Environmental Changes and Implications of Climate Change for Rural Communities in the Grassland Natural Region of Alberta

March 2014

Prepared by Tracy Lee, Greg Chernoff and Ken Sanderson

MIISTAKIS INSTITUTE

Prepared for:

The Biodiversity Management and Climate Change Adaptation Project

Environmental Changes and Implications of Climate Change for Rural Communities in the Grassland Region of Alberta.

January 2014

Prepared by Tracy Lee, Greg Chernoff and Ken Sanderson

Miistakis Institute
Rm U271, Mount Royal University
4825 Mount Royal Gate SW
Calgary, AB
T3E 6K6

Phone: (403) 440-8444
Email: institute@rockies.ca
Web: www.rockies.ca

Disclaimer

Corresponding author:
Tracy Lee,
Miistakis Institute

Alberta Biodiversity Monitoring Institute
CW-405 Biological Sciences
University of Alberta
Edmonton, Alberta, Canada T6G 2E9
Phone: (780) 492-6322
E-mail: abmiinfo@ualberta.ca

This report was produced as part of the Biodiversity Management and Climate Change Adaptation Project. This project is led by the Alberta Biodiversity Monitoring Institute, with collaborators from the University of Alberta and the Miistakis Institute. The project receives its core funding from the Climate Change and Emissions Management (CCEMC) Corporation.

Alberta Biodiversity Monitoring Institute | CCEMC | UNIVERSITY OF ALBERTA | MIISTAKIS INSTITUTE

Biodiversity Management and Climate Change Adaptation Project Background

The Biodiversity and Climate Change Adaptation Project was conceived by the Alberta Biodiversity Monitoring Institute (ABMI) in response to the need to define the scope of change required to effectively manage biodiversity under a changing climatic regime, and to support Alberta's biodiversity management system with essential knowledge and tools for successful adaptation to a changing future climate.

The rationale for this initiative rests on the importance of biodiversity to Albertans, and the complex relationship between climate and biodiversity. Biodiversity, which includes species and their ecosystems, supports the delivery of numerous ecosystem services. These include provisioning services (e.g., food, fibre, fuel, water), regulating services (e.g. water and air filtration, flood regulation), cultural services (e.g., nature recreation, wildlife viewing) and supporting services such as soil formation and wildlife habitat. Because these biodiversity related services are impacted by a changing climate, and because the relationship between climate and biodiversity is uncertain, knowledge gaps constrain effective adaptation. Proactive investments in the knowledge and tools for effective biodiversity management under a changing climate regime will deliver significant benefits to people and avoid crisis-driven interventions that are by their nature reactive, costly and often ineffective.

The goal of the *Biodiversity Management and Climate Change Adaptation* project is to develop essential knowledge and tools to support the management of Alberta's biodiversity and promote successful adaptation to a changing climate. The project is comprised of four objectives:

1. Predicting the impacts of climate change on Alberta's native species and ecosystems

2. Predicting invasive species responses to climate change

3. Assessing strategies to support climate sensitive species-at-risk

4. Developing and evaluating adaptation policy and tools to manage biodiversity in a changing climate

The *Local adaptations for biodiversity-related ecosystem services* sub-project (concisely, the *Local Adaptations* sub-project) lead by the Miistakis Institute directly supports objective 4.

Executive Summary

This assessment provides a summary of existing and possible future climate impacts for the prairie region of southern Alberta and describes the environmental impacts in relation to community well-being based on a review of the literature. While acknowledging there are some real and significant impacts, we also demonstrate, through narratives, humans' long history of adapting to environmental change and set the stage for communicating the expected impacts and considering climate resilient strategies to help rural communities maintain resilience of the prairie landscape.

Approximately half of southern Alberta remains in native vegetation, predominately grasslands and forests while the rest of the area has been cultivated and a small percentage occupied by transportation infrastructure, oil and gas infrastructure and urban centers. The main economic drivers in the region are agriculture, tourism and oil and gas. Grasslands in southern Alberta represents the province's most productive land and livestock production (most common cattle and pigs) and cultivation are the main rural economic drivers.

Climate change will bring about increases in average temperature, changes in timing of precipitation, increase in the number of growing degree days and overall reduced moisture, resulting in impacts to hydrological and water resources, flora and fauna and severity and frequency of disturbance regimes.

Climate change will impact hydrology and water resources because of environmental changes such as retreating glaciers, decreases in stream flow and shifts in stream flow timing, falling lake levels, decrease in available water moisture and decrease in number of wetlands.

Climate change will impact Alberta's flora and fauna in the grassland region, because it will lead to shifts in phenology, vegetation's zone shifting northward, a decrease in tree and shrub cover and a decrease in wetlands. These changes will result in many of Alberta species needing to shift their home ranges to more desirable conditions and will tend to favour generalist and invasive species.

Climate change will impact disturbance regimes, by increasing the frequency and severity of extreme weather events, insect outbreaks and invasive species.

These environmental changes will have implications for agriculture, infrastructure, health and recreation. From an agriculture perspective, climate change will result in a warmer and longer growing season and potentially enhanced productivity of forests, some crops and grasslands where there is adequate soil moisture. However, climate change creates the potential for variations in extreme events of a magnitude and scale not previously experienced, leading to implications on grassland and crop productivity. In addition, the conditions will favour pests and invasive species, likely with negative consequences to grassland and crop productivity.

An increase in extreme weather events, such as flooding and drought, will lead to increasing health, such as threats to drinking water supply.

Infrastructure, including transportation (roads and bridges), buildings, water (dams, reservoirs and irrigation canals) and wastewater (swear, storm drains) will be at risk from increases in heavy precipitation, flooding events, increases in the freeze thaw cycle and to some extent intensive heat.

Recreational activities such as hunting (waterfowl) and fishing are expected to be negatively impacted due to changes to wildlife migration patterns, reduced water quality (increase in erosion) and decrease in number of wetlands. In addition, lower water volumes in lakes and streams in the late summer may impact popular water sports, such as white water activities, boating and swimming.

To help a local community better understand the importance of developing climate change adaptation strategies we develop some example narratives, where we tell the story in a way that might resonate to a rural municipality. Narratives will focus on the economic, social and environmental implications most concerning for a rural municipality by linking climate variables, environmental changes, implications to human well- being and strategies for building a climate resilient community. Next steps are to test narratives on a local community and identify adaptation strategies around chosen narratives that focus on building a climate resilience community.

Table of Contents

INTRODUCTION

This assessment provides a summary of existing and possible future climate impacts for the prairie region of southern Alberta and describes the environmental impacts in relation to community well-being based on a review of the literature. While acknowledging there are some real and significant impacts, we also demonstrate, through narratives, humans' long history of adapting to environmental change and set the stage for communicating the expected impacts and considering climate resilient strategies to help rural communities maintain resilience of the prairie landscape.

.

Specifically, this report aims to;

- identify predicted environmental changes based on climate change modeling;
- link environmental changes to impacts on human well-being;
- identify key overarching climate change messages;
- provide example of narratives to communicate climate change to local; municipalities; including water scarcity and increase in flood events; and
- develop a graphical of a narrative, demonstrating climate change implications to a rural agricultural community.

