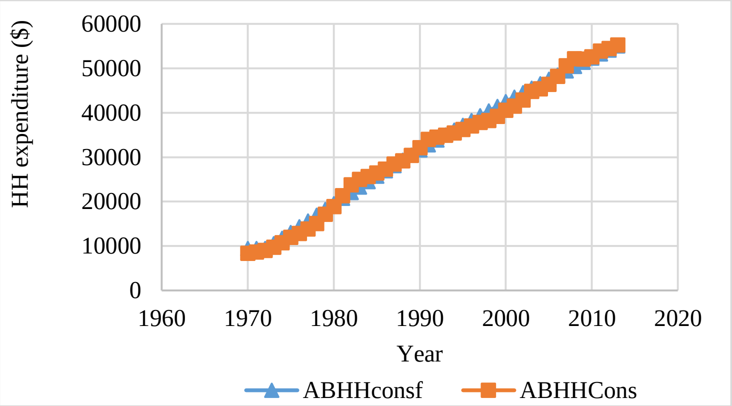

Figure 5.7 Observed against within sample forecast of Alberta average family consumption expenditure ($/year), 1970-2013

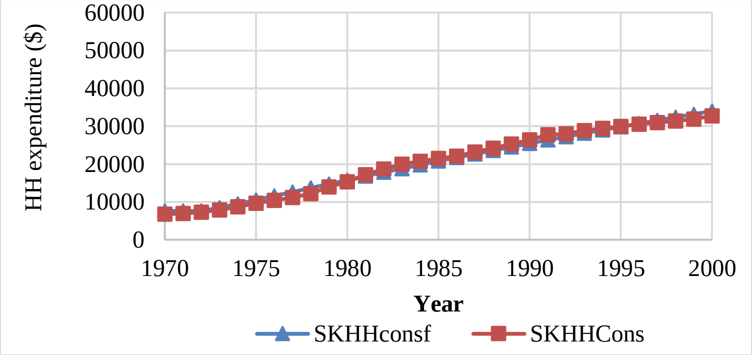

Figure 5.8 Observed against within sample forecast of Saskatchewan average family consumption expenditure ($/year), 1970-2013

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[25] Time series regression model combined with *Monte Carlo* simulation is used as in price and COPs forecasting.

5.5.3.5 Net worth analysis

Net worth is the amount by which assets exceed liabilities. Positive and consistent increases in net worth indicate good financial health of a business. Net worth may fluctuate or be depleted due to annual operating losses or a decrease in the value of assets (Hofstrand, 2009). Therefore, an estimation of annual net worth helps show the economic vulnerability of the farm. The net worth in this study is calculated by adding the value of all assets, including the beef herd and any cash generated from sales, and subtracting all the liabilities, including operating costs and loans. Net worth calculation is shown in equation (5.41).

$$Net\ worth = Cashflow + AV - L \tag{5.41}$$

where, *cash flow* is the cash flow of the farm; *AV* is the value of all the assets including beef cattle herd; and L is the total amount of outstanding liabilities.

Due to the possibility of misguiding results by potentially increasing land value over time, the value of land is not considered in the net worth calculation in this study. Value of land is affected by both agricultural productivity as well as non-agricultural factors. It is also affected by macro-economic factors such as the interest rate (Weerahewa et al., 2008; Devadoss and Manchu, 2007); inflation rate (Alston, 1986), debt to asset ratio and credit availability (Devadoss and Manchu, 2007), unemployment (Pyykkönen, 2005), and government subsidies and payouts (Goodwin et al., 2003; Pyykkönen, 2005). Thus, its inclusion may not truly reflect a farm's performance. Therefore, this study excludes land value in the net worth calculation under both the baseline and future scenarios. Also, it is assumed that the farms take loans to purchase all the capital assets and to meet the operational expenses at the start of the simulations. Therefore, the farms start with zero net worth under both the scenario periods.

5.6 Summary of the methodology

This chapter described the MF-CCE model and its different economic and biological components used in evaluating the economic impact of climate change and extremes on the study farms. The selected study farms are mixed farms, having cow-calf, backgrounding, and finishing beef cattle operations combined with crops and pasture production to support the beef herd. Climate variables do not enter directly into the whole farm simulation model. The impacts of climate change on beef cattle production are linked through the impact on feed grain, hay and pasture production affecting feed supply under climate change. No direct impacts of climate change on livestock, such as changes in beef cattle productivity, are modelled in this study. All the information is linked in an excel spreadsheet for the simulation and scenario analysis. As noted earlier, MF-CCE has a structure of more than 100 excel worksheets: 15 excel sheet vertically layered and more than 85 sheets linked horizontally to produce the final economic outputs. An example MF-CCE work sheet showing the summary of activity gross margin and farm profit calculation for baseline scenario of 1971-2000 period for the Pincher Creek site is shown in Appendix H.

The baseline scenario is simulated for the 30 year period from 1971 to 2000, and the future scenario is simulated over the 2041-2070 period. Economic data for both the scenarios are estimated using a time series regression approach using historical information. The farm's overall economic position is evaluated using both the profitability and liquidity measures. The present value of the annual net profit is calculated by discounting the annual profit, and the annual cash flow is calculated to assess the liquidity position of the farm during the simulation periods.

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Chapter 6 CROP AND PASTURE YIELD ESTIMATION

6.1 Introduction

This chapter presents the description and results of the crop model used for crops and hay yield estimation as well as the pasture yield model used for pasture yield estimation. A description of the climate scenarios used in estimating crops, hay and, pasture yield estimation is also presented. The MF-CCE model used in the whole farm simulation in this study runs in yearly time steps; hence all the biological and economic information, including crop and forage yield, are estimated and fed into the MF-CCE model yearly. The crop model is the AquaCrop model, an agronomic crop growth simulation model created by the Food and Agriculture Organization (FAO), which, under given management and climate inputs, provides the crop and hay yield estimates. The pasture yield model is the Forage Calculator for Native Rangeland developed by Saskatchewan Research Council (SRC), which relates the pasture production with the moisture availability.

6.2 Crop and hay yield estimation

Climate scenario projections from the RCM3_CGCM3_A2 model (Third generation Regional Climate Model driven by the third generation Coupled Global Climate Model and A2 emission scenario) are used to simulate crop growth and production as well as hay yield for the baseline and future scenarios.[26] Descriptions of the climate scenario and crop model and the results of crop and hay yield estimations are discussed in Sections 6.2.1 and 6.2.2.

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[26] Climate scenario and crop yield estimation results were available for two climate scenarios- the HRM3_GFDL_A2 and the RCM3_CGCM3_A2. The HRM3_GFDL is considered to be a relatively extreme warmer and drier scenario. The long term average crop growing season (April to October) maximum temperature (Tmax), minimum temperature (Tmin), and mean precipitation change for the 2041-2070 period relative to the baseline period of 1971-2000 are, 2.6^0C, 3.2^0C and -2.6%, respectively. The RCM3_CGCM3_A2 scenario is milder in temperature change with the increase of only about 2^0C in both the Tmax and Tmin and more extreme in precipitation change with 18% increase in long term average crop growing season precipitation for the 2041-2070 period relative to 1971-2000 baseline period (Kienzle, 2015). One scenario represents extreme dry and another represents extreme wet conditions. It would have been better if both of these scenarios were simulated but given the limited time frame of the study one scenario had to be selected. Being somewhat optimistic about the future climate, RCM3_CGCM3_A2 scenario was selected for the simulation of climate change and extremes in this study.

6.2.1 Climate model and scenarios in crop and hay yield estimation

A climate scenario is a plausible representation of the future climate that is constructed through the use of Global Climate Models (GCMs) by specifying the different emission scenarios of future forcing agents[27] (Houghton et al., 2001), called emission scenarios. The IPCC (2000) defines a GCM as a simplified mathematical representation of the physical processes between the atmosphere, ocean, cryosphere and land surface. The GCMs can be used for the simulation of the future climates by specifying the major components of the climate system namely atmosphere, ocean, land surface, cryosphere and biosphere, along with their interactions (IPCC, 2000). The values of the climate variables are calculated across grid points and over time to predict future values. Most GCMs have quite coarse resolutions: 250 to 600 km horizontal resolution, with 10 to 20 vertical layers in the atmosphere and as many as 30 layers in the ocean (Barrow, 2009). This coarse resolution makes the use of GCMs difficult to match the scale in the impact assessment at small scale (Sykes, 2008). On the other hand, several Regional Climate Models (RCMs) can take account of some of the local scale features that are missed when using GCMs (Foley, 2010). The RCMs are atmospheric limited-area models that combine the thermo-dynamics of upper soil level (Feser et al., 2011). A RCM is based on the local topographical features but it does not have capacity to take account of all the components (atmosphere, ocean, land surface, cryosphere and biosphere) that affect climate. The World Meteorological Organization (WMO) recommends the nested modeling technique that is a RCM linked to a global model. Results of GCMs for a given region are used as initial and boundary conditions for the RCM, and the RCM, with detailed regional characteristics, can provide the climate forecast with finer details for small scale impact studies (Barrow, 2009; Feser et al., 2011).

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[27] IPCC (2000) prepared a Special Report on Emission Scenarios (SRES) that describes the mechanism of GHG emissions, their radiative forcing capacity, and different alternative emission scenarios depending on different future possible states of the world. Future population growth rate, technology use, and economic development are considered as major driving forces for emission levels (IPCC, 2000). The possible future emission scenarios are grouped into four storylines (A1, A2, B1 and B2) with several families for each storyline. The A1 storyline and scenario family considers a future world with a high rate of economic growth and mixed technology use: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). The A2 storyline and scenario family considers a future world with moderate economic growth. The B1 storyline and scenario family emphasize global solutions to future economic, social, and environmental sustainability. The B2 storyline and scenario family assumes a future world with emphasis on local solutions to economic, social, and environmental sustainability (IPCC, 2000).

In this study, the climate scenario is based on the third generation RCM (RCM3) embedded with third generation Coupled Global Climate Model (CGCM3) and A2 emission scenario. The climate scenario was developed by Dr. Elaine Barrow, Adjunct Professor at University of Regina, as part of the VACEA project. Climate scenario results in terms of temperature and precipitation change for the 2050s relative to the 1971-2000 baseline period are presented in Figures I.1 to I.10 in Appendix I. Under this scenario, annual average temperature increase is projected to be in the range of 2-3^{0}C in most of the Canadian regions. Annual and winter temperature increments will increase more in the northern parts with some regions experiencing more than 3^{0}C temperature increase. Spring temperature increases will be in the range of 0-1^{0}C with little variation across the regions. Summer and fall temperature increments will be in the range of 0-2.5^{0}C with higher changes in the southern regions, including the study areas. Precipitation change is projected to be highly variable with some decreases to increases depending on the regions and seasons. The study areas are expected to have significant increases in growing season precipitation with up to 18% increment in some regions. However, the confidence is high for the temperature change but low for the precipitation change (Teutschbein and Seibert, 2012; Barrow, 2014).

6.2.2 Crop and hay yield estimation model results

The study relies upon the yearly crop yield forecasts[28] made by using the Food and Agriculture Organization's (FAO's) AquaCrop (version 3) model for further economic assessment of climate change and extremes. The crop yield estimates are done under non-irrigated conditions in both the Pincher Creek and Swift Current sites. The primary reason for the use of AquaCrop model in this study is that the model is believed to be superior in simulating crop behavior in a dry region, like the Canadian Prairies, where water is a limiting factor (Mkhabela and Bullock, 2012; Steduto et al., 2009). The model generates yearly grain and biomass estimates for various crops by utilizing growing season climate information. The model relates the crop yield response to water as given in equation (6.1), where relative yield $\left(1-\frac{Y}{Y_x}\right)$ loss is proportional to relative

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[28] Dr. Stefan Kienzle, Professor of hydrology at the Department of Geography, University of Lethbridge, calibrated the model to estimate the impact of climate and non-climate variables on crop biomass and grain production. The yearly value of crop and forage yields provided by Dr. Kienzle are used in this study.

evapotranspiration $(1 - \frac{ET}{ET_x})$ decline, and (Ky) is the yield response proportional factor (Steduto et al., 2009).

$$\left(1 - \frac{Y}{Y_x}\right) = K_y\,(1 - \frac{ET}{ET_x}) \tag{6.1}$$

where Y_x and Y are the maximum and actual yield and ET and ET_x are the maximum and actual evapotranspiration, and K_y is the proportionality factor between relative yield decline and relative reduction in evapotranspiration (Steduto et al., 2009).

The model includes soil (with its water balance), plants (with their development, growth and yield processes) and atmosphere (with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration) (Steduto et al., 2009). Management aspects, such as irrigation and fertilizer applications, can be considered, but the model does not simulate the pests, diseases, and weeds (Steduto et al., 2009). Five weather input variables are required to run the model: maximum and minimum temperatures, rainfall, evaporative demand of the atmosphere (expressed as reference evapotranspiration, ET_0)[29], and mean annual carbon dioxide concentration in the atmosphere (Steduto et al., 2009). Temperatures (minimum and maximum), rainfall and ET_0 may be provided at different time scales, such as daily, 10-day, and monthly records. However, at run time AquaCrop processes the 10-day and monthly records into daily values (Steduto et al., 2009). Evapotranspiration (ET_0) is simulated separately into two components: crop transpiration (T_a) and soil evaporation (E_s). The daily crop transpiration (T_a) is used to estimate the daily biomass gain through the normalized biomass water productivity[30] of the crop (Steduto et al., 2009). The AquaCrop model is considered to be superior in relating water to biomass production as the separation of ET_a into E_s and T_a avoids the confounding effect of the non-

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[29] According to Allen et al. (2006), evapotranspiration (ET) rate from the reference surface is called Reference Evapotranspiration (ET_0), which can be stated as: “Reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23 (where albedo is shortwave radiation reflected from the earth back into space, and is a measure of the reflectivity of the earth's surface). The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The fixed surface resistance of 70 s m^{-1} implies a moderately dry soil surface resulting from about a weekly irrigation frequency”.

[30] “Biomass water productivity (WP_b) is defined as the aboveground dry matter (g or kg) produced per unit land area (m^2 or ha) per unit of water transpired (mm or m^3). The units of WP_b are then either kg m^{-3} or kg ha^{-1} mm^{-1}” (Steduto et al., 2009).

productive consumptive use of water (E_s) (Steduto et al., 2009). Major input and output variables of the model are shown in Table J.1 in Appendix J.

Under the RCM3_CGCM3_A2 climate scenario, the long-term average crop yield for the Pincher Creek site is projected to increase in the range of 50% to more than 100% across various crops under the future scenario. Spring wheat and feed barley are expected to gain more than canola, maize and alfalfa hay (Table 6.1). The long-term average crop yield under the future scenario for the Swift Current site is projected to be almost double of that under the baseline scenario for most of the crops. Maize, spring wheat and feed barley are expected to gain more in terms of average long-term yield relative to canola and alfalfa hay (Table 6.2).

Table 6.1 Mean and variability of crop yield under the baseline and future scenario in the Pincher Creek site

Crop yield indicators	Spring wheat (ton/ha)	Feed Barley (ton/ha)	Canola (ton/ha)	Maize (ton/ha)	Alfalfa hay (ton/ha)
Baseline scenario					
Average yield	1.19	1.31	2.90	3.13	4.63
Coefficient of Variation	0.93	0.75	0.28	0.59	0.29
Observations below one std. dev.* from the mean	2	5	8	6	5
Future scenario					
Average yield	2.70	2.27	4.59	4.99	7.16
% of baseline (average yield)	227.77	172.79	158.49	159.28	154.75
Coefficient of Variation	0.59	0.65	0.22	0.33	0.19
Observations below one std. dev.* from the mean	6	9	8	7	5

*Standard deviation

Table 6.2 Mean and variability of crop yield under the baseline and future scenario in the Swift Current site

Crop yield indicators	Spring wheat (ton/ha)	Feed Barley (ton/ha)	Canola (ton/ha)	Maize (ton/ha)	Alfalfa hay (ton/ha)
Baseline scenario					
Average yield	1.35	0.90	2.53	0.74	4.63
Coefficient of variation	0.71	0.81	0.34	1.99	0.29
Observations below one std. dev.* from the mean	9	7	6	0	5
Future Scenario					
Average	3.10	2.16	4.40	1.79	8.03
% of baseline (average yield)	228.72	238.79	174.13	240.05	173.62
Coefficient of variation	0.47	0.62	0.21	0.94	0.28
Observations below one std. dev.* from the mean	6	7	5	0	3

*Standard deviation

Lower coefficient of variations under the future scenario indicates that the crop yield variability will be lower in the future in both study sites (Tables 6.1 and 6.2). The number of years with poor crop yields, however, increases for the majority of crops under the future scenario for the Pincher Creek site while it decreases for the Swift Current site.

The average long-term crop yield change under the future scenario in this study seems to be optimistic[31] compared to the result of previous studies. The previous studies projected maize yield to double and most of the cereal yield to increase in the range of 20-60% (Brklacich, 1998; Bootsma et al., 2005). There might be several reasons for the estimation of significantly higher future yield in this study including: carbon fertilization effects, warmer and wetter future climate and the crop model's assumption of no plant nutrient limitation. Available literature claims that above-ground biomass will increase with elevated CO_2 levels (Ainsworth and Long, 2005; Vanuytrecht et al., 2011). According to Kienzle (2014), the carbon fertilization effect and atmospheric CO_2 are projected to increase in the future. Atmospheric CO_2 under IPCC A2 future emission scenario is projected to increase by more than 60%, from 347 ppm under the baseline scenario (1971-2000) to 561 ppm under the future scenario (2041-2070). The water productivity parameter in the AquaCrop model captures this effect, as it is based on ET_0 and CO_2 which is used to calculate the crop biomass (Steduto et al., 2009). The AquaCrop model is known to overestimate yields under conditions of elevated CO_2 (Vanuytrecht et al., 2011). The AquaCrop model assumes that there is no restriction in nutrient availability (Kienzle, 2015); relatively warmer and wetter future climate with the sufficient nutrients might contribute to higher crop yields under the future scenario. The RCM3_CGCM3_A2 scenario projects more than 2^0C growing season maximum and minimum temperature increases and about 18% growing season precipitation increase. The RCM3_CGCM3_A2 scenario's confidence of temperature increase is high but the confidence of precipitation change is low. Therefore, another reason for the optimistic crop yield estimation for the future might be that many crop models (including the AquaCrop model) do not simulate extreme dry conditions very well (Hasiao et al., 2009; Heng et al., 2009). Therefore, the result might be slightly upward biased. Atmospheric CO_2 level projections under RCM3_CGCM3_A2 scenario are given in Figure K.1 in Appendix K. Crop transpiration estimates are given in Figures

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[31] The AquaCrop model was calibrated using the observed yield for the project location. Detailed information on the model calibration and result validation can be obtained from Dr. Stefan Kienzle (Stefan.kienzle@uleth.ca).

L.1 through L.10 in Appendix L. Yield estimates of the crops and hay for the Pincher Creek site are presented in Figures M.1 through M.10 in Appendix M and the yield estimates for the Swift Current site are presented in Figures N.1 through N.10 in Appendix N.

6.3 Pasture yield estimation

To estimate the yearly pasture productivity under the baseline and future scenario, the Forage Calculator for Native Rangeland developed by the Saskatchewan Research Council (Thorpe, 2014) was used. The Forage Calculator estimates the forage production for a given forage-year-precipitation (PPTfy). Taking the average long-term production and corresponding monthly precipitation value as a reference, the calculator estimates forage production using the current year's "forage-year" precipitation. The "forage-year" precipitation is the independent variable in equation (6.2), and is estimated as the 12-month total from the September 1st of the previous year to August 31st of the current year,

$$Production = -165 + 1.67 * PPTfy \tag{6.2}$$

$R^2 = 71.5\%$,

where, production is in kg/ha, and PPTfy is in mm.

The long term pasture production data required to calibrate the Forage Calculator including its source and methods are discussed in Section 6.3.1 and climate scenarios to construct "forage-year-precipitation" data are discussed in Section 6.3.2.

6.3.1 Long term pasture yield for the calibration of forage calculator

The Forage Calculator, as represented by equation (6.2), first needs to be calibrated for the specific location, which requires average long-term pasture yield for that location. Hence, the long-term average pasture yield estimation provided by Thorpe (2011) for the two study sites were used to calibrate the Forage Calculator. To estimate the long-term pasture yield, Thorpe (2011) related the measured grassland production to 1961-1990 normal climates at the measurement locations using multiple linear regression approach. Equation (6.3) is developed based on the climate and production data for the all the prairies grasslands and the US Great Plains. The grassland production in Kg/ha is related to the annual precipitation (PPT in mm), annual potential evapotranspiration (PET in mm), and proportion of precipitation falling in May through September (MAYSEP). However, he found that closer fitting regression results can be obtained if Canada-only data are used as shown in equation (6.4). For best results, baseline and future production are calculated from equation (6.3), and the percentage change in the future from baseline production is then applied to the baseline production estimated from equation (6.4).

$$Production = -3004 + (4.72 * PPT) + (-0.98 * PET) + (5316 * MAYSEP) \tag{6.3}$$

$R^2 = 58.6\%$

All coefficients are statistically significant ($p<0.05$)

$$ln(Production) = 2.97 + (0.0045 * PPT) + (-0.0026 * PET) + (6.18 * MAYSEP) \tag{6.4}$$

$R^2 = 68.7\%$

All coefficients statistically significant ($p<0.05$)

The above process is applied to each grid point in the baseline climate grid size of approximately 3 km east-west by 5 km north-south to produce the data surface of grassland production for the entire region under consideration. The grassland production data surface for both Saskatchewan and Alberta is made available by Dr. Jeff Thorpe (April 24, 2014). These forecasts are available for five different climate scenarios for Saskatchewan: the Coupled Global Climate Model A1B emission scenario (CGCM3_T47_A1B), the Geophysical Fluid Dynamics Laboratory Climate Models B1 emission scenario (GFCM20 B1), the National Institute for Environmental Studies Japan B1 emission scenario (MIMR_B1), the UK Meteorological office Climate Model A2 emission scenario (HADCM3_A2), and the Max Planck Institute for Meteorology A2 emission scenario (ECHAM4_A2). However, there are only two climate scenarios for Alberta: the HADCM3_A2 and the ECHAM4_A2. In this study the average 1971-2000 pasture yield has been used for the baseline and 2050s average yield has been used for the future scenario period (2041-2070).

6.3.2 Choice of climate scenarios for the calibration of Forage Calculator

The climate scenarios used in the crop simulation model are different from the ones used by Thorpe (2011) to predict long-term forage production. Two common sets of climate scenarios used by Thorpe for both the study sites are the HADCM3_A2 and ECHAM4_A2 as shown in

Table 6.3. The HADCM3_A2 represents a warmer scenario with higher temperature increases and the ECHAM4_A2 represents a cooler scenario with only moderate increases in temperature. The precipitation is projected to range from a small increase in HADCM3_A2 to a small decrease in ECHAM4_A2 (Thorpe, 2011). To decide which of these two climate scenarios to use, as crop yield was simulated under CGCM3-RCM3_A2 model, future pasture yield forecast from ECHAM4 and HADCM3 were compared with CGCM3 pasture yield forecast available for only Swift Current site (Table 6.3). For Swift Current, the ECHAM4_A2 projects a pasture yield that is more closely aligned with the CGCM3. Therefore the ECHAM4_ A2 scenario was chosen for pasture yield forecasts for both the study sites.

Table 6.3 Average grassland productivity (ton/ha) for 1961-1990 observed and 2050s climate for five different climate scenarios

Climate Scenarios	Pincher Creek (49.4583 N and -113.9583 W)		Swift Current (50.2917 N and -107.7917 W)	
	1961-90	2050s	1961-90	2050s
CGCM3_A1B	1.86	NA	1.42	1.24
GFCM_B1	1.86	NA	1.42	1.02
MIMR_B1	1.86	NA	1.42	1.07
HADCM3_A2	1.86	1.69	1.42	1.09
ECHAM4_A2	1.86	1.76	1.42	1.15

*Not Available. Climate scenario results for Pincher Creek was available only for HADCM3_A2 and ECHAM4_A2 Scenario only.

Source: Thorpe (2011)

6.3.3 Pasture yield results

As discussed above, three items were needed to calibrate and run the Forage Calculator: the long-term average yield and the forage-year-precipitation as reference yield and precipitation, and the current year forage-year-precipitation to estimate current year pasture production. The average long-term monthly precipitation and corresponding pasture yield obtained from Thorpe (2011) for 1961-1990 period and the 2050s are taken as the reference forage-year-precipitation and the reference yield to calibrate the calculator. Yearly precipitation values to prepare current year forage-year-precipitation for ECHAM4_A2 scenario were downloaded from Environment Canada (2014). Some key statistics of the pasture yield results are shown in Table 6.4.

Average pasture productivity is estimated to be lower under the future scenario in both study sites (Table 6.4). Furthermore, average pasture productivity is lower in the Swift Current site than in the Pincher Creek site for both the study scenario periods. Average annual yield variability is almost the same across the two periods as indicated by coefficient of variations. Yearly pasture productivity estimates for the Pincher Creek site are shown in Figures O.1 and O.2 and for the Swift Current site are presented in Figures O.3 and O.4 in Appendix O.

Table 6.4 Mean and measure of variability of pasture production under the baseline and future scenarios in the Swift Current and the Pincher Creek study sites

Pasture yield indicators	Pincher Creek	Swift Current
Baseline scenario		
Average yield (ton/ha)	1.86	1.42
Coefficient of variation	0.11	0.11
Observations below one std. dev.* from the mean	4	8
Future scenario		
Average yield (ton/ha)	1.76	1.15
% of baseline yield	95.67	80.37
Coefficient of variation	0.12	0.11
Observations below one std. dev.* from the mean	5	6

*Standard deviation

The overall results confirm that the pasture productivity is estimated to decrease slightly under the future scenario in the study sites. Thorpe (2011) suggested that this may be a result of the warmer future with little increase in precipitation predicted by the ECHAM4 A2 scenario leading to very high potential evapotranspiration (PET). A major part of the increase in precipitation will be lost through spring runoff. Moisture will be a limiting factor for future pasture production. In this study carbon fertilization effect, which may cause an average 30% yield increase (Campbell and Staford Smith 2000), is not considered. Sykes (2008) also estimated that productivity of native pasture in summer, especially wheatgrass, which is a dominant native pasture species in both the study sites, will decrease in the future.

6.3.4 Pasture yield for the alternate pasture yield scenario

The crop yields are estimated to increase while the pasture yields are estimated to decrease under the future scenario. To check the sensitivity of the future scenario results to pasture productivity, the MF-CCE model is also simulated under the assumption that the pasture response to climate change is similar to that observed for the crops. As noted above, crop yields are projected to increase in the range of 154% to 227% in the Pincher Creek site and in the range of 173% to

238% in the Swift Current site. Therefore, an average of 190% increment in Pincher Creek and an average of 200% increment in Swift Current baseline pasture yield were applied to estimate the future pasture yield for the simulation of the alternate pasture yield scenario.

6.4 Summary of the crop and pasture yield estimation

The FAO's AquaCrop model is used for estimating crop yields and the Forage Calculator for Native Rangeland obtained from Saskatchewan Research Council is used in estimating yearly pasture productivity. Crop productivity under the future scenario is estimated to increase significantly in both the study sites. Crop yields are projected to be at least 1.5 times to more than double in both the study sites. Pasture yield, on the other hand, is projected to decrease at both the study sites except under the alternate pasture yield scenario. Some of the major factors in explaining differences in crops and pasture yield forecasts include the difference in consideration of CO_2 fertilization effect, the consideration of plant water use by the AquaCrop model and the Forage Calculator, and the AquaCrop model's assumption of non-limiting nutrient availability.

Chapter 7 STUDY SCENARIO AND ADAPTATION STRATEGIES

7.1 Introduction

This chapter details the scenarios analyzed in this study. As noted earlier, the study is conducted for two climate periods: the baseline period of 1971-2000 and the future period of 2041-2070, which are simulated to assess the impacts of climate and climate extremes. Furthermore, the climate change impacts are analyzed under two price scenarios: the projected future price, and the baseline price together with the future climate. This is done to see the sensitivity of the results to the price assumptions. The chapter also reports results of two pasture yield estimates: one estimated based on the Forage Calculator, and an alternative pasture yield estimate by assuming that the pasture productivity behaves similarly to that of crops under the future climate. Additionally, the chapter discusses different adaptation strategies tested in this study.

7.2 Study scenarios

Unlike most of the climate change impact studies that consider future average climate, this study captures the impacts of climate change and extremes by incorporating the inter-annual climate variation in both the baseline climate as well as the future climate. As discussed in Chapter 5, climatic variation enters into the simulation indirectly through its effect on crop yield and pasture productivity.

7.2.1 Description of baseline and future scenarios

The study farms have been simulated under two climate periods of 30 years each: the baseline period of 1971 to 2000 and future period of 2041 to 2070. The MF-CCE model is estimated in yearly time steps; therefore, all the model inputs, such as commodity price, COPs, and crop yields, are estimated annually. The estimation of annual crops and pasture yield is very important to the study as the effects of climate change are captured by linking crop and pasture yields to the climate variables. The inter-annual climate variation is of particular interest in this study as it determines the manner in which farmers make adjustments in their farming operations or management to adapt to sudden variability in climate conditions.

The area under pasture, and hay at the start of the simulation under both the scenarios is set in such a manner that their supply and the herd feed demand match exactly under an average situation. Any changes in hay and pasture productivity impacts the herd feeding plan as total area of crops, hay and pasture could not be transferred from one use to another in a short period. Impact on pasture productivity is considered to be the main factor that links the climate to the beef herd management decision by affecting carrying capacity of pastureland. It is assumed that pasture can neither be sold nor bought to match pasture demand and supply. Therefore, the farmer needs adaptation measures in managing summer feeding to compensate for pasture shortages during extreme climate years. It is assumed that maintaining the beef herd by purchasing feed during feed shortages is the most common beef herd strategies (AARD 2014c; Hernani, 2013; SMA, 2008). In this study, this strategy is regarded as the "reference adaptation practice" in evaluating the climate change impacts under both the baseline and future scenarios. Table 7.1 presents considerations used in building the baseline and future scenarios of this study.

Table 7.1 Baseline and future scenarios description

Scenario	Climate period	Cost and prices period	Pasture yield	Beef herd adaptation	Crop activity adaptation
Baseline scenario	1971-2000	1971-2000	Regular estimation*	Purchase feed	Crop mix selection
Future scenario	2041-2070	2041-2070	Regular estimation	Purchase feed	Crop mix selection

*Regular pasture yield estimation is the pasture yield estimated by using the Forage Calculator. The details on the regular pasture yield estimation are given in Chapter 6. Scenarios to evaluate the sensitivity of the result to pasture yield are discussed in Section 6.3.

Some alternative adaptations are also simulated under both scenarios to evaluate their efficacy in dealing with climate change and extremes. Details on the adaptation practices in managing beef cattle herd are discussed in Section 7.2.2, whereas the adaptation in crops is discussed in Section 7.2.3.

7.2.2 Climate change adaptation strategies for beef cattle activities

Bastian et al. (2006) have observed several beef herd coping strategies in extreme years: purchasing additional feed for livestock, livestock herd liquidation, participating in government assistance programs, and undertaking other management alternatives, like weaning calves early, selling retained yearlings, and adding alternative crop and livestock enterprises. Ritten et al. (2011)

have recommended different drought management strategies for cattle producers which can be broadly grouped into two classes: purchasing additional feed, and reducing feed demand of the herd. The first strategy is the most common and involves purchasing feed to substitute for reduced forage production. The choice of feed depends on its availability, season of feeding, type of animal, and price of feed alternatives. The second strategy helps reduce nutritional demands of the herd. This can be done by partial liquidation of the herd, which provides some immediate revenues and reduces pressure on forage and pasture. However, this adds cost to rebuilding the herd after the drought and reduces farm profit in future years. Another option in reducing herd nutritional demand is early weaning of calves, which does not add additional costs of securing feed. However, this scenario can result in either fewer or lighter weight animals to sell in the future.

Some producers may want to keep the herd and purchase feed instead of selling the herd immediately and purchasing more cattle later. In evaluating the effect of drought on cattle farms in Australia, Foran and Smith (1991) tested three different coping strategies. The strategy of an average firm was to ignore the drought in the hope that rain would come soon. The high-stock herd farm sold the cattle immediately after the first indication of the drought. In contrast, the low-stock farm maintained herd size even in drought by introducing different management strategies. Nagler et al. (2007) reported the common drought coping strategies in the US are purchasing additional feed, reducing herd size, weaning calves early, selling retained yearlings, and adding alternative crop enterprises. The Ontario Ministry of Agriculture Food and Rural Affairs (OMAFRA, 2012) advises three options for dealing with feed shortages: moving livestock where abundant feed and forages are available, buying feed, and culling the herd.

Gillard and Moneypenny (1990) evaluated different rates of culling as a drought management strategy and their effect on farm cash-flow in Australia. Smith and Foran (1992) also investigated the economic effects of alternative destocking rates as management strategies under extreme events in Australia. They found that a strategy of substantial destocking is better for longer term drought management than the policy of hopeful inaction. They showed that immediate destocking of 20% in a single year drought is a sensible decision while 40% destocking is more appropriate if the drought lasts for two years or more. According to Ritten et al. (2011), maintaining herd size by purchasing feed adds extra cost to the farm and is beneficial only if the cattle price is expected to increase or at least remain the same; otherwise herd liquidation may be a useful strategy during periods of feed shortages. However, Rasby (2013) advised some adjustment in timing and management of farm operation to cope with the effect of drought events before herd liquidation. He suggested early weaning of calves, and early pregnancy testing and early selling of open cows as drought management strategies. Similarly, DEPI (2014) recommends limiting feeding and controlling the weight loss of cattle to lower the pressure on feed, which can be a good coping strategy for drought-induced feed shortage periods. SMA (2008), AARD (2014c), and an interview of mixed crop-beef cattle farmers in the Alberta Taber region undertaken by the VACEA project team in 2012 (Hernani, 2013) suggested that purchasing feed is the most common practice in dealing with drought events, followed by changes in management practices (such as early weaning of calves) changes in timing of herd operations, and reduction in herd size.

