Mount Assiniboine Provincial Park
Climate Change Assessment

A project supporting the development of a new
20-year Park Management Plan

Submitted by Compass Resource Management Ltd.
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Photos provided by BC Parks

Compass Resource Management

Table of Contents

Introduction

The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that the global atmosphere is warming, noting that the average global surface temperature has increased by nearly 1 ^{o}C over the past century and is likely to rise by another 1.4 to 5.8 ^{o}C over the next century (IPCC, 2001). Such simple statements however mask the highly variable and site-specific effects of climate change predictions. Atmospheric warming affects other aspects of the climate system: the pressure and composition of the atmosphere; the temperature of surface air, land, water, and ice; the water content of air, clouds, snow and ice; wind and ocean currents; ocean temperature, density, and salinity; and physical processes such as precipitation and evaporation. Climate change effects are expected to occur faster and be more pronounced over the mid and high latitudes of the Northern Hemisphere continents (IPCC, 2001).

Here in British Columbia, some of the detected changes in climate over the past century (BC WLAP 2002) include:

- Average annual temperature warmed by 0.6ºC on the coast, 1.1ºC in the interior, and 1.7ºC in northern BC.
- Precipitation increased in southern BC by 2 to 4 percent per decade.
- Sea level rose by 4 to 12 centimeters along most of the BC coast.
- Lakes and rivers become free of ice earlier in the spring.

Against the backdrop of these past and future predicted changes in climate, natural resource management planners across many sectors are turning toward impacts and adaptation planning. Climate change has important policy and planning implications for protected areas. Scott and Lemieux (2005) for example highlight the need to re-visit park management objectives and to take long-term climate change into account in the development of specific management strategies for individual species management, natural disturbances and visitation patterns.

This project adds a climate change component to the Mount Assiniboine Provincial Park Master Management Plan that is currently under development. The Climate Change Section of the BC Ministry of Environment provided funding and implementation support for the project. The broad purpose of this project is to explore and document the potential impacts of climate change in Mount Assiniboine Provincial Park, and to develop recommendations that can form part of adaptation response.

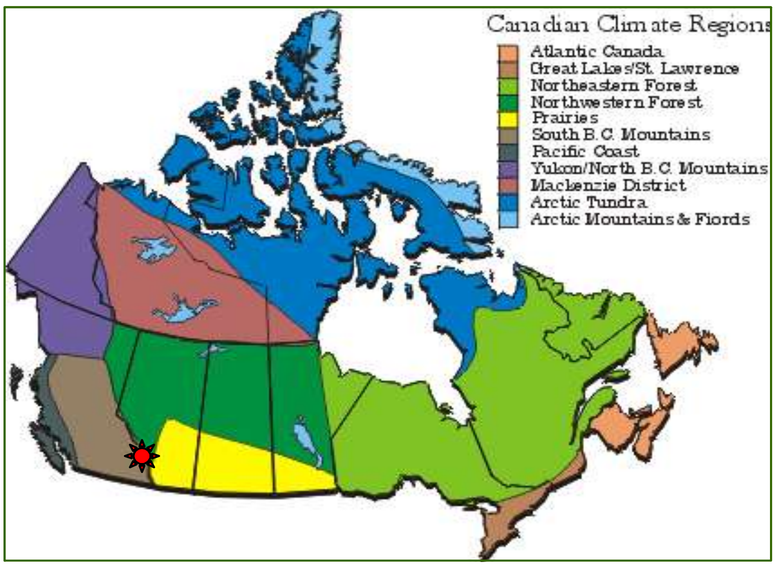
Specific project objectives include:

- To provide future climate change scenarios,
- To identify potential impacts in relation to key Park Management Objectives,
- To develop potential adaptation strategies for consideration in the Plan,
- To increase public awareness of climate change, and
- To identify gaps in knowledge and areas requiring further research

Potential Future Climate in Mount Assiniboine Provincial Park

Background on Current Climate and Recent Trends

Lying along the continental divide, between the southern British Columbia Mountains and Northwestern Forest Canadian climate regions (Figure 1), the area's climate is variously determined by the long-term frequency of air masses originating from the Pacific Ocean and the Arctic. This brings with it, high precipitation on the western side of the Rockies, particularly in the area of the highest mountains (generally, precipitation increases and temperature decreases with increasing elevation). Above approx. 2000 m, 75-80% of the annual precipitation falls as snow.



Source: Environment Canada website: http://www.msc-smc.ec.gc.ca/ccrm/bulletin/figclimate_e.html

Figure 1: Canadian climate regions

Historical trend analysis undertaken by the Canadian Institute for Climate Studies for the province of BC (BC MWLAP, 2002) indicate a general historical trend toward higher annual average temperature (Figure 2) and higher annual precipitation (Figure 3) in the Southern Interior Mountains Ecoprovince where the park is located. Changes in seasonal temperature and precipitation have also occurred in the region.

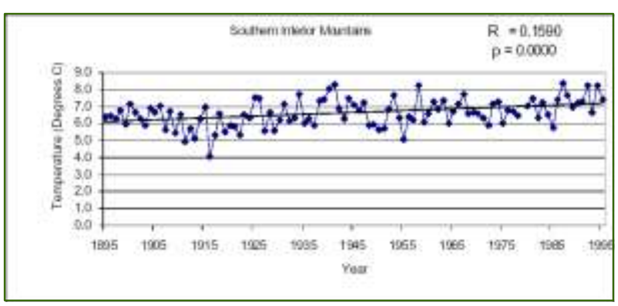


Figure 2: Historical trend in annual average temperature for the Southern Interior Mountains Ecoprovince. Statistically significant at the 5% level.

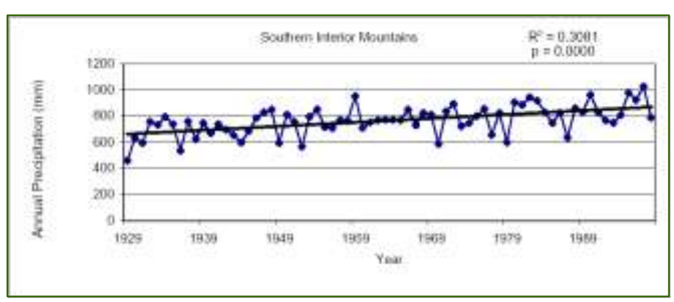


Figure 3: Historical trend in annual average precipitation for the Southern Interior Mountains Ecoprovince. Statistically significant at the 5% level.

Future Climate Scenarios

Climate change impact assessments begin with the development of future climate scenarios. Climate scenarios are descriptions of the future climate that are based on global circulation models (GCMs) of the atmosphere-ocean system and how it will evolve in the future using specific assumptions of future greenhouse gas emissions.

For this assessment, we selected five climate variables generally available from the GCM results that are thought to have the largest driving influence on natural ecosystem processes and human activities in the park. Table 1 presents a description of these variables and the basic rationale for including them.