OVERVIEW OF GRASSLANDS REGION

Alberta's grassland natural region encompasses 95,565 km^2, representing 14.4 percent of the province (Natural Regions Committee 2006). Predominate vegetation is grasses, with shrubs and narrow forests in moist wetter areas, usually along river systems. The grassland natural region represents the warmest driest region in Alberta, with both warmer summers and a longer growing season. In general, there is a moisture deficit during the later periods of the growing season (Natural Regions Committee 2006). Only 1-2 percent of the region has standing water, from major rivers, associated with the Milk River and Saskatchewan River Basin or shallow lakes. Wetlands are typically temporary with some permanent marshes in wetter areas. The region supports a wide range of native wildlife species that are not found elsewhere in the province, including several threatened, endangered or species of special concern, such as Burrowing owl (*Athene cunicular*i), long billed curlew (*Numenius americanus*) and sprauges pipet (*Anthus spraguei*i) (Alberta Environment Sustainable Resource Development 2012). There are also a number of rare vascular plants occurring within the Grassland natural region (Natural Regions Committee 2006).

Approximately half of southern Alberta remains in native vegetation, predominately grasslands and forests while the rest of area has been cultivated and a small percentage occupied by transportation infrastructure, oil and gas infrastructure and urban centers ((Alberta Environment 2007)). The main economic drives in the region are agriculture, tourism and oil and gas (Martez et al. 2007). Grasslands in southern Alberta represents the province's most productive land and livestock production (most common cattle and pigs) and cultivation are the main rural economic drivers. Livestock production (cattle) take place on forage crops (43%), confined feeding operations (38%) and on native pasture (19%). Livestock production for pigs is 100% confined feeding. Cultivation includes a variety of crops types including cereals, tame grass, forage, oils and pulses. Eighteen percent of the crops are irrigated within the South Saskatchewan River basin, representing 87.9% of water allocation for the basin (Wagner 2007), the remain water allocations are for municipal (7.7%) and industry (4.9%). Irrigation is supported by water run-off from the Rocky Mountains and Cypress Hills and is therefore very sensitive to changes in stream flow.

The natural grassland system provides essential ecosystem services such as, food production, raw materials, fresh water and water regulation, pollination, habitat for species, moderation of extreme events, local climate and air regulation, biological control and recreational opportunities (hunting, fishing and leisure pursuits) and important cultural heritage values.

Current land use trends in the grasslands region

The southern region continues to experience economic growth and an expanding population resulting in increasing pressures on the ecosystem services provided by grassland natural system. A cumulative effects modeling exercise by Alberta Environment (2007) established a base case for 2000 and projected two 50 year trend scenarios, a business as usual scenario based on current trends and a more aggressive economic trajectory. The modeling did not take into consideration climate change. The business as usual scenario projected continued population and economic growth, the main drivers of change relating to urban growth and energy. Some of the changes projected included;

- Conversion of native vegetation to crops;
- Conversation of crops to urban settlement and energy development;
- Increased linear disturbance of roads, oil and gas infrastructure leading to a highly fragmented landscape;
- Increase in spread of invasive species in most cover types (due to fragmentation and linear disturbance)
- Increased development will lead to increase risks to water quality and less net flow in river basin.

The 50 year projections do not consider changes to the landscape as a result of climate change, but highlight a scenario of increased ecosystem degradation due to current land use trends (Alberta Environment 2007). The notion that current land use trends may not be sustainable is important when considering climate change impacts, which will likely exacerbate ecosystem risks. In addition, it is likely that climate resilience strategies focused on building or maintaining ecosystem resilience will also encourage best management practices and more sustainable land use practices.

OVERVIEW OF GRASSLAND REGION SUSCEPTIBILITY TO CLIMATE CHANGE

Climate change will lead to increases in temperatures, extending the growing season and increasing humidity in the grassland region of Alberta. Although, these factors could lead to additional plant growth and increasing productivity of certain crops, the warmer temperatures can also stress plants. In addition with a longer, warmer growing season, plants need more water to survive, and warmer temperatures will lead to increases in water scarcity particularly during periods of low water in late summer. Scientists are already seeing evidence that plants in the Northern Hemisphere slow their growth in the summer because of warm temperatures and water shortages. Dry, water-stressed plants are also more susceptible to fire and insects when growing seasons become longer (NASA, 2013). Increasing warm temperatures and water scarcity will impact the number of wetlands, an important ecosystem in the prairie landscape for improving water quality, flood attenuation, wildlife habitat and water storage.

In the grassland region of Alberta, climate change is predicted to increase the frequency and severity of extreme weather events, such as drought, wind and flooding. Although the grasslands in Alberta have shown substantial ecological plasticity based on resilience of system to recover from past drought periods, the economic impacts of extreme events can be devastating, as demonstrated in the 2002 drought, which resulted in a production drop of $2 billion across Canada (Agriculture and AgriFood Canada 2013)

Warmer temperatures will shift the grassland community types northward. Schneider (2013) summarized the expected impacts of climate change on the grasslands (based on both a 'cool' and a 'hot' modeling scenario) as a grassland shift of approximately one sub region northward. This will have implications on wildlife species whose habitat is shifting and will tend to favour generalists , including invasive species.

The current land use trends in the grassland region, as demonstrated by Alberta Environment (2007), including linear disturbance (roads, oil and gas infrastructure), increase in invasive species and conversation of native grassland to crops and other development will be further exasperated by climate change. For communities to begin to plan for adapting to climate change it is imperative they understand the expected environmental changes and the implications of these changes to ecosystem, health, agricultural and infrastructure.

Predicted Changes to Climate Variables in Alberta

There are many different measurable variables related to climate extremes that will influence how climate change will impact our environment and society. For these variables to be meaningful at a local level the data must be downscaled. Downscaling can be defined as:

> *Downscaling is the interpretation of the outputs of Global Climate or Global Circulation Models (GCMs) at finer scales than the original data. In many cases, downscaling takes the form of a spatially explicit interpolation of GCM data, commonly at the resolution of*

tens or hundreds of kilometres, down to scales and resolutions that are more meaningful at a local or regional level. This type of downscaling relies on locally-recorded historic climate data, topography, and other inputs to convert global-scale data to much more detailed interpretations of GCM outputs. (Chernoff, 2013)

The report "Alberta's Natural Subregions Under a Changing Climate: Past, Present, and Future" (Schneider, 2013) uses ClimateWNA model for downscaling climate variables. ClimateWNA uses interpolated weather station data to downscale future trends for Alberta.

Three emission scenarios are available in ClimateWNA for most models: A2, A1B, and B1 (IPCC, 2000). Given the general uncertainty of climate change, two scenarios at opposite ends of the spectrum are used in this report:

1. A2: Greenhouse gas emissions rise continuously, reaching the highest levels of all scenarios by the end of the century.
2. B1: Greenhouse gas emissions initially rise faster than in the A2 scenario, with a low mid-century peak and the subsequent decline in emissions is faster.

For the purposes of this report a smaller list of primary and secondary variables than that included in the scenarios will be discussed as they have the most potential impact on the Grassland Natural Region. These are as follows:

- Mean Average Temp
- Mean Coolest Month Temp
- Mean Warmest Month Temp
- Available Moisture (CMI)
- Growing Degree-Days
- Mean Average Precipitation

A breakdown of the expected future changes, by the end of century, to each of these variables as follows (Schneider, 2013).

MEAN AVERAGE TEMP (MAT)

Averaging across all models, the MAT for Alberta is projected to rise by 4.2 degrees under the high-emission A2 scenario, and 2.8 degrees under the more restrained B1 scenario. None of the models projects an increase of less than 2.0 degrees.

MEAN COOLEST MONTH TEMP

Averaging across all models, the high-emission A2 scenario indicates an estimated increase of 5.1 degrees Celsius in the coolest month and an estimated increase of 3.9 degrees Celsius in the more restrained B1 scenario.

Mean Warmest Month Temp

Averaging across all models, the high-emission A2 scenario indicates an estimated increase of 4.3 degrees Celsius and an estimated increase of 2.5 degrees Celsius in the more restrained B1 scenario.