According to the literature discussed above, coping strategies under extreme weather events for a livestock farm can be broadly grouped into three categories: maintain the herd size by feeding purchased feeds, maintain the herd size by adjustment in timing and activities of farm operations, and reduce the size of the herd. There may also be other alternatives or combination of different activities within each strategy, such as deciding which feed to purchase, what adjustments to be made, what percentage of the herd to liquidate and so forth. Such decisions always vary depending on the individual farmer's management style, farming experience, risk attitude, among others; therefore they are not considered in this study.

As discussed in Section 7.2.1, purchasing feed, if necessary, without other changes in management or reduction in herd size is considered as the reference adaptation for the estimation of climate extremes' impact on the baseline and future scenarios. Two other alternative adaptations are modeled for poor crop and pasture yield years to meet the beef herd feed demand in this study: (1) Farmer reduces total feed demand of the herd by changing herd management practices, like weaning calves earlier and limiting feeding of feedlot animals. This strategy is named the "early weaning and limiting feeding strategy"; and (2) Culling herd decision starting from open cows to exactly match the reduced feed supply due to extreme weather events. This strategy is named as "cull herd strategy". It is assumed that producer cannot combine two strategies at the same time as discussed in Section 5.3. Alternative adaptation scenarios are described in Table 7.2. Further actions for purchasing feed as well as alternative adaptation options are given in Table 7.3.

Table 7.2 Description of the alternative beef herd adaptations strategies

Period	Adaptation scenario	Cost and price used	Pasture yield	Beef herd adaptation	Crop activity adaptation
1971-2000	Early weaning and limit feeding strategy	1971-2000	Regular estimation	Early weaning and limit feeding	Crop mix selection
	Cull herd strategy	1971-2000	Regular estimation	Cull herd	Crop mix selection
2041-2070	Early weaning and limit feeding strategy	2041-2070	Regular estimation	Early weaning and limit feeding	Crop mix selection
	Cull herd strategy	2041-2070	Regular estimation	Cull herd	Crop mix selection

Table 7.3 List of actions of beef herd adaptation alternatives in dealing with extreme climate events

Enterprise	Purchase feed strategy	Early weaning and limit feeding strategy	Cull herd strategy
CROPS	NA	NA	NA
COW-CALF	***Summer Feeding*** Purchase feed if inventory is not enough.	***Summer Feeding*** Early sale of open cows and, Early weaning of calves If summer feeding is still deficit, Purchase feed if inventory is not enough	***Summer Feeding*** Early sale of open cows If not enough, sell more cows to exactly compensate summer drought
	Winter Feeding Buy hay to supplement inventory hay for the winter feeding	***Winter Feeding*** Buy hay to supplement inventory hay for the winter feeding	***Winter Feeding*** Buy hay to supplement inventory hay for the winter feeding
Feed-Lot (including replacement heifer)	Purchase feed if inventory is not enough.	Lower than recommend feeding (lowers the desired weight gain) for other than herd replacement heifer	
Rebuild the herd by keeping replacement heifer in the year following the drought in case of cull cow strategy			

NA = Not applicable

7.2.2.1 Purchase feed strategy

Cow-calf animal feeding plan: In a normal year, cows are placed on pasture and calves are fed on milk and pasture from March until weaning in October. In the event of extreme climate, which reduces total pasture production, grain is fed to supplement the summer pasture deficit. If the grain inventory is insufficient, additional grain is purchased to supplement the pasturing of cows. In this strategy, a least cost linear programming problem was formulated to decide which grains to purchase to meet the given nutritional requirement of the herd. For winter feeding, hay is fed first and if the inventory is not enough, hay is purchased at market price.

Feedlot animal feeding plan: The producer keeps enough grain and silage to feed feedlot animals including replacement heifers. However, lower crop yields due to summer drought may impact grain availability for feedlot animals. Hence, if grain inventory is insufficient, extra grain is purchased to meet the grain demand of feedlot animals.

7.2.2.2 Early weaning and limit feeding strategy

Changes in cow-calf herd: In this strategy, the producer tries to adjust the timing of different beef herd operations and changes the amount of ration fed to animals to lower the total feed requirement without severely compromising the herd performance. To meet the pasture deficit, the producer performs two adjustments over time: one, identify open cows as early as possible, and two, wean the calves earlier to reduce the feed requirements of the cows. According to Wagner and Osborne (2014), pregnancy tests can be done as early as 40 days after mating. Since cows conceive in May, pregnancy tests can be done by the end of June. This identifies open cows and allows for them to be sold by the first week of July, instead of August in normal years.

According to SMA (2008; 2010) and AARD (2014c), the early weaning of calves can save the cow substantial energy during feed shortages. Wagner and Osborne (2014) suggest nutritional requirement of a dry cow is about 50% to 65% of that of a cow nursing a calf; therefore in the drought years, calves were weaned at the age of 4 months instead of 7 months. In this study, calves were weaned in July and it is assumed that a cow without a nursing calf needs 60% of the total DM requirement. Any feed deficit after these adjustments are made is met by purchasing feed.

Changes in feedlot management: Grain production during a poor crop year may not be limited as grain supply includes grain produced in the previous year. However, forages in summer and grain in winter may be limited due to the current year drought. Choosing the lower bound of expected average daily gain (ADG) of feedlot animal can lower the amount of feed requirements. DEPI (2014) has suggested a different limit-feeding and weight loss program to cope with feed shortages during drought. This adaptation alternative involves decreasing the total feed given to feedlot animals, thus lowering the daily weight gain of the animals. Expected daily gain of backgrounding and finishing animals in a normal year were 2.5 lbs and 3 lbs, respectively. During the period of feed shortages, the expected daily gain is reduced to 1.5 lbs and 2 lbs for backgrounding and finishing animals, respectively. However there are no changes in the feeding plan of herd replacement cattle, because such a strategy may have a negative effect on the herd performance in the later years.

7.2.2.3 Cull herd strategy

In this strategy, instead of an adjustment in timing and other management practices, farmers sell cows to reduce feed deficit. In this study, herd size is reduced starting from the selling of open cows to exactly match the feed requirement and reduced feed supply. If the herd has already been downsized in the summer, on-farm production may be enough to meet the winter feed requirements of the herd. If not, the farmer would purchase extra feed to meet the feed demand for the herd.

7.2.3 Adaptation strategy in crops

The future climate of the Prairies is, in general, projected to be warmer with little or no change in summer precipitation, which may have an impact on the choice of crop in the long run. IISD (1997) highlighted the need for and advantage of growing dryland crops, like grain maize in the Canadian Prairies, under the global warming scenario. Bradshaw et al. (2004) anticipated the likelihood of changing crop mix of the Prairies with more non-traditional crops that can thrive in warmer and drier condition, such as maize. However, adaptation to sudden onset of extreme events, such as a drought, is difficult due to the problem in timely recognizing the onset of the events (Wheaton et al., 2008). Kulshreshtha and Marleau (2005) add that adaptation in crop production during the 2001 and 2002 Canadian Prairie droughts was minimal mainly because drought conditions were not recognized until most management decisions had been already made.

The methodology in this study allows the farmer to choose crop mixes annually to maximize the profit under given climate and crop yield scenarios in order to adapt to changes in the long-term climate, with no adaptation to sudden onset of extreme events. Once the planting decision has been made, adaptation to extreme events could mainly be done through the appropriate management practices, such as the timely irrigating[32] of crops to cope with droughts. This study assumes that the weather conditions projected by the climate model used in this study

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[32] As the study simulates non-irrigated dryland farms, the coping to moisture stress is out of the scope of this study.

will happen with certainty and producers decide the appropriate crop choice beforehand. Therefore, no stochastic weather behavior is modelled.

7.3 Sensitivity analysis

As discussed in Section 7.2, this study includes future scenarios, such as future projected input and output prices, and future projected climate and resulting crops and pasture yield. The sensitivity of the results is tested by alternating prices and pasture yield in the future scenarios. Scenarios of sensitivity analysis are discussed in Sections 7.3.1 and 7.3.2.

7.3.1 Alternate price scenarios

The economic impact of climate changes and extremes in the future periods are simulated under alternate input and output price scenarios. The future scenarios described in Section 7.2.1 are simulated under the baseline price and costs of production to check the sensitivity of economic impacts of future climate change to the price assumption. Also, the results of the future scenario under baseline prices and costs are compared with the results of the baseline scenario to understand the net impact of climate change. An alternate price scenario is given in Table 7.4.

Table 7.4 Description of the alternative price scenarios

Climate Period	Cost and price used	Pasture yield	Beef herd adaptation descriptions	Crop activity adaptation
2041-2070	**1971-2000**	Regular estimation	Purchase feed	Crop mix selection

7.3.2 Alternate pasture yield scenarios

The MF-CCE model is simulated under an alternate pasture yield assumption. The future scenario discussed in Section 7.2.1 uses the regular pasture yield estimated by using the Forage Calculator for Native Rangeland while the alternate pasture yield scenario uses the pasture yield aligned with crop yield as discussed in Section 6.3.4. The alternate pasture yield scenario is shown in Table 7.5.

Table 7.5 Description of the alternate pasture yield scenario

Period	Cost and price used	Pasture yield	Beef herd adaptation descriptions	Crop activity adaptation
2041-2070	2041-2070	**Linked to crop yield**	Purchase feed	Crop mix selection

7.4 Summary of the study scenarios

Table 7.6 summarizes the scenarios analyzed in this study. Two climate periods, the baseline and future, are considered to compare the impacts of climate change in the future. Major components of the study scenarios developed include the climate change and resulting crop and pasture yields, beef herd coping in extreme events linked to yield effects, and assumptions related to input and output price. The baseline and future scenarios are taken as reference scenarios and all other scenarios are compared with them: alternate adaptation scenarios are simulated under both the scenarios while alternate price and pasture yield scenarios are simulated under the future scenarios only. The major components of the scenarios are contrasted in bold in table 7.6.

Table 7.6 Summary of the scenarios simulated in this study

Scenarios	Consideration	Period	Cost and price used	Pasture yield	Beef herd adaptation	Crop activity adaptation
Baseline and Future Scenarios	Baseline scenario	1971-2000	1971-2000	Regular estimation	Purchase feed	Crop mix selection
	Future scenario	2041-2070	2041-2070	Regular estimation	Purchase feed	Crop mix selection
Alternate adaptation scenarios	Early weaning and limit feeding	1971-2000	1971-2000	Regular estimation	**Early weaning and limit feeding**	Crop mix selection
	Cull herd	1971-2000	1971-2000	Regular estimation	**Cull herd**	Crop mix selection
	Early weaning and limit feeding	2041-2070	2041-2070	Regular estimation	**Early weaning and limit feeding**	Crop mix selection
	Cull herd	2041-2070	2041-2070	Regular estimation	**Cull herd**	Crop mix selection
Alternate Price scenarios	Future period with baseline price	2041-2070	**1971-2000**	Regular estimation	Purchase feed	Crop mix selection
Alternate pasture yield scenario	Future period with alternate pasture yield forecast	2041-2070	2041-2070	**Pasture yield linked to crop yield**	Purchase feed	Crop mix selection

Chapter 8 RESULTS AND DISCUSSION

8.1 Introduction

This chapter presents the results of the MF-CCE model. As indicated above, this model integrates the sub-models of beef cattle, crops, and pasture activities with a model of economic decisions (such as a model of crop choices) to simulate farm financial position. The MF-CCE is simulated under the baseline scenario period 1971-2000, and the future scenario period 2041-2070. Results under both scenarios with reference adaptation (purchase feed to maintain beef herd during the period of extreme events) are taken as bases for comparison. These results are compared with the two alternative adaptation strategies: the early weaning and limit feeding strategy, and the cull herd strategy. This comparison provides a basis for the decision on the choice of adaptation measures. The choice of beef herd adaptation not only affects the beef herd management and profit, but also crop revenue and thus the whole farm profit. As discussed in Chapter 6, this study considers only one adaptation in crops, i.e., changing the crop mix to maximize profit under the given climate scenarios. Therefore, the results of adaptation alternatives presented in this chapter should be understood as beef herd management alternatives under climate change and extreme event period.

As noted earlier, the MF-CCE model is simulated for two study sites: Pincher Creek and Swift Current. Differences in the results of two study farms could be attributed to the differences in climate, soil type and the vulnerability to climate changes and extremes. Furthermore, the chapter also discusses the future climate change result in terms of alternate price and pasture yield assumptions.

8.2 Baseline results and impact of climate change

As discussed in Chapter 4, the Pincher Creek farm is primarily a beef cattle oriented farm with a higher number of beef cattle compared to the Swift Current farm. The latter farm is more crop oriented with a larger crop area and fewer head of beef cattle. Climate wise, on average, the Pincher Creek site receives more precipitation, whereas the Swift Current site experiences a hotter and drier climate. These characteristics affect crop yields, vegetation types, and carrying capacity of pastureland. All biological and farm size differences are reflected in terms of the impact on the response to climate risk under the baseline and future scenarios.

8.2.1 Beef cattle production activities

As noted earlier, beef cattle activities in this study consist of raising cow-calf, backgrounding and finishing cattle, managing feed, and finally marketing of feedlot and cull animals for slaughter. Profitability from the beef cattle production activities depends on the number of beef cattle sold and their respective prices, on-farm feed production cost, cost of adaptation during the year of feed shortages, and other production costs including yardage and labor.

Under the baseline scenario, the number and live weight of slaughter cattle sold in the Pincher Creek site are 79 and 102,961 lbs, respectively. The values for the Swift Current site are 67 and 87,423 lbs, respectively (Table 8.1).

Table 8.1 Number and live weight beef cattle sold, Pincher Creek and Swift Current sites, average under the baseline and future scenarios

Scenarios	Slaughter cattle sold (Number/year)	CV	Live weight slaughter cattle sold (‘000 lbs /year)	CV
Pincher Creek				
Baseline scenario	79	0.07	102.96	0.07
Future scenario	79	0.07	102.96	0.07
Swift Current				
Baseline scenario	67	0.13	87.42	0.13
Future scenario	67	0.13	87.42	0.13

There is no change in the number of slaughter cattle sold or their weights, as this study assumes no change in the level of cattle productivity performance under the future climate change scenario. Both the baseline and future scenarios considered reference adaptation strategy[33] which involves purchasing feed to maintain the beef herd in the events of feed shortages caused by extreme climate events. Farm profitability and liquidity situations across the two scenarios are

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[33] Results of two alternative adaptation strategies are presented in the next section. The number and live weight sold would be different under alternative strategies as they reduce the feed demand either by making changes in regular feeding plan or by reducing herd size.

different due to the differences in adaptation costs (purchase feed) resulting from differences in the climatic conditions including the magnitude and frequency of the extreme events.

The proportion of the cost of feed production to the total beef cattle variable cost of production under the baseline scenario is about 40% in the Pincher Creek site and about 42% in the Swift Current site. Under the future scenario, this share is projected to increase to about 45% in the Pincher Creek site but remains almost same in the Swift Current site. However, the share of the total feeding cost, which includes the cost of feed purchase in addition to on-farm feed production cost, under the baseline scenario is about 46% in the Pincher Creek site and 53% in the Swift Current site. These costs are projected to increase to 50% and 58%, respectively, under the future scenario. Comparatively, a higher share of total feeding cost in the Swift Current site reflects the relatively lower carrying capacity of pastureland resulting in the higher cost of purchased feed under both scenarios. Average yearly feed production cost in the Pincher Creek site is estimated to be $17,000, which is projected to double to $34,000 under the future scenario. On-farm feed production costs in the Pincher Creek site under the baseline and future scenarios are shown in Figures 8.1 and 8.2. Distribution of beef cattle COP in the study sites is shown in Table P.1, Appendix P.

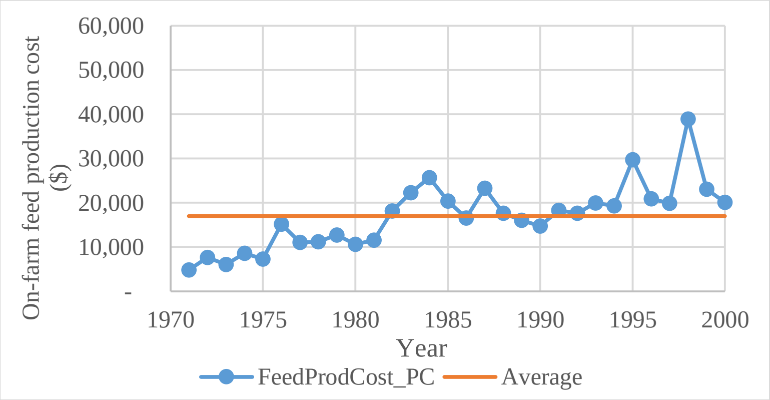

Figure 8.1 Pincher Creek on-farm feed production cost under the baseline scenario, 1971-2000

At the Swift Current site, the average on-farm feed production cost under the baseline scenario is estimated to be $18,000/year. In the future, this is estimated to increase by more than 80% to $33,000/year. These costs under both the scenarios are shown in Figures 8.3 and 8.4.

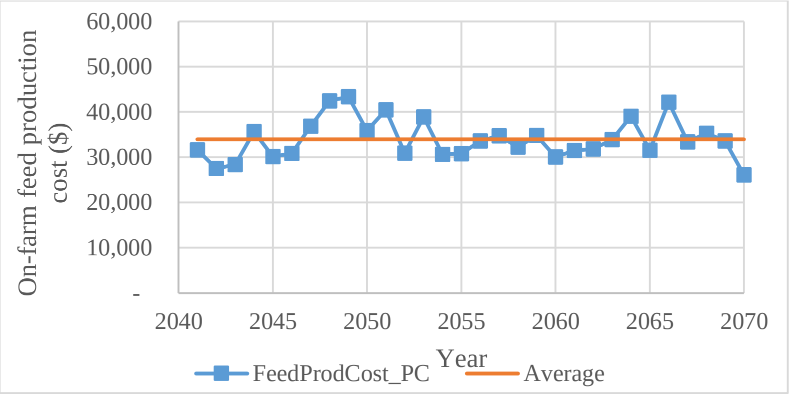

Figure 8.2 Pincher Creek on-farm feed production cost under the future scenario, 2041-2070

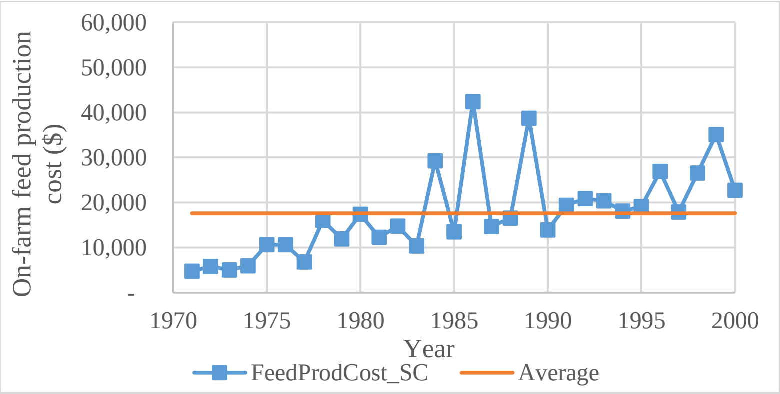

Figure 8.3 Swift Current on-farm feed production cost under the baseline scenario, 1971-2000

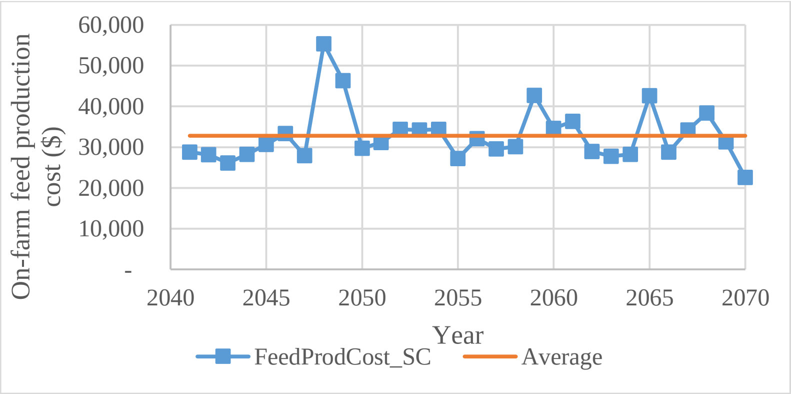

Figure 8.4 Swift Current on-farm feed production cost under the future scenario, 2041-2070

As discussed in Chapter 5, the impacts of climate change and extremes on beef cattle production is linked through their impacts on pasture, hay and feed grain production. The severity of effects of climate extremes on pasture production determines the cost of beef herd coping during the periods of extreme events. The number of years of pasture deficit and average yearly cost of feed purchase during climate extreme years are shown in Table 8.2. Decreasing pasture carrying capacity increases the cost of adaptation and directly affects the farm profitability and liquidity. This effect is more evident in the Swift Current site as the average cost of feed purchase to meet the feed deficit is estimated to increase from about $4,570/year under the baseline scenario to more than $13,560/year under the future scenario. This is largely a result of the relatively lower carrying capacity of pastureland in the Swift Current site combined with more years of feed shortages under the future scenario.

Table 8.2 Number of years of feed shortages and cost of feed purchase, Pincher Creek and Swift Current sites under the baseline and future scenarios

Scenarios/sites	Pasture shortage (Number of years)	Hay shortage (Number of years)		Average cost of feed purchase during climate extreme years (‘000 $/year)
		Without extra inventory	With extra inventory	
Baseline scenario				
Pincher Creek	16	12	2	3.00
Swift Current	14	13	2	4.57
Future scenario				
Pincher Creek	20	0	0	3.74
Swift Current	28	0	0	13.56

Gross margin from the beef cattle production activities is presented in Table 8.3. In the Pincher Creek site, the average annual gross margin from the beef cattle activities is estimated to be about $46,000/year under the baseline scenario. The present value of total gross margin from the beef cattle activities for the entire simulation period is estimated to be $634,000, which is projected to increase by 50% to about one million dollars under the future scenario. The estimated yearly gross margin from the beef cattle activities in the Swift Current site is relatively smaller at $30,000/year. The total present value of the gross margin for this site is estimated to be $395,000 under the baseline scenario, which is projected to increase by about 40% under the future scenario.

Table 8.3 Simulation period gross margin (GM) from beef cattle production activities under the baseline and future scenarios by study sites

Scenarios	GM (PV, ‘000 $)	% change	Average (‘000 $/year)	CV
Pincher Creek				
Baseline scenario	633.87		45.74	0.36
Future scenario	950.98	50.03	67.32	0.29
Swift Current				
Baseline scenario	395.06		29.53	0.56
Future scenario	553.69	40.15	44.49	0.60

The comparison of gross margins for the two study sites indicates the differences in herd size and pastureland carrying capacity. The herd size in the Pincher Creek site is bigger than that of the Swift Current site, resulting in more live weight of beef cattle sold and higher gross margin. In the Swift Current site, the smaller herd size and lower carrying capacity of pastureland results in more frequent feed shortage periods and eventually results in higher beef herd management cost. Therefore, the gain under the future scenario is estimated to be higher in the Pincher Creek site. In spite of the negative impact on pasture, which increases the cost of feed purchase and feed production, beef cattle activity in the future in both sites will still be a profitable enterprise, provided that the herd size is maintained and feeding practices are not altered.

8.2.2 Crop production activities

The crop mix for the market is selected on the basis of maximizing present value of gross margin using a multi-period linear programming problem (MLP) under a given set of costs, prices and crop yields. As noted earlier, the crops for beef cattle ration are selected by formulating a linear programming (LP) given a set of COPs only. As noted earlier, the total available land is used first to produce grain and silage for beef feed and the remaining area is allocated for crop production to be sold.

8.2.2.1 Crop production for beef cattle ration

Maize is the most preferred crop to use in feeding livestock under both the baseline and future scenarios as shown in Tables 8.4 and 8.5. It is also evident that the use of maize would be significant for feeding livestock in the future in both sites[34]. The total area required to feed the beef herd will decrease in the future due to increase per acre production of the feed grains. At the Pincher Creek site, the baseline scenario's required average feed area is estimated as 243 acre/year, which is estimated to decrease by almost half to 126 acres/year under the future scenario.

Table 8.4 Crop mix for beef cattle ration under the baseline and future scenarios in the Pincher Creek site

Crops	**Baseline scenario**		**Future scenario**		Type of use for feed
	Use in feed mix (no. of years)*	Total area (acre) **	Use in feed mix (no. of years)	Total area (acre)	
Spring wheat	10	2,177.17	17	1,563.90	Grain only
Barley	10	2,389.24	5	625.78	Grain and silage
Canola	7	110.46	7	69.32	Silage only
Maize	22	2,612.65	24	1,534.40	Grain and silage
Total area (acre)		7,289.53		3,793.41	
Average (acre/year)		242.98		126.44	

*Use in feed mix is the number of years the crop is used in feeding beef cattle during the 30 years simulation period.
**Total area reported under crop mix for ration and crop mix for market are the total area under the respective use for the entire simulation period. They are the sum of the yearly area devoted to specific crop.

Table 8.5 Crop mix for beef cattle ration under the baseline and future scenarios in the Swift Current site

Crops	**Baseline scenario**		**Future scenario**		Type of use for feed
	Use in feed mix (no. of years)*	Total area (acre)**	Use in feed mix (no. of years)	Total area (acre)**	
Spring wheat	10	2,245.28	11	1,362.65	Grain only
Barley	13	7,916.97	19	2,384.52	Grain and silage
Canola	12	184.42	13	133.00	Silage only
Maize	22	11,318.68	24	1,015.48	Grain and silage
Total area (acre)		12,936.55		4,895.67	
Average (acre/year)		431.21		163.18	

*Use in feed mix is the number of years the crop is used in feeding beef cattle during the 30 years simulation period.
**Total area reported under crop mix for ration and crop mix for market are the total area under the respective use for the entire simulation period. They are the sum of the yearly area devoted to specific crop.

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[34] The optimal crop mix for beef ration contains maize for the most of the years. However, maize is not a historically popular crop in the project sites, and therefore, machinery needed for its production is not included in the model. Custom rate could have been applied for the machinery that are not in the machinery base of the farm; however, due to difficulty projecting such information for the future, the study could not take account the need of different machinery in different crop mix. This might have caused a slight underestimation of capital costs in this study.

8.2.2.2 Crop production for market sales

It is assumed that farmers choose the most profitable crop mix every year under the given market and climate conditions. Production of various types of crop for the market sale is determined by total production minus the amount needed for feeding. Canola is the most profitable crops under the baseline scenario, which is expected to dominate the future crop mix in both sites (Tables 8.6 and 8.7). The popularity of canola as market crop is expected to grow even more in the future.

Table 8.6 Crop mix for market under the baseline and future scenarios in the Pincher Creek site

Crops	Baseline scenario		Future scenario	
	Crop produced* (number of years)	Total area (acre)	Crop produced (number of years)	Total area (acre)
Spring wheat	0	0	0	0
Barley	0	0	0	0
Canola	20	4,017.78	26	6,414.92
Maize	3	741.87	3	831.63
Total area (acre)		4759.66		7246.56
Average (acre/year)		158.65		241.55

*Crop produced is the total number of years the crop is produced for the purpose of market sales during the 30 years simulation period.

Table 8.7 Crop mix for market under the baseline and future scenarios in the Swift Current site

Crops	Baseline scenario		Future scenario	
	Crop produced* (number of years)	Total area (acre)	Crop produced (number of years)	Total area (acre)
Spring wheat	1	537.20	1	674.62
Barley	0	0	0	0
Canola	23	12,327.05	29	18,775.69
Maize	2	1,371.77	0	0
Total area (acre)		14236.03		19450.32
Average (acre/year)		474.53		648.34

*Crop produced is the total number of years the crop is produced for the purpose of market sales during the 30 years simulation period.

In regards to the sales of crops, it should be noted that these areas are estimated under the assumption of profit maximization only. This is different than the estimation of crops for feed mix, which used the criteria of cost minimization. More than ¾ of the simulation years have maize and canola in crop mix, which does not seem like a good choice from an agronomic point of view.[35] If a rotation constraint was included in the model, results would likely be different.

There are quite a few years under the baseline scenario when crop activity is hard hit by climate extremes and the entire available crop area was devoted to meet the feed grain and silage demand of the beef herd. However, such a frequency of extremes, as represented through crop yield, is not projected for the crop production during the period of future scenario. This result does not agree with the climatological studies, as most of them project the likelihood of increasing droughts in the future (Price et al., 2011; Bonsal et al., 2013; PaiMazumdar et al., 2013), but, in terms of future crop yield change, the findings of this study are similar to the findings of past studies such as Brklacich (1998), Bootsma (2005) and Robertson (2012). Nonetheless, as discussed in crop yield results in Chapter 7, it should be noted that the impact of climate change on future crop production estimated in this study is more optimistic than past studies.

The results of the Pincher Creek site crop area for market are shown in Figures 8.5 and 8.6. The crop areas for market under the baseline scenario are highly variable over the years, reaching zero in some years. The crop area for market under the future scenario is comparatively less variable across the simulation period with none of the years reaching zero.

Similar to the Pincher Creek site, the crop area for market sale in the Swift Current site is highly variable under the baseline scenario with zero acres in some years as shown in Figures 8.7 and 8.8. This result implies that crop activity is hard hit by the climate extremes in some years and all the available crop area had to be devoted to meet the grain and silage demand of the herd. The crop areas for market under the future scenarios are comparatively stable with none of the years reaching zero.

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[35] Growing the same crop over several years has many risks including the development of crop specific pests and diseases and exploitations of the same soil root zone that leads to decreases in root development and crop yield. Kutcher et al. (2013) observed that crop specific disease in canola crop can be mitigated through appropriate crop rotation and resistant cultivar, but more intensive use of same crop in crop rotation can still lead to risk of diseases and yield loss. Heinemann et al. (2013) observed an increasing yield gap in staple crop in US and Canada during the period of 1961-2010 period. This yield gap is believed to be partly attributed to large-scale monoculture practices (Sirinathsinghji, 2013; Heinemann et al., 2013).