Table 1: Climate variables selected for Mt. Assiniboine Park climate change assessment

Climate Variable	Description	Rationale
Temperature	Air temperature is a fundamental climate property and driver of all other climate systems (i.e., precipitation, wind speed, snow/ice development, etc.).	Temperature, both annual and seasonally, are a primary driving factor of natural ecosystem processes. Human activities are also closely linked to seasonal temperature patterns.
Precipitation	Precipitation – in all its forms – is another fundamental climate property.	Precipitation, both annual and seasonally, are a primary driving factor of natural ecosystem processes. Human activities are also closely linked to seasonal precipitation patterns.
Soil Moisture	Soil moisture is a derivative of both precipitation and temperature-driven evapotranspiration rates.	Soil moisture regimes are a key determinant of plant growth and other ecosystem processes.
Wind Speed	Wind speed	Wind speed plays a significant role in summer forest fire dynamics and winter snowpack loadings.
Snow Water Equivalent (SWE)	SWE is the depth of water from a column of melted snow, and therefore is a measure of how much water is stored as snow, and hence an indirect measure of snowpack / snow depth.	Snowpack dynamics are an important consideration for the park as a winter recreation destination. Changes in snowpack may affect the amount of water that is stored over the winter and released to groundwater aquifers and streams in the spring and summer.

Method

Future change projections in the selected climate variables were derived from the results of a range of GCMs run under a broad range of future greenhouse gas emission scenarios. This approach, which applies methods generally in accordance with the IPCC Data Distribution Center guidelines on the use of scenario data for impacts and adaptation assessments (IPCC-TGCIA, 1999), provides an opportunity for identifying both potential trends and the full range of uncertainty around them.

All data was extracted using tools provided by the Canadian Climate Impacts and Scenarios (CICS) project website at: www.cics.uvic.ca/scenarios/. This source provides access to a range of GCM results [Box 1].

Box 1: Global Climate Change Models / Centres

CGCM2	Canadian Centre for Climate Modelling and Analysis
HADCM3	Hadley Centre for Climate Prediction and Research
CSIRO-Mk2	Australia's Commonwealth Scientific and Industrial Research Organization
CCSR/NIES	Center for Climate System Research / National Institute for Env. Studies
ECHAM4	Max-Planck Institute for Meteorology
GFDL-R30	Geophysical Fluid Dynamics Laboratory
NCAR-PCM	National Centre for Atmospheric Research

For each climate variable analyzed, the following inputs were used to download results from the CICS scenarios website:

Geographic Reference: The tool extracts results from GCM model grid cells containing a specific geographic reference. We used 51oN 115.5oW, which represents a central location within Mt. Assiniboine Park. The procedure used is the recognized method of scenario application, which simply assumes that grid cell changes can be applied equally to any specific location within the grid cell (i.e., no spatial or temporal downscaling of global climate model information was undertaken).

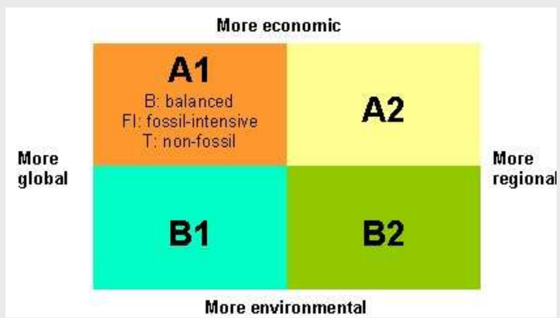
Time of Year: The time period can be specified over which results are averaged. We selected both seasonal and annual results for each climate variable.

Emissions Scenarios: We chose to extract the modeling results from the most recently available “SRES” emission scenarios that were developed for the IPCC’s Third Assessment Report (Nakicenovic et al., 2000). The SRES scenarios cover a wide range of the main driving forces of future emissions, from demographic to technological and economic developments [Box 2].

Box 2: The SRES Emission Scenarios

The main suite of SRES (Special Report on Emission Scenarios, IPCC) scenarios are differentiated using primary assumptions along two axes: Economic / Environmental and Global / Regional. The storylines for each family of SRES scenarios describe alternative future global development patterns:

- A1: Very rapid economic growth and the rapid introduction of new and more efficient technologies.
- A2: Regionally-oriented economic development and technological change more fragmented and slower.
- B1: Rapid change toward a global service / information economy based on clean and resource-efficient technologies.
- B2: Intermediate levels of economic development and less rapid and more diverse technological change; emphasis on local level.



From the overall database of downloaded results – which varied from 8 to 25 predictions depending on the climate variable since not all GCMs calculate all variables – we chart the full "envelope" of scenario results for each time slice (Figures 4 and 5). We then examine each climate variable range envelope over time in order to interpret both potential trends and the magnitude of uncertainties.

The GCM results comprise 30-year monthly mean changes (i.e., no information is presented about changes in inter-annual or inter-daily variability.) All data is extracted as change values, expressed either in absolute or percentage terms, with respect to the 1961-1990 model-simulated baseline period. Results are therefore generally reported as the change between the 1961-1990 30-year mean period, and the future 30-year mean period (e.g., 2020s, 2050s or 2080s). These time periods represent 30-year mean fields centred on the decade used to name the time period, e.g., the 2020s represent the 30-year mean period 2010-2039, the 2050s represent 2040-2069 and the 2080s represent 2070-2099.

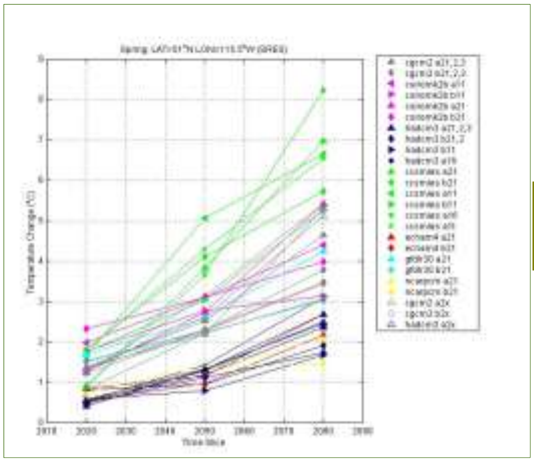


Figure 4: Example chart of change field data extracted for mean temperature change during the spring time period. In this case, a total of 25 different results are available from the combination of GCMs run over various SRES scenarios.

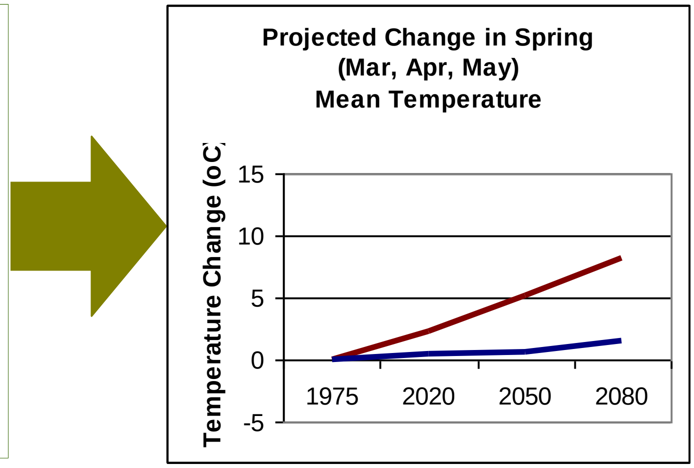


Figure 5: Example of simplified chart used for summary purposes. In this case, only the change is presented, therefore the 1975 point of reference is placed at zero. The upper and lower lines represent the highest and lowest possible scenario results at each time slice.