Growing Degree-Days (GDD)

Growing Degree-Days will increase overall due to an earlier onset of spring. In the high-emission A2 scenario there is an estimated increase of 55.6% in the number of GDD and an estimated increase of 33.2% in the length of the number of GDD in the more restrained B1 scenario.

Mean Average Precipitation (MAP)

The average provincial increase in Mean Average Precipitation across all models is 9.4% for the A2 scenario and 7.2% for the B1 scenario. None of the models predicts a decline in MAP. Although overall annual precipitation is projected to increase, most models predict a decline during the summer months, or at least no increase. The average decline is 2.4% in July and 6.5% in August for the A2 scenarios and 0.2% in July and 2.3% in August for the B1 scenarios.

Available Moisture (CMI)

Although overall precipitation is projected to increase, most climate models predict that Alberta will become substantially drier in coming decades. By averaging across all models, provincial mean CMI decreases from 5.9 cm for the historical norm to -5.1 cm under the A2 scenario and to -0.6 cm under the B1 scenario. The main reason for this decline is that warmer temperatures increase the rate of evapotranspiration from vegetation and soils. In addition, although total precipitation is projected to increase, precipitation during midsummer, when moisture stress is greatest, is expected to decline. There is general agreement among the models that the Grassland and Parkland, which already experience a moisture deficit, will face additional drying in the future. At a minimum we can expect a northward shift of CMI values from northern Montana into Alberta's Grassland, and Grassland CMI values into the Parkland. In the most extreme case, represented by the Hot model, Alberta's Grasslands would experience the CMI values from the driest parts of Wyoming.

Other variables which we do not currently have specific data on, but may be important to consider, depending on the narratives chosen in future work, include:

- Snowfall
- Frost Free days
- Rain on Frozen Ground
- Rain on Snow
- Rapid Snow Melt.

Environmental changes to the grassland natural region

The changes in climate variables, increase in temperature, changes in timing of precipitation, increase in growing degree days and reduced moisture will result in significant changes in the grassland region, such as change to the hydrological and water resources, impacts to flora and fauna, and changes in severity and frequency of disturbance regimes.

Hydrology and Water Resources

The increase in temperature leads to a number of environment changes to hydrology and water resources, such as retreating glaciers, decreased in stream flow and sifts in stream flow timing, falling lake levels, decreases in available water moisture and decrease in number of wetlands. The implications from changes to hydrology and water resources include implications to food production (decreased moisture availability, reduced stream flow impacting agriculture (specifically irrigation), water regulation, including water storage, flood attenuation and water filtration (decreased moisture availability, reduced stream flow, decrease in number of wetlands) and recreation (reduced water in lake levels, impacts waterfowl and fish species).

Retreating glaciers

Glacier area in Alberta's Eastern Slopes decrease by 20% from 1985 to 2005 and the areal extent of glaciers is expected to continue to decrease due to increases in temperature (Marshall and White 2010). Glaciers play an important role in stream flow timing and contribute to water volume. Glaciers, due to their coldness are responsible for delaying snow melt and run-off to rivers until later in the summer when water scarcity is a concern. As glaciers retreat, it is expected to result in earlier melting and runoff, thus changing the timing of steam flows (Marshall and White 2010). In addition, glaciers play an important role in snow accumulation, as they tend to trap snow, impacting snowpack volume and reducing late season run-off.

As glaciers melt there will be more run-off, but once glaciers are gone, total volume of runoff will be reduced, impacting stream flow levels and water levels in the South Saskatchewan River Basin. This will result in less predictable environments for aquatic species (Fagre 2007).

Decrease in annual stream flow

Southern Alberta is largely dependent on stream flow from the Rocky Mountains for primary water supply. Modeling predicts that climate change will results in changes in the magnitude and timing of stream flow (Sheppard et al. 2010). Pietroniro et al. (2006) coupled hydrological models and climate change scenarios to estimate the following mean annual changes in flow by the 2050s; a decrease by 4% for the Oldman River at the mouth and a decrease of 8.5% for the South Saskatchewan River at Lake Diefenbaker. Sheppard et al. (2010) estimated a 15% reduction in summer stream flow and a 5% decrease over all annual stream flows for the Oldman River and adjacent rivers between 2005 and 2050.

The reduction is stream flow is caused by warming temperatures and changes in precipitation, causing a reduction in snow accumulation, due to higher rain/snow ratios and shorter accumulation period (MacDonald et al. 2012, Larson et al. 2011, Sauchyn and Kulshreshtha 2008) Reduced annual stream flows will result in concerns for water resource managers, creating challenges for irrigators and municipal water supplies (Sauchyn and Kulshreshtha 2008). In addition, reduced water supply will have ecological impacts on both aquatic and riparian systems and the biodiversity these systems support (Sheppard et al. 2010).

Shifts in stream flow timing

An earlier spring snow melt is expected resulting in changes to stream flow timing (Larson et al. 2011). The shift in stream flow timing is related to warming temperatures, causing higher snow melt frequency in the winter (Larson et al. 2011), thus causing an early onset of runoff, and resulting in drier summer conditions and reduced late season water supply (MacDonald et al. 2012).

Through-out the Prairies, the end of summer is already a period of low water supply, a further decrease in water supply could lead to water scarcity concerns in the later summer and would be further exacerbated during a drought year.

Falling Lake Levels in closed lake systems

Sauchyn et al. (2008) predict falling lake levels due to longer summer season, reduced precipitation and increase rates of evapotranspiration. This may have implications for water management in terms of recreation.

Decrease in available moisture

Although overall precipitation is expected to increase, the grasslands natural region is predicated to experience a moisture deficit (including in the soil), due to timing of perception (spring), increase in evapotranspiration and a decrease in snow on ground (Schneider 2013).
Thorpe (2011) estimates higher rates of evapotranspiration due to warmer temperatures and a decrease in precipitation levels at certain times of the year. Evaporation occurs from surface water and terrestrial systems, such as lakes, wetlands, reservoirs, bare soil and snow cover. Transpiration is the loss of water from living plants. Evapotranspiration is the sum of evaporation from the land and water surface plus transpiration from plants to the atmosphere. Higher rates of evapotranspiration lead to a reduction in leaf height and, if prolonged, densities of plant cover.
A decrease in available moisture has implications for agriculture, as it may lead to decreased forage production. In addition, surface water systems will lose more water due to evaporation leading to decline in water volume that may not be replenished due to longer summer season.

Decrease in wetlands

Wetland area and the number of wetland basins decreased by 5% in grassland region from 1985 to 2001 due to elimination or degradation by artificial drainage (Watmough and Schmoll 2007).
Larson (1995) predicted that a 3°C rise in temperature with no change in precipitation would result in a 15% decrease in basins holding water in the grassland.
An increase in temperature results in a shift from permanent to more temporary wetlands (Thorpe 2011). Average water level of wetlands is predicted to decline and the amount of time that seasonal wetlands remain dry will increase (Johnson et al. 2010). Also reduced run off from wetlands will impact ground water flows (Larson 1995).
The implications of reduced number and areas of wetlands include reduced:

- Flow of ground water recharge;
- Opportunities for flood control;

- Potential for water filtration (improved water quality); and
- Plant and animal species dependent on wetlands.

Impacts on Flora and Fauna

The increase in temperature leads to a number of environment changes that will impact Alberta's flora and fauna in the grassland region. Environmental changes such as shifts in phenology, vegetation zones shifting northward, a decrease in tree and shrub cover and a decrease in wetlands will results in Alberta species needing to shift their home ranges to more desirable conditions and will favour generalist and invasive species.