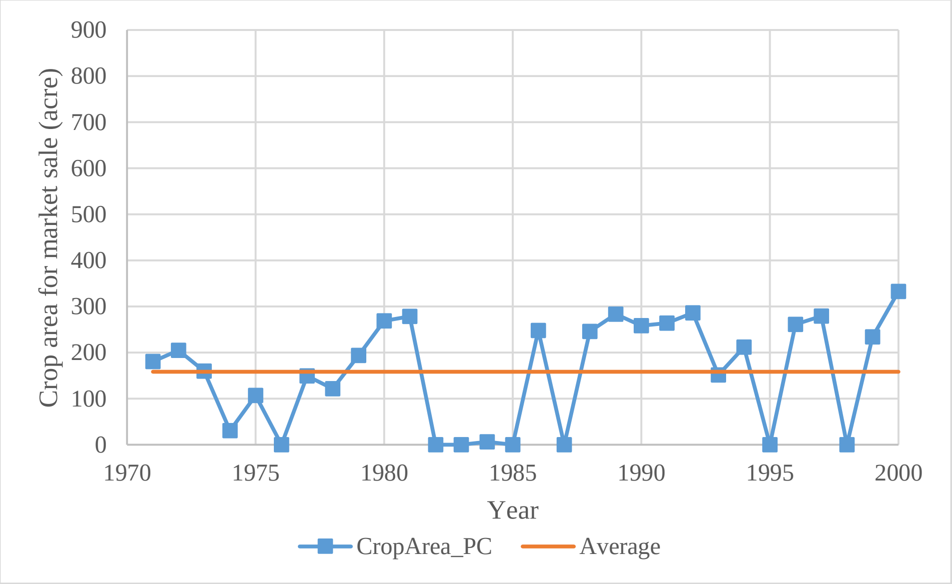

Figure 8.5 Pincher Creek total crop area for market under the baseline scenario, 1971-2000

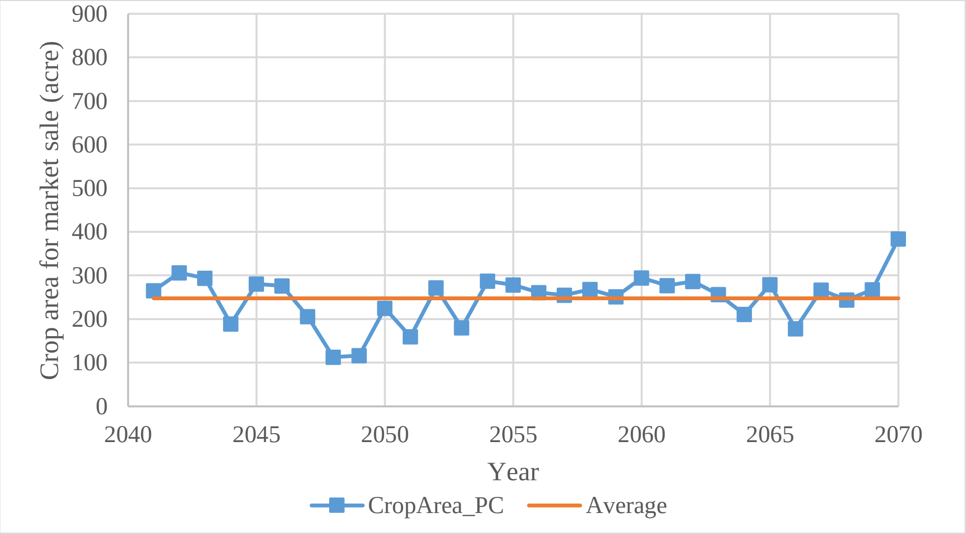

Figure 8.6 Pincher Creek total crop area for market under the future scenario, 2041-2070

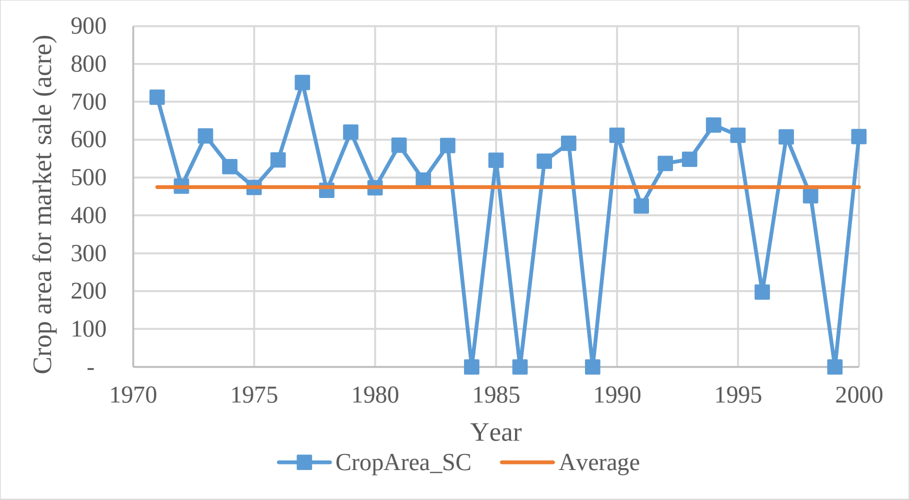

Figure 8.7 Swift Current crop area for market under the baseline scenario, 1971-2000

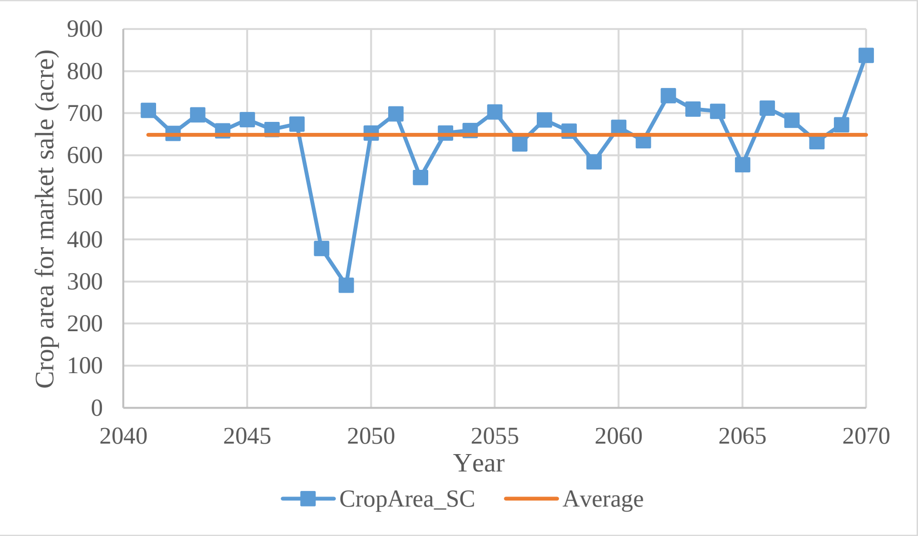

Figure 8.8 Swift Current crop area for market under the future scenario, 2041-2070

The gross margin from the crop production activities for the two study sites is presented in Table 8.8. Under the baseline scenario, the total present value of the 30-year annual gross margin from the crop production activities for the Pincher Creek site is estimated to be $451,130. The average return from the crop activities is estimated to be $31,300/year. The present value of the gross margin under the future scenario is estimated at $833,230 with an average gross margin per year of about $67,690, which is almost double the level in the baseline period. In the Swift Current site, present value of yearly gross margin is estimated to be $914,280 under the baseline scenario. Average gross margin under the baseline scenario is estimated to be $48,750/year. The gross margin in the Swift Current site is projected to increase by 200% under the future scenario.

Table 8.8 Gross margin from crop activities in the study site under the baseline and future scenarios

Scenarios	GM (PV, ‘000 $)	% change from baseline scenario	Average GM (‘000 $/year)	CV
Pincher Creek				
Baseline scenario	451.13		31.30	0.91
Future scenario	833.23	84.70	66.69	0.72
Swift Current				
Baseline scenario	914.28		48.75	1.53
Future scenario	2,757.83	201.64	186.63	0.56

Income risk from the crop activities is expected to decrease in the future as indicated by a substantial decrease in the coefficient of variation for the annual crop gross margin for both the study sites.

Increased return from the crop activities in the future can be attributed to two factors: yield change and area change. As crop productivity increases in the future, the same amount of feed can be produced from a smaller land base, which frees up more area to produce grain for the market. About 41% of projected increment of the future income is estimated to come from transfer of feed area to production of crops for market, while the remaining 59% from the crop productivity (yield) increases. A slightly higher area effect is estimated for the Swift Current site (43%). Table 8.9 shows the share of yield change and area change in both the study sites.

Table 8.9 Yield and area effect in total crop revenue under the baseline scenario in the study sites

Scenarios	Average crop area for market (acre)	CV	Average crop area increase in the future (acre/year)	% Area effect	% Yield effect
Pincher Creek					
Base scenario	159	0.71			
Future scenario	248	0.23	88.90	40.81	59.19
Swift Current					
Baseline scenario	475	0.44			
Future scenario	648	0.15	173.81	43.10	46.90

Substantial increases in the gross margin and significant decreases in income variability under the future scenario indicate that the crop activities will have significant positive and more stable gains under the assumptions that farmers anticipate appropriate weather and market information and select the most profitable crop mix.

It is also important to note the farm size differences between the two study sites to understand the differences in the gross margin from the crop activities between the study sites. The Swift Current site farm is more than 50% larger than the Pincher Creek site farm. Total crop area of the Swift Current site farm is 1,075 acres, including hay and pasture, while that of the Pincher Creek site farm is only 686 acres. Average crop area for market sale of the Pincher Creek site farm under both the climate scenarios is less than half than that of the Swift Current site farm (Table 8.9).

8.2.3 Whole farm profitability analysis

The whole farm gross margin includes the gross margin from beef cattle activities and crop activities minus variable costs related to capital items for the entire farm. As noted in Section 5.5, the calculation of beef and crop activity gross margins were based on their direct costs. This approach was used since allocation of common capital item costs across these enterprises is complex and requires more information than is available. Net profit (NP) at farm level is then calculated by subtracting capital depreciation and other fixed expenses from farm gross margin. Tables 8.10 and 8.11 show the whole farm level gross margin and net profit, respectively.

The Pincher Creek site farm is estimated to generate an average gross margin of \$83,690/year under the baseline scenario. This farm's gross margin is estimated to increase by more than 50% under the future scenario. The present value of gross margin for the 30-year period is more than a million dollars under the baseline scenario and projected to be slightly less than two million dollar under the future scenario. Under the baseline scenario, the Swift Current farm generates almost similar yearly gross margins to that of the Pincher Creek farm, but it is projected to increase by 146% under the future scenario. The present value of gross margin for the 30-year period is estimated to be \$1.37 million under the baseline scenario and estimated to go up to about \$3.37 million under the future scenario.

Net profits of $71,250/year are estimated under the baseline scenario for the Pincher Creek site. The present value of total net profit generated over the 30-year period is projected to be a little less than one million dollar under the baseline scenario, which increases to more than $1.3 million under the future scenario. A net profit increment is estimated at 35% under the future scenario (Table 8.11). The Swift Current site farm is estimated to generate an average net profit of $72,580/year and the total discounted net profit of about $1.2 million under the baseline scenario. Net profit is projected to increase by 143% for this farm under the future scenario. The present value of total net farm income is estimated to be almost three million under the future scenarios with an average annual net profit of $209,550/year.

Table 8.10 Whole farm gross margin estimated for study site farms under the baseline and future scenarios

Scenarios	GM (PV, ‘000 $)	% change from baseline scenario	Average GM (‘000 $/year)	CV
Pincher Creek				
Baseline scenario	1,169.19		82.69	0.47
Future scenario	1,824.68	56.06	137.84	0.45
Swift Current				
Baseline scenario	1,372.49		82.52	0.94
Future scenario	3,377.41	146.08	236.44	0.51

Table 8.11 Whole farm net profit estimated for study site farms under the baseline and future scenarios

Scenarios	Net Profit (PV, ‘000 $)	% change from baseline scenario	Average NP (‘000 $/year)	CV
Pincher Creek				
Baseline scenario	980.96		71.25	0.56
Future scenario	1,326.62	35.00	107.04	0.63
Swift Current				
Baseline scenario	1,215.74		72.58	1.07
Future scenario	2,961.06	143.56	209.55	0.57

In both the study sites, profit is estimated to grow significantly in the future. The gain would be lower for beef cattle enterprise, which is compensated by a high return from the crop enterprise. In terms of income variability, there will not be a significant difference in beef cattle gross margins, but the income risk is estimated to decrease sharply for the crop enterprise. At the whole farm level, income risk in the future is estimated to decrease substantially in the Swift Current site but only a small change is expected for the Pincher Creek site.

8.2.4 Cash flow and net worth analysis

On average, simulated farms have viable operations during most years, but there are a few years when they face liquidity problems under both the baseline and future scenarios. In terms of both the average net cash flow and cash flow variability, the farms are expected to be in better financial positions under the future scenario. As noted in Chapter 5, the farm cash flow calculation takes into account all the income and expenses related to farming only, while family cash flow subtract average family expenditure from farm cash flow. The results are presented in Tables 8.12 and 8.13.

Table 8.12 Farm cash flow of the study farms under the baseline and future scenario

Scenarios	Average net cash flow (‘000 $/year)	No. of years with negative cash flow	CV
Pincher Creek			
Baseline scenario	138.69	0	0.43
Future scenario	213.25	0	0.52
Swift Current			
Baseline scenario	143.82	3	0.74
Future scenario	416.32	0	0.45

Table 8.13 Family cash flow of the study farms under the baseline and future scenarios

Scenario	Average net cash flow (‘000 $/year)	No. of years with negative cash flow	CV
Pincher Creek			
Baseline scenario	112.74	0	0.49
Future scenario	127.62	2	0.85
Swift Current			
Baseline scenario	117.87	3	0.93
Future scenario	330.69	1	0.56

At the farm level, some liquidity issues are observed under the baseline scenario for the Swift Current site but they are expected to vanish under the future scenario. At the family level, however, few periods of cash flow issues are observed to meet family expenditures. For the Pincher Creek site, the annual increase in net income under the future scenario is lower compared to that for the Swift Current site. A larger farm coupled with significant crop yield increases create this increase in the Swift Current site. In the Pincher Creek site, the percentage of net income increase is comparatively lower, largely due to a smaller crop area.

Overall cash flow analysis results imply that the Swift Current farm will be in a better liquidity positions under the future scenario as indicated by the increase in annual average net cash flow amount, substantial decrease in inter-annual variability of both the cash flows, and decrease in the number of cash flow crisis periods. The Pincher Creek farm will not have the liquidity problem to cover farming expenses but if the farm family depends completely on farming, this farm may also face some liquidity issues under the future scenario.

The estimated value of net worth of both the farms shows that these farms are more prosperous under the future scenario[36]. As noted in Chapter 5, both farms take loans to purchase all the capital assets, and to meet the operational expenses at the start of simulation. As noted earlier, land cost and its appreciation are excluded in the net worth calculation. The farm starts with a zero net worth under both the scenarios; therefore the ending value of net worth are compared between two scenarios and shown in Table 8.14.

Table 8.14 Ending value of farm net worth (excluding land) under the baseline and future scenarios for the study farms

Scenario	Net worth at start (‘000 $)	Ending value of net worth (‘000 $)	% ending value of net worth change from baseline scenario
Pincher Creek			
Baseline scenario	0	262.15	
Future scenario	0	539.73	105.88%
Swift Current			
Baseline scenario	0	116.06	
Future scenario	0	711.81	513.02%

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[36] Other than the macro-economic factors discussed in Section 5.5.3.5, climate change will have profound effects on land value as climate change directly affects the productivity of a land (Mendelsohn et al., 1994; Reinsborough, 2003; Amiraslany, 2010). This study, however, estimated the climate change impact separately without considering the value of land. The change in profit from given land under climate change can be applied to estimate the land value. Amiraslany (2010) estimated that 1% increment in rainfall will increase land value by more than 6% whereas summer temperatures are negatively associated with the land value. He further estimated that the direct effect of climate change results in 31% increase in land value, and if indirect factors, such as area effect, are included, land value in the Prairies will be increased by 51%. If the results of economic impact of the climate change estimated in this study were applied to estimate values, the results should be optimistic than that of Amiraslany (2010) as the precipitation increment in this study is projected to be 18% in the future, and crops yield estimation of this study is also more optimistic in comparison to Amiraslany’s study.

The ending value of farm net worth of both study farms grows significantly under the future scenario. Similar to the increment in farm net profit the net worth of the Swift Current farm grows comparatively higher mainly due to the very high increase in the return from crop enterprise.

8.2.5 Summary of the baseline and future scenario results

In both the study sites, the farm profit is estimated to grow significantly in the future. The long-term average[37] and present value of both the whole farm gross margin and net profit show that both the crop and beef cattle activities individually and combined at the farm level make positive and significant gains under the future scenario. The net profit under the future scenario is estimated to increase by 35% at the Pincher Creek site and by 144% at the Swift Current site.

Both the crop and beef cattle production activities are expected to benefit under the future scenario. The gain would be lower for the beef cattle activities than for the crop activities. This is largely because of the negative impact projected for pasture productivity under the future scenario. Beef cattle activities at the Swift Current site would be affected more due to more frequent events of feed shortages, resulting in the higher cost of beef herd management. Nevertheless, the gross margin from beef cattle activities is projected to increase by 50% in the Pincher Creek site and 40% in the Swift Current site. The changes in crop gross margin under the future scenario is estimated to be positive and significant relative to the baseline level in both the study sites; however, comparatively larger farm size and more area transferred from feed use to market sales resulted in a higher gain for the Swift Current site relative to the Pincher Creek site. The crop gross margin is estimated to increase by about 85% for the Pincher Creek site and by more than 202% for the Swift Current site.

In terms of variability, there will not be significant difference in the beef cattle gross margin between the baseline and future scenarios, but income risk in the crop enterprise is estimated to go down sharply under the future scenario, largely due to higher level of income resulting from increased crop area and higher crop yield. At the whole farm level, income risk in the future is estimated to decrease substantially for the Swift Current site but there will not be much change for

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[37] The long-term average value refers to the average value from the 30-year simulation period under both the baseline and future scenarios.

the Pincher Creek site. The results indicate that climate change will positively impact both the study sites; however, the Swift Current site will benefit more than the Pincher Creek site.

Maize is identified as the predominantly cost effective feed grain under the baseline scenario and its use in the future is estimated to grow. Similarly, canola is identified as the preferred crop for market sales under both the scenarios for both the study sites.

The net cash flow at the farm and family level are estimated to improve significantly. However, the family cash flow in the Pincher Creek site is projected to face some liquidity problems in the future. Significant increases in the ending value of net worth in the future are projected for both the sites.

8.3 Simulation of alternative adaptation strategies

In this study, two alternative adaptation strategies are evaluated and compared with the reference adaptation of purchasing feeds to manage pasture shortages during extreme climate event periods. As noted in Sections 7.2.1 and 8.1 the baseline and future scenarios use the purchase feed strategy. For this reason, the baseline and future scenarios' results presented in Section 8.2.3 are considered as the results for the reference adaptation. These results are used to evaluate the effects of implementing alternative adaptation strategies. The effects of adopting those alternatives are evaluated separately for the beef cattle activities, crop activities, and whole farm level. Section 8.3.1 discusses the effect of adopting an "early weaning and limit feeding" strategy and Section 8.3.2 discusses the effect of adopting a "cull herd" strategy to reduce the beef herd's feed demand to cope with feed shortages during extreme climate events.

8.3.1 Simulating "early weaning and limit feeding" strategy

The early weaning and limit feeding strategy consists of two major measures: weaning calves early to reduce the cows' pasture demand, and limit feeding to reduce the winter feed demand of feedlot animals. This strategy directly affects the weight gain of feedlot animals; hence it impacts the live weight of the cattle sold. Since the number of cattle sold remains the same, lowering the amount of feed given to the herd also affects the area required to produce crops for feed.

Tables 8.15 and 8.16 compare the results of early weaning and limit feeding strategy with that of reference adaptation in the Pincher Creek site. Though the number of animal marketed remain unchanged, live weight cattle sold has decreased by slightly more than 20% under both baseline and future scenarios. However, this results in only a small change in area required to produce feed. Thus, feed production costs are not significantly different from that of the reference adaptation. The decrease in live weight of cattle marketed and the insignificant changes in feed production cost has resulted in an approximately 34% decrease in the gross margin for the beef cattle enterprise relative to reference adaptation under the baseline scenario. The gross margin under the future scenario is also estimated to decline by 45% relative to the reference adaptation. Under both scenarios, the inter-annual variability of gross margin doubled from that of the reference adaptation case.

At the crop enterprise, the impact of this strategy is observed in terms of the changes in area available to produce crop for market sales but this impact is very small. The crop area has increased by only about 1% under both the scenarios. The gross margin from crop has increased by about 6% under the baseline and only about 2% under the future scenario.

The results of adopting the early weaning and limit feeding strategy in the Pincher Creek farm amounted to a large negative impact at the whole farm level resulting in a significant decrease in gross margin, net profit, and liquidity. Relative to the reference adaptation, the gross margin and net profits have decreased by about 23% and 27%, respectively, under the baseline scenario and about 21% and 30% under the future scenario. The average cash flow has declined by more than 21% under the baseline scenario and by 22% under the future scenario. Despite the slight increment in the ending value of the farm's net worth under both the baseline and future scenarios, most of the economic measures indicate that the farm economic situation would be worse if producers were to adopt the early weaning and limit feeding strategy. Also farm financial risk is estimated to increase as indicated by an increase in the coefficient of variation of all the indicators.

Table 8.15 Simulation results for the “early weaning and limit feeding” strategy in the Pincher Creek site under the baseline scenario

S N	Activity	Reference adaptation* results	Results under early weaning and limit feeding	% change from reference adaptation
1	**Beef cattle activity level**			
1.1	Beef cattle sold			
	Average slaughter cattle sold (Number/year)	79	79	0.17%
	CV of slaughter cattle sold	0.07	0.08	6.85%
	Live weight sold (‘000 lbs)	102.97	81.45	-20.89%
	CV of live weight sold	0.07	0.17	130.40%
1.2	Beef cattle feed			
	Average feed area (acres/year)	243.39	238.29	-2.09%
	CV of feed area	0.67	0.68	0.40%
	Total feed production cost (PV, '000 $)	218.54	212.24	-2.88%
	Average feed production cost ('000 $/year)	16.97	16.52	-2.66%
	CV of feed cost	0.43	0.42	-0.61%
1.3	GM from beef cattle activities			
	Total beef cattle GM (PV, 000 $)	633.86	416.23	-34.33%
	Average GM ('000 $ /year)	45.75	31.07	-32.08%
	CV of beef cattle GM	0.36	0.64	79.42%
2	**Crop activity level**			
2.1	Crop area			
	Average crop area (acres/year)	158.66	160.60	1.22%
	CV of crop area	0.71	0.73	2.84%
2.2	GM from crop activities			
	Total crop GM (PV, '000 $)	451.13	478.92	6.16%
	Average ('000 $/year)	31.30	33.33	6.49%
	CV of crop GM	0.91	0.89	-1.89%
3	**Whole farm level**			
3.1	GM and net profit			
	Total farm GM (PV, '000 $)	1,169.20	905.56	-22.55%
	Average GM ('000 $/year)	82.69	65.83	-20.40%
	CV of farm GM	0.47	0.63	34.34%
	Farm net profit (PV, '000 $)	980.97	717.33	-26.88%
	Average net profit ('000 $/year)	71.26	54.39	-23.67%
	CV of farm net profit	0.56	0.79	40.53%
3.2	Farm cash flow			
	Average net farm cash flow ('000 $/year)	138.70	109.61	-20.97%
	CV of net farm cash flow	0.43	0.56	30.78%
	Negative farm cash flow (no. of year)	-	-	-
3.3	Ending value of net worth (‘000 $)	262.15	284.35	8.46%

* Reference adaptation is the purchase feed to deal with the feed shortages during extreme climate events. Under this adaptation herd size is maintained with regular feeding plan regardless of the severity of impact of extreme events on feed production.

Table 8.16 Simulation results for the "early weaning and limit feeding" strategy in the Pincher Creek site under the future scenario

S N	Activity	Reference adaptation results	Results under early weaning and limit feeding	% change from reference adaptation
1	**Beef cattle activity level**			
1.1	Beef cattle sold			
	Average slaughter cattle sold	79	79	0.17%
	CV of slaughter cattle sold	0.07	0.08	6.85%
	Live weight sold ('000 lbs)	102.97	81.45	-20.89%
	CV of live weight sold	0.07	0.17	130.40%
1.2	Beef cattle feed			
	Average feed area (acres/year)	126.45	124.58	-1.48%
	CV of feed area	0.41	0.44	9.11%
	Total feed production cost (PV, '000 $)	506.48	506.35	-0.03%
	Average feed production cost ('000 $/year)	33.92	33.75	-0.49%
	CV of feed cost	0.13	0.14	7.59%
1.3	GM from beef cattle activities			
	Total beef cattle GM (PV, 000$)	950.98	527.97	-44.48%
	Average GM ('000 $/year)	67.33	41.44	-38.45%
	CV of beef cattle GM	0.29	0.67	128.80%
2	**Crop activity level**			
2.1	Crop area			
	Average crop area (acres/year)	247.55	249.42	0.75%
	CV of crop area	0.23	0.24	5.98%
2.2	GM from crop activities			
	Total crop GM (PV, '000 $)	833.24	851.77	2.22%
	Average ('000 $/year)	66.69	68.56	2.80%
	CV of crop GM	0.72	0.87	0.21%
3	**Whole farm level**			
3.1	GM and net profit			
	Total farm GM (PV, '000 $)	1,824.69	1,433.42	-21.44%
	Average GM ('000 $ /year)	137.84	115.56	-16.16%
	CV of farm GM	0.45	0.65	44.50%
	Farm net profit (PV, '000 $)	1,326.63	935.36	-29.49%
	Average net profit ('000 $/year)	107.04	84.76	-20.82%
	CV of farm net profit	0.63	0.95	50.06%
3.2	Farm cash flow			
	Average net farm cash flow ('000 $/year)	213.26	167.25	-21.57%
	CV of net farm cash flow	0.52	0.80	52.34%
	Negative farm cash flow (no. of year)	-	2	
3.3	Ending value of net worth ('000 $)	539.73	575.43	6.61%

The effects of the early weaning and limit feeding strategy on beef cattle production and the resulting impact on crop activities and the whole farm financial situation in the Swift Current site are also estimated to be similar to the results of Pincher Creek site. Tables 8.17 and 8.18 present the results for the Swift Current site farm of adopting the early weaning and limit feeding strategy under the baseline and future scenarios, respectively.

In the case of Swift Current site, the live weight cattle sold has decreased by more than 20% from the reference adaptation under both the scenarios. Change in the area required to produce feed is negligible; therefore, total feed production cost does not decrease significantly. The feed area has also decreased by about 3%, but the feed production cost has decreased by only about 2% under the baseline scenario and about 1% under the future scenario by the adoption of this strategy.

Gross margins from beef cattle activities declined by about 37% under the baseline scenario and more than 60% under the future scenario. Under both scenarios, the inter-annual variability of the gross margin is estimated to double from the reference adaptation suggesting the beef cattle enterprise would be riskier, if the early weaning and limit feeding strategy is followed to cope with feed shortages during extreme events.

Adoption of this strategy has negligible impact on crop production activities relative to the reference adaptation. The crop area for market increases by little more than 2% and total present value of crop gross margin increases only by 5% under the baseline scenario. Both the crop area and crop gross margin change are negligible under the future scenario.

Under the early weaning and limit feeding strategy, the gross margin and net profit at the whole farm level for the Swift Current site have declined by about 12% and 14% under the baseline scenario and by about 9% and 10% under the future scenario. Analysis of cash flow also indicates that farm financial situation would be weaker under the early weaning and limit feeding strategy as indicated by a decrease of about 12% under the baseline and 10% under the future scenarios. Ending farm net worth, however, has increased under both the baseline and future scenario. Similar to that in the Pincher Creek site, the early weaning and limit feeding strategy would lead to increased financial risk as indicated by a significant increase in the coefficient of variation of all the indicators.

Table 8.17 Simulation results for the “early weaning and limit feeding” strategy in the Swift Current site under the baseline scenario

S N	Activity	Reference adaptation results	Results under early weaning and limit feeding	% change from reference adaptation
1	**Beef cattle activity level**			
1.1	Beef cattle sold			
	Average slaughter cattle sold	67	67	0.00%
	CV of slaughter cattle sold	0.13	0.14	2.47%
	Live weight sold (‘000 lbs)	87.42	69.51	-20.49%
	CV of live weight sold	0.13	0.20	50.15%
1.2	Beef cattle feed			
	Average feed area (acres/year)	431.22	416.87	-3.33%
	CV of feed area	1.07	1.10	2.06%
	Total feed production cost (PV, '000 $)	223.84	218.52	-2.38%
	Average feed production cost ('000 $/year)	17.60	17.20	-2.28%
	CV of feed cost	0.54	0.94	0.75%
1.3	GM from beef cattle activities			
	Total beef cattle GM (PV, 000$)	395.07	247.47	-37.36%
	Average GM ('000 $/year)	29.54	19.13	-35.25%
	CV of beef cattle GM	0.56	0.98	74.39%
2	**Crop activity level**			
2.1	Crop area			
	Average crop area (acres/year)	474.53	484.57	2.12%
	CV of crop area	0.44	0.43	-1.30%
2.2	GM from crop activities			
	Total crop GM (PV, '000 $)	914.28	959.31	4.93%
	Average ('000 $/year)	48.76	52.28	7.22%
	CV of crop GM	1.53	1.42	-7.54%
3	**Whole farm level**			
3.1	GM and net profit			
	Total farm GM (PV, '000 $)	1,372.50	1,205.61	-12.16%
	Average GM ('000 $ /year)	82.52	71.77	-13.03%
	CV of farm GM	0.94	1.08	13.98%
	Farm net profit (PV, '000 $)	1,215.75	1,048.86	-13.73%
	Average net profit ('000 $/year)	72.59	61.84	-14.81%
	CV of farm net profit	1.07	1.25	16.45%
3.2	Farm cash flow			
	Average net farm cash flow ('000 $/year)	143.82	126.24	-12.22%
	CV of net farm cash flow	0.74	0.82	11.48%
	Negative farm cash flow (no. of year)	3	3	-
3.3	Ending value of net worth (‘000 $)	116.06	142.15	22.47%

Table 8.18 Simulation results for the “early weaning and limit feeding” strategy in the Swift Current site under the future scenario

S N	Activity	Reference adaptation results	Results under early weaning and limit feeding	% change from reference adaptation
1	**Beef cattle activity level**			
1.1	Beef cattle sold			
	Average slaughter cattle sold	67	67	0.00%
	CV of slaughter cattle sold	0.13	0.14	2.47%
	Live weight sold (lbs)	87.42	69.51	-20.49%
	CV of live weight sold	0.13	0.20	50.15%
1.2	Beef cattle feed			
	Average feed area (acres/year)	163.19	157.56	-3.45%
	CV of feed area	0.58	0.58	-1.03%
	Total feed production cost (PV, '000 $)	491.53	486.44	-1.04%
	Average feed production cost ('000 $/year)	32.80	32.38	-1.29%
	CV of feed cost	0.20	0.19	-5.29%
1.3	GM from beef cattle activities			
	Total beef cattle GM (PV, 000 $)	553.69	216.60	-60.88%
	Average GM ('000 $/year)	44.49	21.58	-51.50%
	CV of beef cattle GM	0.60	1.27	111.01%
2	**Crop activity level**			
2.1	Crop area			
	Average crop area (acres/year)	648.34	653.97	0.87%
	CV of crop area	0.15	0.15	-4.91%
2.2	GM from crop activities			
	Total crop GM (PV, '000 $)	2,757.84	2,773.11	0.55%
	Average ('000 $/year)	186.63	188.02	0.74%
	CV of crop GM	0.56	0.56	-0.78%
3	**Whole farm level**			
3.1	GM and net profit			
	Total farm GM (PV, '000 $)	3,377.41	3,067.85	-9.17%
	Average GM ('000 $/year)	236.45	216.77	-8.32%
	CV of farm GM	0.51	0.56	11.20%
	Farm net profit (PV, '000 $)	2,961.06	2,651.50	-10.45%
	Average net profit ('000 $/year)	209.56	189.88	-9.39%
	CV of farm net profit	0.57	0.65	12.64%
3.2	Farm cash flow			
	Average net farm cash flow ('000 $/year)	416.32	375.80	-9.73%
	CV of net farm cash flow	0.45	0.50	11.67%
	Negative farm cash flow (no. of year)	-	1	
3.3	Ending value of net worth (‘000 $)	711.81	725.75	1.95%

The economic impacts of adopting the early weaning and limit feeding strategy are predominantly negative for both the study sites. The impact at the whole farm level is more severe in the Pincher Creek site while the impact on beef cattle production is more severe in the Swift

Current site under both the scenarios. Because the beef cattle gross margin comprises only about 33% of the whole farm gross margin, under both the baseline and future scenarios for the Swift Current site, changes in beef cattle gross margin has less influence on the whole farm level. For the Pincher Creek site the gross margin from beef cattle activity comprises about 50% of the whole farm gross margin under both the scenarios, so any changes in it have more influence on whole farm gross margin. Overall results confirm that the early weaning and limit feeding is not an economically preferred strategy in dealing with droughts for either of the study sites.

8.3.2 Simulating "cull herd" strategy

Under the cull herd strategy, the herd size is reduced to match the pasture demand to reduced pasture supply in years of extreme events. It is assumed that farmers cull the herd starting with open cows, followed by old cows, until pasture demand and supply are matched. This strategy would have an impact on both the number of slaughter cattle and live weight sold. However, such decisions have implications in the long run. Decreasing herd size affects the crop activities by lowering feed area demand, thereby releasing more area to produce crops for market sales in the period after the extreme event.

The results of adopting the cull herd strategy for the Pincher Creek site are compared with that of the reference adaptation and shown in Tables 8.19 and 8.20. In the Pincher Creek site, the number and live weight of cattle sold under the cull herd strategy have declined by about 18% from the reference adaptation under the baseline scenario. This led to about 13% decline in feed area demand but only about 7% decline in cost of feed production. Under the future scenario, due to decreasing pasture carrying capacity, the number and live weight of cattle sold have declined by about 24%. This led to an 11% decline in feed area demand and a 5% decline in the cost of on-farm feed production. The gross margin from the beef cattle activities has declined by about 17% under the baseline scenario and more than 30% under the future scenario as a result of culling herd to cope with the extreme climate events. Under the baseline scenario, adoption of this strategy has resulted in an increase in the area available to produce crop for sale by 8% and the crop gross margin by about 23%, relative to reference adaptation. This change resulted in a slight increase in both the net profit as well as ending net worth of the farm. Under the future scenario, the crop area and gross margin improve by only 6% and 8%, respectively, compared to the reference adaptation.

The ending farm net worth has slightly increased under the baseline scenario but shows a decrease under the future scenario. This is because an increase in crop gross margin is not enough to compensate for the loss occurred in beef cattle activity for the future scenario. As a result, farm cash flow and ending farm net worth has declined by similar 7%, from the reference adaptation (Table 8.19 and 8.20).