Results

Figure 6 presents further information regarding the interpretation of the climate envelope projections that are provided below for each of the selected climate variables in Table 1.

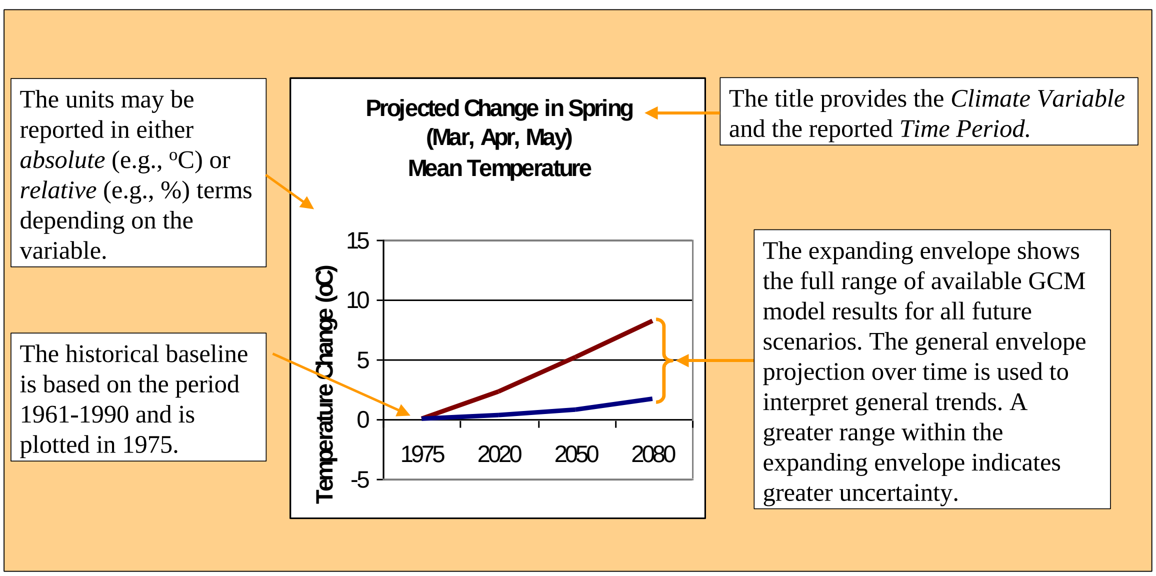
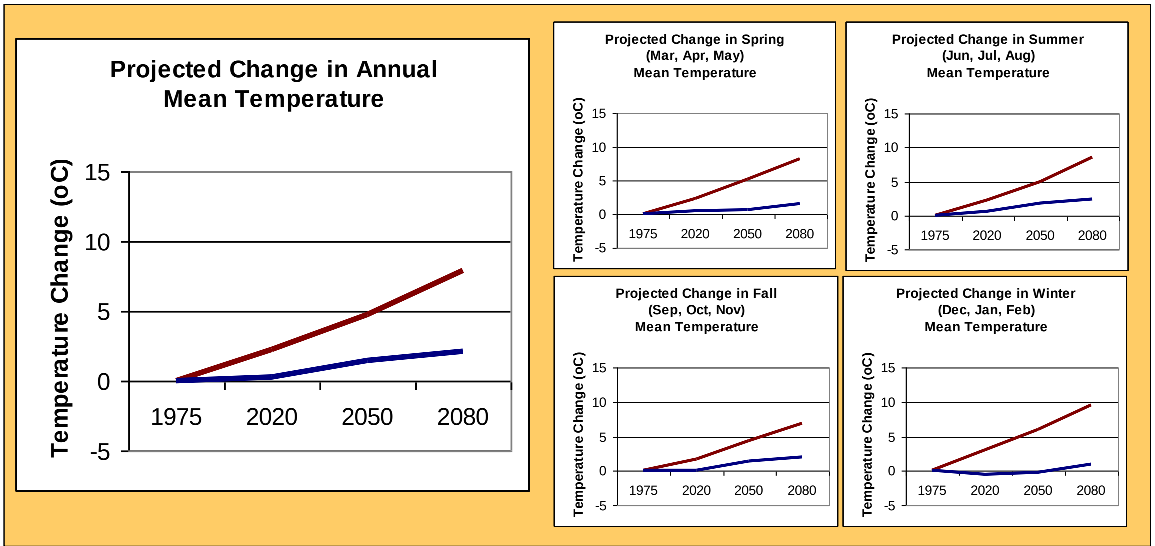


Figure 6: Interpretation of the climate projection envelope line charts

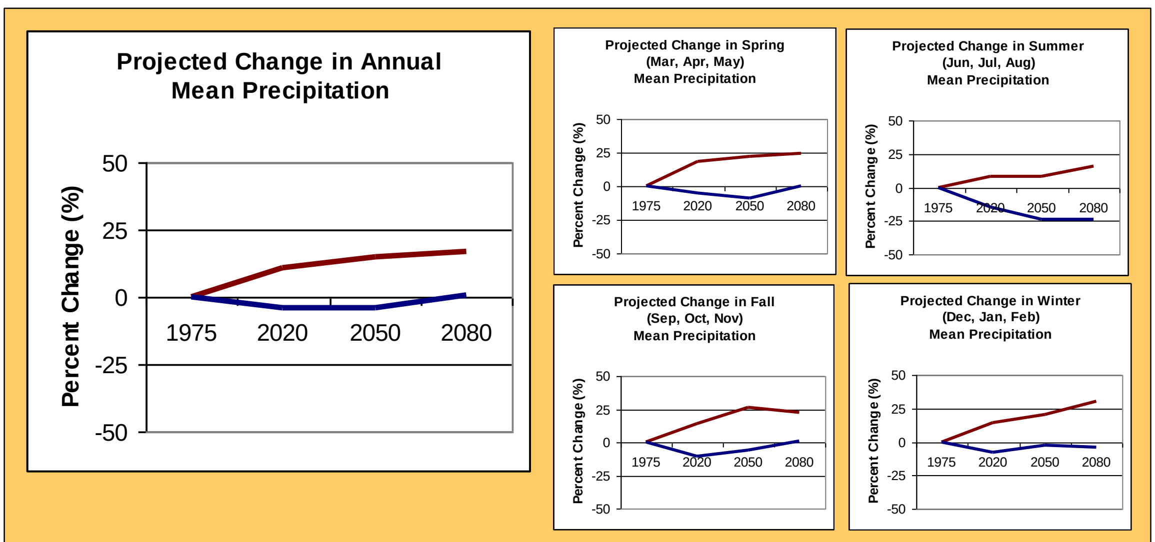
The following figures present the climate change scenario results for the five climate variables analyzed for Mount Assiniboine Provincial Park: temperature, precipitation, soil moisture, wind speed, and snow water equivalent.