The implications from changes to flora and fauna include implications to food production (decreasing productivity for livestock and crops because of increases in invasive species), and recreation (decreased in waterfowl and fish populations for hunting and fishing).

Shifts in phenology

A warming climate will have effects on timing in phenology, such as migrations of species (earlier) and flowering of plants (earlier). Indeed, Beaubien and Freeland (2000), noted a 26-day shift to earlier onset of spring has already occurred over the past century from an analysis of Plant Watch data in Alberta. This may have implications for predator prey relationships, pollinators and host plants and herbivores (Thorpe 2011).

Vegetation zones shifting northward

Modeling predicts there will be a shift northward of vegetation zones in grasslands natural region in Alberta. Schneider (2013) indicates under a cooler scenario that grassland sub-regions are expected to shift one sub-region northward by 2050. The hotter scenarios predict the possibility of a shift from grasslands to sand dune areas becoming active again (Wolf et al 2001, Sauchyn et al. 2008). This shift is caused by decrease moisture availability due to warming temperatures and shifts in timing of precipitation resulting in competition that favours plant species that prfer drier conditions (Schneider 2013).

Shifting vegetation zones will result in shifts in species distribution and ranges, and will favour rapid dispersers such as invasive species (Hellmann et al. 2008). Due to differences in dispersal rates, genetic variation and environmental tolerances, the rate and success of species migration as vegetation shifts will vary greatly (Thrope 2011).

In addition, although there is considerable uncertainty around the impacts of climate change on forage production, research in Alberta indicates a decrease in forage biomass (White et al. 2013) . Changes to forage biomass will result in livestock producers facing greater uncertainty around stocking rates and animal breeds and species (Izaurralde et al. 2011).

Decrease in tree and shrub cover

Past drought years have led to an increased rate of tree mortality, and as a warmer climate causes vegetation zone shifts, some forest ecosystems will be converted to grasslands. A recent study found that trees in the prairies were growing more slowly and dying younger through the period from 1963 to 2008, with trends accelerating after 2000. The primary cause is linked to drought – reduced precipitation and increased temperatures (Peng et al. 2011)

CHANGES TO DISTURBANCE REGIMES: EXTREME WEATHER EVENTS, PATHOGENS, INSECTS AND INVASIVE PLANTS

The increase in temperature and changes in the timing of precipitation leads to a number of environment changes to disturbance regimes, such as increase frequency and severity of extreme weather events, insect outbreaks and invasive species.
The implications from changes to disturbance regimes include food production (from decreased crop and forage production due to storms and drought, increases in insect outbreaks and invasive species).

Increase in extreme weather events

The IPCC 2012 special report on climate extremes notes, "*A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events.*" Within Alberta's grassland region, an increased frequency of hydrological extremes, drought, ice storms, extreme wind and flood events are predicted (Thorpe 2011). Increased annual and seasonal temperatures will exacerbate drought conditions as well as increase the likelihood of extreme rain events (Groisman et al. 2005, Laprise et al. 2003).

Although total annual precipitation amount may stay the same, environmental changes such as timing of precipitation, changes in stream flow timing, intensity of glacier melt and rain on frozen ground events will increase the frequency of extreme rain events. An increase in extreme rainfall leads to increased potential for erosion and slope failure, potentially leading to nutrient overload in water bodies and increasing eutrophication (Sauchyn 1998; Ashmore and Church, 2001). An increase in nutrient loading and eutrophication will have negative impacts on aquatic ecosystems. From a human health perspective, outbreaks of water-borne disease have been linked to intense precipitation, flooding and runoff from agricultural livestock areas (Millson et al. 1991; Bridgeman et al. 1995; Charron et al. 2004; Schuster et al. 2005). Flooding can also cause damage to infrastructure (culverts, bridges and transportation and heavily impact agriculture community as rangelands and crops flood.

The Grassland region is currently susceptible to drought and with a warming climate the frequency, severity and duration of drought events is expected to increase. Warmer temperatures will cause a decrease in annual steam flow, shift in timing of stream flow away from the late summer when moisture deficits are highest, increases the length of summer and heightens evapotranspiration. Drought has major implications for agriculture community from an economic, health and social perspective (Sauchyn and Kulshreshtha 2008).

Increase in insect outbreaks

Due to the complexity of variables affecting insect outbreaks, it is difficult to predict the impacts of climate change on insect outbreaks. However, historically during times of drought, insect outbreaks are more common. For example, grasshopper outbreaks are more common after several years of warm weather (Powell et al. 2007). Hoggs et al. (2005) found tent caterpillar invasions (aspen trees) are common after mild winters and dry summers.

Increase in invasive species

Invasive species have traits that improve their chances of rapid evolution in response to climate change, including large population size, rapid population growth, short generation times, high habitat connectivity (because of use of disturbed habitats), and generalist phenotypes (Running and Mills 2009). Currently the most prevalent and best documented invasive in Alberta are plant species, but there are also vertebrate invasive species, such as birds and trout species which out compete or hybridize with native species and disease like the West Nile Virus.

A report by McClay et al. (2004) suggests that potential threat, such as climate change will open up new introduction pathways from neighbouring jurisdictions into Alberta through natural dispersal. The report identified a number of species not currently in Alberta but that may be a concern in the future, including, plants species such as salt cedar, yellow star-thistle, communion crupina, and Eurasian water milfoil; vertebrate species such as swine (wild boar), and exotic deer species; and diseases such as Lyme disease and chronic wasting disease.

The Grassland region is expected to shift northward and the expected increased frequency of extreme rain events will favour expansion of invasive plant species which tend to be rapid adapters and favor wet environments (Hellmann et al. 2008). The cost of invasive species to the economy is difficult to quantify, but a rough estimate based on extrapolation from the US suggests it cost Alberta $1 billion to the economy annually (McClay et al 2004). The major impact of invasive plant species in Alberta is to rangeland, such as displacement of native species and desirable forage plants and the introduction of species that are poisonous to livestock (McClay et al 2004). In addition, new threats such as salt cedar, which in the United States has clogged irrigation canals, would also largely impact agriculture production (McClay et al. 2004).

Implications: Impacts on People and their resources

Agriculture

A continued trend of warming, and higher spring temperatures in particular, will result in a warmer and longer growing season and potentially enhanced productivity of forests, crops and grassland where there is adequate soil moisture. However, climate change creates the potential for variations in extreme events of a magnitude and scale not previously experienced, leading to implications on grassland and crop productivity. In addition, the conditions will favour pests and invasive species, likely with negative consequences to grassland and crop productivity.

Grassland productivity

A warming temperature and changes in precipitation will impact grassland productivity in both quantity and quality, although the severity of these conditions ranges from negligible to large depending on the emissions scenario. A warmer emissions scenario (HADCM 3 A2) indicates a potential 40% decline in grassland quantity in some areas, with an average of 25% in the grassland region. This is concerning from a livestock production perspective as 25% decline in forage quantity equates to a 25% decrease in stocking rates (Thorpe 2011).

In addition, forage quality is also found to decrease with increases in temperature and decreases in precipitation (Craine et al. 2009). However, CO_2 might act as a fertilizer and increase plant production, by increasing photosynthesis and plant water efficiency. But the ability of CO_2 to compensate for overall impacts of reduced moisture and a drier climate on forage quality and quantity are uncertain. A recent study by White et al. (2013) suggests a decrease in quantity and quality of forage for grazing and concludes adaptability of grazing management will need to be considered. The authors do, however, highlight difficulty in generalizing the impacts across Alberta's grasslands due to the complexity of local variables.