Table 8.19 Simulation results for the "cull herd" strategy in the Pincher Creek site under the baseline scenario

S N	Activity	Reference adaptation results	Results under cull herd	% change from reference adaptation
1	**Beef cattle activity level**			
1.1	Beef cattle sold			
	Average slaughter cattle sold (Number/year)	79	65	-18.04%
	CV of slaughter cattle sold	0.07	0.25	239.26%
	Live weight sold ('000 lbs)	102.97	84.39	-18.04%
	CV of live weight sold	0.07	0.25	239.26%
1.2	Beef cattle feed			
	Average feed area (acres/year)	243.39	212.09	-12.86%
	CV of feed area	0.67	0.62	-8.61%
	Total feed production cost (PV, '000 $)	218.54	203.99	-6.65%
	Average feed production cost ('000 $/year)	16.97	15.93	-6.15%
	CV of feed cost	0.43	0.42	-1.06%
1.3	GM from beef cattle activities			
	Total beef cattle GM (PV, 000 $)	633.86	527.98	-16.70%
	Average GM ('000 $ /year)	45.75	38.70	-15.41%
	CV of beef cattle GM	0.36	0.47	31.46%
2	**Crop activity level**			
2.1	Crop area			
	Average crop area (acres/year)	158.66	171.22	7.92%
	CV of crop area	0.71	0.69	-2.62%
2.2	GM from crop activities			
	Total crop GM (PV, '000 $)	451.13	555.24	23.08%
	Average ('000 $/year)	31.30	36.65	17.08%
	CV of crop GM	0.91	0.87	-4.43%
3	**Whole farm level**			
3.1	GM and net profit			
	Total farm GM (PV, '000 $)	1,169.20	1,185.39	1.38%
	Average GM ('000 $/year)	82.69	81.99	-0.85%
	CV of farm GM	0.47	0.49	3.21%
	Farm net profit (PV, '000 $)	980.97	997.16	1.65%
	Average net profit ('000 $/year)	71.26	70.55	-0.99%
	CV of farm net profit	0.56	0.58	3.12%
3.2	Farm cash flow			
	Average net farm cash flow ('000 $/year)	138.70	138.01	-0.49%
	CV of net farm cash flow	0.43	0.42	-2.08%
	Negative farm cash flow (no. of year)	-	-	
3.3	Ending value of net worth ('000 $)	262.15	289.99	10.61%

Table 8.20 Simulation results for the “cull herd” strategy in the Pincher Creek site under the future scenario

S N	Activity	Reference adaptation results	Results under cull herd	% change from reference adaptation
1	**Beef cattle activity level**			
1.1	Beef cattle sold			
	Average slaughter cattle sold	79	60	-24.28%
	CV of slaughter cattle sold	0.07	0.24	234.00%
	Live weight sold (‘000 lbs)	102.97	77.96	-24.28%
	CV of live weight sold	0.07	0.24	234.00%
1.2	Beef cattle feed			
	Average feed area (acres/year)	126.45	112.54	-11.00%
	CV of feed area	0.41	0.47	15.46%
	Total feed production cost (PV, '000 $)	506.48	486.58	-3.93%
	Average feed production cost ('000 $/year)	33.92	32.36	-4.60%
	CV of feed cost	0.13	0.14	8.04%
1.3	GM from beef cattle activities			
	Total beef cattle GM (PV, 000 $)	950.98	658.36	-30.77%
	Average GM ('000 $/year)	67.33	46.21	-31.36%
	CV of beef cattle GM	0.29	0.57	92.09%
2	**Crop activity level**			
2.1	Crop area			
	Average crop area (acres/year)	247.55	261.46	5.62%
	CV of crop area	0.23	0.22	-2.94%
2.2	GM from crop activities			
	Total crop GM (PV, '000 $)	833.24	895.99	7.53%
	Average ('000 $/year)	66.69	72.23	8.30%
	CV of crop GM	0.72	0.71	-1.40%
3	**Whole farm level**			
3.1	GM and net profit			
	Total farm GM (PV, '000 $)	1,824.69	1,822.51	-0.12%
	Average GM ('000 $/year)	137.84	136.55	-0.93%
	CV of farm GM	0.45	0.45	-0.09%
	Farm net profit (PV, '000 $)	1,326.63	1,324.45	-0.16%
	Average net profit ('000 $/year)	107.04	105.75	-1.20%
	CV of farm net profit	0.63	0.63	-0.40%
3.2	Farm cash flow			
	Average net farm cash flow ('000 $/year)	213.26	198.79	-6.78%
	CV of net farm cash flow	0.52	0.57	9.08%
	Negative farm cash flow (no. of year)	-	-	
3.3	Ending value of net worth (‘000 $)	539.73	503.33	-6.74%

The results indicate that adoption of the cull herd strategy under the baseline scenario relative to reference adaptation can result in a slight gain for the Pincher Creek site. The difference in the preference of adaptation strategy at whole farm level between baseline and future scenario in the Pincher Creek site is mainly associated with the impact of climate extremes on pasture carrying capacity and the average number of slaughter cattle sold per year. As a result of adopting the cull herd strategy, both the number and live weight of beef cattle sold, relative to the reference adaptation, have declined relatively more than the change under the future scenario. As a result of adopting the cull herd strategy, the gross margin from the beef cattle activities has declined by more than 30% under the future scenario from 17% under the baseline scenario.

At the Swift Current site, the number and live weight cattle sold under the cull herd strategy for the baseline scenario has declined by about 12%, relative to the reference adaptation (Tables 8.21 and 8.22). This has led to a similar relative decline in feed area demand but has reduced the feed production costs by only about 4%. Due to the negative impact of climate change on pasture carrying capacity, the average herd size is reduced by half under the future scenario. The live weight of cattle sold has also declined by more than 50%. This, however, has reduced the feed area demand by about 36% but reduced the feed production cost only by about 12%. The gross margin from the beef cattle production has declined by about 33% under the baseline and about 88% under the future scenarios compared to the reference adaptation strategy. The crop area for market sale has increased due to the decreased herd size but this effect is rather negligible. Increase in crop area due to the decrease in herd size is estimated to be about 4% under the baseline and 9% under the future scenarios. Crop gross margin has increased by about 17% under the baseline and about 11% under the future scenarios.

Despite the severe impact of adopting the cull herd strategy on beef cattle production in the Swift Current site, the whole farm level indicators imply that the farm as a whole would be better off relative to the reference adaptation strategy under both the scenarios. Farm net profit has increased by 2.5% under the baseline and 1.6% under the future scenario. Average cash flow has increased slightly under the baseline scenario but decreased slightly under the future scenario. Ending farm net worth has also increased by about 1% under both the scenarios.

The pasture carrying capacity of Swift Current is already low at about an average 0.38 AUM/acre resulting in very high cost of feed purchases under the reference adaptation as noted in Table 8.21. A large decrease in herd size results in two positive effects at the whole farm level: the decrease in feed purchase cost, and the large transfer of feed area to crop production for market sale. Therefore, the choice of adaptation is dependent on many factors, such as existing carrying capacity of grazing, feeding cost, severity of climate extremes, and integration of crop and livestock activities.

Table 8.21 Simulation results for the “cull herd” strategy in the Swift Current site under the baseline scenario

S N	Activity	Ref adaptation results	Results under cull herd	% change from reference adaptation
1	**Beef cattle activity level**			
1.1	Beef cattle sold			
	Average slaughter cattle sold (Number/year)	67	59	-12.31%
	CV of slaughter cattle sold	0.13	0.28	109.02%
	Live weight sold (‘000 lbs)	87.42	76.66	-12.31%
	CV of live weight sold	0.13	0.22	65.96%
1.2	Beef cattle feed			
	Average feed area (acres/year)	431.22	378.72	-12.17%
	CV of feed area	1.07	1.03	-4.36%
	Total feed production cost (PV, '000 $)	223.84	211.67	-5.43%
	Average feed production cost ('000 $/year)	17.60	16.87	-4.17%
	CV of feed cost	0.54	0.54	-0.40%
1.3	GM from beef cattle activities			
	Total beef cattle GM (PV, 000 $)	395.07	265.38	-32.83%
	Average GM ('000 $/year)	29.54	20.39	-30.96%
	CV of beef cattle GM	0.56	0.95	68.88%
2	**Crop activity level**			
2.1	Crop area			
	Average crop area (acres/year)	474.53	495.27	4.37%
	CV of crop area	0.44	0.44	-0.58%
2.2	GM from crop activities			
	Total crop GM (PV, '000 $)	914.28	1,067.39	16.75%
	Average ('000 $/year)	48.76	59.41	21.86%
	CV of crop GM	1.53	1.22	-20.22%
3	**Whole farm level**			
3.1	GM and net profit			
	Total farm GM (PV, '000 $)	1,372.50	1,403.01	2.22%
	Average GM ('000 $/year)	82.52	84.47	2.36%
	CV of farm GM	0.94	0.92	-2.64%
	Farm net profit (PV, '000 $)	1,215.75	1,246.25	2.51%
	Average net profit ('000 $/year)	72.59	74.54	2.69%
	CV of farm net profit	1.07	1.04	-2.95%
3.2	Farm cash flow			
	Average net farm cash flow ('000 $/year)	143.82	147.70	2.70%
	CV of net farm cash flow	0.74	0.67	-8.41%
	Negative farm cash flow (no. of year)	3	3	-
3.3	Ending value of net worth (‘000 $)	116.06	118.09	1.75%

Table 8.22 Simulation results for the “cull herd” strategy in the Swift Current site under the future scenario

S N	Activity	Reference adaptation results	Results under cull herd	% change from reference adaptation
1	**Beef cattle activity level**			
1.1	Beef cattle sold			
	Average slaughter cattle sold	67	32	-52.14%
	CV of slaughter cattle sold	0.13	0.30	128.32%
	Live weight sold (‘000 lbs)	87.42	41.84	-52.14%
	CV of live weight sold	0.13	0.30	128.32%
1.2	Beef cattle feed			
	Average feed area (acres/year)	163.19	105.08	-35.61%
	CV of feed area	0.58	0.91	55.93%
	Total feed production cost (PV, '000 $)	491.53	434.83	-11.54%
	Average feed production cost ('000	32.80	28.94	-11.77%
	CV of feed cost	0.20	0.20	0.94%
1.3	GM from beef cattle activities			
	Total beef cattle GM (PV, 000 $)	553.69	64.99	-88.26%
	Average GM ('000 $/year)	44.49	5.26	-88.17%
	CV of beef cattle GM	0.60	4.05	571.84%
2	**Crop activity level**			
2.1	Crop area			
	Average crop area (acres/year)	648.34	706.46	8.96%
	CV of crop area	0.15	0.14	-8.78%
2.2	GM from crop activities			
	Total crop GM (PV, '000 $)	2,757.84	3,056.16	10.82%
	Average ('000 $/year)	186.63	205.85	10.30%
	CV of crop GM	0.56	0.54	-3.00%
3	**Whole farm level**			
3.1	GM and net profit			
	Total farm GM (PV, '000 $)	3,377.41	3,424.15	1.38%
	Average GM ('000 $/year)	236.45	232.06	-1.85%
	CV of farm GM	0.51	0.54	6.46%
	Farm net profit (PV, '000 $)	2,961.06	3,007.80	1.58%
	Average net profit ('000 $/year)	209.56	205.17	-2.09%
	CV of farm net profit	0.57	0.61	6.44%
3.2	Farm cash flow			
	Average net farm cash flow ('000	416.32	397.99	-4.40%
	CV of net farm cash flow	0.45	0.48	7.31%
	Negative farm cash flow (no. of year)	-	-	
3.3	Ending value of net worth (‘000 $)	711.81	714.23	0.34%

8.3.3 Choice of adaptation strategy

This section summarizes the result of adopting alternative adaptation strategies as presented in Sections 8.3.1 and 8.3.2. These results are compared with the reference adaptation under the baseline and future scenarios to identify the best adaptation option for the two study sites.

The farm income and financial indicators discussed in earlier sections show that the choice of adaptation strategy plays an important role in maintaining economic viability of a farm. The choice of adaptations is contextual, and preference of adaptation strategy differs across activities, farms, and climate scenarios. The return to the purchase feed strategy is estimated to be highest at the beef cattle activity under both the scenarios and for both the study sites. But the return from the cull herd strategy is estimated to be highest at crop activity level under both the scenarios and for both the study sites. The choice is dependent on many factors, such as the existing carrying capacity of grazing, existing feeding cost, severity of climate extremes, and integration of crop and beef cattle production.

Results of changes in economic indicators at various enterprises and strategies on the Pincher Creek site are shown in Table 8.23. At the beef cattle activity level in the Pincher Creek site, the present value of gain under the purchasing feed strategy over the cull herd strategy is estimated to be $105,881, whereas the gain over the early weaning and limit feeding is estimated to be almost double that amount.

Table 8.23 Comparison of adaptation options for the Pincher Creek study site, by scenarios

Comparisons of strategies	Beef cattle activity GM (‘000 $, PV)	Crop activity GM (‘000 $, PV)	Whole farm net profit* (‘000 $, PV)
Baseline scenario			
Gain of purchase feed over cull herd strategy	105.88	- 104.11	- 16.19
Gain of purchase feed over early weaning and limit feeding strategy	217.63	- 27.79	263.64
Future scenario			
Gain of purchase feed over cull herd strategy	292.21	- 62.75	2.18
Gain of purchase feed over early weaning and limit feeding strategy	422.76	-18.54	391.01

*Crop activity GM and beef activity GM do not add to whole farm net profit because whole farm net profit takes account of operating and fixed capital costs in addition to activity GM as discussed in Sections 5.5.3.1 and 5.5.3.2. Also whole farm profit adds the revenue generated by selling surplus hay which is not considered in either activity gross margin calculation. As amount of surplus hay sold vary greatly across the scenarios so does the total farm profit.

The gain of purchasing feed strategy over the other adaptations has increased twice under the future scenario indicating that maintaining herd size would be more beneficial in the future. The cost of feed purchase during drought periods is estimated to be negligible compared to the extra gross margin generated by maintaining the herd size (Table 8.23). The comparison of cost of feeding and extra gross margin generated by maintaining herd size is presented in Table Q.1 in Appendix Q. For the Pincher Creek site, the extra gross margin is estimated to increase two times under the baseline scenario and estimated to increase 16 times under the future scenario.

A summary of the relative change in farm profitability, liquidity and net worth as a result of adopting the two strategies relative to purchase feed strategy in the Pincher Creek site is shown in Table 8.24. At the crop activity level, the gains from adopting alternative strategies are estimated to be higher than the gains from adopting a purchasing feed strategy, as the former releases more crop area for market sales. A mixed result is obtained at the whole farm level. The cull herd strategy is identified as superior under the baseline scenario while the purchase feed strategy is superior under the future scenario. The results show that the adoption of a cull herd strategy improves most of the farm level economic indicators relative to the purchase feed strategy under the baseline scenario.

Table 8.24 Percentage change in farm profitability and liquidity under alternative adaptation strategies relative to the purchase feed strategy for the Pincher Creek site

Changes	Profitability				Cash flow	Net worth
	PV of beef activity GM	PV of crop activity GM	PV of whole farm GM	PV of whole farm NP	Average farm cash flow	Ending value of net worth (excluding land)
Baseline scenario						
Changes under " early weaning and limit feeding " from purchase feed	-34.33%	+6.16%	-22.55%	-26.88%	-20.21%	+8.46%
Changes under "cull herd" from purchase feed	-16.17%	+23%	+1.38%	+1.65%	+0.50%	+10.61%
Future scenario						
Changes under " early weaning and limit feeding " from purchase feed	-44.48%	+2.22%	-21.44%	-29.49%	-21.57%	+22.47%
Changes under "cull herd" from purchase feed	-30.77%	+7.53%	-0.12%	-0.16%	-7%	-6.74%

For the Swift Current site's beef cattle production, the gain from purchasing feed over reducing herd size is estimated to be $129,687 and this gain is estimated to be even higher over the early weaning and limit feeding strategy (Table 8.25). Compared to the baseline scenario, the net gain from purchasing feed over culling the herd has increased by more than three times ($488,700) and the gain over the early weaning and limit feeding strategy has increased twice under the future scenario from $147590 to $337100 as shown in Table 8.25. The comparison of the costs of feeding and the extra gross margin generated by maintaining herd size is presented in Table Q.2 in Appendix Q. For the Swift Current site, the estimated extra gross margin by maintaining herd size during a drought period is double the feeding cost incurred in maintaining herd size under the baseline and more than 16 times under the future scenario.

Table 8.25 Comparison of the adaptation options under the baseline and future scenarios for the Swift Current site

Comparisons	Beef cattle activity GM ('000 $, PV)	Crop activity GM ('000 $, PV)	Whole farm net profit* ('000 $, PV)
Baseline scenario			
Net Gain of purchase feed over cull herd strategy	129.69	- 153.11	- 30.51
Net Gain of purchase feed over early weaning and limit feeding strategy	147.59	- 45.03	166.89
Future scenario			
Net Gain of purchase feed over cull herd strategy	488.70	- 298.32	- 46.73
Net Gain of purchase feed over early weaning and limit feeding strategy	337.10	- 15.27	309.56

*Crop activity GM and beef activity GM do not add to whole farm net profit because whole farm net profit takes account of operating and fixed capital costs in addition to activity GM as discussed in Sections 5.5.3.1 and 5.5.3.2. Also whole farm profit adds the revenue generated by selling surplus hay which is not considered in either activity gross margin calculation. As amount of surplus hay sold vary greatly across the scenarios so does the total farm profit.

Similar to the Pincher Creek site results, crop revenue for the Swift Current site has increased under both the alternative strategies compared to the purchasing feed strategy. At the whole farm level, the reduction in herd size generated more profit compared to purchasing feed under both the scenarios. Therefore, the cull herd strategy is the most preferred strategy under both the scenario for the Swift Current site. Most of the farm level profitability, and liquidity values have improved significantly by adopting cull herd strategy relative to purchase feed strategy under both the scenario as shown in Table 8.26.

Table 8.26 Percentage change in farm profitability and liquidity under the alternative adaptation strategies relative to reference adaptation in the Swift Current site

Changes	Profitability				Cash flow	Net worth
	PV of beef activity GM	PV of crop activity GM	PV of whole farm GM	PV of whole farm NP	Average farm cash flow	Ending value of net worth (excluding land)
Baseline scenario						
Changes under "early weaning and limit feeding" over purchase feed	-37.36%	+4.93%	-12.16%	-13.73%	-12.22%	+22.47%
Changes under "cull herd" over purchase feed	-38.85%	+16.75%	+2.21%	+2.51%	+2.70%	+1.75%
Future scenario						
Changes under "early weaning and limit feeding" over purchase feed	-60.88%	+0.55%	-9.17%	-10.45%	-9.73%	+1.95%
Changes under "cull herd" from purchase feed	-88.26%	+10.82%	+1.38%	+1.58%	-4.40	+0.34%

8.4 Sensitivity analysis

The above set of results was obtained under two assumptions: one, price and costs are as projected by the forecasting models, and two, pasture productivity is as estimated using the Forage Calculator. These assumptions are modified and the sensitivity of results to these changes are reported in this section. This may provide a check on robustness of the results presented above. The price sensitivity analysis has been conducted to evaluate the future scenario results under the baseline price and cost scenario. The pasture sensitivity analysis is conducted to assess the future scenario results under the assumption that pasture and crop respond similarly to climate change and extremes.

8.4.1 Sensitivity with respect to input and output price

Under this sensitivity analysis, the future scenario simulation is conducted by using the COP and commodity prices used for the baseline scenario. Therefore, the difference between the results of future scenario and this analysis is that the future scenario above used projected prices and costs while this scenario used the price and COP from the baseline scenario. The results of this analysis, therefore, can be understood as the pure effect of climate change in the future without consideration of other changes.

Results of alternate price analysis for the Pincher Creek site are shown in Table 8.27. For the Pincher Creek site, beef cattle production under the future scenario with baseline price is projected to make smaller gains relative to the gains under the projected prices and costs. The cost of feed production relative to the future scenario has decreased by 67% but the gross margin has declined by 27% from the gross margin estimated under the projected prices and costs.

Table 8.27 Results of the sensitivity analysis of input and output prices for the Pincher Creek site farm

SN	Activity/Price	Baseline scenario results	Future scenario results	Future scenario with baseline Price		
				Result of alternate price scenario	% change from baseline result	% change from future scenario results
1	**Beef cattle activity level**					
	Total feed production cost (PV, '000 $)	218.54	506.48	166.98	-23.59%	-67.03%
	Average feed production cost ('000 $/year)	16.97	33.92	13.40	-21.05%	-60.49%
	CV of feed cost	0.43	0.13	0.37	-12.65%	190.45%
	Total beef cattle GM (PV, 000 $)	633.86	950.98	687.59	8.48%	-27.70%
	Average GM ('000 $/year)	45.75	67.33	49.17	7.47%	-26.97%
	CV of beef cattle GM	0.36	0.29	0.31	-11.48%	6.75%
2	**Crop activity level**					
	Total crop GM (PV, '000 $)	451.13	833.24	1,451.91	221.84%	74.25%
	Average ('000 $/year)	31.30	66.69	94.24	201.06%	41.31%
	CV of crop GM	0.91	0.72	0.44	-51.47%	-38.57%
3	**Whole farm level**					
	Farm net profit (PV, '000 $)	980.97	1,326.63	2,056.65	109.66%	55.03%
	Average net profit ('000 $/year)	71.26	107.04	136.61	91.71%	27.62%
	CV of farm net profit	0.56	0.63	0.34	-39.14%	-45.89%
	Average net farm cash flow ('000 $/year)	138.70	213.26	269.71	94.46%	26.47%
	CV of net farm cash flow	0.43	0.52	0.22	-48.32%	-58.04%
	Negative farm cash flow (no. of year)	-	-	-		
	Ending value of net worth (‘000 $)	262.15	539.73	417.02	59.07%	-22.73%

In contrast to beef cattle activity, the crop gross margin under baseline prices and costs has increased by more than 70% from the future scenario results. Thus baseline prices and costs assumption at the whole farm level has produced positive results. The gain under the future scenario with baseline price is estimated to be significantly higher than that under the projected future prices. Farm profit is estimated to increase by 55% of that under the projected price. This increment in farm net profit is 110% higher than the baseline scenario.

For the Swift Current site, feed production costs and the gross margin in the future with the baseline prices have declined by 68% and 33%, respectively, relative to the future scenario results. The gross margin from crops is estimated to be 20% higher than that for the future scenario. Farm net profit and cash flows all have increased by more than 20% from future scenario. Changes in farm net profit under this scenario are 197% from the baseline scenario results. Results of the alternate price simulation for the Swift Current site are shown in Table 8.28.

Table 8.28 Results of the sensitivity analysis of input and output price in the Swift Current site

S N	Activity/Price	Baseline scenario results	Future scenario results	Future scenario with baseline price		
				Result of alternate price scenario	% change from baseline result	% change from future scenario results
1	**Beef cattle activity level**					
	Total feed production cost (PV, '000 $)	223.84	491.53	156.33	-30.16%	-68.19%
	Average feed production cost ('000 $/year)	17.60	32.80	12.37	-29.72%	-62.28%
	CV of feed cost	0.54	0.20	0.39	-27.03%	94.45%
	Total beef cattle GM	395.07	553.69	368.29	-6.78%	-33.48%
	Average GM ('000 $/year)	29.54	44.49	27.97	-5.32%	-37.14%
	CV of beef cattle GM	0.56	0.60	0.62	11.02%	3.21%
2	**Crop activity level**					
	Total crop GM (PV, '000 $)	914.28	2,757.84	3,297.58	260.67%	19.57%
	Average ('000 $/year)	48.76	186.63	232.02	375.86%	24.32%
	CV of crop GM	1.53	0.56	0.41	-73.21%	-26.72%
3	**Whole farm level**					
	Farm net profit (PV, '000 $)	1,215.75	2,961.06	3,610.65	196.99%	21.94%
	Average net profit ('000	72.59	209.56	254.30	250.33%	21.35%
	CV of farm net profit	1.07	0.57	0.41	-61.86%	-28.73%
	Average net farm cash flow	143.82	416.32	498.66	246.72%	19.78%
	CV of net farm cash flow	0.74	0.45	0.31	-58.41%	-31.54%
	Negative farm cash flow (no. of year)	3	-	-		
	Ending value of net worth (‘000 $)	116.06	711.81	714.24	515.37%	0.34%

For both the study site farms, average annual net cash flow is estimated to improve under the baseline price scenario relative to the projected price scenario. Farm cash flows have increased by 26% and 20% from the projected price scenario for the Pincher Creek and Swift Current farms, respectively. Inter-annual variability of gross margin, net profit, and cash flow are estimated to decrease significantly from the projected price scenario indicating that income risk would be lower if the baseline price and cost prevail in the future. The farm's net worth position, however, has decreased for the Pincher Creek site and does not change much for the Swift Current site.

A significant increase in crop yield under the future scenario without any change in per acre COP results in a substantial decrease in feed production costs. Despite the decrease of feed production cost under the baseline price assumption, decrease in the beef cattle gross margin for both study sites indicates that the model provides optimistic values under the future price projection. A comparison of gross margin from crop between the two price scenarios indicates that crop COP increases faster than the crop prices under the future scenario with projected prices. The comparison of overall farm level results with two price scenarios shows that pure gain from climate change will be relatively more than the results from the future scenario under projected prices and costs.

8.4.2 Sensitivity with respect to pasture productivity

The model has also been simulated with revised pasture yield forecast to assess the sensitivity of the future scenario results to pasture productivity. Under this scenario, future pasture production is assumed to increase in the same proportion as crop yield increase, as discussed in Section 6.3.4.

Results from both sites show that, if pasture response to climate change is similar to the crop response under the future scenario, the given pastureland at both study sites is enough to meet the summer pasture needs of the beef herd. Hence, producers do not need to implement any strategies to deal with feed shortages during the study simulation period. Therefore, this result is compared with only the reference adaptation strategy.

At the Pincher Creek site, revenue from the beef cattle production in the future with the revised pasture productivity is estimated to be 6% higher than that under the future scenario with original pasture productivity (Table 8.29). Crop revenue is estimated to increase by 4% under this scenario compared to the regular pasture yield scenario. Similarly, the farm net profit under the revised pasture yield scenario is estimated to increase by 6% compared to the original pasture yield scenario. It should be noted that this farm net profit increment is about 41% higher than that under the baseline results. Variations in income from crops and beef cattle production, as well as at the whole farm level decreased significantly from the regular pasture yield scenario.

Table 8.29 Sensitivity of the results to changes in pasture yield for the Pincher Creek site

				Future scenario with alternate pasture yield		
S N	Activity/pasture yield	Baseline scenario results	Future scenario results	Alternate pasture yield simulation result	% change from baseline result	% change from future scenario results
1	**Beef cattle activity level**					
	Total beef cattle GM (PV, 000 $)	633.86	950.98	987.45	55.78%	5.75%
	Average GM ('000 $/year)	45.75	67.33	69.82	52.62%	5.45%
	CV of beef cattle GM	0.36	0.29	0.27	-22.76%	-5.68%
2	**Crop activity level**					
	Total crop GM (PV, '000 $)	451.13	833.24	851.29	88.70%	4.00%
	Average ('000 $/year)	31.30	66.69	67.89	116.87%	3.82%
	CV of crop GM	0.91	0.72	0.70	-22.56%	-1.55%
3	**Whole farm level**					
	Farm net profit (PV, '000 $)	980.97	1,326.63	1,381.15	40.79%	5.56%
	Average net profit ('000	71.26	107.04	110.73	55.40%	5.18%
	CV of farm net profit	0.56	0.63	0.61	8.29%	-4.18%
	Average net farm cash flow ('000 $/year)	138.70	213.26	220.63	59.08%	5.32%
	CV of net farm cash flow	0.43	0.52	0.51	19.84%	-3.31%
	Negative farm cash flow (no. of year)	-	-	-		
	Ending value of net worth (‘000 $)	262.15	539.73	555.49	111.89%	2.91%

For the Swift Current site, in comparison to the future scenario with regular pasture yield model, the beef cattle gross margin has decreased by 38%, the crop gross margin has increased by 1%, and the whole farm net profit has increased by 8%. It should be noted that the farm net profit under the baseline price assumption has increased by 163% relative to the baseline scenario results. Pasture sensitivity results for the Swift Current site are given in Table 8.30.

Table 8.30 Sensitivity of the results to changes in pasture yield for the Swift Current site

				Future scenario with alternate pasture yield		
S N	Activity/pasture yield	Baseline scenario results	Future scenario results	Alternate pasture yield simulation result	% change from baseline result	% change from future scenario results
1	**Beef cattle activity level**					
	Total beef cattle GM (PV, 000 $)	395.07	553.69	761.45	92.74%	37.52%
	Average GM ('000 $/year)	29.54	44.49	58.26	97.24%	30.95%
	CV of beef cattle GM	0.56	0.60	0.41	-26.07%	-31.26%
2	**Crop activity level**					
	Total crop GM (PV, '000 $)	914.28	2,757.84	2,786.85	204.81%	1.05%
	Average ('000 $/year)	48.76	186.63	188.61	286.84%	1.06%
	CV of crop GM	1.53	0.56	0.55	-63.86%	-1.14%
3	**Whole farm level**					
	Farm net profit (PV, '000 $)	1,215.75	2,961.06	3,197.84	163.03%	8.00%
	Average net profit ('000 $/year)	72.59	209.56	225.31	210.39%	7.52%
	CV of farm net profit	1.07	0.57	0.53	-50.16%	-6.87%
	Average net farm cash flow	143.82	416.32	447.82	211.38%	7.57%
	CV of net farm cash flow	0.74	0.45	0.42	-43.33%	-6.73%
	Negative farm cash flow (no. of year)	3	-	-		
	Ending value of net worth (‘000 $)	116.06	711.81	844.48	627.58%	18.63%

In both the study sites, farm cash flow, family cash flow, and ending farm net worth are estimated to improve significantly in the future under the revised pasture yield scenario. Inter-annual variations of the gross margin from crops and beef cattle production as well as at the whole farm level, are estimated to decrease relative to the regular pasture yield scenario. If pasture response to climate change is similar to the crop response in the future, gains in both the study sites will be much higher than the gain under the projection made with the regular pasture yield scenario. The gain would be particularly higher for the beef cattle enterprise at both study sites. Under the revised pasture yield scenario, pasture production is enough to meet the grazing need of the herd throughout the simulation period without need of any adaptation measures. Costs associated with the adaptation strategies are avoided under the revised pasture yield scenario, such as the cost of feed purchase compared to the reference case and forgone revenue from beef cattle sold compared to the other alternative strategies.

8.5 Summary of results and discussion

This chapter presented the results of whole farm simulation model highlighting the economic impact of climate change and extremes on the Prairie mixed farms. The results of this study indicate that an average Prairie mixed farm is economically viable, as indicated by long-term profitability and liquidity position under both the baseline and future scenarios. In both the study sites, the economic impact of climate change is projected to be positive. The net profit of the farm under the future scenario is estimated to increase by 35% in the Pincher Creek site, and 144% in the Swift Current site from the baseline scenario results. Relatively speaking, the gains are higher for the crop activities relative to the beef cattle activities. The crop gross margins are estimated to increase by 85% in the Pincher Creek site and by more than 200% in the Swift Current site. Beef cattle enterprise in the future would be impacted through the decrease in pasture productivity and frequent events of feed shortages. Decreased pasture productivity would results in higher cost of maintaining the beef herd. Nonetheless, the beef cattle enterprise, measured in terms of gross margin, under the future scenario is estimated to gain by 50% in the Pincher Creek site and 40% in the Swift Current site.

The choice of adaptations to deal with climate extreme events is contextual and the preference of adaptation strategy differs across activities, study farms and study periods. An appropriate choice of adaptation in managing beef herd plays an important role in determining the profitability of not only beef cattle activities, but also the financial position of the whole farm. At the beef cattle enterprise level, maintaining the beef herd, without any compromise of herd size, is superior to early weaning and limit feeding as well as cull the herd under both the study scenarios for both the sites. At the whole farm level for the Pincher Creek site, the cull herd method is preferred under the baseline scenario, and the purchase feed strategy is preferred under the future scenario. For the Swift Current site, culling the herd is preferred under both the study scenarios. Therefore, the choice of adaptation is dependent on many factors, such as the existing carrying capacity of pastureland, existing feeding cost, severity of climate extremes, and integration of crop and beef cattle production.

Commodity prices and cost of farm inputs profoundly affect the economic position of a farm under the future climate change scenarios. The farm net profit under the future scenario with the baseline price assumption compared to projected price is 50% more in the Pincher Creek site and about 25% more in the Swift Current site. The pure effect of climate change measured in terms of farm net profit, assuming all inputs and output prices remain same as under the baseline scenario, is estimated to be more than 100% in the Pincher Creek and about 200% in Swift Current, compared to the baseline scenario.

The assumption regarding future pasture response to climate change scenario is important in estimating the impact of climate change both for beef cattle production and at the whole farm level. If pasture response is similar to crop responses to future climate, the gross margin from beef cattle would be 37% higher in the Swift Current and 6% higher in the Pincher Creek relative to regular projection of pasture production under the future scenario.

Chapter 9 SUMMARY AND CONCLUSION

9.1 Summary

Climate change is expected to impact both the average and the variability of climate in the Canadian Prairies in the future. Prairie agriculture is projected to obtain positive impacts from normal climate change (Kulshreshtha and Wheaton, 2013); however, the likelihood of increased variability of climate in the future negatively impacts both crop and livestock production (Kulshreshtha, 2011). Therefore, a consideration of not only average but also inter-annual variability of future climate is important in understanding the likely economic impacts of climate change.

The study built on the existing literature on climate change impacts on the Canadian Prairie agriculture by addressing some of the major knowledge gaps. In particular, the study focuses on incorporating the climate extremes in economic impact assessment, measuring climate change impacts on livestock by developing linkages with crops and forages, and, considering the efficacy of adaptation measures during periods of climate change and extremes. The major objectives of this study were to estimate the impact of climate change and extremes on crops, forages and beef cattle production activities; to estimate the impact of climate change and extremes on the economic viability of Prairie mixed farms; and to evaluate selected adaptation measures to assist producers to cope with climate change and extremes.

This study considers normal climate scenarios as well as climate extremes by including projected inter-annual climate variability, and estimating their economic impact on crops, beef cattle, and economic viability of a farm as a whole. Two climate scenarios are analyzed: a baseline scenario covering the 1971-2000 period, and a future scenario covering the 2041-2070 period. Two mixed farms, having both crops and beef cattle activities, one in Swift Current, Saskatchewan and one in Pincher Creek, Alberta, were developed using a farm construction approach. The study uses a whole farm discrete simulation model that integrates models of beef cattle herd, crops and pasture simulation with models of economic decision. The impacts of climate change and extremes on crops, hay, and pasture have been estimated by relating the crop yields to climate forecasts. These estimated yield impacts have been related to beef herd through impacts on feed availability. The farm is assumed to produce enough crop, hay and pasture to support the beef cattle feed demand in an average climate year. Pasture demand and supply are linked by Animal Unit Month (AUM) pasture requirement and production. Beef herd feed grain and silage demand and on-farm supply are linked by formulating a least cost ration using a linear programming approach. The crop mix for the market is selected by formulating a multi-year linear programming problem by maximizing the present value of gross margin. Gross margins from crops and beef cattle production have been calculated separately, and are added together to calculate the farm level profit by including whole farm capital costs. The economic positions of the farms under the baseline and future scenarios are evaluated in terms of profitability, liquidity and net worth measures.