Summary:

- Mean temperature is generally predicted to rise steadily over time annually and across all seasons in Mt. Assiniboine Park.
- By 2080, the increase over the baseline mean temperature is predicted to be in the range of:
    - +2.1 to +7.9 °C on an annual basis
    - +1.5 to +8.2 °C in the spring months
    - +2.3 to +8.5 °C in the summer months
    - +1.9 to +6.9 °C in the fall months
    - +1.0 to +9.5 °C in the winter months

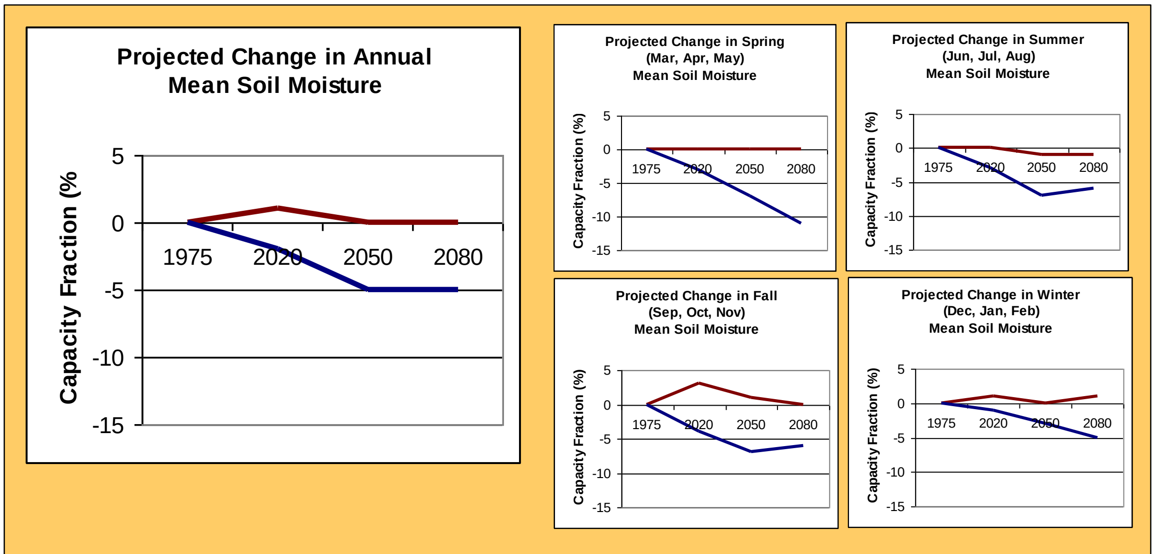
Figure 7: Projected change in mean temperature in Mt. Assiniboine Park



Summary:

- Mean precipitation may either rise or fall over time in Mt. Assiniboine Park depending on the season and timeframe of interest. Over the long term, there is greatest uncertainty in the summer, where results indicate there may be either a rising or falling trend.
- By 2080, the change in mean precipitation is predicted to be in the range of:
    - +1% to +17% on an annual basis
    - 0% to +24% in the spring months
    - –24% to +16% in the summer months
    - +1% to +22% in the fall months
    - –4 % to +30% in the winter months

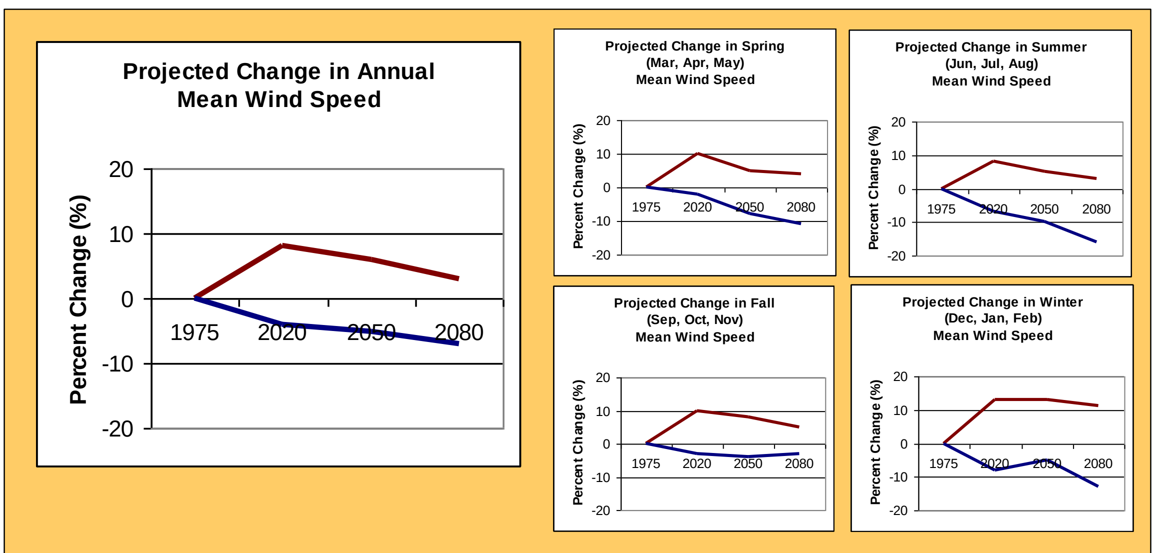
Figure 8: Projected change in mean precipitation in Mt. Assiniboine Park



Summary:

- Mean soil moisture is generally predicted to drop over time across all seasons in Mt. Assiniboine Park.
- By 2080, the change in soil moisture capacity fraction (percent) is predicted to be in the range of :
  - 0% to –5% on an annual basis
  - 0% to –11% in the spring months
  - –1% to –6% in the summer months
  - 0% to –6% in the fall months
  - +1% to –5% in the winter months

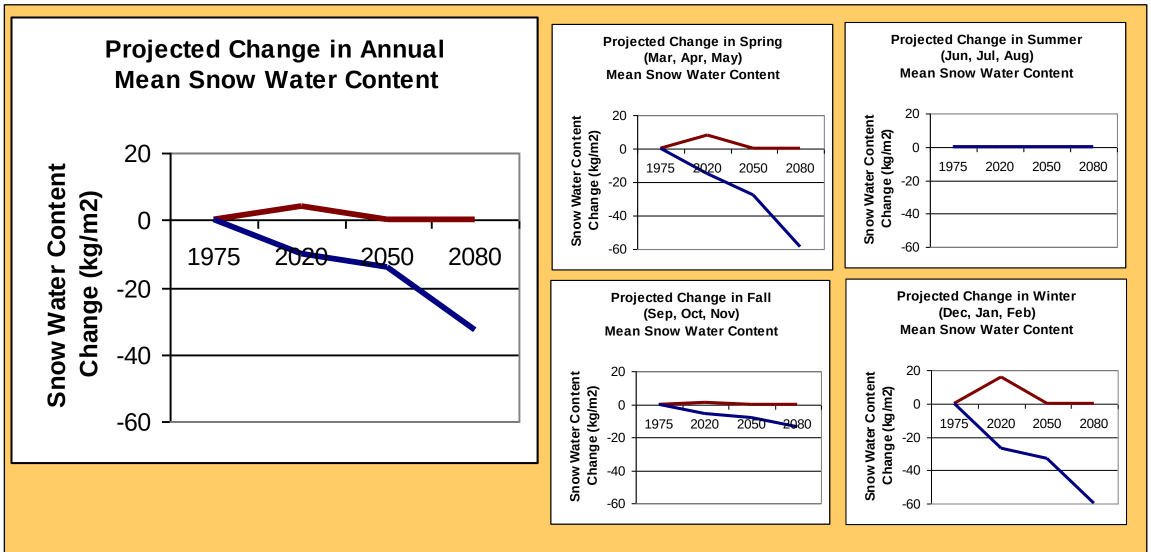
Figure 9: Projected change in mean soil moisture in Mt. Assiniboine Park