Crop productivity

A warming temperature and changes in precipitation will impact crop productivity, up to a certain threshold plant productivity will increase, but ultimately productivity will be limited by the suitable amount and timing of water (Sauchyn and Kulshreshtha 2008). Currently, 4% of southern Alberta crops are irrigated, contributing 18.4% of Alberta's agri-food gross domestic product. Irrigation water is supplied by stream run off from the Rocky Mountains, which under climate change scenarios are predicted to decrease in water quantity (Sauchyn and Kulshreshtha 2008). The irrigation community continues to improve water loss and leakage through improvements in infrastructure, such as converting open channels to pipelines. It is difficult to predict the impacts of water shortage on irrigation, but as water demands increase (longer growing season and greater evapotranspiration) and stream flows declines the basins will experience water shortfalls.

Recreation

Recreational activities such as hunting (waterfowl) and fishing are expected to be negatively impacted due to changes to wildlife migration patterns, reduced water quality (increase in erosion) and decrease in number of wetlands (Inkley et al. 2004). In addition, lower water volumes in lakes and streams in the late summer may impact popular water sports, such as white water activities, boating and swimming (Henderson et al. 2002).

Infrastructure

> "*Climate change has the potential to substantially affect the effectiveness and lifespan of infrastructure in Canada, particularly in transportation, buildings and water management infrastructure. The exposure and vulnerability of these different types of infrastructure varies greatly. Collectively, though, substantial economic costs have already been attributed to the impact of climate hazards on such infrastructure, and these costs are only expected to increase in the future*" (Boyd et al. 2013).

Land transportation infrastructure (roads and bridges), will be susceptible to deterioration from increase in freeze- thaw cycles, flooding events and number of hot summer days. Building infrastructure will be susceptible to deterioration from hot dry summers (increase reliance on cooling systems, premature weathering), increased precipitation events (such as structural damage, increase in mold growth, and deterioration of building facades) and increased rainfall and storm surges (damaged or flooded structures).

Water infrastructure (dams, reservoirs, aquifers, irrigation) has been identified as highly susceptible to climate change (Natural Resources Canada 2007). For example drought may lead to increases in water demand and pressure on infrastructure, and increased water quality and allocation problems. While flooding may lead to water borne health effects, and unpleasant taste and odour in municipal water supply.

Lastly wastewater infrastructure (treatment facilities, culverts, sewers, storm drain pipes) could be put under stress during periods of heavy rainfall, leading to flooding events and damage to infrastructure.

Health

An increase in extreme weather events, such as flooding and drought, increases concerns about health, such as threats to drinking water supply. Heavy runoff after severe rainfall can also contaminate recreational waters and increase the risk of human illness (Schuster et al., 2005) through higher bacterial counts.

In addition warmer temperatures, may lead to increase in certain diseases. For example, Lyme disease is a prevalent tick-borne disease in North America for which there is new evidence of an association with temperature (Ogden et al., 2004) and precipitation (McCabe and Bunnell, 2004). A report by McCay et al (2004) identified Lyme disease as a new threat for Alberta.

COMMUNICATING CLIMATE CHANGE

This section moves beyond the science and starts to explore how climate change information can be communicated to a local community in a way that promotes action.

Communicating Climate Change in the Face of Uncertainty

Climate change is often perceived by communities as overwhelming, and it can be challenging for a local community to understand their role in mitigating and adapting to climate change. There is confusion around levels of uncertainty in the science and the way we frame climate change. Therefore, it is important to set context, to highlight what we do know and where there is still uncertainty.

We know the climate is changing, the average global temperature is warming and that humans have caused the warming by increasing CO_2 and other greenhouse gases into the atmosphere through fossil fuel emissions and land use changes (IPCC 2013). There is unequivocal consensus that humans are the cause of climate change, but there is uncertainty around the severity of future impacts, mainly due to the complexity of trying to accurately model the climate, but also because it is largely dependent on how we as a species respond to global emission reduction targets. What we do know is it is not too late to avoid the worst; lower emissions will mean reduced climate change and less sever impacts (Somerville and Hassol 2011).

Climate Change as a Social, Economic and Environmental Issue

Climate change is often framed as an environmental issue occurring at a global scale. This framing of the issue may be contributing to the inability of individuals, communities and even governments to take action. In reality, climate change needs to be framed equally as an environmental, economic and social issue. The implications from climate change will have a profound impact on economies and other aspects of human well-being. Likewise, environmental changes as a result of climate change will have implications at a local level (municipal) in terms of impacts on ecosystem services such as maintaining water quality and quantity, regulating extreme weather events, providing wildlife habitat, recreational opportunities and other cultural values.

If change is coming, but people are uncertain of the severity, it is a challenge for a local community to effectively plan to adapt to these changes. The key is for them to understand that addressing climate change wisely will yield benefits to the economy and the quality of life. Acting sooner would be less disruptive than acting later (Somerville and Hassol 2011). Local communities can adapt and in many cases are already implementing strategies that promote climate resiliency. Through the development of climate change action plans to help build climate resiliency, a common policy to adopt is "No Regret Strategies", meaning actions that generate net benefits whether or not predicted climate change conditions occur (CBT, 2012). An example of a no regret strategy might be a municipal government protecting a wetland through a conservation easement, which builds climate resiliency by increasing the ability of the ecosystem to respond to drought and flooding. Even if the predicted climate conditions do not occur, the benefits of protecting wetlands to ecosystem function and health (protecting wildlife habitat, regulate extreme weather events, and providing water storage) – and therefore human well-being – are significant.

Climate Change Narratives

To help a local community better understand the importance of developing climate change adaptation strategies Miistakis will use a series of narratives highlighting the implications of climate change that matter to a rural municipality. Narratives will focus on the economic, social and environmental implications most concerning for a rural municipality by linking climate variables, environmental changes, implications to human well-being and strategies for building a climate resilient community.

The following are two examples of how narratives could be structured for this purpose.

Water Scarcity

Already a concern

The Prairies is one of the most drought- susceptible regions in Canada, and has experienced a long history of multi-year droughts, most recently during the early 2000s (Bonsal, 2008). From the 1900 to 2005 Alberta has experienced 35 recorded droughts. Many of these droughts have had severe economic impact on the rural agriculture community, for example loss of agriculture production; during the drought of 2001-2002 an approximate $3.6 billion drop in agricultural production occurred and there was a shortage of livestock feed. But drought affects more than agricultural productivity, according to the Canadian government's discussion paper on drought the 1977 drought in western Canada cost over $100 million in additional electric power generation costs, $20 million in unanticipated fire-fighting charges, $10 million in emergency federal and provincial drought programs, plus losses in tourism and costs of additional water treatment.

Add in climate change

The agricultural community has been susceptible to climate variability and periods of low water availability and to a certain extent is adept at adapting to changing conditions. However, climate change will cause the prairies to get hotter resulting in changes to the hydrological cycle, such as reduced water flow during late summer and increases in evapotranspiration further reducing moisture levels. These environmental changes have the potential to exacerbate the conditions that lead to drought and an increased frequency of drier years is expected (Sheffield and Wood 2007). The Government of Canada climate change report of 2008 stated that increases in water scarcity resulting from climate change presents the greatest risk to the Prairie Provinces, including Alberta.

The implication

Re-occurring water deficits (drought) has implications on economy, environment and culture of the prairie communities. The most immediate effect for agriculture is a decrease in production of crops and grassland ecosystems, impacting crop yields and livestock stocking rates. Furthermore drought conditions may lead to an increase frequency and severity of pests and invasive species further reducing crop productivity. The consequences of increase frequency of water scarcity will have consequences for food production in Southern Alberta, by impacting the health and quality of crops and pasture and livestock. Ultimately, water scarcity may have severe economic impacts on the livelihoods of many southern Alberta communities.