A total of three adaptation strategies of beef herd management during the period of feed shortages are evaluated. It is assumed that maintaining the beef herd by purchasing feed during feed shortages is the most common beef herd strategy and thus is considered as the reference adaptation strategy. Two alternative adaptations, one, changes in beef herd management practices that include early weaning of calves combined with limiting feeding of feedlot animals and, the other, culling the herd to meet the reduced feed supply, are compared with the reference adaptation strategy. Two sensitivity analyses are done to check the robustness of the future economic impacts of climate change and extremes estimated. Price sensitivity analysis evaluates the future scenario results by simulating the farm under baseline price and cost condition. Another sensitivity analysis has been conducted to estimate its impact of pasture yields under the assumption that pasture's response to climate change in the future would be similar to that of crop's response.

9.2 Conclusions

Results of this study indicate that an average Prairie mixed farm is an economically viable business under both the baseline and future scenarios. Similar to the findings of other past studies (e.g., Bootsma, 2005; Weber and Hauer, 2003; Robertson, 2012), this study found that climate change would positively impact economic situation of Prairie agriculture.

Beef cattle production in the future would be affected, to some extent, due to the decrease in average pasture carrying capacity and increase of the events of feed shortage. This effect would be relatively greater in the Swift Current site because the lower carrying capacity of pastureland and the stronger effect of climate extremes would result in the higher costs of beef herd management during the climate extreme events. Nonetheless, beef cattle activity in the future will still be a profitable enterprise if the herd size is maintained and no compromise is made in feeding at both the study sites. The beef cattle enterprise gross margin in the future is estimated to increase by 50% for the Pincher Creek site and by 40% for the Swift Current site.

The gross margin from crops, including both area and yield effect, are estimated to increase by about 100% for the Pincher Creek site and about 200% for the Swift Current site from the baseline scenario. For both the study sites, about 40% of projected increment in crop gross margin is estimated to come from area effect – the transfer of feed area to production of crops for market – and 60% from yield effect. In terms of crop mix, canola and maize are identified as the two dominating crops under both the scenarios; canola is selected as the dominating crop for the market and maize as the main feed crop.

Whole farm profitability under the future scenario is also projected to increase significantly from the baseline scenario, but, decrease in its variability. Farm net profit from the baseline scenario is estimated to increase by 35% for the Pincher Creek site and by 144% for the Swift Current site under the future scenario. The income risk will be lower in the future as indicated by either constant or a decreased coefficient of variation of annual net profit. An analysis of farm financial indicators, such as cash flow and net worth, reveals that the farms' financial positions would be much better under the future scenarios. The long-term average value of the farm financial indicators is significantly higher in the future for both the farms. Few events of liquidity crisis are observed for the Swift Current site under the baseline scenario, which is not persistent under the future scenario. At the family level, however, few events of liquidity crisis are noted under the future scenario, but, in light of significant improvement in other economic indicators, this effect is considered to be negligible.

A comparison of income risk (as represented by the coefficient of variation of the activity gross margin, whole farm gross margin and net profit) indicates that crop production activities are riskier than beef cattle production activities under both the scenarios and for both the study sites. However, the income risk decreases significantly when beef cattle activities are integrated at the whole farm level. Hence, the income risk of climate change on crop production can be lowered to some extent through diversification of the farm operations - by adding the beef cattle component on the farm.

An appropriate choice of adaptation strategy of managing beef herd during extreme climate events plays an important role in determining profitability of not only the beef cattle activities, but also the financial position of the whole farm. Choice of adaptations, however, is contextual and differs across activities, farms and study scenarios. At the beef cattle enterprise, maintaining the beef herd without any compromise of herd size and regular feeding plan is preferred over other adaptation alternatives. At the whole farm level for the Pincher Creek site, the cull herd strategy is preferred under the baseline scenario, and the purchase feed strategy is preferred under the future scenario. In the case of the Swift Current site, the cull herd strategy is preferred under both scenarios. The choice of adaptation at the whole farm level depends on factors such as the existing carrying capacity of grazing, existing feeding cost, severity of climate extremes, and farm characteristics such as the share of crop and beef cattle activities at the whole farm level, and whether the changes in one activity can be offset by the changes in another.

Commodity prices and cost of farm inputs profoundly affect the economic position of a farm under the future climate change scenarios. The nature and degree of the future climate change impacts depend on future input and output prices. If the commodity prices and COP remain the same, the future farm profit is estimated to be 50% higher in Pincher Creek and about 25% higher in Swift Current compared to the estimated profits under the projected future prices.

The assumption related to future pasture response to climate change scenario is an important consideration in estimating climate change impacts on beef production and through that on the profitability and liquidity positions of a mixed farm. If pasture productivity decreases, as estimated by the Forage Calculator, an appropriate adaptation is necessary to benefit from climate change in the future. If pasture productivity under the future scenario increases similar to crop yield increases, existing pastureland is enough to maintain the beef herd in the future. This will avoid the cost of beef herd adaptation during climate extremes and increase the gross margin from beef cattle production by 37% for the Swift Current site and 6% for the Pincher Creek site.

The estimated impacts on individual beef cattle production and crops as well as at whole farm level, suggest that the gain in normal years in the future would be more than any losses incurred due to climate variability and extremes. The severity of extreme events in the future, at least for the period of future scenario considered in this study, would not be significant to threaten the economic viability of the Canadian Prairie agriculture. The climate change in fact brings positive impacts by increasing long-term profitability, liquidity, and net worth position of Prairie farms. This gain, however, is dependent on adaptation strategies, such as the appropriate choice of feed management and appropriate crop mix selection.

The study contributes to the knowledge of climate change impact assessment at farm level by offering a simple and flexible yet comprehensive assessment framework, MF-CCE model. The MF-CCE model developed in this study is a generic spreadsheet model that is applied to four crops, hay, pasture, combined with cow-calf, backgrounding and finishing beef operation; however, the model can be customized to fit any number of production activities. The model can be solved for other regions and countries by using local information.

9.3 Study Limitations

This study has six major limitations as discussed below which should be noted in interpreting the results of this study.

(1) Generalization of the study at regional level:

One of the major limitations of this study is the number of study farms simulated in this study. This study was limited to only two farms, one in Swift Current, Saskatchewan and another in Pincher Creek, Alberta. This might be considered inadequate to generalize the results to the Prairie region as a whole.

(2) Consideration of the effect of climate change:

The existing literature indicates that climate change has an impact on global production of agricultural commodities that in turn would affect their global supply. Other than economic factors, weather affects the estimation of future input and output prices. However, recent assessment of climate change impacts on commodity prices, specifically relating to Canadian domestic prices, is currently not available. Therefore, the price effect of climate change is not taken into consideration in this study.

Climate change, especially global warming, could directly affect livestock production, such as increased feed conversion ratio affecting beef cattle productivity performance, and increased incidence of livestock diseases. Climate change is also believed to increase crop insects, pests and diseases, and change forage quality. These impacts are not estimated in this study due to the inadequate available information.

(3) Consideration of future periods, and climate model/scenario used

Perhaps another factor to consider is the study period. This study refers 2041-2070 as the future period, and thus all the estimated future impacts should be understood as impacts for that period. Any change in future may also change the results, as the climate projections especially intensities and magnitudes of climate extremes may not be similar to those in the study period.

The results of this study are heavily dependent on the results of climate models and emission scenarios. These scenarios may change with human activities, particularly population growth and rate of economic development. Therefore, any change in the future emission levels may change the projected climate, and thus the magnitude and direction of the impacts estimated in this study.

Future climate scenario projections are not consistent across climate models and scenarios. As discussed in Section 6.2, this study had an option of selecting one of two climate scenarios, the RCM3_CGCM3_A2 and the HRM3_GFDL_A2. These climate scenarios vary greatly in terms of precipitation and temperature change in the future. The RCM3_CGCM3_A2 scenario projects both the growing season temperature and precipitation increases while the HRM3_GFDL_A2 scenario projects an increase in temperature but decrease in precipitation relative to the baseline scenario. Furthermore, the Regional Climate Models (RCMs), such as the RCM3, project future temperature change as high but precipitation change as low (Teutschbein and Seibert, 2012; Barrow, 2014). Therefore, the climate change impacts could be different if other climate models/scenarios are considered for climate change and extreme events impacts.

(4) Crops and pasture yield estimation:

The AquaCrop model is used in this study to estimate crop and hay yields under the RCM3_CGCM3_A2 climate scenario. This model assumes that there are no nutrient limitations, which may have resulted in high crop yields. This could be attributed to the combination of future warmer and wetter climate with unlimited nutrient supply. But the cost of the plant nutrient use simulated by AquaCrop model is not considered in this study. This might have caused a slight overestimation of the farm profit.

Pasture yield estimation used in this study was done under the ECHAM4_A1B climate scenario. The result of pasture yield estimation and crop yield estimation are not consistent in the future. Although an alternative analysis is done by assuming pasture yield change will be similar to crop yield change under the future scenario, the use of the same climate scenario to estimate crop and pasture yield may provide better results.

(5) Crop and beef herd adaptations:

When there is summer pasture deficit (due to droughts), farms may buy extra feed to carry over this period, however, if the drought is lengthy, they will likely liquidate some of the herd to more correctly match the pasture supply to current pasture availability. Furthermore, farms may combine different possible adaptation alternatives simultaneously to efficiently manage the extreme climate events. However, for the purpose of comparing adaptation alternatives, this study assumes that farms cannot combine more than one adaptation strategy at a time. This assumption may seem to be somewhat rigid.

The study assumes that the farm size remains the same throughout the 30-year simulation period and also between baseline and future scenarios. There is a possibility that farm size could change due to many reasons, such as increasing demand of agriculture commodity, favorable government policies, and climate change. Due to the possible change in production practices under climate change, farm size may increase (or decrease) to adapt to the prevalent climate. However, since the total land assets in a region is fixed, an increase in size of a farm is only possible by exit of other producers. This study, therefore, does not consider this possibility mainly due to difficulty in predicting exact nature and degree of such a change in the future.

(6) Model assumptions:

The MF-CCE is a non-stochastic model. The model assumes that all the input parameters are known with certainty. In the model, one scenario simulation consists of one simulation cycle with 30 yearly sub-runs. Hence bringing stochastic factor into the analysis with multiple simulation cycle per scenario may provide different estimates of climate change impacts. Also, the model is linear in nature.

(7) Technology, policy and other exogenous factors:

The study does not take account of the exogenous factors that are very likely to interact with climate change in determining agriculture output, such as use of GMO crop varieties and BSE disease in livestock. Resistance of GMO crop varieties might be different from the resistance of the ones tested in this study. Therefore, the impact estimated in this study does not apply to GMO crop varieties. Also the possibility of BSE disease are not considered in this study.

The other factors that need to consider in interpreting the result of this study is that this study does not take into account possible structural change in the Prairie agriculture. Advancement in technologies and government policies affect the composition of the industry. As similar production technologies and policy environment are considered under both the baseline and future scenarios, any change in the structure of the industry may lead to totally different impact of climate change extremes.

9.4 Policy analysis and recommendations

The result of this study suggests that economic impact of climate change on Prairie agriculture would be positive. However, the appropriate choice of adaptations is necessary to endure the effect of short-term extreme events and to benefit from the longer term climate change scenarios. Therefore, appropriate technologies and efficient policies to help farmers minimize possible negative effects of extreme climate and to continually adapt to changes under normal climate are necessary to realize the benefit of climate change by the Prairie producers.

At present a major government policy the Prairie producers depend upon to cope with the impact of climate extremes is Business Risk Management (BRM) program (Kulshreshtha et al., 2015). The BRM includes Crop Insurance, AgriStability, AgriInvest, and AgriRecovery programs. The BRM covers the income loss resulting from natural and market risks. Included here is the AgriRecovery, which is a disaster relief program designed to support agricultural producers, together with core BRM programs, to recover from natural disasters (AAFC, 2014b). The BRM suite, especially the insurance program, provides producers an opportunity to reduce economic vulnerability to climate change by supporting them in the event of extreme climate events. Cabas (2006) observed that producers' participations in insurance program depends on expected weather and crop yield among other economic factors. A producer's participation in insurance program may be beneficial if the production level is low, especially during climate extreme years, but higher climate variability potentially impacts the viability of the insurer. Higher variability of climate and production may increase the producers' insurance participation but it also increases the costs to the government (or insurance agency). Governments may offer premium subsidy and indemnity payment from insurers, which may seriously threaten economic viability of the program itself. This, however, poses no threat in the future period considered in this study since a significant increase in farm profit, and improvements in farm cash flow and net worth situation, along with negligible events of liquidity problem. However, as identified by Abbasi (2014), the BRM especially crop insurance and AgriStability programs, are highly criticized because of their complexity, predictability, timeliness issues and additional financial burdens due to high premiums and low coverage. These may require changes to improve producer participation.

The findings of this study indicate that the impact on livestock depends on the choice of appropriate adaptation to climate change. Livestock can be vulnerable due to projected decrease in pasture carrying capacity and frequent events of feed shortages in the future. The BRM program, however, is not clear on how it covers any productivity or output decline in the livestock sector. The only risk management program for livestock is the Western Livestock Price Insurance Program (WLPIP) that can protect farmers from a price decline (WLPIP, 2015). The WLPIP does not deal with climate change and extremes, and other programs to support beef producer to cover output loss due to climate change and extremes are not available at the current time.

Timely adaptation to climate extremes such as drought can be improved in the Canadian Prairies. Wheaton et al. (2008) observed the problem of timely recognizing the onset of the events in the timely adaptation to climate extremes in the Canadian Prairies. According to Kulshreshtha and Malreau (2005), the Canadian Prairie droughts of 2001-2002 were not recognized until after most management decisions were already made. The crop yield results used in this study also show that the crop for market sale was zero for many years under both the baseline and future scenarios. However, a program to support producers in timely recognition of climate extreme events to allow producers to adapt to climate extremes, especially droughts, is not in place in either Alberta or

Saskatchewan.

The importance of a program to enhance the long-term capacity of agriculture in dealing with the climate change and extremes is very important. Stern (2007) proposes that adaptation should build agriculture's resilience to deal with climate change and that cost of climate change to the societies can be minimized to some extent by building more climate-resilient agriculture and infrastructure. IISD (1997) anticipates that cost of adaptation would be much higher if investment in building resilient agriculture, like the development of drought resistant crops and forage cultivars, is not undertaken. This calls for more focused programs to support producers to enhance the agriculture's resilience to and ability to adapt to a changing climate.

Based on the issues identified in this study and the review of the agricultural policy in place, the following suggestions are made to address the development of future government agricultural policy frameworks;

- From a risk management perspective, existing the BRM framework under Growing Forward 2 (GF2) seems to be adequate for the future period considered in this study. However, this program should be reviewed to incorporate adaptation components, such as best management practices (BMPs) in crop and livestock together with risk management as suggested by IISD (1997). One way of incorporating BMPs in insurance programs of BRM could be through offering lower premium rates to producers who adopt BMPs.

- Promoting participatory research on BMPs with producers would be helpful in identifying the best practices to enhance the adaptive capacity of producers.

- A formulation of policy to expand insurance and support programs beyond existing Growing Forward 2 coverage to cover the direct impacts of climate change on livestock performance is required.

- Programs to support producers in timely recognition of climate extreme events, like droughts, by developing early warning systems can minimize the economic impacts of climate extremes for producers as well as for the government.

- Policies to develop and promote climate-resilient technologies, such as drought resistant crops and forage cultivars, would be highly useful in dealing with both the long-term climate change as well as climate extreme events.

- Policies to support diversification on farming would be helpful in reducing farms' economic vulnerability. Economic uncertainty and annual income variability is higher for crop production and lowers when beef cattle activity is integrated. Therefore focused and continued emphasis on diversification is necessary.

9.5 Areas for future research

Based on the results and limitation of the study, following areas are recommended to be addressed through future research;

- A study by Thorpe (2011) suggested that crop and forage area will be extended towards north in the future. Forage productivity may decline in the existing grassland but total regional forage production may gain due to increased grassland area. Regional level studies incorporating the possibility of grassland shift northwards may provide better estimates of climate change impacts on Prairie agriculture on a regional scale.

- As identified in the study limitations, this study does not consider the impacts of climate change and extremes on commodity prices in Canada. Studies that address this issue can form an extension of this research.

- Crop yield estimation in this study was done using the RCM3_CGCM3_A2 scenario by using agronomic crop simulation model while pasture yield estimation used in this study was done under the climate scenario of the ECHAM4_A2 using the Forage Calculator developed by Saskatchewan Research Council. Thus, the results of pasture yield and crop yield estimation are not consistent for the future period. A study using same climate scenario to estimate crops and pasture productivity deserves some merit.

- Climate scenario projections and their confidence vary across the climate models (Teutschbein and Seibert, 2012; Barrow, 2014). Therefore, a study using more than one climate models/scenario may provide a range of possible climate change impact estimates.

- In this study, the impact on beef cattle production has been linked through the impact on feed supply under climate change. This study has not modeled direct linkages of changes in beef cattle production. Also the impact of climate change on crop and livestock diseases has not been considered in this study. Future studies that address the direct effect of global warming on livestock performance, and incidence of crop and livestock pest and diseases may provide more realistic impacts of climate change.

- There can be many promising adaptations other than ones tested in this study to manage crops and beef herd in the events of climate change and extremes. These include changes in crop husbandry practices, changes in timing of operations, and use of resilient crop cultivars. Keeping small body weight animals, whose feed requirements would be lower, can be another adaptation to reduce the feed demand during periods of feed shortages. Marketed live weight may be lower from small sized beef cattle; however, this practice can be beneficial if the extreme events are more frequent as adaptation cost in either maintaining herd or reducing herd can be much higher for larger sized animals. Studies are recommended to assess the benefit of adopting these and similar adaptations.

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APPENDIX

Appendix A: Feeding plan for different types of beef cattle

Table A.1 Beef herd feeding plan for different types of beef cattle

Beef cattle type	March-April	May-June	July-Sep	Oct	Nov-Feb	Days and feeding
Days	61	61	92	31	120	
Calves (0-7months)	Milk and good quality hay	Milk and Pasture	Milk and Pasture			Milk and hay 61 days and Milk and pasturing 153 days
Backgrounding calves (8-12 months)				High Forage	High Forage	151 days high forage
Steer and heifer Finishing (13-16 months)	High grain	High grain				122 days high grain
Heifer for herd replacement (8-14 months)	High Forage			High Forage	High Forage	212 days high forage
Growing breeding bull (8-14 months)	High Forage			High Forage	High Forage	212 days high forage
Breeding cow	Hay	Pasture	Pasture	Pasture	Hay	181 days hay and 184 days pasture
Breeding Bull	Hay	Pasture	Pasture	Pasture	Hay	181 days hay and 184 days pasture

Appendix B: Variable cost items included in crop and beef cattle cost of production

Table B.1 Items included in the variable cost estimate of crops

SN	Items	Sources
1	Seed & Seed Cleaning	SMA (2013); Paynne (2013); Wood (2013); AARD (2013) and MAFRI (2010, 2012a, 2013a, 2013b and 2013c)
2	Fertilizer	
3	Chemicals	
4	Crop Insurance Premiums	
5	Trucking & Marketing	
6	Fuel	
7	Utilities & Miscellaneous Expenses	
8	Custom Work & Specialized Labour	
9	Paid Labour & Benefits	
10	Unpaid labor	
11	Operating interest	Author’s estimate

Table B.2 Items included in the variable cost estimate of beef cattle

SN	Items	Sources
1	Veterinary and Medicine	AARD (2004); Larson (2013)
3	Feeding	Author’s estimate
4	Operating interest	Author’s estimate
5	Operator and hired labor	
6	Other cost of production	

Appendix C: Unit root and P.A.C. tests of COP and price series

Table C.1 Augmented Dicky Fuller test statistic values from unit root test results for variable COP series

COP series	Without Trend	With trend	First Difference
SK Spring wheat COP	-0.241	-1.939	-4.805***
AB Spring wheat COP	-0.241	-1.939	-4.805***
SK Canola COP	-0.241	-1.939	-4.805***
AB Canola COP	-0.241	-1.939	-4.805***
SK Barley COP	-0.241	-1.939	-4.805***
AB Barley COP	-0.241	-1.939	-4.805***
SK Corn COP	-0.241	-1.939	-4.805***
AB Maize COP	-0.241	-1.939	-4.805***
Hay COP	-0.241	-1.939	-4.805***
Silage COP	-0.241	-1.939	-4.805***
Pasture COP	-0.241	-1.939	-4.805***
Cow-Calf COP	-1.617	-2.960	-6.164***
Bull COP	-1.617	-2.960	-6.164***
Feeder Cattle COP	-1.617	-2.960	-6.164***

*** significant at 1% level.

Table C.2 Augmented Dicky Fuller test statistic value from unit root test results for price series

Price series	Without Trend	With trend	First Difference
AB Spring Wheat Price	-2.622*	-3.626**	-6.019***
AB Barley Price	-2.050	-4.230**	-5.926***
AB Canola Price	-2.080	-3.492**	-5.965***
AB Maize Price	-2.176	-6.056***	-7.012***
Hay Price	-3.166**	-4.800***	-9.875***
Silage Price	-3.623*	-5.081***	-6.775***
Pasture Price	-2.102	-5.938***	-6.580***
AB Cull Cow Price	-2.341	-2.208	-5.590***
AB Cull Bull Price	-2.533	-2.625	-7.425***
AB Heifer (500-600 lbs) Price	-2.444	-2.652	-7.438***
AB Steer(500-600 lbs) Price	-2.415	-2.521	-7.220***
AB Heifer >800 Price	-2.407	-2.486	-6.801***
AB Steer >800 Price	-2.400	-2.442	-6.815***
AB Finishing Steer Price	-2.330	-2.022	-5.106***
AB Finishing Heifer Price	-2.333	-2.025	-5.169***
SK Spring Wheat Price	-2.423	-3.396*	-6.301***
SK Barley Price	-2.341	-3.416*	-6.261***
SK Canola Price	-1.305	-4.015*	-6.566***
SK Maize Price	-1.855	-5.959***	-6.882***
SK Cull Cow Price	-2.713*	-3.129	-6.082***
SK Cull Bull Price	-1.989	-1.875	-11.685***
SK Heifer (500-600 lbs) Price	-2.126	-2.474	-5.021***
SK Steer(500-600 lbs) Price	-2.188	-3.556**	-4.888***
SK Heifer >800 Price	-2.545	-3.188	-5.688***
SK Steer >800 Price	-2.522	-3.070	-5.829***
SK Finishing Steer Price	-2.334	-3.198	-4.811***
SK Finishing Heifer Price	-3.406**	-3.765**	-7.427***

***significant at 1%, ** significant at 5% and * significant at 10% error level.

Table C.3 Partial Auto Correlation (PAC) test results for variable COP Series

	COP series at Level		COP series at First difference	
COP Series	Significant lag/s (Level)	Coefficient/s of significant lag/s	Significant lag/s (First difference)	Coefficient/s of significant lag/s
SK Spring Wheat COP	1	+0.835	third	-0.346
AB Spring Wheat COP	1	+0.835	third	-0.346
SK Canola COP	1	+0.835	third	-0.346
AB Canola COP	1	+0.835	third	-0.346
SK Barley COP	1	+0.835	third	-0.346
AB Barley COP	1	+0.835	third	-0.346
SK Maize COP	1	+0.835	third	-0.346
AB Maize COP	1	+0.835	third	-0.346
Hay COP	1	+0.843	1, 2	0.32, -0.44
Silage COP	1	+0.835	third	-0.346
Pasture COP	1	+0.835	third	-0.346
Cow-Calf COP	1	+0.863	third	-0.293
Bull COP	1	+0.863	third	-0.293
Feeder Cattle COP	1	+0.863	third	-0.293

Table C.4 Partial Auto correlation (PAC) test results for price series

Price Series	Price at Level		Price Series at First difference	
	Significant lag/s	Coefficient/s of significant lag/s	Significant lag/s	Coefficient/s of significant lag/s
AB Spring Wheat Price	1	0.773	2, 13	-.37,-0.28
AB Barley Price	1	0.713	2	-0.32
AB Canola Price	1	0.827	2	-0.36
AB Maize Price	1, 2	0.664, -0.324	1,2	0.34 -0.56
Hay Price	1	0.621	1, 3, 4	-0.40, -0.32, -0.29
Silage Price	1, 4	0.500, 0.303	3	-0.48
Pasture Price	1	0.655	1, 2	0.31, -0.51
AB Cull Cow Price	1	0.807	3	-0.28
AB Cull Bull Price	1	0.756	4	-0.26
AB Heifer (500-600 lbs) Price	1	0.791	3	-0.30
AB Steer(500-600 lbs) Price	1	0.801	3	0.26
AB Heifer >800 Price	1	0.804	3	0.27
AB Steer >800 Price	1	0.807	3	0.27
AB Finishing Steer Price	1	0.840	3	0.27
AB Finishing Heifer Price	1	0.840	3	0.25
SK Spring Wheat Price	1	0.766	3	-0.28
SK Barley Price	1	0.773	2	-0.32
SK Canola Price	1	0.776	2	-0.42
SK Maize Price	1, 2	0.711 -0.329	1, 2	0.32, -0.56
SK Cull Cow Price	1, 3	0.77, 0.30	2	0.47
SK Cull Bull Price	1, 2	0.47, 0.44	1	-0.61
SK Heifer (500-600 lbs) Price	1	0.823	2, 4	-0.26 -0.24
SK Steer(500-600 lbs) Price	1	0.817	2, 4	-0.26 -0.24
SK Heifer >800 Price	1	0.74	2	0.32
SK Steer >800 Price	1	0.74	2	-0.31
SK Finishing Steer Price	1, 15	0.82 -0.30	2, 4, 14	-0.35 -0.32 0.30
SK Finishing Heifer Price	1	0.52	1, 2	-0.25 -0.27

Appendix D: Time series model of price and COP series

Table D.1 COP time series model representation

COP series	Estimated function (at level)	Adj. R^2
SK Spring Wheat COP	= 2.365 + 0.989*SKSPRING WHEATCOST(-1)	93%
AB Spring Wheat COP	= 3.927 + 0.989*ABSPRING WHEATCOST(-1)	93%
SK Canola COP	= 4.437 + 0.989*SKCANOLACOST(-1)	93%
AB Canola COP	= 4.437 + 0.989*ABCANOLACOST(-1)	93%
SK Barley COP	= 2.369 + 0.989*SKBARLEYCOST(-1)	93%
AB Barley COP	= 3.870 + 0.989*ABARLEYCOST(-1)	93%
SK Maize COP	= 32.024 + 0.857*ABMAIZECOST(-3)	93%
AB Maize COP	= 32.024 + 0.857*ABMAIZECOST(-3)	93%
Hay COP	= 1.307 + 1.392*HAYCOST(-1) - 0.412*HAYCOST(-2)	93%
Silage COP	= 3.780 + 0.989*SILAGECOST(-1)	93%
Pasture COP	= 0.050 + 0.989*PASTURECOST(-1)	93%
Cow-Calf COP	= 11.492 + 0.928*COWCALFCOST(-1)	78%
Bull COP	= 18.353 + 0.928*BULLCOST(-1)	78%
Feeder Cattle COP	= 0.019+ 0.928*FEEDERCATTLECOST(-1)	78%

Table D.2 Price time series model representation

Price series	Estimated Function (at level)	Adj. R^2
AB Spring Wheat Price	= 31.180 + 0.992*ABSPRING WHEATPRICE(-1) - 0.402*ABSPRING WHEATPRICE(-2)	68.8%
AB Barley Price	= 21.172 + 0.793*ABARLEYPRICE(-1)	58%
AB Canola Price	40.945 + 0.860*ABCANOLAPRICE(-1)	75%
AB Maize Price	= 49.478 + 1.027*ABMAIZEPRICE(-1) - 0.419*ABMAIZEPRICE(-2)	61%
Hay Price	= 21.059 + 0.630*HAYPRICE(-1)	39%
SK Spring Wheat Price	= 30.876 + 0.776*SKSPRING WHEATPRICE(-1)	61%
SK Barley Price	= 21.163 + 0.784*SKBARLEYPRICE(-1)	64%
SK Canola Price	= 42.324 + 0.863*SKCANOLAPRICE(-1)	70%
SK Maize Price	= 49.478 + 1.027*ABMAIZEPRICE(-1) - 0.419*ABMAIZEPRICE(-2)	61%
Hay Price	= 15.255 + 0.287*HAYPRICE(-1) + 1.053*@Year	50%
Silage Price	= 28.688 - 0.3889*SILAGEPRICE(-3) + 0.498*@Year	
Pasture Price	= 6.741 + 1.142*PASTUREPRICE(-1) - 0.918*PASTUREPRICE(-2) + 0.321*PASTUREPRICE(-3)	67%
AB Cull Cow Price	= 6.869 + 0.813*ABCULCOWPRICE(-1)	74%
AB Cull Bull Price	= 8.122 + 0.761*ABCULBULLPRICE(-1)	60%
AB Finishing Steer Price	= 14.028 + 0.793*ABSTEER(-1) + 0.135*@Year	82%
AB Finishing Heifer Price	= 13.635 + 0.846*ABFINISHINGHEIFERPRICE(-1)	82%
SK Cull Cow Price	= 8.523 + 1.106SKCULCOWPRICE(-1) - 0.681*SKCULCOWPRICE(-2) + 0.373*SKCULCOWPRICE(-3)	71%
SK Cull Bull Price	= 17.871 + 0.5679*SKCULBULLPRICE(-2)	61%
SK Finishing Steer Price	= 15.045 + 0.813*SKFINISHINGSTEERPRICE(-1)	74%
SK Finishing Heifer Price	= 34.355 + 0.532SKFINISHINGHEIFERPRICE(-1)	31%

Appendix E: Observed against forecasted price and COP series

Table E.1 Observed against forecasted price series

	Observed	Forecast		
Price series	1971-2000 average	1971-2000 average	2041-2070 average	% change in 2041-2070 from 1971-2000 forecast value
Alberta				
Spring wheat ($/tonne)	135.00	132.11	137.26	3.90
Barley ($/tonne)	97.00	106.06	103.31	-2.59
Canola ($/tonne)	280.00	238.17	306.26	28.59
Maize ($/tonne)	114.00	125.91	164.21	30.42
Slaughter Heifer ($/cwt)	76.00	77.96	88.80	13.89
Slaughter steer ($/cwt)	76.00	74.60	87.40	17.16
Saskatchewan				
Spring wheat ($/tonne)	142.00	147.54	157.69	6.88
Barley ($/tonne)	102.00	105.48	140.28	32.98
Canola ($/tonne)	268.00	238.55	335.23	40.53
Maize ($/tonne)	90.00	129.42	156.68	21.06
Slaughter heifer ($/cwt)	70.14	69.52	71.60	2.99
Slaughter steer ($/cwt)	70.18	75.75	78.37	3.45

Table E.2 Observed against forecasted crop COP series

	Observed	Forecast		
COP series	1971-2000 average	1971-2000 average	2041-2070 average	% change in 2041-2070 from 1971-2000 forecast value
Alberta				
Spring wheat ($/acre)	63.00	71.66	225.77	215.05
Barley ($/acre)	62.00	71.33	222.84	212.39
Canola ($/acre)	71.00	81.09	256.12	215.83
Maize ($/acre)	110.00	125.42	395.32	215.19
Saskatchewan				
Spring wheat ($/acre)	68.07	70.94	225.93	218.49
Barley ($/acre)	38.13	43.72	137.46	214.42
Canola ($/acre)	72.00	79.60	255.31	220.75
Maize ($/acre)	110.77	128.54	393.48	206.12

Table E.3 Observed against forecasted beef cattle COP series

Cost Items	Observed	Forecast		
	1971-2000 average	1971-2000 average	2041-2070 average	% change in 2041-2070 from 1971-2000 forecast value
Hay ($/acre)	22.00	26.49	60.07	126.78
Silage ($/acre)	61.00	65.22	182.43	179.73
Pasture($/AUM)	0.82	0.89	2.91	228.01
Feeder Beef Cattle Yardage Cost ($/head/day)	0.17	0.19	0.28	46.33
Cow-calf Yardage Cost ($/head/year)	104.00	110.52	161.45	46.09
Service Bull ($/head/year)	166.00	176.74	258.49	46.26

Appendix F: Capital items of the study farms

Table F.1 Capital assets and their values included in building capital investment of the study farms

Machinery and equipment	Value	Buildings	Value
2294 Tractor	$40,000	Feeders	$17,500
886 Tractor	$15,000	Houses	$20,000
784 Tractor	$17,000	Shop	$10,000
660 Baler	$18,000	Quonset	$8,000
116 Hay Bin	$18,000	Livestock facilities	$20,000
Roller Mill	$6,000	Grain storage	$35,000
Cattle Trailer	$5,000	Dugouts/water	$5,000
Flatbed Trailer	$4,000	Fencing value	$10,000
Grain Augers	$1,700	Solar watering systems	$6,000
Cultivator	$3,000	**Total**	$131,500
Harrows	$2,000		
Hoe Drill	$9,000		
Swather	$1,500		
Sprayer	$6,000		
Bale Wagon	$2,000		
Manure Spreader	$1,500		
Disc	$1,200		
Hopper Wagon	$1,000		
Grain Truck	$15,000		
GMC 4X4	$3,500		
Total	$170,400		

Source: Larson (2014)

Table F.2 Result of PAC test of capital item series

Series	Number of Lag/s	Coefficient
Building and Structure (original series)	1	0.854
Building and Structure (first difference)	1, 11	0.286, 0.364
Machinery and Equipment (original series)	1	0.89
Machinery and Equipment (first difference)	1	0.633

Table F.3 Time series model of capital item series

Series	Selected Model	Adjusted R^2
Building and Structures (original series)	= 7479.202 + 0.925*BUILDING(-1)	91%
Building and Structures (first difference)	= -0.643*DBUILDING(-1) + 1.366*DBUILDING(-11)	53%
Machinery and Equipments (original series)	= 13998.457 + 1.159*MACH(-1) - 0.301*MACH(-3) + 897.990*@TREND	98%
Machinery and Equipments (first difference)	= 0.467*DMACHEQUIP(-1) + 87.158*@TREND	47%

Table F.4 Observed against forecasted value of capital items at the start of the simulation

Capital Items	Year 1971		Year 2041	
	Observed	Forecast	Forecast	Forecast
Value of used Building	57,973.3	61,498.1	104,642.2	104, 678.0
Value of used Machinery and Equipment	83,642.6	94,084.2	265,172	302,466.4
Total Value of Building and Machinery	141,615.9	155,582.4	369,814.2	302,466.4

Appendix G: Average provincial household expenditure estimates

Table G.1 Result of PAC test of average provincial household expenditure series

Series	Number of Lag/s	Coefficient
Saskatchewan Household expenditure (Level)	1	0.93
Saskatchewan Household expenditure (First Difference)	1	0.536
Alberta Household expenditure (Level)	1	0.936
Alberta Household expenditure (First Difference)	1, 2	0.485, -0.309

Table G.2 Time series model of average provincial household expenditure series

Series	Selected model	Adjusted R^2
Saskatchewan Household Expenditure (original series)	= 876.314 + 1.495*SKHHCONS(-1) - 0.560*SKHHCONS(-2) + 52.549*@TREND	98%
Saskatchewan Household Expenditure (first difference)	= 406.137 + 0.540*DSKHHCONS(-1)	29%
Alberta Household Expenditure (original series)	= 1599.188 + 1.412*ABHHCONS(-1) - 0.563*ABHHCONS(-2) + 167.435*@TREND	98%
Alberta Household Expenditure (first difference)	=770.215 + 0.623*DABHHCONS(-1) - 0.305*DABHHCONS(-2)	28%

Appendix H: An example MF-CCE worksheet summarizing activity gross margin and farm profit calculation for the period of 1971-2000 for the Pincher Creek site.