Summary:

- Mean wind speed may either rise or fall over time in Mt. Assiniboine Park depending on the season.
- Wind speed displays significant uncertainty, results indicate that there may either be a rising or falling trend both annually and across all seasons.
- By 2080, the change in mean wind speed is predicted to be in the range of:
  - +3% to –7% on an annual basis
  - +4% to –11% in the spring months
  - +3% to –16% in the summer months
  - +5% to –3 % in the fall months
  - +11% to –13% in the winter months

Figure 10: Projected change in mean wind speed in Mt. Assiniboine Park



Summary:

- Mean snow water equivalent is generally predicted to drop over time in Mt. Assiniboine Park, most significantly in the winter and spring seasons.
- By 2080, the change in mean snow water equivalent is predicted to be in the range of:
  - –33 to 0 kg/m^2 on an annual basis
  - –59 to 0 kg/m^2 in the spring months
  - No change in the summer months
  - –14 to 0 kg/m^2 in the fall months
  - –60 to 0 kg/m^2 in the winter months

Figure 11: Projected change in mean snow water equivalent in Mt. Assiniboine Park

Summary and Discussion

Table 2 provides a summary of the climate change scenario results for key climate variables that influence natural ecosystem processes and human activities in Mt. Assiniboine Park. Mean temperature is generally projected to rise steadily over time, both annually and seasonally. Mean precipitation is generally projected to rise over time, varying annually and seasonally, with the greatest uncertainty in summer. Mean soil moisture is generally projected to decrease over time, both annually and seasonally. Mean wind speed projects significant uncertainty both annually and seasonally, with the greatest uncertainty in winter. Mean snow water content is generally projected to decrease over time, both annually and seasonally, with the greatest decreases projected for winter and spring.

The trends and envelope ranges found here are generally consistent with those reported by the IPCC for northern hemisphere (IPCC, 2001). They are also generally consistent with the results reported in a screening level assessment of climate change impacts on Jasper, Banff and other surrounding national parks (Scott and Suffling, 2000).

Table 2: Summary of change scenarios for selected climate variables to 2080

Variable	Focus Period	Range of Magnitude / Directions of Change	Summary of Projections
Mean Temperature	Annual	+2.1 °C to +7.9 °C	- Generally projected to rise steadily over time, annually and seasonally
	Summer Winter	+2.3 °C to +8.5 °C +1.0 °C to +9.5 °C	
Mean Precipitation	Annual	+1% to +17%	- Generally projected to rise over time, varying annually and seasonally - Greatest uncertainty in summer
	Summer Winter	-24% to +16% -4% to +30%	
Mean Soil Moisture	Annual	0% to -5%	- Generally projected to decrease over time, annually and seasonally
	Spring Summer	0% to –11% -1% to –6%	
Mean Wind Speed	Annual	-7% to +3%	- Significant uncertainty both annually & seasonally - Greatest uncertainty in winter
	Summer Winter	-16% to +3% -13% to +11%	
Mean Snow Water Equivalent	Annual	-33 to 0 kg/m^2	- Generally projected to decrease over time, annually & seasonally - Greatest decrease in winter and spring
	Spring Winter	-59 to 0 kg/m^2 -60 to 0 kg/m^2	

Cautionary Note

While some comfort can be found in the consistency of the climate variable envelope predictions found for the Mt. Assiniboine Park region and those of other studies, we must stress the limitations that face the application of any GCM-derived results for detailed impact and adaptation planning.

A primary limitation is that the spatial grid resolution of most GCMs is between 250 and 600km. This coarse scale clearly presents a challenge for the interpretation of results in BC, where significant differences in local climate can occur over a much smaller scale. A derivative of this spatial resolution limitation is that the current generation of GCMs does not perform as well in complex terrain, and cannot incorporate climate influences at the micro-scale (Suffling & Scott, 2002).

Hamlet et al. (In Press) point out additional limitations regarding the base data used to initiate GCMs. First, the sparseness of primary driving data in some areas can artificially suppress spatial variability. Second, in some areas the "forcing data" (precipitation and temperature) are derived from low or moderate elevation stations, and therefore may provide an incomplete indication of potential trends at very high elevations.

B.C.'s climate is strongly influenced by cyclical changes in the surface temperature of and atmospheric sea level pressure over the Pacific Ocean (i.e., the El Nino Southern Oscillation and the Pacific Decadal Oscillation). The natural climate variability caused by these cycles make it a challenge to draw inferences across past climate records on record and future climate scenarios from GCMs (PCIC, 2006).

Fortunately, improvements are underway on several fronts. The CICS scenarios project website (http://www.cics.uvic.ca/scenarios/) provides an overview of both statistical downscaling and regional climate modeling approaches that show some promise in resolving both the spatial and temporal resolution scale problems.

Despite these limitations, GCMs provide a good source of accessible future climate information. From an adaptation planning perspective, the primary challenge is to incorporate the potential trends in key climate variables while simultaneously recognizing the inherent uncertainties associated with GCM-derived predictions.

Potential Climate Change Impacts on Mount Assiniboine Provincial Park

Based on the above climate variable envelope predictions, our second focus was to identify potential impacts on park resource values.

The steps we took included:

- preliminary identification of potential climate sensitivities based on a review of previous Park management plans and background documents,
- literature review of recent climate change research and impact studies completed in the region of the Park, e.g., adjacent National Parks,
- participation in a multi-stakeholder workshop, attended by park users, interest groups, tourism operators, and management staff,
- refinement based on feedback from staff and contractors involved in the development of the Park Plan.

As an outcome of these steps, we organized the assessment around three priority impact areas: 1) the potential for ecosystem shifts and the impact on alpine meadows, 2) the potential increase of natural disturbances such as wildfire and insect outbreak, and 3) the potential for impacts to glaciers, snowpack, and hydrology. Each of these areas has both underlying ecosystem concerns and parallel human resource use concerns as discussed in the following sections.

Ecosystem Shifts: A Threat to Alpine Meadows

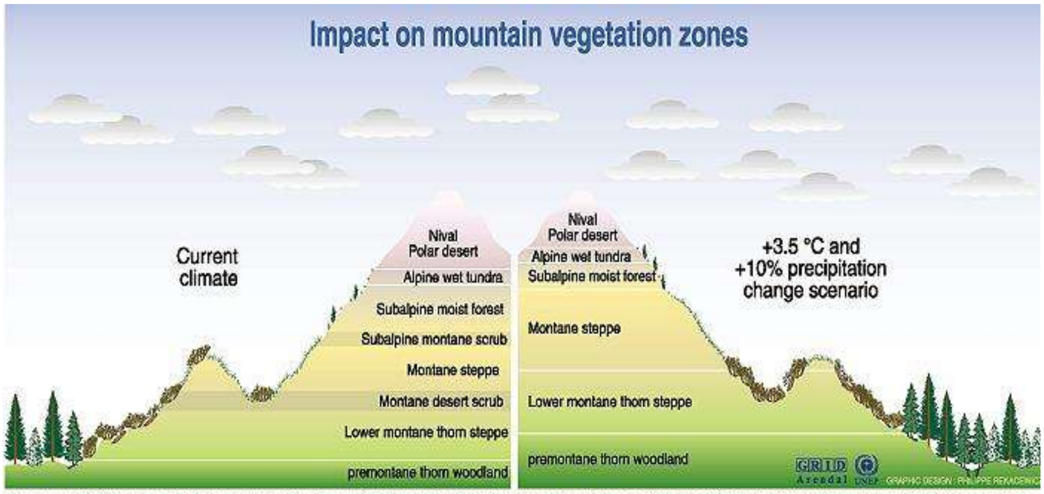
Numerous studies have concluded that we can expect significant changes in forest and alpine ecosystems from changes in the primary climate variables of temperature and precipitation, and resultant changes in such compound variables as soil moisture, growing season length, and other climate-related drivers of vegetation.