Flooding

Already a concern

The prairie system has long experienced extreme weather events, many are still recovering from the 2013 flood and costs are estimated at $5 billion and counting. The 2005 floods in southern Alberta caused an estimated $400 million in damage to infrastructure, such as sewer back-up and damage to roads, sewers, buildings and agricultural infrastructure.. Flooding is the second most recorded natural disaster in Alberta, from 1900 to 2005 there were 34 flood events (Public Safety 2013).

Add in climate change

Changes in the timing of precipitation and an increase in extreme precipitation events due to climate change are a particular concern, and are expected to increase in frequency and severity by 2050 in Alberta. For example, in southern Alberta extreme precipitation events which resulted in 25-50mm of rain within 24 hours, are predicted to increase in severity by 10-15% by 2050 over those experienced between 1958 and 2007. An increase in severity of this magnitude could result in a 20 year flooding event frequency occurring every 10 years (McBean 2012).

The implications

Flooding can have sever effects on infrastructure (water treatment facilities, storm water system, roads, bridges, culverts), and can result in damage to residential and municipal properties (buildings, houses). In addition, there are health implications as flooding can threaten safe drinking water supply. Other immediate health concerns include exposure to sewage contamination, growth of toxic mold and dealing with spoiled food items.

Agriculture can also be impacted by flood damage, from loss of equipment, farm animals, stored feed and crop damage.

Clickable Narratives Concept

To organize and communicate some of the information contained in this report, some of the data and findings from BMCCA Project partners, and other relevant information, Miistakis has conceptualized a "clickable narratives" framework.

Focused on individual themes, each narrative will tell the story of a specific aspect of climate change – for example, issues of water scarcity as a result of changing weather and precipitation patterns – allowing the user to interact with maps, stories, and facts and figures that support the theme. The narratives are designed to transcend the different scales – global, national, regional, and local – at which climate change needs to be considered. They are also explicitly based on, and will serve to link across the four Story Lines of the *Local Adaptations* sub-project's Communications Strategy, namely: the Story of Change; the Story of Impacts; the Story of Resilience; and the Story of Effectiveness/Efficacy. Figure 1: illustrates the generic concept of the clickable narrative.

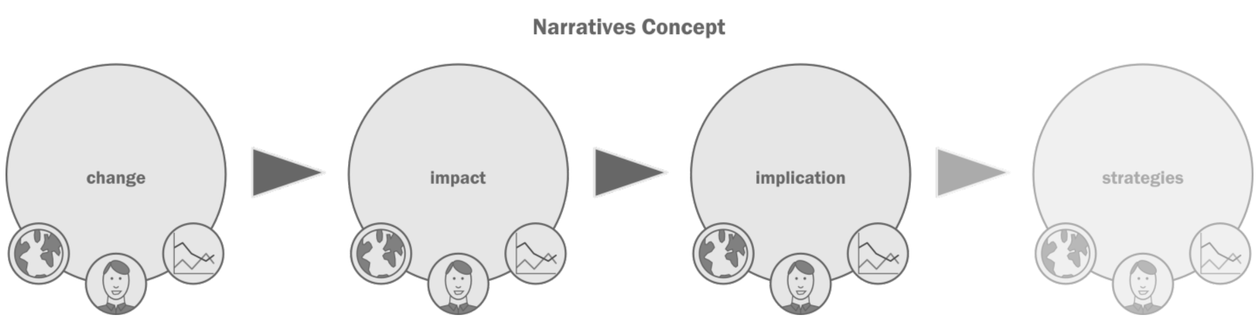

Figure 1 - Clickable Narratives Concept Diagram.

Each stage of the narrative focuses on a specific element of climate change adaptation:

- *Change* – The broad changes to temperature, precipitation, and other factors that can be expected under anticipated future climate scenarios. For example, future climate models predict recession of glaciers, decreased precipitation, and decreased in-stream flows for Alberta's grassland natural regions.

- *Impact* – The impacts, at the scale of a natural region, that can be expected from the modeled future climate change. For example, the changes described above are expected to lead to increased water scarcity.
- *Implication* – This is the "so what?" of climate change and regional impacts in a local context. It is an explicit attempt to make climate change matter locally, and to make the information about changes and impacts relevant to rural municipalities in Alberta's grassland communities. For example, increased water scarcity will result in a reduction of domestic water supply, increased prevalence and frequency of drought, and decreased productivity of plant biomass, resulting in reduced yields for both crop and livestock agriculture.
- *Strategies* – Highlighting the opportunities for creating and implementing local actions that will promote resiliency and adaptation to the anticipated climate change implication. An example would be exploring options for more drought-resistant agriculture. Note: As indicated by the "ghosting" of this stage of the clickable narrative, Miistakis intends to begin developing this component subsequent to this report.

Narrative Icons

Each stage of the clickable narrative is comprised of an identical set of symbols and icons. Figure 2 describes the purpose of each icon, and the resources that will be available to the use upon clicking.

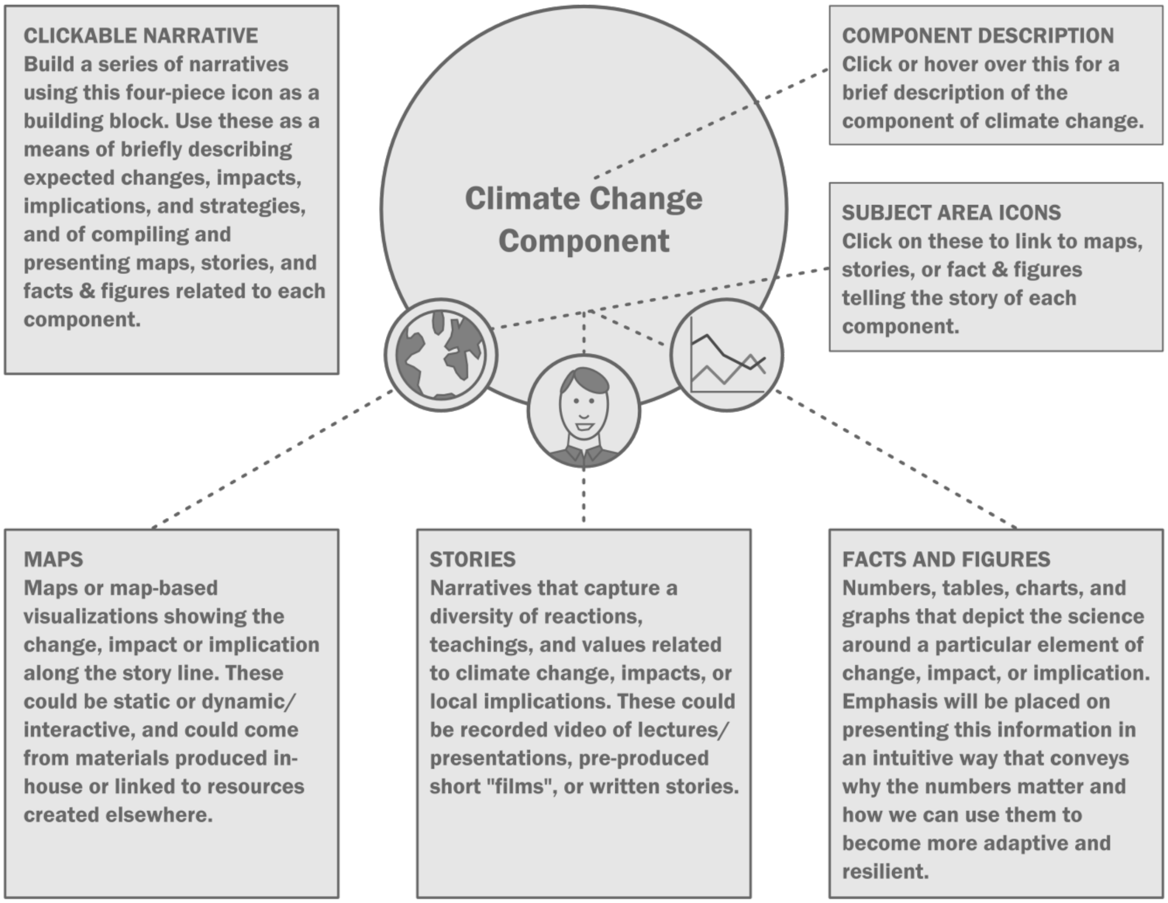

Figure 2 - Diagram of Clickable Narrative Icons

Miistakis is concurrently further developing the clickable narratives concept as a supplemental resource to this report. This will further demonstrate the concept and provide example content.