		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
BEEF CATTLE	Revenue from Beef Sold	56778.2	47409.2	65321.2	59014.8	66024.3	71976.6	73597.8	83036.1	81286.4	76620.8
	Beef yardage cost	7758.8	7874.8	8819.9	10841.7	10186.0	12479.8	12995.2	14607.4	15046.1	16233.6
	On farm feed production	4845.4	7616.7	6086.8	8571.8	7254.1	15192.0	11032.8	11214.1	12732.5	10595.2
	Feed Purchase *(grain and hay in deficit year)*	3028.7	97.0	11521.6	7869.4	2892.2	3419.6	236.0	0.0	3735.3	0.0
	Beef Variable cost of production	*15632.9*	*15588.5*	*26428.3*	*27282.9*	*20332.3*	*31091.3*	*24264.0*	*25821.5*	*31513.9*	*26828.8*
	Operating interest	*781.6*	*779.4*	*1321.4*	*1364.1*	*1016.6*	*1554.6*	*1213.2*	*1291.1*	*1575.7*	*1341.4*
	Death loss	2082.2	2091.6	2308.7	3559.8	4453.1	3284.8	3475.5	4736.4	5196.3	4238.3
	Beef Gross Margin	*38281.5*	*28949.7*	*35262.9*	*26807.9*	*40222.3*	*36045.9*	*44645.1*	*51187.1*	*43000.5*	*44212.3*
	Beef GM *(including hay and pasture sold)*	***38382.1***	***29432.5***	***49723.6***	***37821.6***	***54130.1***	***38155.5***	***53577.3***	***63104.7***	***44075.2***	***62293.2***
CROPS	Revenue from Crop sold	35204.4	35697.0	65161.6	12205.7	36645.2	0.0	37071.6	38703.5	35392.2	85524.1
	Inventory grain sold	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1451.0	0.0	1848.8
	Crop variable cost of production *(including inventory grain)*	5358.7	7024.4	4148.4	1567.7	4679.8	1054.2	7538.9	7655.1	17943.2	13755.7
	Crop Operating interest	*267.9*	*351.2*	*207.4*	*78.4*	*234.0*	*52.7*	*376.9*	*382.8*	*897.2*	*687.8*
	Crop Gross Margin	***29577.7***	***28321.3***	***60805.8***	***10559.6***	***31731.4***	***-1106.9***	***29155.8***	***32116.6***	***16551.8***	***72929.3***
WHOLE FARM	Mach. Repairs and maintenance	**0.0**	**1881.7**	**1881.7**	**1881.7**	**1881.7**	**1881.7**	**1881.7**	**1881.7**	**1881.7**	**1881.7**
	Building repairs	**0.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**
	Capital interest	**0.0**	**6643.2**	**6643.2**	**6643.2**	**6643.2**	**6643.2**	**6643.2**	**6643.2**	**6643.2**	**6643.2**
	Total Farm GM	**67938.8**	**54621.2**	**107396.8**	**45248.5**	**82728.8**	**33915.9**	**79600.4**	**92088.7**	**57494.4**	**132089.9**
CAPITAL PURCHASE	Machines and Equipment Purchase	**94084.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	Building and Structures	**61498.0**									
	Herd purchase	*110145.6*									
DEPRECIATION	*Building depreciation*		*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*
	Machinery and equip depreciation	*0.0*	*6272.3*	*6272.3*	*6272.3*	*6272.3*	*6272.3*	*6272.3*	*6272.3*	*6272.3*	*6272.3*
	Herd depreciation	*0.0*	*7343.0*	*7343.0*	*7343.0*	*7343.0*	*7343.0*	*7343.0*	*7343.0*	*7343.0*	*7343.0*
	Total Capital cost	**0.0**	**15665.2**	**15665.2**	**15665.2**	**15665.2**	**15665.2**	**15665.2**	**15665.2**	**15665.2**	**15665.2**
WHOLE NET Farm Income-Measure	***Net farm income***	**67938.8**	**38956.0**	**91731.6**	**29583.3**	**67063.6**	**18250.7**	**63935.2**	**76423.5**	**41829.2**	**116424.6**

		Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
BEEF CATTLE	Revenue from Beef Sold	78302.7	86494.0	87178.4	91917.8	88286.6	91353.7	90087.3	101308.6	91155.4	91957.5
	Beef yardage cost	16927.7	17145.1	16478.3	17385.8	18901.6	19209.1	18817.5	19549.2	20230.4	20339.1
	On farm feed production	11579.6	18113.6	22276.0	25657.1	20363.4	16535.7	23305.1	17621.8	16017.4	14718.2
	Feed Purchase *(grain and hay in deficit year)*	0.0	3185.5	238.0	1251.6	2370.5	1816.3	1830.5	4822.0	420.0	0.0
	Beef Variable cost of production	*28507.3*	*38444.2*	*38992.3*	*44294.5*	*41635.5*	*37561.1*	*43953.1*	*41993.1*	*36667.8*	*35057.3*
	Operating interest	*1425.4*	*1922.2*	*1949.6*	*2214.7*	*2081.8*	*1878.1*	*2197.7*	*2099.7*	*1833.4*	*1752.9*
	Death loss	4168.3	4412.6	5949.8	4739.5	4972.6	4055.8	4851.5	5346.0	5320.5	5031.3
	Beef Gross Margin	*44201.7*	*41715.1*	*40286.7*	*40669.1*	*39596.7*	*47858.7*	*39085.0*	*51869.9*	*47333.7*	*50116.1*
	Beef GM *(including hay and pasture sold)*	***55557.3***	***48494.8***	***49779.2***	***52364.2***	***43315.0***	***64664.8***	***41606.2***	***63826.4***	***61476.9***	***58787.1***
CROPS	Revenue from Crop sold	111776.3	0.0	0.0	1617.2	0.0	55114.8	0.0	66906.7	124627.9	97982.4
	Inventory grain sold	1014.4	222.8	1729.7	0.0	1906.2	0.0	1978.9	0.0	0.0	1480.2
	Crop variable cost of production *(including inventory grain)*	16234.2	1189.6	1394.4	1988.9	7589.4	20236.0	1992.1	18002.7	40306.9	22986.3
	Crop Operating interest	*811.7*	*59.5*	*69.7*	*99.4*	*379.5*	*1011.8*	*99.6*	*900.1*	*2015.3*	*1149.3*
	Crop Gross Margin	***95744.7***	***-1026.3***	***265.6***	***-471.2***	***-6062.7***	***33867.1***	***-112.8***	***48003.9***	***82305.6***	***75326.9***
WHOLE FARM	Mach. Repairs and maintenance	**1881.7**	**1881.7**	**1881.7**	**1881.7**	**1881.7**	**1862.2**	**1862.2**	**1862.2**	**1862.2**	**1862.2**
	Building repairs	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**
	Capital interest	**6643.2**	**6643.2**	**6643.2**	**6643.2**	**6643.2**	**3889.6**	**3889.6**	**3889.6**	**3889.6**	**3889.6**
	Total Farm GM	**67938.8**	**54621.2**	**107396.8**	**45248.5**	**82728.8**	**33915.9**	**79600.4**	**92088.7**	**57494.4**	**132089.9**
CAPITAL PURCHASE	Machines and Equipment Purchase	**0.0**	**0.0**	**0.0**	**0.0**	**93108.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	Building and Structures										
	Herd purchase										
DEPRECIATION	*Building depreciation*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*
	Machinery and equip depreciation	*6272.3*	*6272.3*	*6272.3*	*6272.3*	*6272.3*	*6207.2*	*6207.2*	*6207.2*	*6207.2*	*6207.2*
	Herd depreciation	*7343.0*	*7343.0*	*7343.0*	*7343.0*	*7343.0*					
	Total Capital cost	**15665.2**	**15665.2**	**15665.2**	**15665.2**	**15665.2**	**8257.1**	**8257.1**	**8257.1**	**8257.1**	**8257.1**
WHOLE NET Farm Income-Measure	***Net farm income***	**132504.2**	**28670.7**	**31247.0**	**33095.2**	**18454.4**	**87161.7**	**30123.2**	**100460.0**	**132412.3**	**122743.7**

		Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30
BEEF CATTLE	Revenue from Beef Sold	94654.9	99714.8	99527.9	93585.0	95229.9	96061.5	98473.4	100841.0	165240.0	113855.8
	Beef yardage cost	20219.8	20614.9	20505.6	19992.1	22148.9	22728.0	20951.0	21329.5	21222.1	2779.7
	On farm feed production	18295.2	17626.5	19955.6	19334.0	29740.7	20900.9	19885.4	38968.6	23093.5	20089.9
	Feed Purchase *(grain and hay in deficit year)*	3398.1	0.0	1005.1	474.4	5585.7	2532.6	0.0	6130.8	0.0	0.0
	Beef Variable cost of production	*41913.1*	*38241.4*	*41466.3*	*39800.5*	*57475.3*	*46161.4*	*40836.3*	*66428.9*	*44315.6*	*22869.7*
	Operating interest	*2095.7*	*1912.1*	*2073.3*	*1990.0*	*2873.8*	*2308.1*	*2041.8*	*3321.4*	*2215.8*	*1143.5*
	Death loss	5284.9	4738.5	5894.9	5964.1	5684.8	5274.9	5324.4	4677.9	5958.7	5808.3
	Beef Gross Margin	*45361.2*	*54822.9*	*50093.4*	*45830.3*	*29196.1*	*42317.1*	*50270.9*	*26412.8*	*112749.9*	*84034.3*
	Beef GM *(including hay and pasture sold)*	***45361.2***	***68187.6***	***65175.0***	***60354.4***	***32947.2***	***48734.9***	***55326.5***	***32949.4***	***128649.4***	***84034.3***
CROPS	Revenue from Crop sold	72272.2	96107.0	34771.6	89788.7	0.0	66297.8	54252.6	0.0	62483.7	67863.5
	Inventory grain sold	756.6	1989.4	0.0	0.0	0.0	0.0	2051.1	1740.7	1255.8	915.3
	Crop variable cost of production *(including inventory grain)*	40589.7	28619.4	13834.1	21481.3	2903.4	29218.0	31283.8	7085.8	27848.5	37061.4
	Crop Operating interest	*2029.5*	*1431.0*	*691.7*	*1074.1*	*145.2*	*1460.9*	*1564.2*	*354.3*	*1392.4*	*1853.1*
	Crop Gross Margin	***30409.6***	***68046.0***	***20245.7***	***67233.4***	***-3048.6***	***35618.9***	***23455.7***	***-5699.5***	***34498.5***	***29864.4***
FARM	Mach. Repairs and maintenance	**1862.2**	**1862.2**	**1862.2**	**1862.2**	**1862.2**	**1862.2**	**1862.2**	**1862.2**	**1862.2**	**1862.2**
	Building repairs	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**	**1230.0**
	Capital interest	**3889.6**	**3889.6**	**3889.6**	**3889.6**	**3889.6**	**3889.6**	**3889.6**	**3889.6**	**3889.6**	**3889.6**
WHOLE	**Total Farm GM**	**72657.7**	**133120.5**	**82307.7**	**124474.6**	**26785.5**	**81240.7**	**75669.1**	**24136.8**	**160034.7**	**110785.7**
CAPITAL PURCHASE	Machines and Equipment Purchase	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	Building and Structures										
	Herd purchase										
DEPRECIATION	*Building depreciation*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*	*2049.9*
	Machinery and equip depreciation	*6207.2*	*6207.2*	*6207.2*	*6207.2*	*6207.2*	*6207.2*	*6207.2*	*6207.2*	*6207.2*	*6207.2*
	Herd depreciation										
	Total Capital cost	**8257.1**	**8257.1**	**8257.1**	**8257.1**	**8257.1**	**8257.1**	**8257.1**	**8257.1**	**8257.1**	**8257.1**
WHOLE NET Farm Income-Measure	***Net farm income***	**64400.6**	**124863.3**	**74050.5**	**116217.5**	**18528.3**	**72983.6**	**67412.0**	**15879.7**	**151777.6**	**102528.5**

Appendix I: Climate change projection for the Canadian Prairies for the 2050s relative to 1971-2000 baseline period under the RCM3_CGCM3_A2 scenario

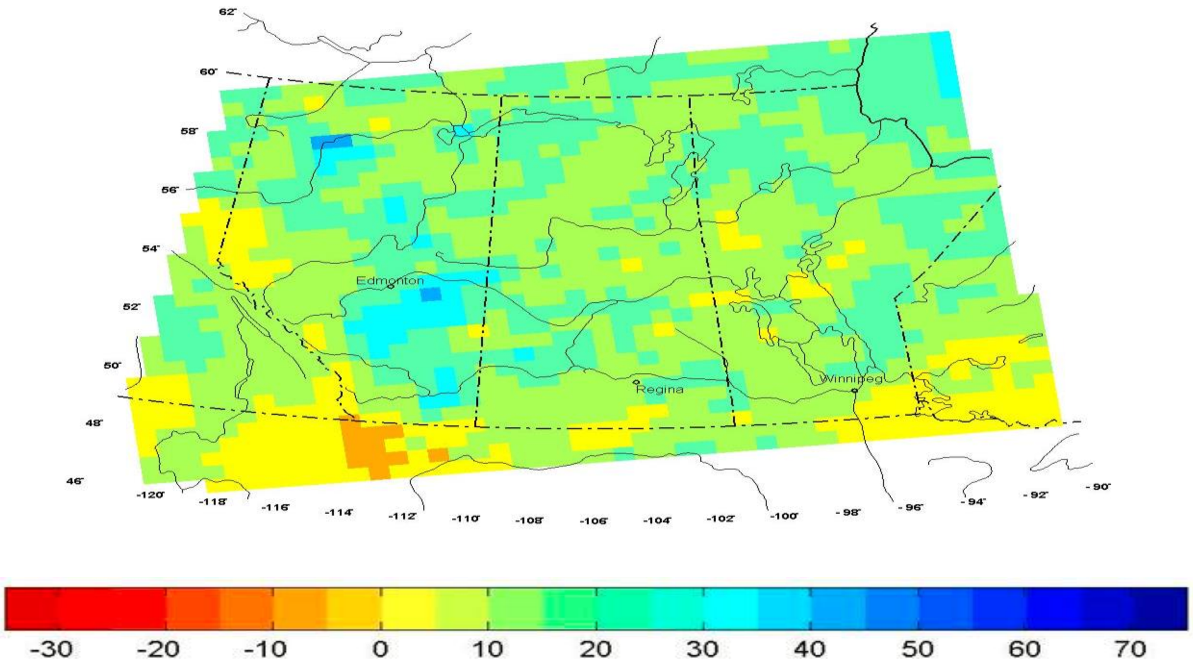


Figure I.1 Annual total precipitation change (%) for the 2050s relative to the baseline scenario of 1971-2000 under RCM3_CGCM3_A2 climate scenario (Source: Barrow, 2012)

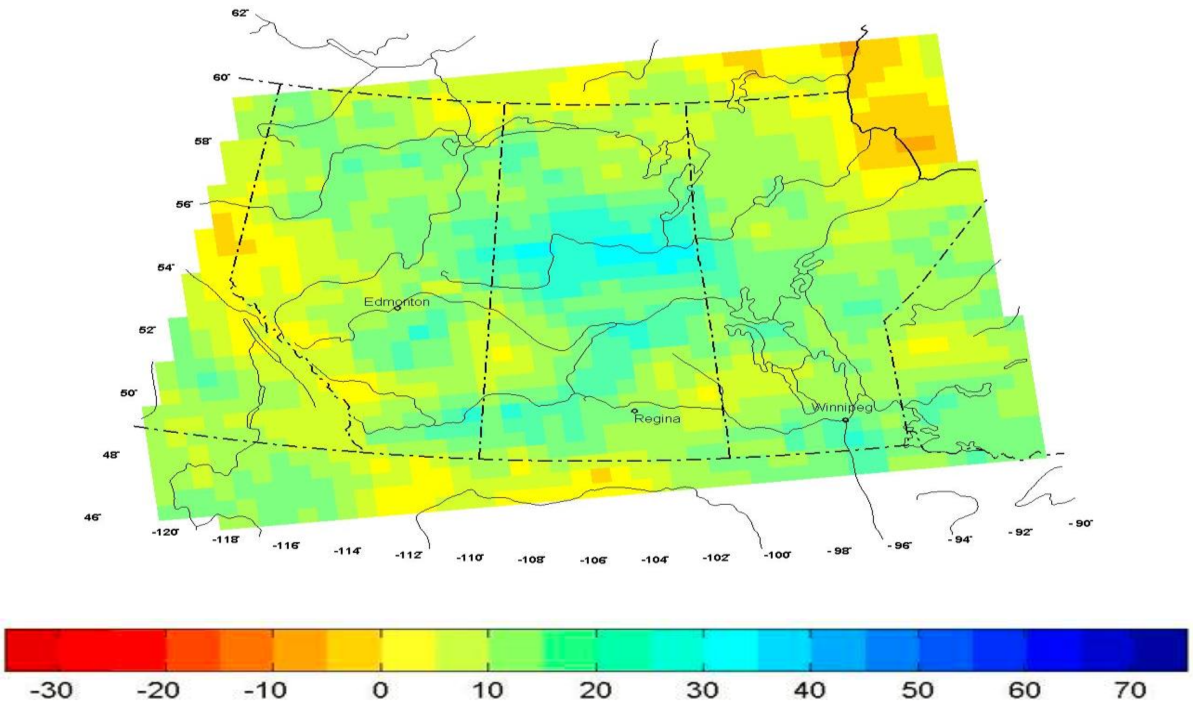


Figure I.2 Spring mean precipitation change (%) for the 2050s relative to the baseline scenario of 1971-2000 under RCM3_CGCM3_A2 climate scenario (Source: Barrow, 2012)

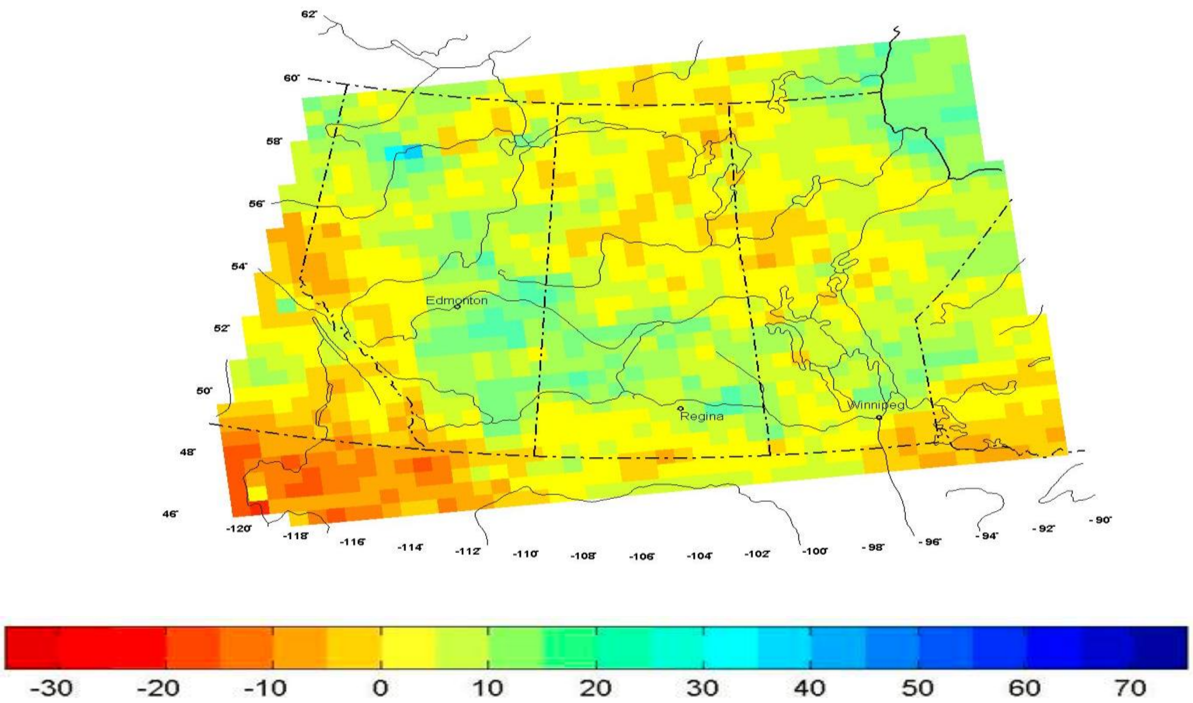


Figure I.3 Summer mean precipitation change (%) for the 2050s relative to the baseline scenario of 1971-2000 under RCM3_CGCM3_A2 climate scenario (Source: Barrow, 2012)

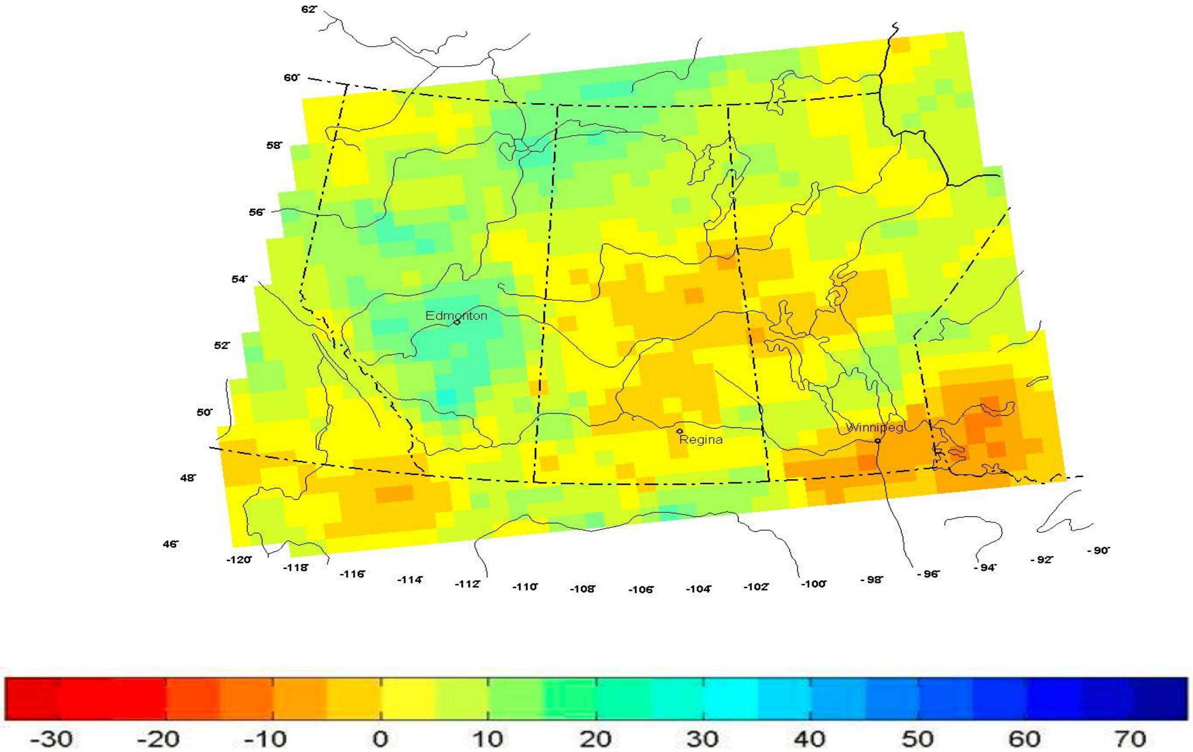


Figure I.4 Fall mean precipitation change (%) for the 2050s relative to the baseline scenario of 1971-2000 under RCM3_CGCM3_A2 climate scenario (Source: Barrow, 2012)

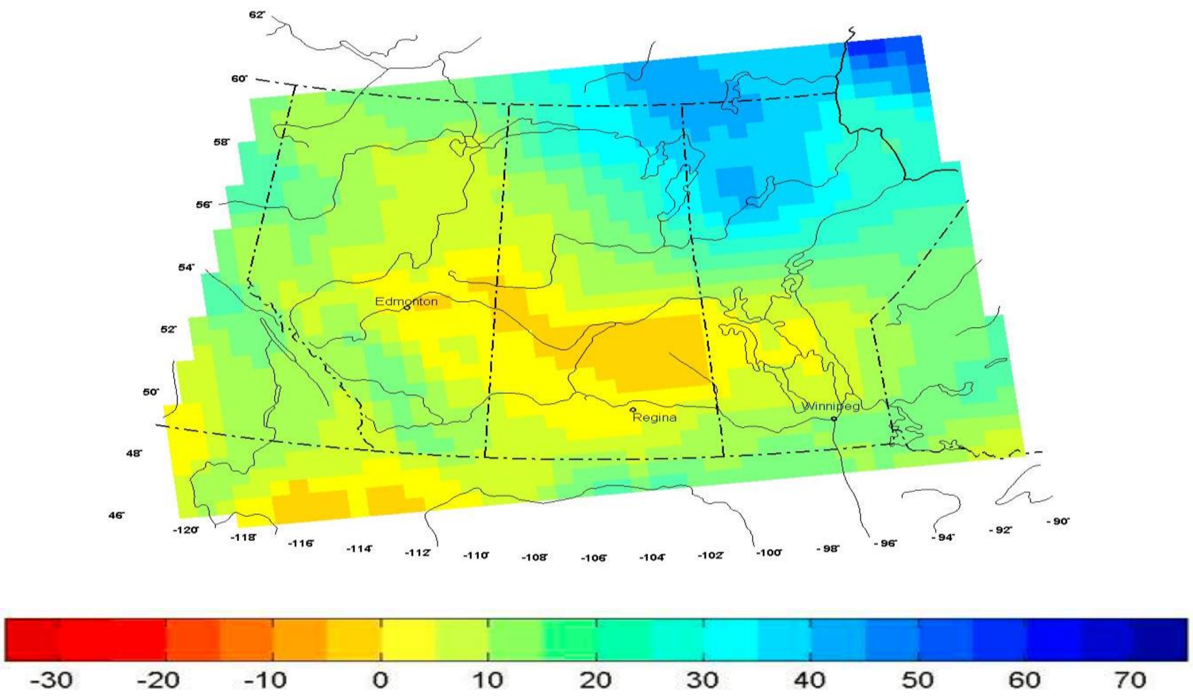


Figure I.5 Winter mean precipitation change (%) for the 2050s relative to the baseline scenario of 1971-2000 under RCM3_CGCM3_A2 climate scenario (Source: Barrow, 2012)

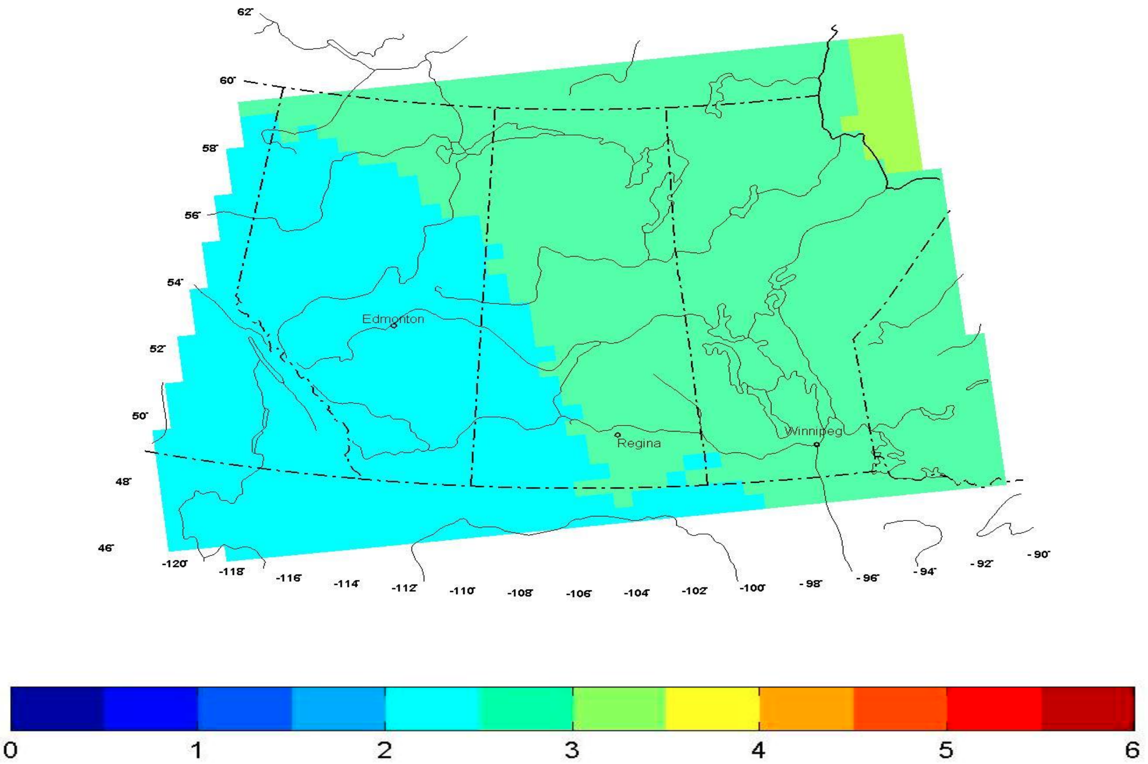


Figure I.6 Annual mean temperature (^{0}C) change for the 2050s relative to the baseline scenario of 1971-2000 under RCM3_CGCM3_A2 climate scenario (Source: Barrow, 2012).

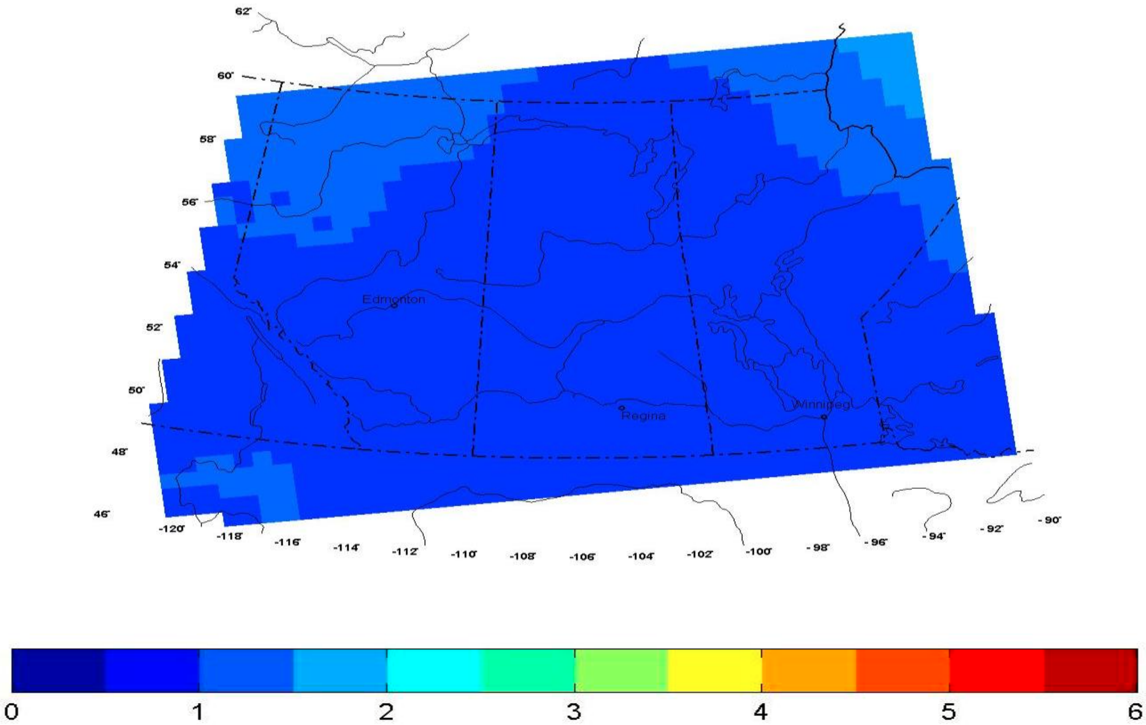


Figure I.7 Spring mean temperature (^{0}C) change for the 2050s relative to the baseline scenario of 1971-2000 under RCM3_CGCM3_A2 climate scenario (Source: Barrow, 2012).