BC Parks

Of primary concern, is the potential impact on alpine meadows in the Park, which currently represent only 2% (776 ha) of the Park area (Stevens, 2006). The existing range and distribution of forest ecosystem types and tree species that exist today in the Park are a result of long-term climate patterns.

The Vegetation section of the Management Plan Background Document (Wildland Consulting Inc., 2005) describes the current forest ecosystems in the Park using the BC Biogeoclimatic Ecosystem Classification (BEC) system, which is a hierarchical classification system that delineates major forest types with homogeneous macroclimate (Meidinger & Pojar, 1991). The document describes the 2 zones currently in the Park: Engelmann Spruce – Subalpine Fir Zone (ESSF) dk, dku, dkp variants, which currently occurs in the sub-alpine between approximately 1500 m to 2500 m; and Alpine Tundra Zone (AT), which occurs above the ESSF (greater than 2500 m). The spectacular alpine meadows, which are of high visual and recreation value, are covered with vegetation that is sensitive, fragile, and in some cases already damaged, making these meadows of high conservation value (BC Parks Conservation Risk Assessment, 2002, as cited in Wildland Consulting Inc., 2005). A third major BEC zone of note exists just to the west of the current park boundary, in Kootenay National Park: Montane Spruce Zone (MS) dk variant, which occurs below the elevation of the ESSF.

There has been a great deal of research conducted into the potential changes in forest ecosystems as a result of climate change (Lemmen and Warren, 2004; Iverson and Prasad, 2002; Lenihan and Neilson, 1995). Based on the generally predicted ‘warmer-wetter’ scenario, such as we have shown for the Park region, some of the most commonly cited predictions are that forest ecosystems and individual tree species will migrate northward and to higher elevations (see Figure 10). This general trend is supported by evidence of tree line shifts in the Canadian Rockies during the warming over the last century (Luckman and Kavanagh, 2000).



Sources: Martin Benitson, Mountain environments in changing climates, Routledge, London, 1994; Climate change 1995, Impacts, adaptations and migration of climate change, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change (IPCC), UNEP and WMO, Cambridge press university, 1996.

Figure 13: Conceptual diagram of shifting mountain vegetation zones

However, ecosystems will not shift as a unit, but rather species will respond individually to changes in climate over time (Scott & Suffling, 2000). Altered competitive relationships, human interference, altered disturbance regimes, e.g., insect, disease, fire, drought, wind, microclimatic effects, and local topographic/site factors (e.g., north- vs. south-facing slopes) also influence composition and distribution (Scott, Malcolm & Lemieux, 2002; Luckman & Kavanagh, 2000). While species will shift as they track more ideal climatic conditions, new assemblages of species will not stabilize overnight, or even over decades. In the past, it has taken centuries for the vegetation and soils to reflect a major change in climate regime, and for new ecological communities to stabilize (see Lemieux & Scott, 2005 and Suffling & Scott, 2002). In the case of Mt. Assiniboine Park, the potential for generally decreased soil moisture in the spring and summer seasons could be expected to limit the general trend toward forest ecosystem range expansion to higher elevations.

Based on 1) the future climate envelope projections in the previous section, i.e., a generally warmer-wetter future climate, and 2) the general forest ecosystem response trends, e.g., migration to higher elevations, we can hypothesize the potential for forest ecosystem boundary shifts in Mt. Assiniboine Park. The general response (shown conceptually in Figure 14), is that over the long term we should expect to see:

- AT: A general decrease in area, caused by encroachment of the forested ESSF zone to higher elevations.
- ESSF: A net increase in area, with gains in elevation more than offsetting losses at lower elevations.
- MS: An increase in area, expanding into park boundaries from the west.

Two key points to be emphasized in these hypotheses are that 1) changes will occur very slowly over time, and 2) given the overlap in tree species across all forested zones, the actual area representation of any species at any point in the future is more a function of disturbance-driven forest age class distribution.

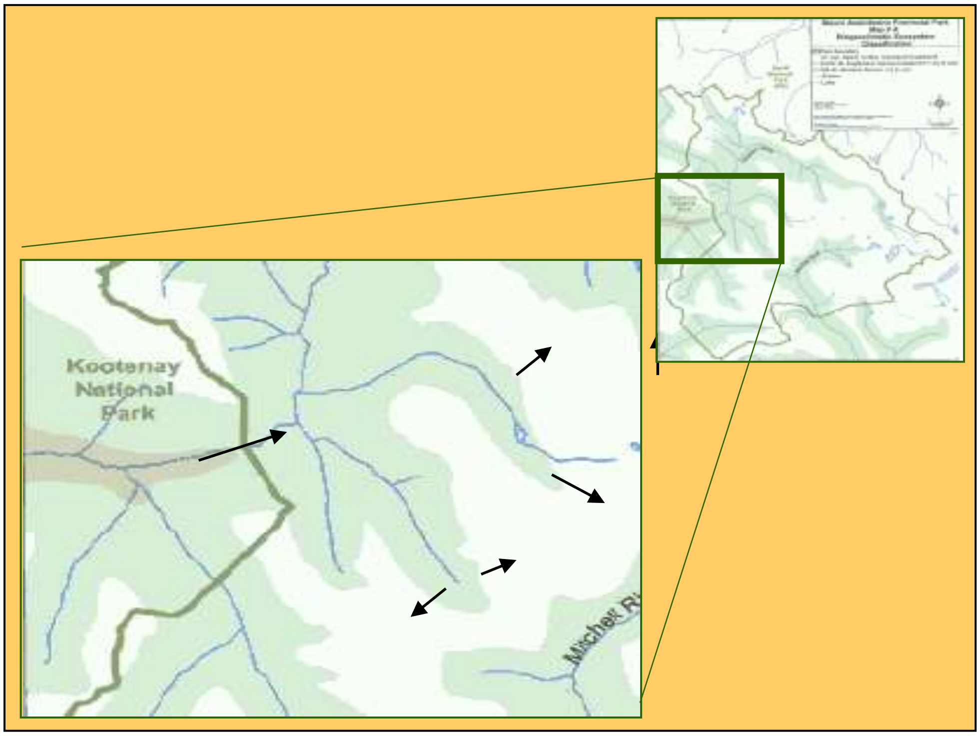


Figure 14: Conceptual Representation of Potential Expansion of ESSF and MS Zones

To augment these initial hypotheses, we reviewed results from a provincial-scale modeling study of the potential effects of climate change on forest ecosystem and tree species distribution as undertaken by researchers at the UBC Department of Forest Sciences. Table 3 below, presents a subset of long-term results (i.e., 2085 projections) from the province-wide study of potential BEC-zone climate envelope shifts (Hamann and Wang), indicating the general potential for future predicted climate to "shift" the AT zone toward ESSF, and ESSF toward MS, IDF and ICH. Although park-specific data are not available, these general results are consistent with the other literature discussed previously.