NEXT STEPS

The next steps in fleshing out the preliminary implications information gathered for this report will be undertaken as part of the Year 3 development of the decision-support tool. This will include:

- Testing a series of narratives with municipal stakeholders to ensure narratives being developed are of concern and interest to a rural municipality in the grasslands region of Alberta;
- Finalizing the structure of the decision-support tool, and the inclusion of the narratives concept into that structure; and
- Developing and applying the appropriate information, graphics and visualizations to those narratives identified as priority through the engagement process.

REFERENCES

Agriculture and Agri-Food Canada. 2013. On-line source: http://www.agr.gc.ca/eng/?id=1326987176314 (February 20 2013).

Alberta Environment Sustainable Resource Development. 2012. Species Assessed by Alberta's Endangered Species Conservation Committee: Short List. Prepared by Wildlife Branch. On-line source: http://srd.alberta.ca/FishWildlife/SpeciesAtRisk/documents/SpeciesAssessed/EndangeredSpeciesConservationCommittee-ShortList-Nov06-2012.pdf (October 18 2013).

Alberta Environment. 2007. Southern Alberta Landscapes: Meeting the Challenges Ahead: An Examination Of The Effects Of Economic Growth On Landscape Features And Processes In Southern Alberta Using ALCES® (A landscape Cumulative Effects Simulator). Government of Alberta. Lethbridge, Alberta.

Alberta Environment. 2005. Alberta Climate Model (ACM) to provide climate estimates (1961-1990) for any location in Alberta from its geographic coordinates. Publ. No. T/749. Alberta Environment. 33 pp.

AMEC. 2009. South Saskatchewan River Basin in Alberta: Water Supply Study. Alberta Agriculture and Rural Development. Lethbridge, Alberta

Ashmore, P. and M. Church. 2001. The impact of climate change on rivers and river processes in Canada. Geological Survey of Canada. Bulletin 555:1–48.

Beaubien, E.G. and H.J. Freeland. 2000. Spring phenology trends in Alberta, Canada: links to ocean temperature. International Journal of Biometeorology 44:53-59.

Bonsal, B. 2008. Droughts in Canada: An overview. CMOS Bulletin SCMO. 36:79-86.

Boyle, J., Cunningham, M. and J. Dekens. 2013. Climate Change Adaptation and Canadian Infrastructure: A Literature Review. International Institute for Sustainable Development.

Bridgman, S.A., Robertson, R.M., Syed, Q., Speed, N., Andrews, N. and P.R. Hunter. 1995. Outbreak of cryptosporidiosis associated with a disinfected groundwater supply. Epidemiology and Infection. 115 (3):555–566.

Charron, D.F., Thomas, M.K., Waltner-Toews, D., Aramini, J.J., Edge, T., Kent, R.A., Maarouf, A.R. and J. Wilson. 2004. Vulnerability of waterborne diseases to climate change in Canada; Journal of Toxicology and Environmental Health. Part A 67(20–22):1667–1677.

Chernoff, G. 2013. *Downscaling Climate data for Climate Change Adaptation Action Planning in Alberta*. Prepared for the Biodiversity and Climate Change Adaptation Project. Miistakis Institute, Calgary, AB

Columbian Basin Trust. 2012. Climate change impacts and adaptation in the Columbian Basin: Dialogue to Action.

Craine, J.M., A.J. Elmore, K.C. Olson, and D. Tolleson. 2009. Climate change and cattle nutritional stress. Global Change Biology. doi: 10.1111/j.1365-2486.2009.02060.x

Demuth, M.N. and A. Pietroniro. 2003. The impact of climate change on the glaciers of the Canadian Rocky Mountain eastern slopes and implications for water resource-related adaptation in the Canadian Prairies; Prairie Adaptation Research Collaborative, Regina, Saskatchewan, Project P55, 111 p.

Fagre, D.B. 2007. Ecosystem responses to global climate change. In: "Sustaining Rocky Mountain Landscapes: Science, policy, and management for the Crown of the Continent ecosystem" (eds.Prato, T., and Fagre, D.). Washington D.C.: Resources for the Future. 187-200.

Garnett, E.R., 2002. The Canadian prairie drought of 2001: A four billion dollar shortfall? CMOS Bulletin, 30, 37-39.

Groisman, P.Y., Knight, R.W., Easterling, D.R., Karl, T.R. and V.N. Razuvaev. 2005. Trends in intense precipitation in the climate record. Journal of Climate. 18(9):1326–1350.

Hellmann, J.J., J.E. Byers, B.G. Bierwagen, and J.S. Dukes. 2008. Five potential consequences of climate change for invasive species. Conservation Biology 22:534-543.

Henderson, N., Hogg, T., Barrow, E. and B. Dolter. 2002. Climate change impacts on the island forests of the Great Plains and the implications for nature conservation policy; Prairie Adaptation Research Collaborative, Regina, Saskatchewan, 116 p.

Hogg, E.H., Brandt, J.P. and B. Kochtubajda. 2005. Factors affecting inter annual variation in growth of western Canadian aspen forests during 1951-2000. Canadian Journal of Forest Research 35:610-622.

Inkley, D.B., Anderson, M.G., Blaustein, A.R., Burkett, V.R., Felzer, B., Griffith, B., Price, J. and T.L. Root. 2004. Global climate change and wildlife in North America. Wildlife Society, Bethesda,Maryland, Technical Review 04-2, 26 p.

IPCC. 2013. Summary for Policymakers. 2013. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung,

A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IPCC. 2012. Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX). On-line source: http://ipcc-wg2.gov/SREX/. (Jan 5 2014)

IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing team, Pachauri, R.K and A. Reisinger (eds.)]. IPCC, Geneva, Switzerland, Section3.2.2

IPCC. 2000. Emissions scenarios: Summary for policy makers. Intergovernmental Panel on Climate Change.

Izaurralde, R.C., A.M. Thomson, J.A. Morgan, P.A. Fay, H.W. Polley, and J.L. Hatfield. 2011. Climate impacts on agriculture: Implications for forage and rangeland production. Agron. Journal 103:371–381. doi:10.2134/agronj2010.0304

Johnson, W., B. Werner, G. Guntenspergen, R. Voldseth, and B. Millett. 2010. Prairie wetland complexes as landscape functional units in a changing climate. BioScience.60:128-140.

Lapp, S., Byrne, J., Townshend, I. and S. Kienzle. 2005. Climate warming impacts on snowpack accumulation in an Alpine watershed: a GIS based modeling approach; International Journal of Climatology. 25(3):521–536.