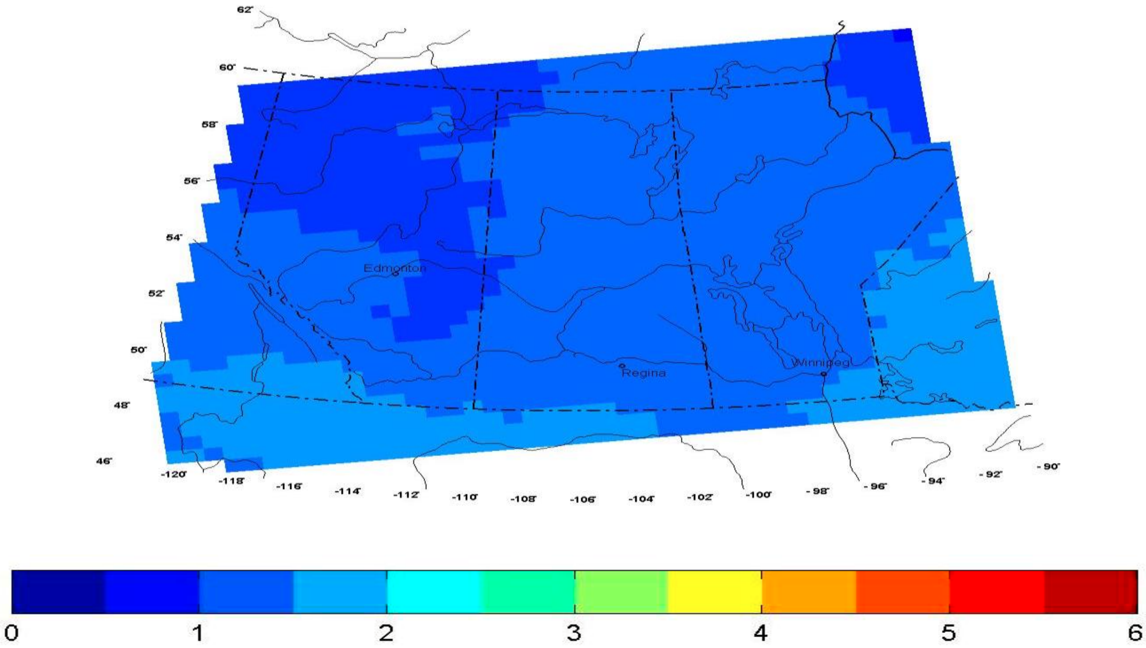


Figure I.8 Summer mean temperature (^{0}C) change for the 2050s relative to the baseline scenario of 1971-2000 under RCM3_CGCM3_A2 climate scenario (Source: Barrow, 2012).

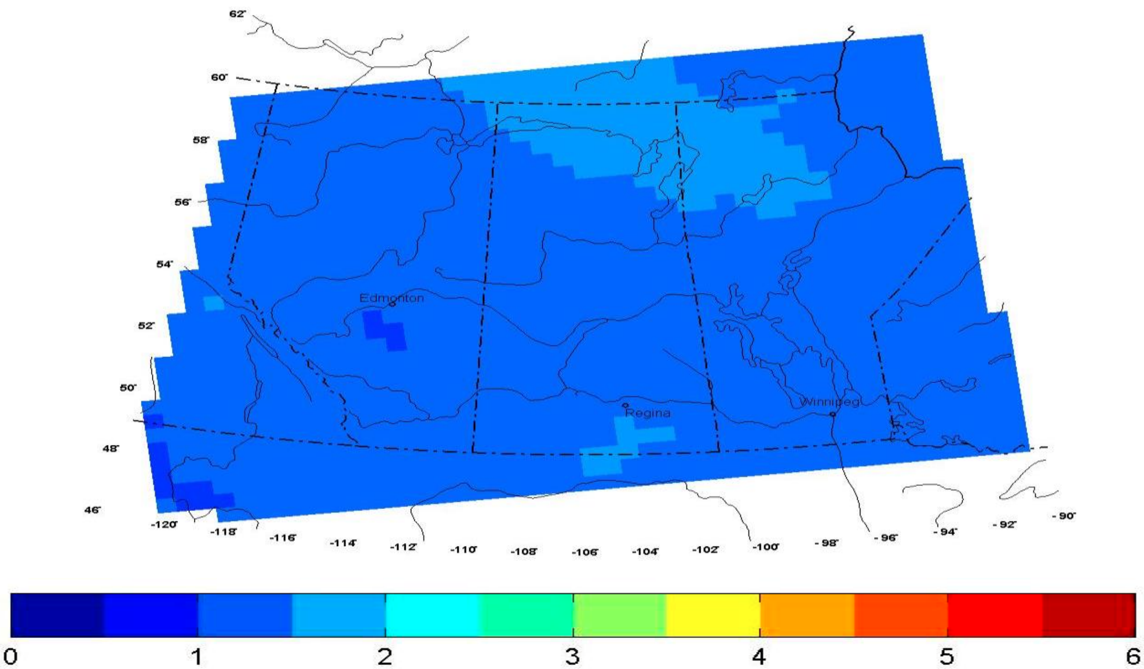


Figure I.9 Fall mean temperature (^{0}C) change for the 2050s relative to the baseline scenario of 1971-2000 under RCM3_CGCM3_A2 climate scenario (Source: Barrow, 2012).

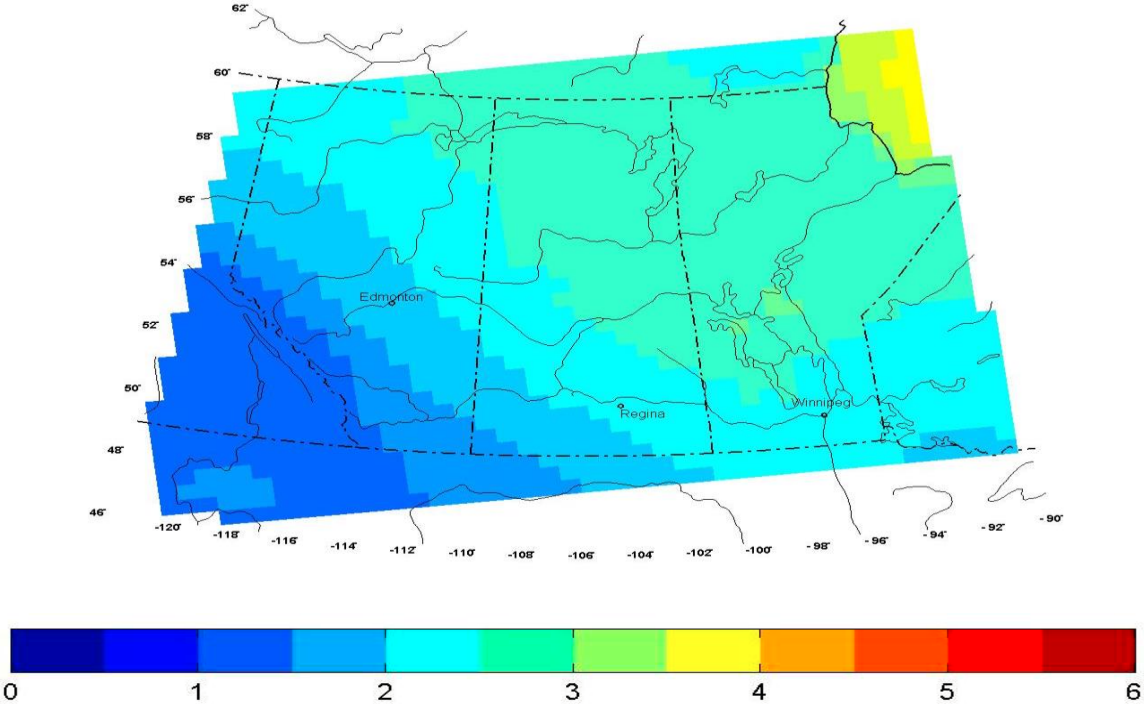


Figure I.10 Winter mean temperature (^{0}C) change for the 2050s relative to the baseline scenario of 1971-2000 under RCM3_CGCM3_A2 climate scenario (Source: Barrow, 2012).

Appendix J: Major variables of AquaCrop model

Table J.1 Input and output variables used by AquaCrop model in simulating crop yield

Input***** Variables	Unit	Descriptions
Rain	mm	Growing season rainfall
ETo	mm	Reference Evapotranspiration
GDD	°C	Growing degree-days
CO_2	ppm	Atmospheric CO2 Concentration
Irri	mm	Water applied by irrigation
Infilt	mm	Infiltrated water in soil profile
Runoff	mm	Water lost by surface runoff
Drain	mm	Water drained out of the soil profile
E	mm	Soil evaporation
E/Ex	%	Relative soil evaporation (100 E/Ex)
Tr	mm	Crop transpiration
Tr/Trx	%	Relative crop transpiration (100 Tr/Trx)
Cycle	days	Length of crop cycle from germination to maturity
TempStr	%	Average temperature stress affecting biomass
ExpStr	%	Average leaf expansion stress
StoStr	%	Average stomatal stress
Output Variables	Unit	Description
Biomass	ton/ha	Cumulative biomass produced
Brelative	%	Relative biomass (reference no water, no soil fertility, no salinity stress)
HI	%	Harvest index adjusted for failure of pollination inadequate photosynthesis and water stress
Yield	ton/ha	Yield

* AquaCrop model can simulate the effect of many other inputs like effect of irrigation, salinity of soil, fertilizer stress and so on. The table here provides the list of only those variables that were used for this study.

Appendix K: Atmospheric CO_2 used in crop yield estimation

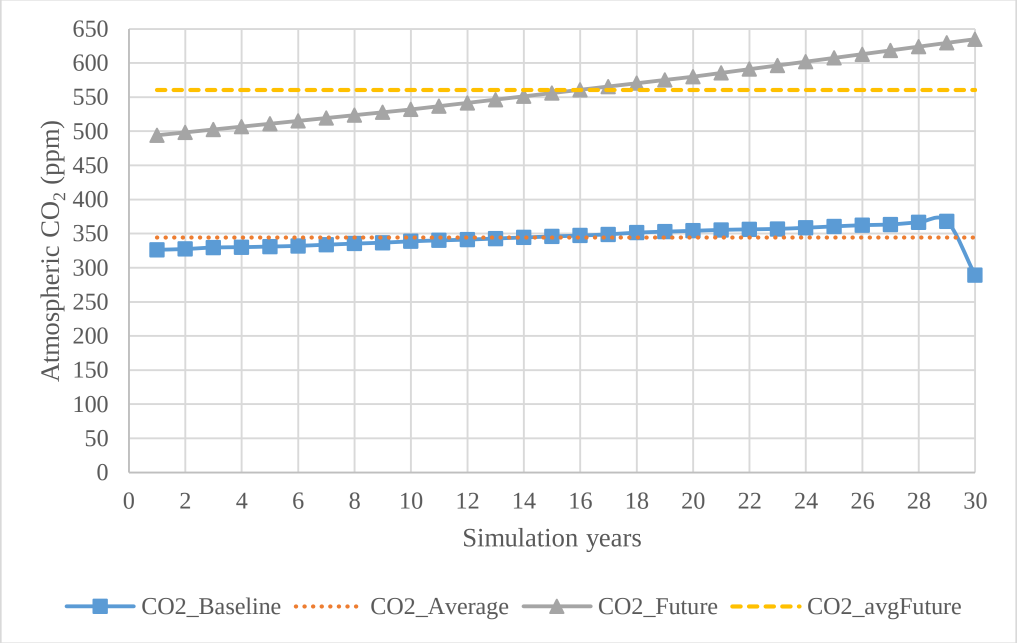


Figure K.1 Atmospheric CO_2 under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

Appendix L: Crop transpirations estimates used in crop yield estimation

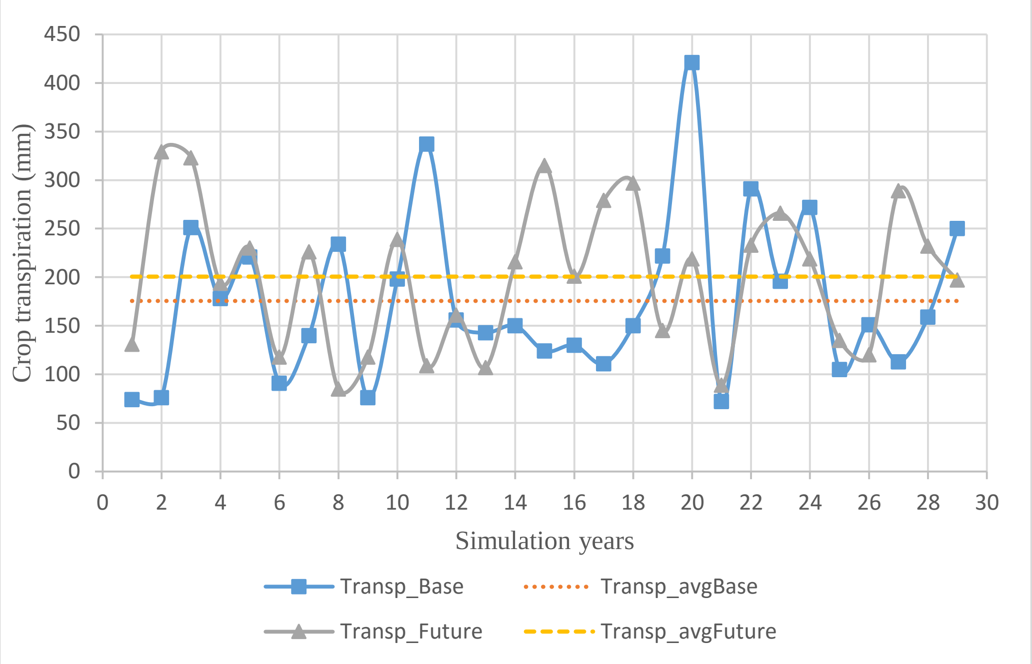


Figure L.1 Pincher Creek spring wheat crop transpiration (mm) under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

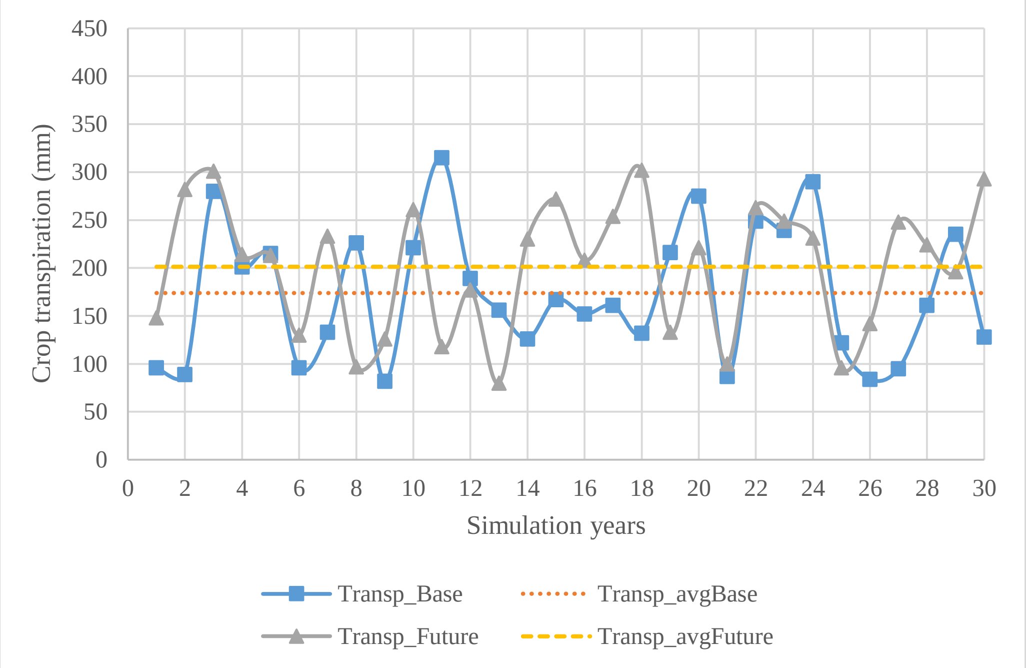


Figure L.2 Pincher Creek barley crop transpiration (mm) under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

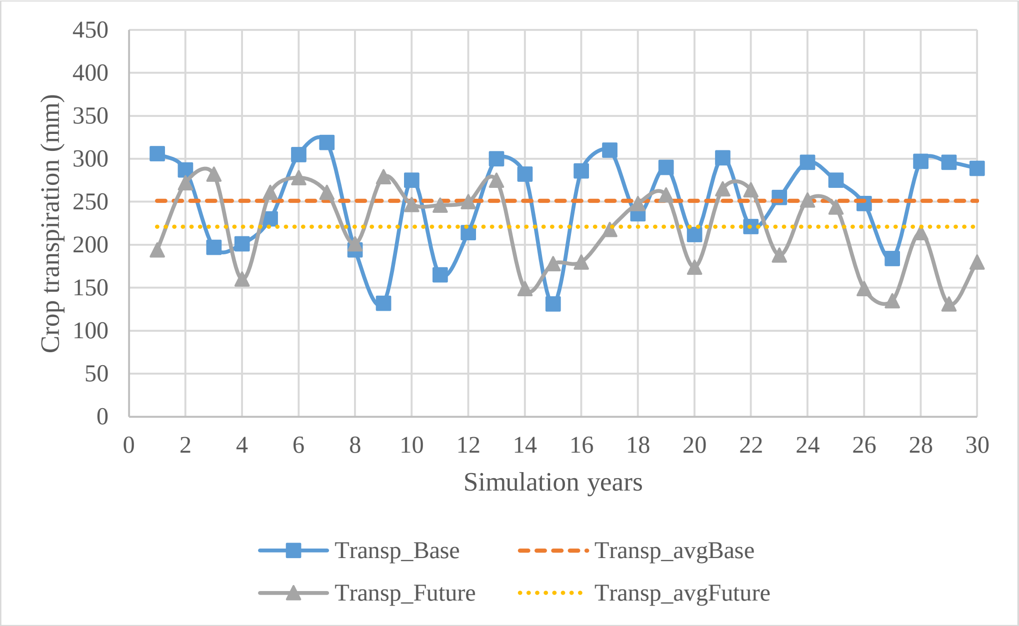


Figure L.3 Pincher Creek canola crop transpiration (mm) under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

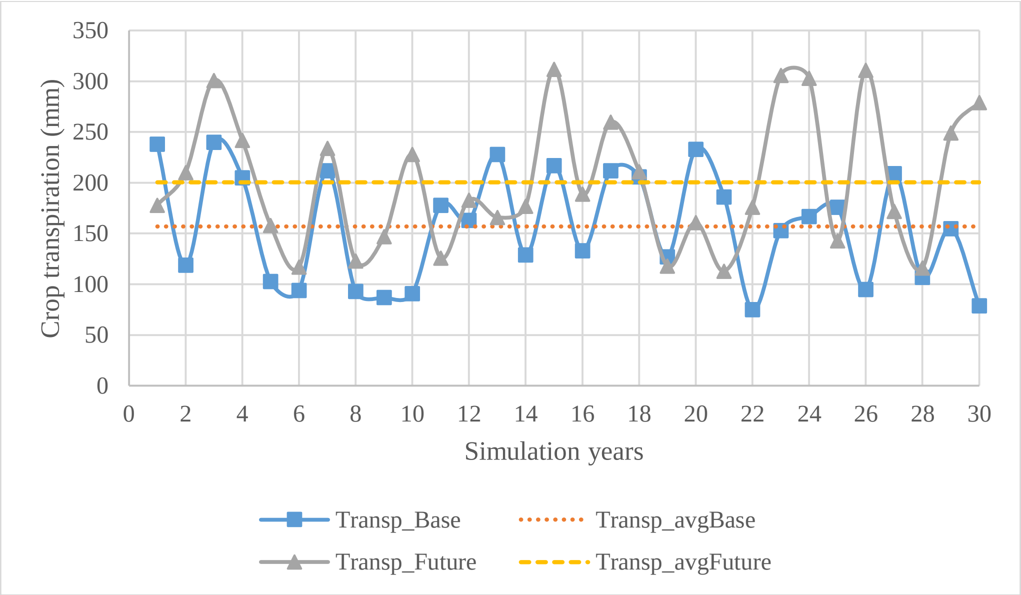


Figure L.4 Pincher Creek corn crop transpiration (mm) under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

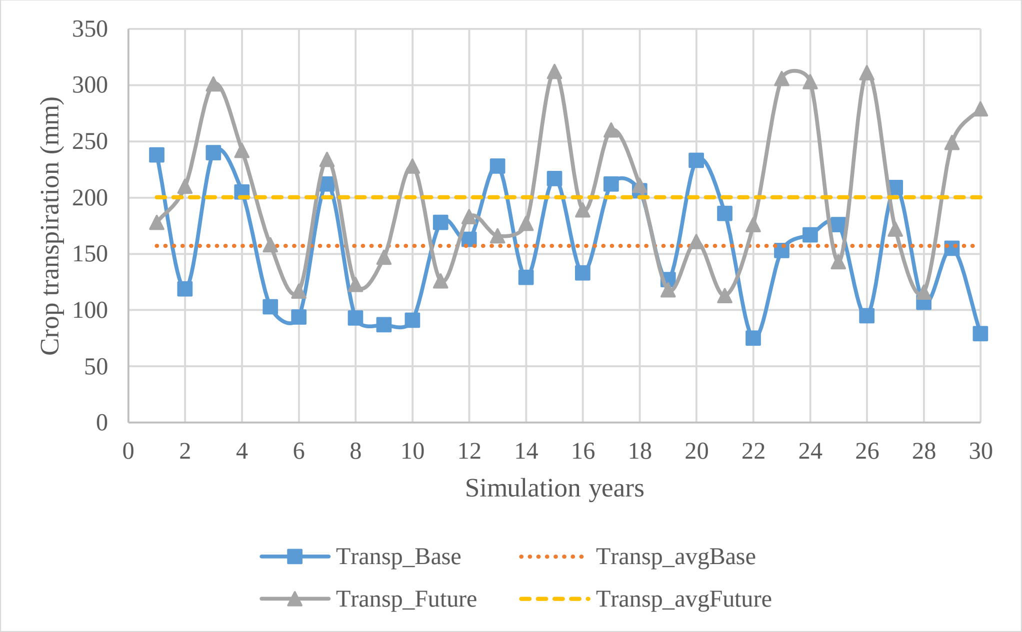


Figure L.5 Pincher Creek alfalfa crop transpiration (mm) under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

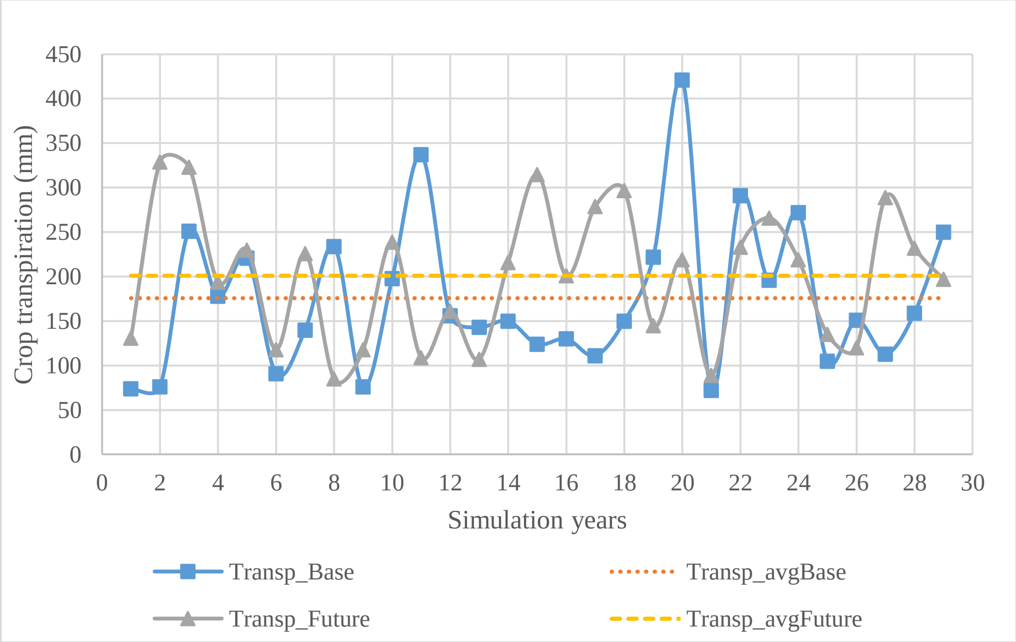


Figure L.6 Swift Current spring wheat crop transpiration (mm) under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

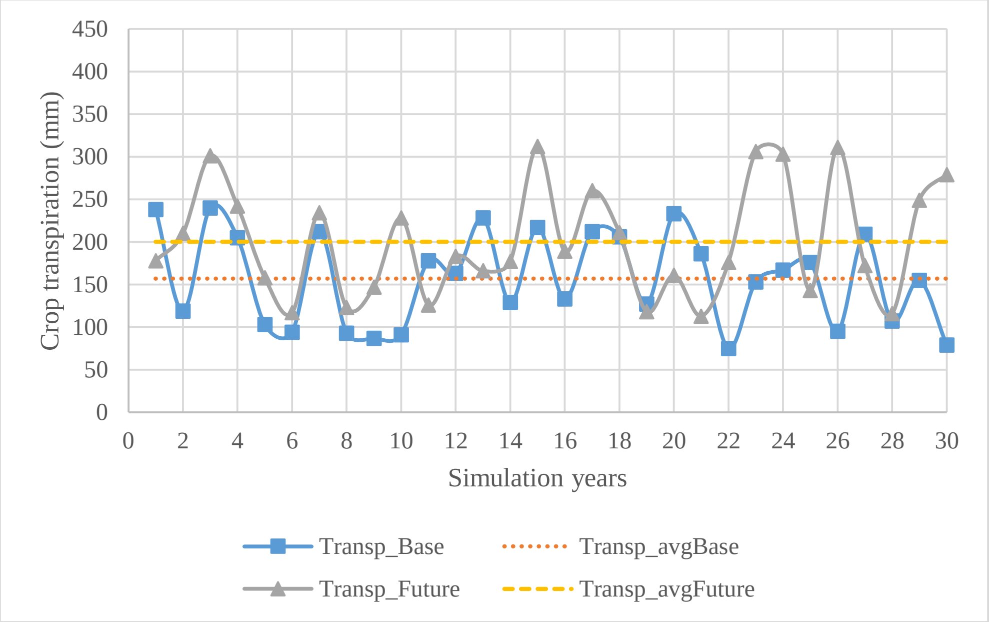


Figure L.7 Swift Current barley crop transpiration (mm) under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

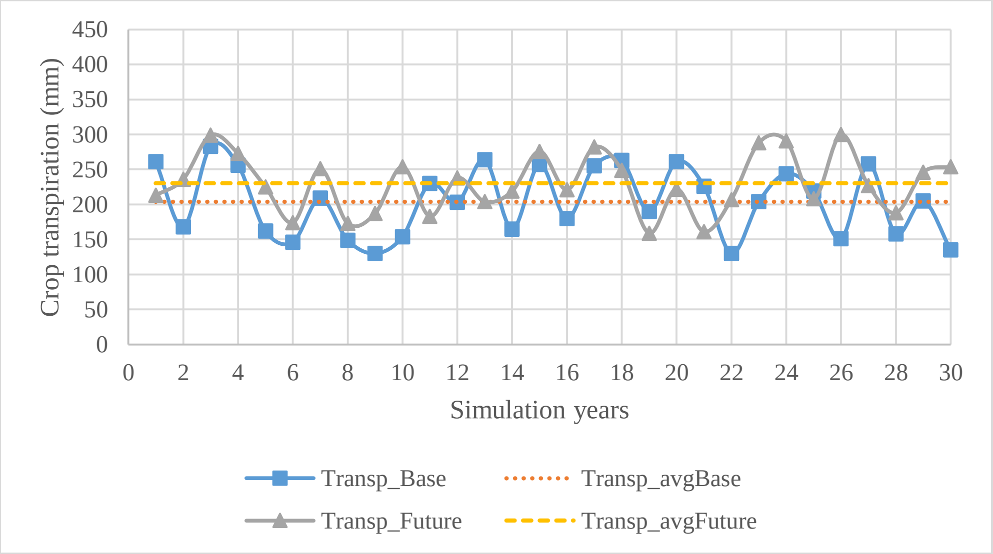


Figure L.8 Swift Current canola crop transpiration (mm) under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

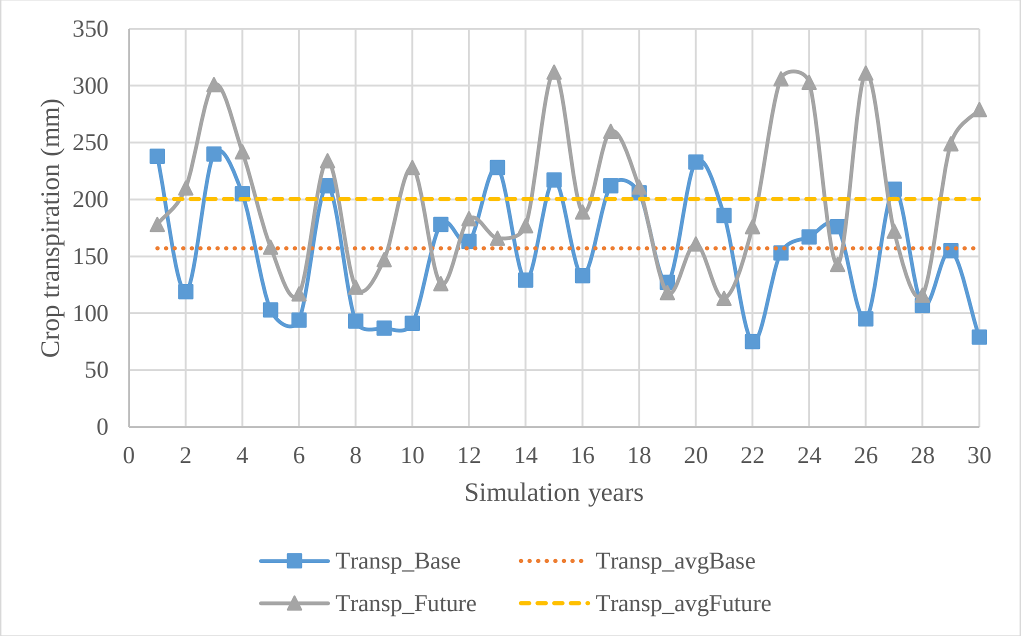


Figure L.9 Swift Current corn crop transpiration (mm) under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

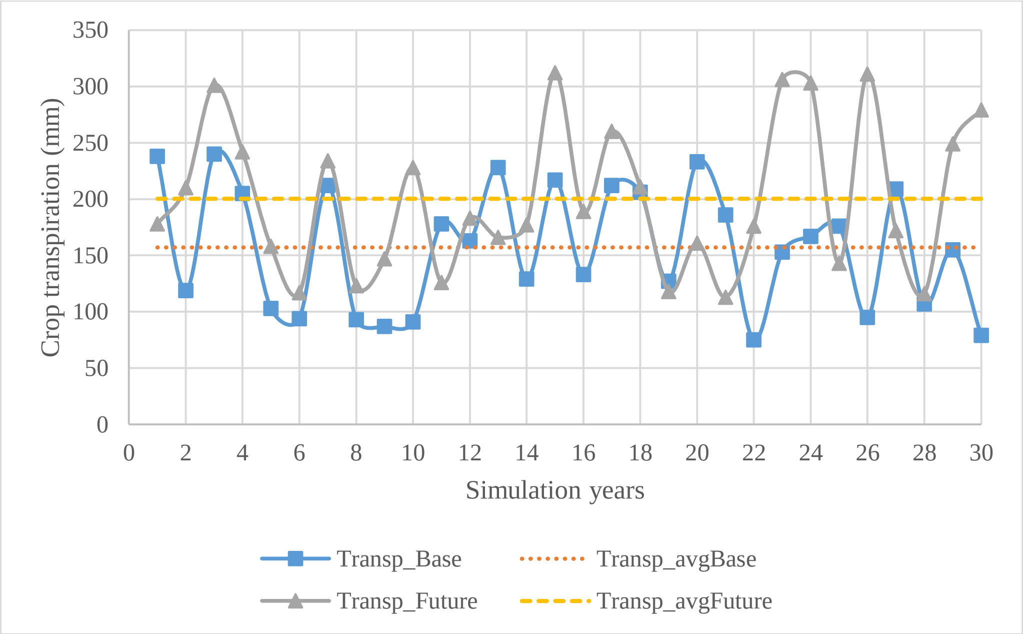


Figure L.10 Swift Current alfalfa crop transpiration (mm) under the baseline scenario, 1971-2000 and future scenario, 2041-2070 (Source: Data obtained from Kienzle, 2013)