Table 3: Shift of Climatic Envelopes for BEC Zones

(Data extracted directly from Appendix 1C in Hamann and Wang)

	To Zone:				
From Zone:	AT	ESSF	MS	ICH	IDF
AT	21%	60%	2%	1%	0%
ESSF	1%	10%	7%	54%	9%

In terms of long-term management implications, the most significant concern is the potential for forest encroachment into alpine meadows in the park, and the resultant potential loss of some species and a net loss of biodiversity. Other implications from a changing alpine treeline include moderated temperatures within forest patches, altered snowpack distribution, and a more continuous fuel source for fire (Fagre, 1999). From a human-use perspective, the warming climate may mean a longer season for warm-weather outdoor recreation activities, which can have negative impacts on fragile alpine meadows. It has been suggested that the 'filling in' of forest vegetation may impact some recreational activities in the Park, such as tree skiing (pers. comm. with Park tourism operator, 2006). A reduction in the extent of alpine meadows, together with glacier recession, may significantly modify the alpine scenery, and result in tourism impacts.

Natural Disturbance Patterns: Wildfire and Insects

In a park setting, natural disturbance is generally recognized as an integral part of the regular functioning of the ecosystem, and as such something to be promoted through management. That said, significant disturbances including major wildfires or insect outbreaks are possible, and the potential for climate change to influence them warrants consideration.

Under climate change, impacts to ecosystems and tree species as discussed above are expected to occur over long periods of transition. Changes to natural disturbance patterns, on the other hand, may occur much more frequently. The Canadian Forest Service states that the changes in disturbance regimes will likely have a greater effect on Canadian forests than the direct effects of climate change on the distribution and migration of forest species (CFS, 1999). For this reason, the potential for climate change effects on natural disturbance patterns, in particular wildfires and insect outbreaks, warrants investigation.

Wildfires


Image provided by MOE

Climate is a primary determinant of wildfire impact, along with fuels, topography and ignition sources. Researchers at the Canadian Forest Service are currently involved in numerous studies into the potential effect of climate change on the fire environment (CFS, 2005). While overview assessments point toward a future significant increase in both fire frequency and severity across most forested regions of Canada under current climate change projections, researchers are quick to emphasize the difficulty in applying GCM trends in general to area-specific wildfire assessments.

In this regard, the climate envelope projections for the Mt. Assiniboine Park region provide a case in point. Although increased summer and annual mean temperatures and reduced soil moistures might point to increased fire activity in the future, the potential for significant decreased wind speeds and increased precipitation might point to reduced fire activity.

Although the climate component of the wildfire equation has significant future uncertainties, the fuels component is clearer. Active fire suppression in the Park over many decades now has disrupted the natural disturbance cycle. The resultant lack of recent fires and subsequent "overgrowth" of vegetation contributes to a general build up of fuels and may act to increase the frequency and severity of fires (pers. comm. with Park tourism operator, 2006). An increased potential for fire can increase the risk to human safety, damage to park infrastructure, impair recreational access to high fire-risk areas, and add management or emergency costs (Suffling & Scott, 2002).

Insect Outbreaks

Numerous research reports point toward a concern over the potential for future climate change to trigger an increase in the frequency and intensity of insect outbreaks (Ayres and Lombardero, 2000; Gauthier *et al* 2004; Climate Change Impacts and Adaptation Directorate, 2004). Although many uncertainties remain, a growing body of research suggests that:

- insect damage may become more severe with warming and atmospheric carbon dioxide enrichment;
- increased growing season length, increased forest stress, and less severe winters may preferentially support range expansion of some insects; and
- climate change may directly impact insect biodiversity, including allowing alien species to survive.

BC Min. of Forests

As a specific BC example, it is widely believed that the current unprecedented mountain pine beetle (MPB) epidemic being experienced in BC is at least partially climate driven. Two important aspects of the MPB outbreak cycle that are particularly linked to climate include (BCMOF, 2005):

- Summer emergence, where adequate daily high temperatures are required to trigger flight and thus dispersion of beetle populations, and
- Cold tolerance, where extreme cold thresholds are known to cause significant larval mortality and thus outbreak collapse.

Researchers at the Canadian Forest Service have undertaken a study of the potential effects of climate change on MPB range expansion in British Columbia (Carroll et al., 2004). The results indicate that during the latter half of the last century there has been a substantial shift in climatically suitable habitats for MPB. And, most importantly, there has been an increase in the number of infestations since 1970 into these newly climatically suitable habitats. The researchers conclude that "given the rapid colonization by mountain pine beetles of former climatically unsuitable areas during the last several decades, continued warming in western North America associated with climate change will allow the beetle to further expand its range northward, eastward and toward higher elevations" (Carroll et al., 2004).

While there is now only a small mountain pine beetle infestation in the lower Mitchell drainage of the Park, the generic potential for this or some other insect population to expand into a major disturbance should be taken into consideration in the long-term management of park values.

Finally, there should be consideration given to the potential increase in invasive species following any climate change induced impacts on natural disturbance patterns in the park. Invasive species often use the opportunity provided by vegetation disturbance to expand their range and thus displace native species. The potential for an increase in invasive species raises an important policy consideration in light of climate change. Scott and Lemieux (2005) note that the arrival of new species may in fact signal successful autonomous adaptation by a species to climate change. This suggests that invasive species “impacts” will need to considered on a case-by-case basis.

Glaciers, Snowpack, and the Hydrological Cycle

Glaciers

Retreating glaciers are perhaps one of the most immediately evident impacts of warmer temperatures in the Northern Hemisphere, and studies elsewhere in BC are already measuring significant effects. For example the study by Luckman and Kavanagh (2000) reports that glacier cover has decreased by at least 25% in some parts of the Canadian Rockies during the 20th century, and glacier fronts have receded to positions last occupied ca. 3000 years ago. Another study of the Columbia River Basin reports a 16% reduction in glacier cover over the period 1986 – 2000 (PCIC, 2006). With warming climate, we should expect continued retreat of low elevation glaciers, perhaps with greater intensity (PCIC, 2006). Glaciers currently represent 10% (3,875 ha) of the Park landscape (Stevens, 2006). While effects on higher elevation glaciers, such as those in the Park, are likely lessened due to some level of continuing snow accumulation during winter and spring (PCIC, 2006), it is still a concern. In addition, earlier spring glacial melt can lead to increase the risk of rock avalanches and erosion of fragile landforms, fossil beds and Karst sites within the Park.

Snowpack

As a winter recreation destination, the effects of climate change on snowpack are of great interest. GCM projections to 2080 for this region point toward a general decrease in snow water equivalent (SWE), an indirect measure of snowpack. This is particularly true during the winter and spring seasons when snowpack reaches its peak and transitions toward melt and runoff (see Table 2 above).