Laprise, R., Caya, D., Frigon, A. and D. Paquin. 2003. Current and perturbed climate as simulated by the second-generation Canadian Regional ClimateModel (CRCM-II) over northwestern North America. Climate Dynamics. 1(5–6): 405–421.

Larson, R. P., Byrne, J.M., Johnson, D.L., Kienzie, S.W., and M.G. Letts. 2011. "Modelling Climate Change Impacts on Spring Runoff for the Rocky Mountains of Montana and Alberta II: Runoff Change Projections Using Future Scenarios." Canadian Water Resources Journal 36(1): 35–52. On-line source: http://www.tandfonline.com/doi/abs/10.4296/cwrj3601035 (September 20, 2013).

Larson, D. 1995. Effects of climate on numbers of northern prairie wetlands. Climate Change. 30:169-180.

MacDonald, R. J., Byrne J.M., Kienzle, S.W. and R. P. Larson, 2011: Assessing the Potential Impacts of Climate Change on Mountain Snowpack in the St. Mary River Watershed, Montana. Journal of Hydrometeor. 12:262–273. http://dx.doi.org/10.1175/2010JHM1294.1

Marshall, S. and E. White. 2010. Alberta Glacier Inventory and Ice Volume Estimation. Crowfoot Ice Research and Consulting, Canmore, AB. 55pp.

Martez, L.W., Bruneau, J.F. and J.T. Rolfe. 2007. Climate Change and Water: SSRB Final Technical Report. Natural Resources Canada: Climate Change Impacts and Adaptation Program (CCIAP) McBean, G. 2012. Telling the Weather Story. Institute for Catastrophic Loss Reduction. Prepared for Insurance Bureau of Canada.

McCabe, G.J., and J. Bunnell. 2004. Precipitation and the Occurrence of Lyme Disease in the Northeastern United States. Vector Borne and Zoonotic Diseases. 4:143-148.

McCay, A.S., Fry, K.M., Korpela, E.J., Lange, R.M. and L.D. Roy. 2004. Cost and Threat of Invasive Species to Alberta's Natural Resources. Alberta Research Council.

Millson, M., Bokhout, M., Carlson, J., Spielberg, L., Aldis, R., Borczyk, A. and H. Lior. 1991. An outbreak of Campylobacter jejuni gastroenteritis linked tomeltwater contamination of amunicipal well; Canadian Journal of Public Health. 82(1):27–31.

NASA Earth Observatory. On line source: http://earthobservatory.nasa.gov/Features/CarbonCycle/page5.php (October 2 2013).

Natural Regions Committee 2006. Natural Regions and Subregions of Alberta. Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta. Pub. No. T/852.

Natural Resources Canada. 2007. From impacts to adaptation: Canada in a changing climate. Ottawa: Government of Canada. Ottawa.

Natural Resources Canada. 2002. Climate Change Impacts and Adaptation: A Canadian Perspective – Water Resources. Climate Change Impacts and Adaptation Directorate. Natural Resources Canada. Ottawa.

Ogden, N.H., L.R. Lindsay, G. Beauchamp, D. Charron, A. Maarouf, C.J. O'Callagjan, D. Waltner-Toews and I.K. Barker. 2004: Investigation of the relationships between temperature and developmental rates of tickIxodes Scapularis (Acari: Ixodidae) in the Laboratory and Field Journal of Medical Entomology. 41: 622-633

Peng, C., Ma, Z., Lei, X., Zhu, Q., Chen, H, Wang, W., Liu, S., Li, W., Fang, X. and X. Zhou. 2011. A drought-induced pervasive increase in tree mortality across Canada's boreal forests. Nature Climate Change. 1. DOI:10.1038/NCLIMATE1293

Pietroniro, A., Toth, B., and T. J. 2006. Water availability in the South Saskatchewan River basin under climate change; presentation at Climate Change and Water in the Prairies Conference, Saskatoon, Saskatchewan, Powell, L.R., A.A. Berg, D.L. Johnson, and J.S. Warland. 2007. Relationships of pest grasshopper populations in Alberta, Canada to soil moisture and climate variables. Agricultural and Forest Meteorology 144:73-84.

Public Safety Canada: Canadian Disaster Database, 2011.

Running, S.W., and L.S. Mills. 2009. Terrestrial ecosystem adaptation. Resources for the Future Report.

Sanderson, Ken. 2013. Climate Change Adaptation Action Plans - Alberta Process Review. Prepared for the Biodiversity and Climate Change Adaptation Project. Miistakis Institute, Calgary, AB.

Sauchyn, D. and Kulshreshtha, S. 2008. Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by D.S. Lemmen, F.J.Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 275-328.

Sauchyn, D.J., Byrne, J.,Henderson, N., Johnson, D., Johnston, M., Keinzle, S. and E. Wheaton. 2007. Assessment of biophysical vulnerability; Alberta Environment, Alberta Vulnerability Assessment Project. Final Report. 79 p.

Schneider, Richard R. 2013. Alberta ' s Natural Subregions Under a Changing Climate : Past , Present , and Future. University of Alberta. Prepared for Alberta Biodiversity Monitoring Institute.

Schuster, C.J., Ellis, A., Robertson, W.J., Aramini, J.J., Charron, D.F. and B. Marshall, 2005: Drinking water related infectious disease outbreaks in Canada, 1974-2001. Can. J. Public Health. 94:254-258.

Sheffield, J. and E.F. Wood. 2007. Projected changes in drought occurrence under future global warming frommulti-model, multi-scenario, IPCC AR4 simulations. Climate Dynamics.

Shepard, A., Gill, K.M. and S.M. Rood. 2010. Climate change and future flows of of Rocky Mountain Rivers: converging forecasts from empirical trend projections and down-scaled global circulation modeling. Wiley Interscience online (www.wileyinterscience.com) DOI: 10.1002/hyp.781

Somerville, R.J.C. and S.J. Hassol. 2011. Communicating the Science of Climate Change. Physics Today. On-line source: http://www.climatecommunication.org/wp-content/uploads/2011/10/Somerville-Hassol-Physics-Today-2011.pdf (October 27 2013).

Thorpe, J. 2012. Adaptation to Climate Change in Management of Prarie Grasslands. Prepared for Prairies Regional Adaptation Collaborative (PRAC). Saskatchewan Research Council. SCR Publication No. 12855-1E12.

Thorpe, J. 2011. Vulnerability of Prairie Grasslands to Climate Change. Prepared for Prairies Regional Adaptation Collaborative (PRAC) Saskatchewan Research Countil. SRC Publication No. 128855-2E11.

Watmough, M. D. and M.J. Schmoll. 2007. Environment Canada's Prairie & Northern Habitat Monitoring Program Phase II: recent habitat trends in the PHJV. Environment Canada, Canadian Wildlife Service, Edmonton, AB.

White, S. R., F.C. James, and Edward W. Bork. 2013. "Implications of Precipitation, Warming, and Clipping for Grazing Resources in Canadian Prairies." Agronomy Journal. 33–42. On-line source: https://www.agronomy.org/publications/aj/abstracts/0/0/agronj2013.0085 (December 17, 2013).

Wolfe, B., Hall, R., Edwards, T. and J. Johnston. 2012. Developing temporal hydroecological perspectives to inform stewardship of a northern floodplain landscape subject to multiple stressors: paleolimnological investigations of the Peace--Athabasca Delta. Environmental Reviews. 20:191-210.

Wolfe, S., and J. Thorpe. 2005. Shifting sands: climate change impacts on sand hills in the Canadian prairies and implications for land use management. Prairie Forum 30:123-141.