Appendix M: Crop and hay yield estimates for the Pincher Creek study site

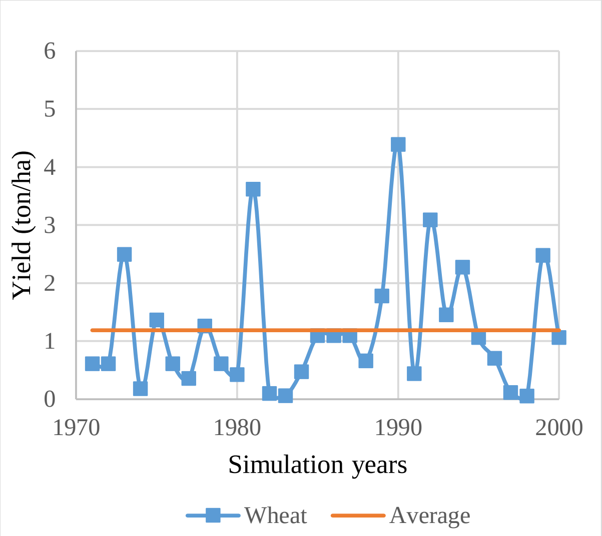


Figure M.1 Spring wheat yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

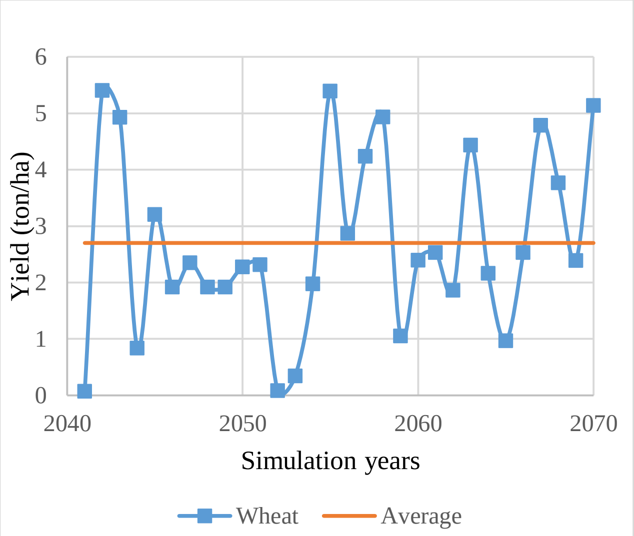


Figure M.2 Spring wheat yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

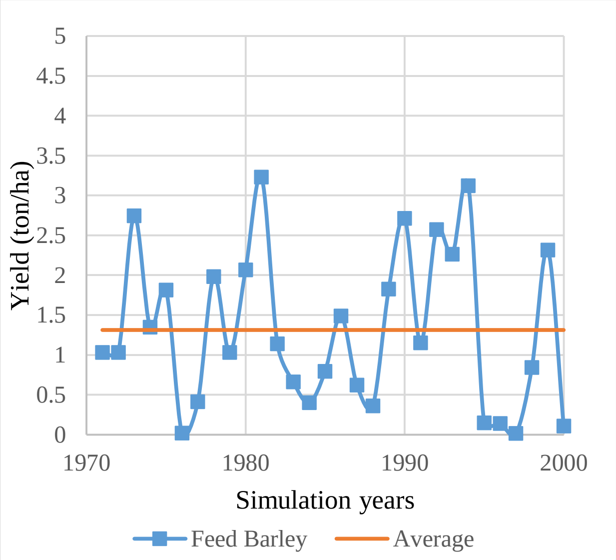


Figure M.3 Barley yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

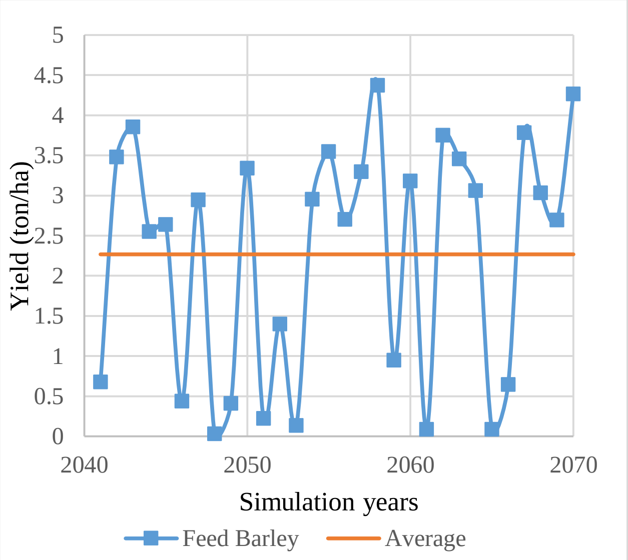


Figure M.4 Barley yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

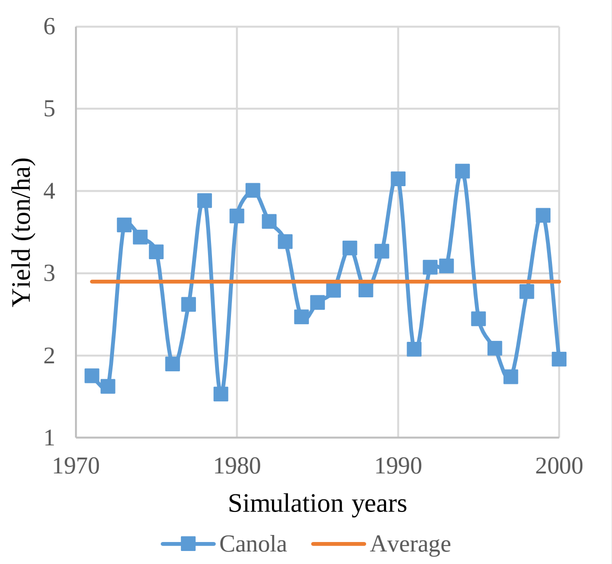


Figure M.5 Canola yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

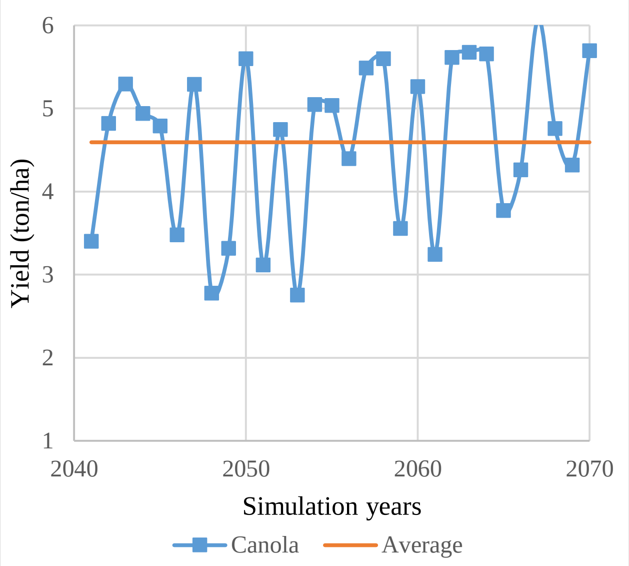


Figure M.6 Canola yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

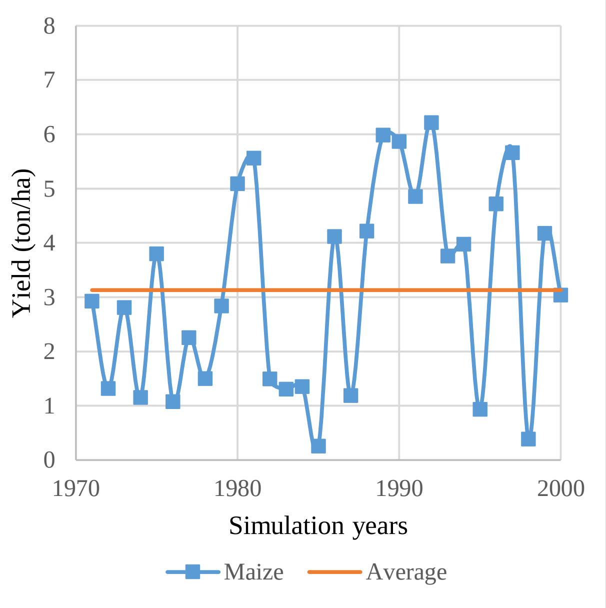


Figure M.7 Maize yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

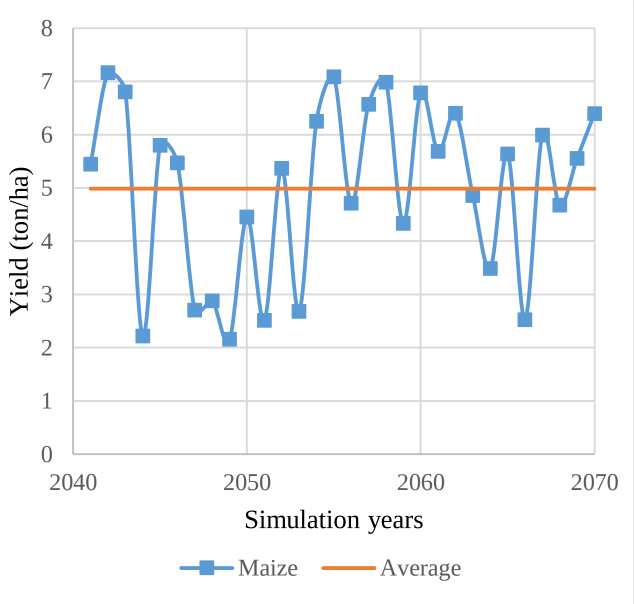
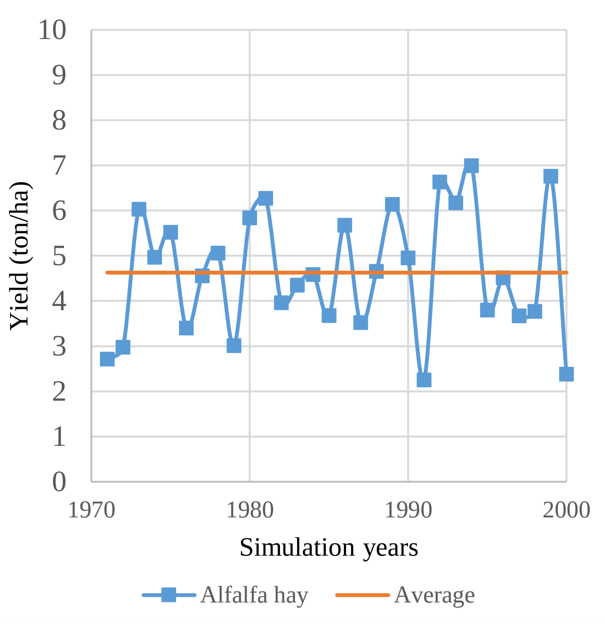


Figure M.8 Maize yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Pincher Creek



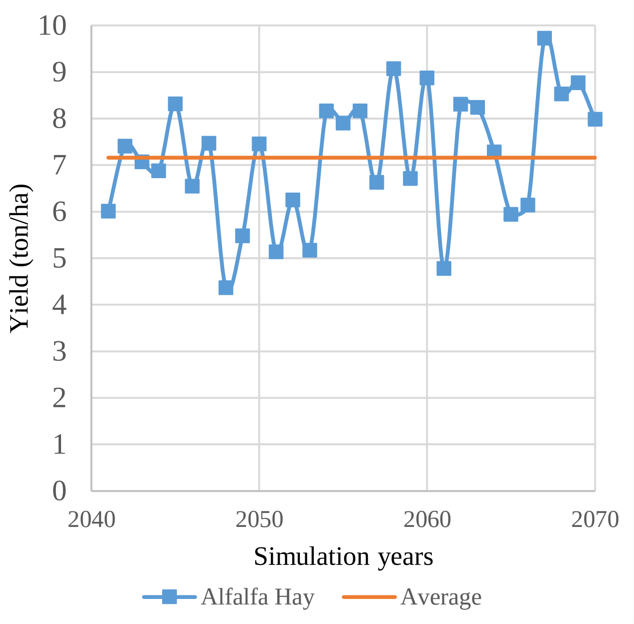


Figure M.9 Alfalfa hay yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

Figure M.10 Alfalfa hay yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Pincher Creek

Appendix N: Crop and hay yield estimates for the Swift Current study site

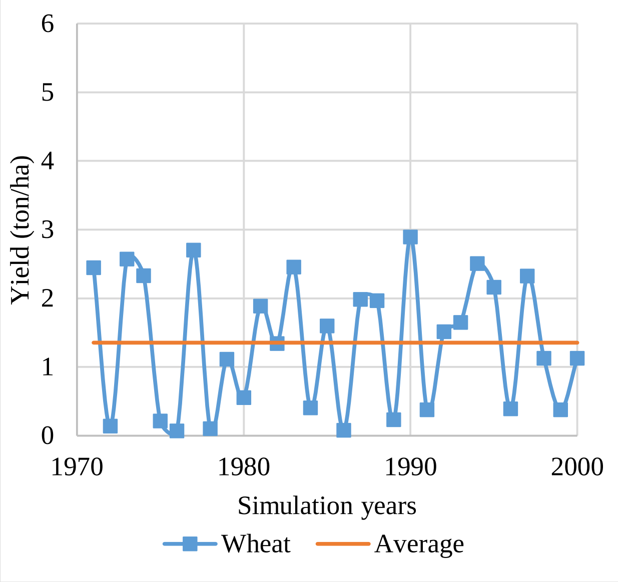


Figure N.1 Spring wheat yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Swift Current

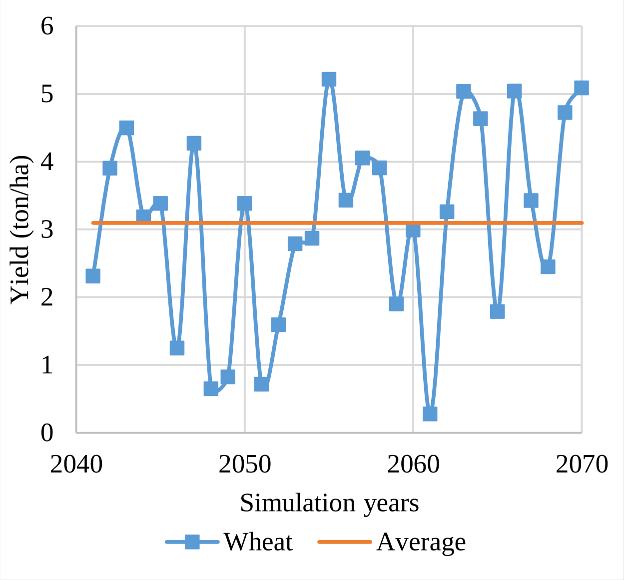


Figure N.2 Spring wheat yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Swift Current

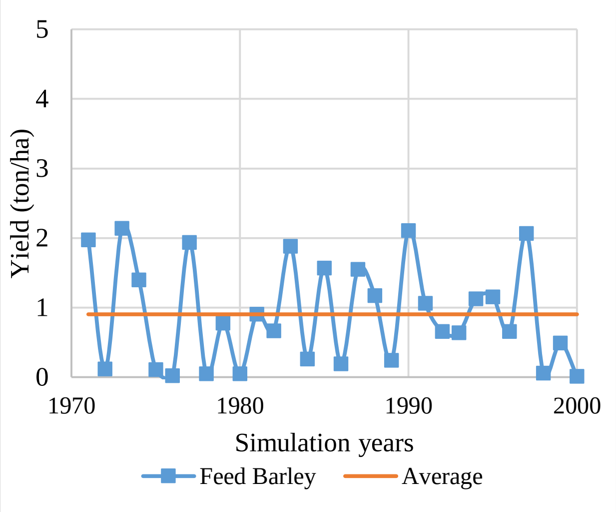


Figure N.3 Barley yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Swift Current

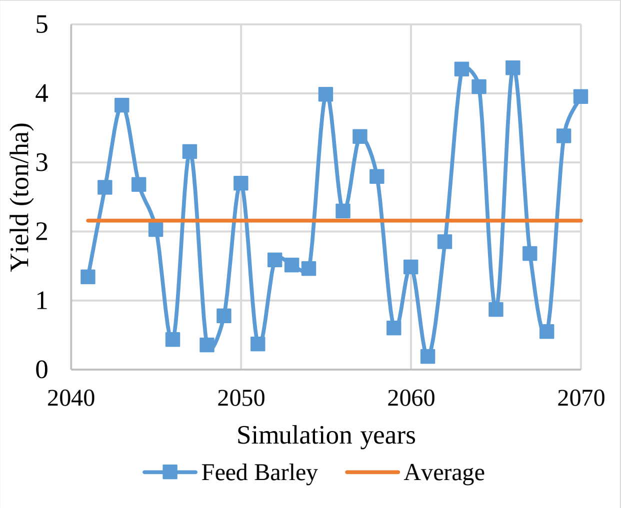


Figure N.4 Barley yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Swift Current

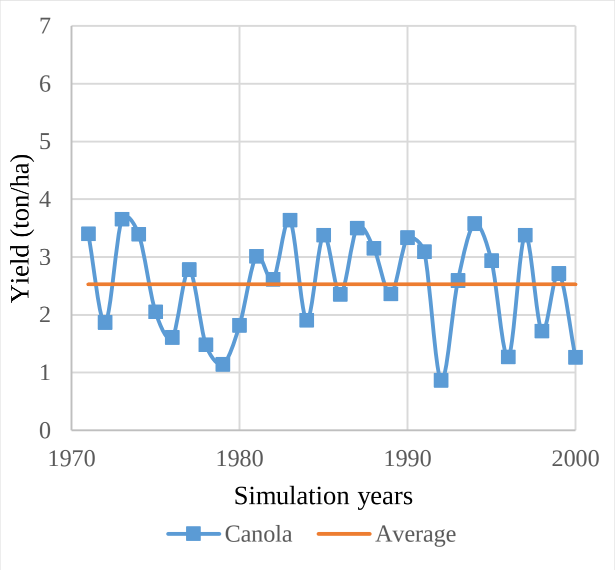


Figure N.5 Canola yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Swift Current

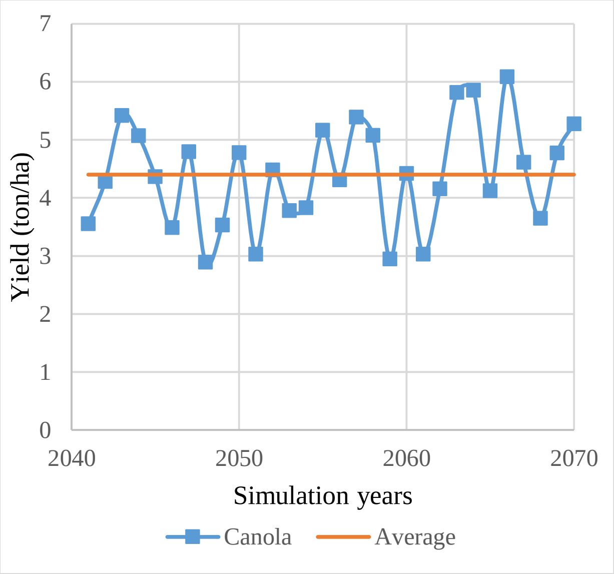


Figure N.6 Canola yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Swift Current

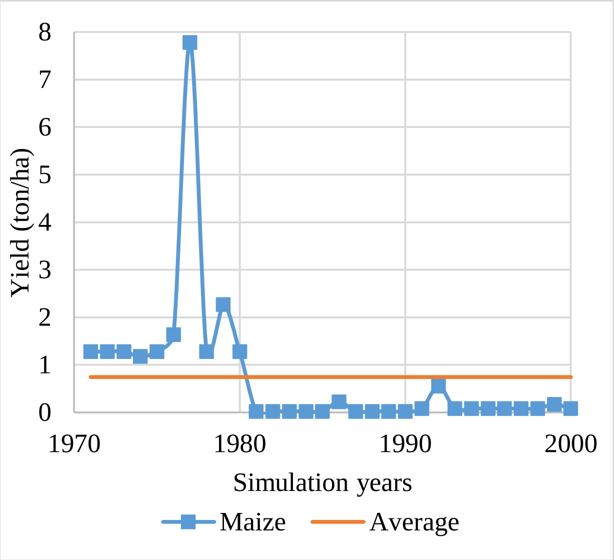


Figure N.7 Maize yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Swift Current

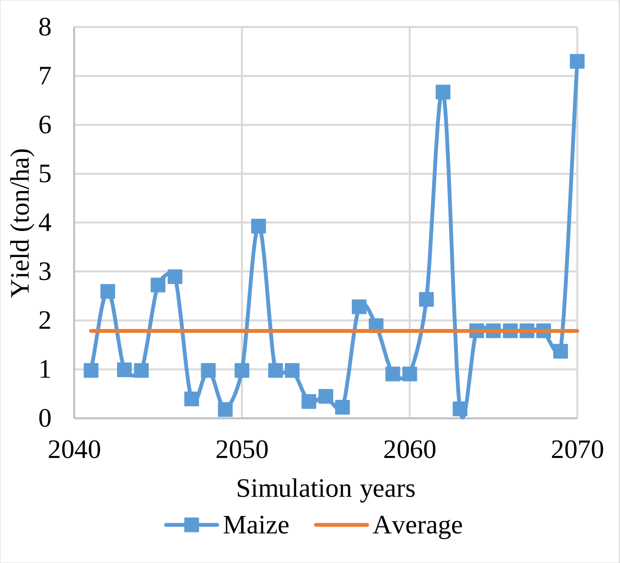
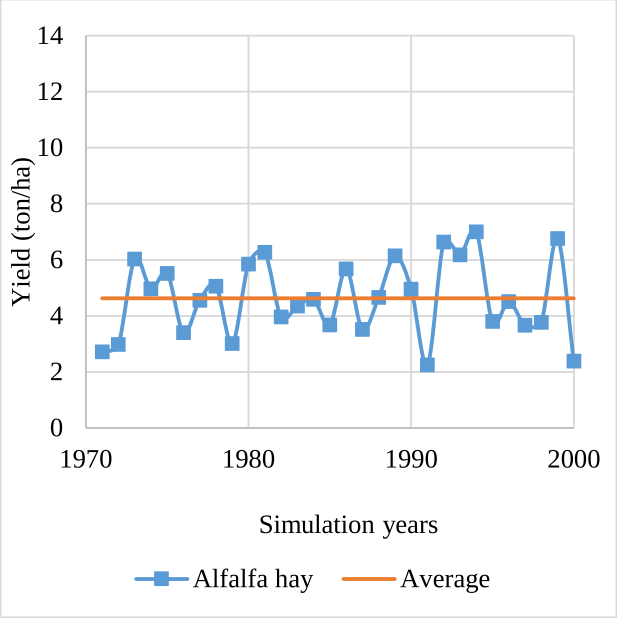


Figure N.8 Maize yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Swift Current



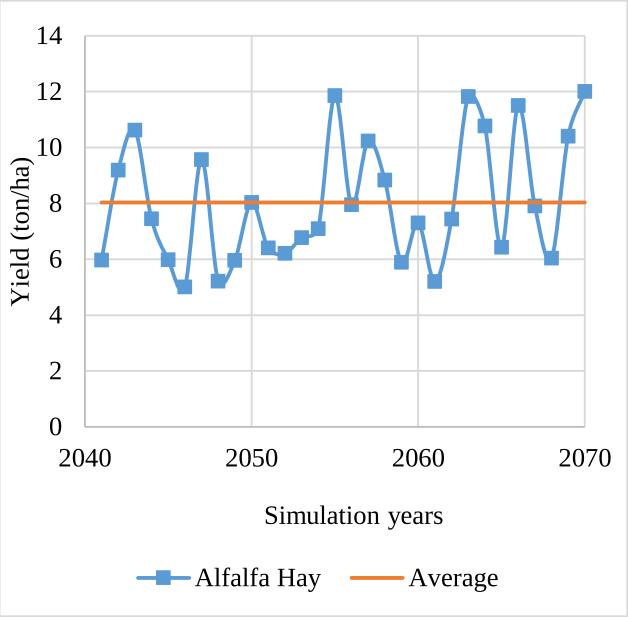


Figure N.9 Alfalfa hay yield forecast under the baseline scenario, 1971-2000, under RCM3_CGCM3_A2 climate scenario, Swift Current

Figure N.10 Alfalfa hay yield forecast under the future scenario, 2041-2070, under RCM3_CGCM3_A2 climate scenario, Swift Current

Appendix O: Pasture yield estimation results

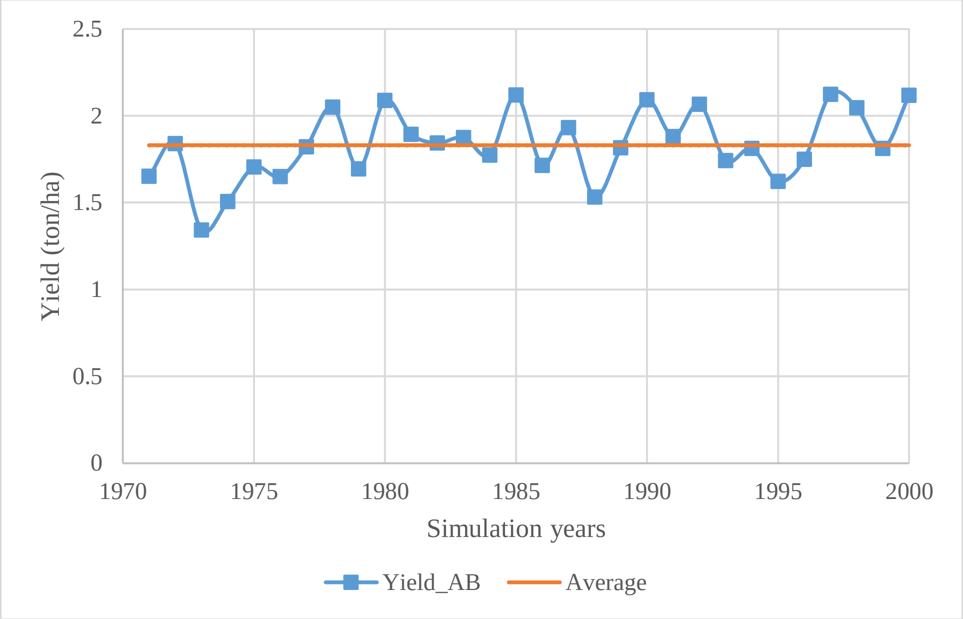


Figure O.1 Pasture yield forecast under the baseline scenario, 1971-2000 for the Pincher Creek site

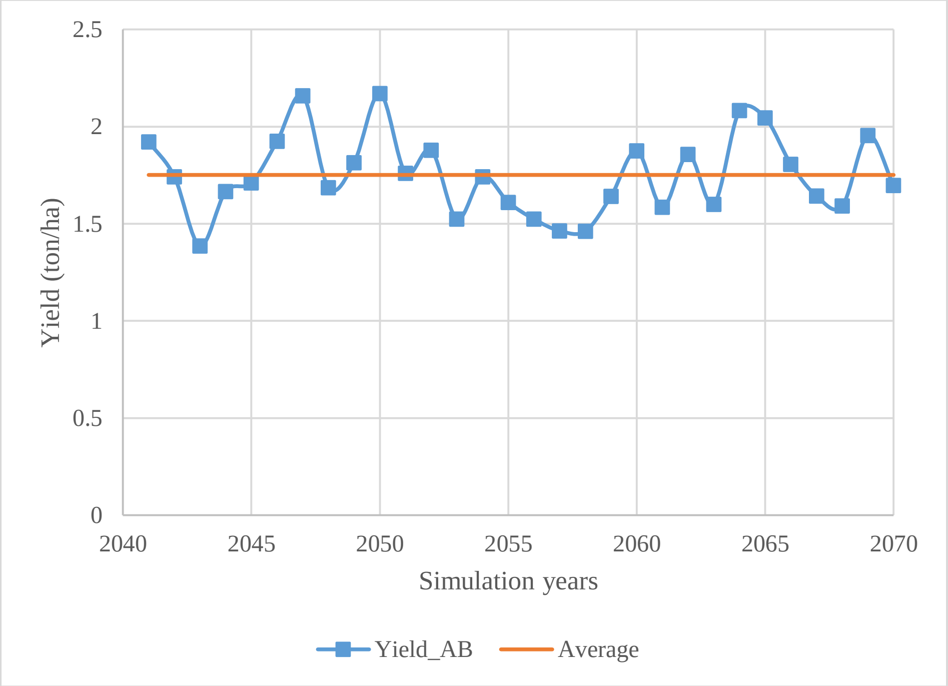


Figure O.2 Pasture yield forecast under the future scenario, 2041-2070, for the Pincher Creek site

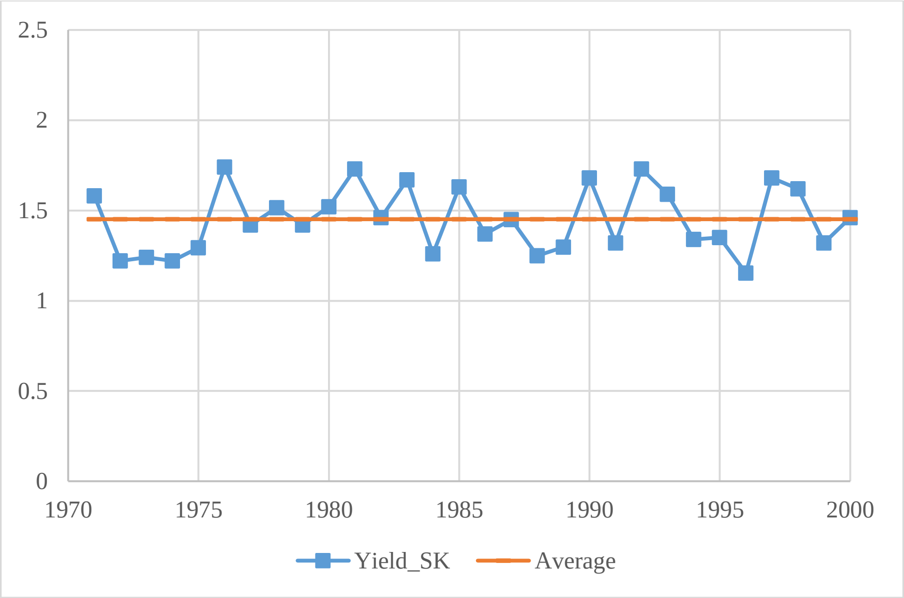


Figure O.3 Pasture yield forecast under the baseline scenario, 1971-2000, for the Swift Current site

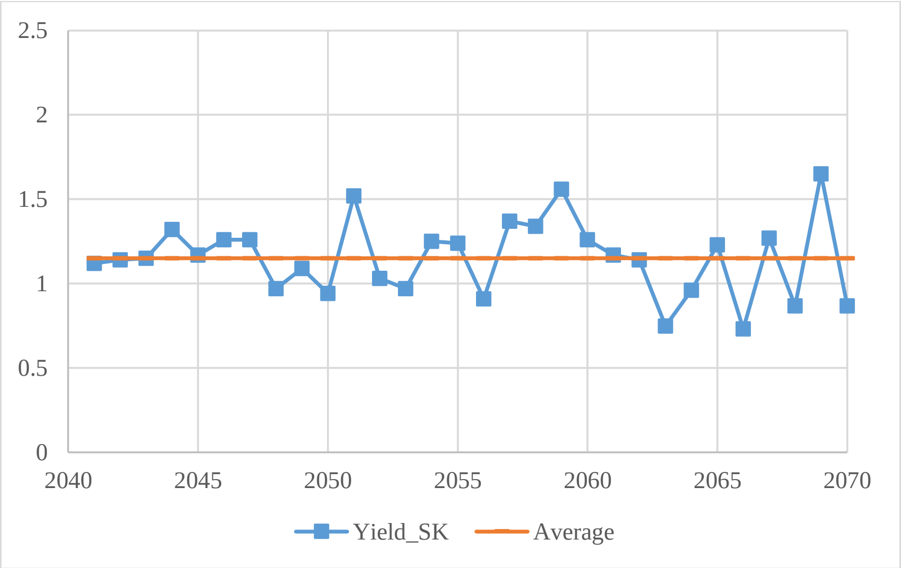


Figure O.4 Pasture yield forecast under the future scenario, 2041-2070, for the Swift Current site

Appendix P: Distribution of beef cattle variable COP estimates

Table P.1 Average per animal selected variable cost of production of cow-calf, backgrounding and finishing operations combined in the project sites under the baseline and future scenario

Cost items	Pincher Creek site		Swift Current site	
	Average ($/year)	% of variable cost	Average ($/year)	% of variable cost
Baseline scenario				
Labor and Yardage cost	16.95	39%	13.96	33%
Feed production cost	16.97	39%	17.60	42%
Feed purchase cost	3.08	7%	4.58	11%
Operating interest and death loss	6.42	15%	6.25	15%
Total variable cost	43.42	100%	42.38	100%
Future scenario				
Labor and yardage cost	24.65	33%	20.24	26%
Feed production cost	33.92	45%	32.80	41%
Feed purchase cost	3.75	5%	13.57	17%
Operating interest and death loss	12.29	16%	12.61	16%
Total variable cost	74.60	100%	79.22	100%

Appendix Q: Comparison of costs and return from purchase feeding strategy during climate extreme events

Table Q.1 Return to drought feeding under the baseline and future scenario for the Pincher Creek site

Scenarios	Cost/Return (‘000 $)	% return over cost
Baseline scenario		
Cost of drought feeding	45.32	
Return to feeding	105.88	233.59
Future scenario		
Cost of drought feeding	17.35	
Return to feeding	283.00	1,630.98

Table Q.2 Return to drought feeding under the baseline and future scenario for the Swift Current site

Scenarios	Cost/Return (‘000 $)	% return over cost
Baseline scenario		
Cost of drought feeding	45.32	
Return to feeding	129.68	286.11
Future scenario		
Cost of drought feeding	17.35	
Return to feeding	464.17	2,675.11