At lower/moderate elevations elevations, we can expect that increasing temperatures will result in more precipitation falling as rain rather than snow, and therefore a future trend toward reduced snowpack (Mote, 2004; PCIC, 2006). Hamlet *et al.* (In press) note that past trends for peak snow accumulation and 90% (of peak) melt have generally been occurring earlier in the year, implying that these changes are primarily a winter temperature regime-related effect. They note that most snow simulations assume that temperatures below -0.5^{o}C result in 100% snow and those above 0.5 ^{o}C result in 100% rain, with a linear relationship between these extremes. Mote *et al.* (2005) suggest that it is the increasing frequency of melt events from warming that produces lower spring SWE, rather than simply an increase in precipitation in the form of rain.

This prediction is consistent with high-resolution model projections of snowpack that show an average reduction of 11.5% by the 2040s for the Columbia Basin (PCIC, 2006).

At higher elevations, the results may be different. Current research suggests that colder areas are predominantly driven by precipitation changes, rather than temperature changes. For example, past trends for high elevation areas with upward precipitation trends have produced concurrent upward trends in snow water equivalent over the same time period in the western U.S. (Hamlet et al., In Press). Another study suggests that most areas in the Rocky Mountains "are so cold that a warm winter has little effect on spring snowpack …and winter precipitation is the major factor" (Mote *et al*., 2005, p. 45). GCM projections to 2080 for the park region are for generally increasing winter and spring precipitation (see Figure 8 above), therefore we are tempted to predict that on average there may be an increase in snowpack over time. However, it is again important to emphasize that both past trend analysis and future GCM projections are driven by records at existing weather stations that are generally at low elevations, therefore extrapolation of results to high elevation areas such as in the Park should be done with caution.

Wildlife winter range and migration may be impaired at higher elevations that experience increasing snowpack (Scott & Suffling, 2000). Increasing precipitation over the long-term may cause increasing frequency of landslides/debris flows (PCIC, 2006), and greater backcountry avalanche risk with subsequent emergency costs (Suffling & Scott, 2002). Park activities that largely depend upon the snowpack for water supply may be at-risk from increasing precipitation as rain rather than snow (PCIC, 2006).

Source unknown

Hydrology

Beyond glaciers and snowpack, further impacts on the hydrological cycle can be expected in the future, although there is a great deal of uncertainty. The net effect of combined changes in predicted temperature, precipitation, glaciers and snowpack on other components of the hydrological cycle is difficult to predict, and few studies exist that focus on the hydrological impacts in high elevation areas.

From other research, some trends are becoming clear, such as the trend toward earlier spring peak flows and reduced runoff volumes from late spring to early fall (Hamlet & Lettenmaier, 1999). There is speculation that the potential for decreased summer precipitation, in combination with longer growing seasons and reduced summer streamflow, may increase droughts, despite increased spring runoff (PCIC, 2006). Reduced soil moisture may contribute to soil erosion, loss of wetlands, slower vegetation growth, and declines in ground-water supplies and water quality in some areas. Reduced late summer and fall flow from decreased glacial inputs may occur, however this may be offset by increases in overall precipitation during these same seasons.

BC Parks

In winter, streams may have higher flows and more frequent flooding, due to a greater proportion of precipitation falling as rain. Warmer temperatures may result in longer ice-free time on lakes and rivers, i.e., earlier thawing and later freezing (PCIC, 2006). And during the transition back toward spring and summer, during periods of increasing melt water, fragile landforms may face increasing risk of erosion (Scott & Suffling, 2000), e.g., South Core fossil beds, Karst topography sites.

Collectively, there are a various changes in the hydrological cycle that may occur over the long term, and further consideration should be given to the potential for impacts on fish, wildlife and other resources that are directly sensitive to change.

Summary

Table 4 provides an overview some of the key long-term trends and major uncertainties in the three priority impact areas identified for assessment in Mt. Assiniboine Park. These results provide a starting point for consideration of the potential management actions to be considered in the next section.

Table 4: Summary of potential climate change impacts in Mt. Assiniboine Park.

Issue	Key Long-term Trends	Confidence[!]	Major Uncertainties
Ecosystem Shifts	Increase in forested area, primarily with ESSF zone tree species migrating to higher elevations.	Likely	The rate of change.
	Decrease in AT zone, potential loss of alpine meadows.	Likely	The extent to which individual tree species are able to utilize new habitat.
Natural Disturbance	Increase in high fire weather indexes, and resultant increase in the probability of major wildfires.	Possible	The rate of change. Future fire season precipitation.
	Increase in the climatic suitability for forest insects, and resultant increase in the potential for major outbreaks.	Likely	The rate of change.
	Increase in the number of invasive species and potential for displacement of indigenous vegetation.	Possible	
Glaciers, Snowpack & Hydrology	Retreat of glaciers at the lowest elevations.	Possible	Elevation thresholds for melting.
	Reduced snowpack at low/moderate elevations.	Likely	The influence of site-specific topographical features
	Earlier spring peak flows and reduced runoff volumes from late spring to early fall	Possible	Summer precipitation trends.

! Note: The subjective confidence rating scales are based on UKCIP framework guidance as follows: Virtually certain (> 99%), Very likely (90–99%), Likely (66–90%), Possible (33–66%).

Managing Impacts due to a Changing Climate

In this section we present a summary of potential management actions to be considered in the Mt. Assiniboine Park Management Plan based on the preceding assessment of potential future climate and potential future climate change impacts. These management actions are grouped into topic areas that align with those in the Management Plan and are intended to augment the current management objectives and strategies.

Climate change impact assessment and adaptation planning is fundamentally a long-term challenge fraught with considerable uncertainty. Not surprisingly then, many of the suggested management actions listed below focus on data gathering in order to improve the knowledge basis upon which to make future decisions. That said, there are many climate-sensitive decisions that can be taken today, for example dealing with forest disturbance management, that have significant short and long term implications for multiple park values.

For these decisions, a key long-term choice facing park managers is whether to continue with a relatively 'hands off' or passive approach to management, or to adopt a more active, interventionist approach to management (Scott, Malcolm, & Lemieux, 2002). Adaptive management, which has both passive and active forms, is a recommended strategy for protected area agencies as they deal with effects of climate change (Scott & Lemieux, 2005; Prato, 2003).

Table 5: Management recommendations

Topic	Assessment / Discussion	Draft Management Recommendation
Ecosystem Management Approach	Most park and protected area planning systems in North America are based on "fixed representational approaches" that aim to preserve representative ecosystems in specific, well-bounded locations. Unfortunately, as other climate researchers have noted, the plans that result from this approach are most often "designed to protect specific natural features, species and communities *in situ*, and are not taking into account landscape-level shifts in ecosystem distribution and structure that could be induced by twenty-first century climate change" (Lemieux & Scott, 2005, p. 385). Direct statements that recognize the challenge to fixed representational systems posed by climate change are now required.	▪ As part of the Park's stated ecosystem management approach, formally recognize that climate change may result in long-term shifts in ecosystem components (e.g., specific species changes) and ecosystem processes (e.g., natural disturbance frequencies). Acknowledge at the policy level the challenge posed to a fixed representational approach. ▪ Cooperate with adjacent parks and other landowners to address potential climate change impacts on ecosystem components and ecosystem processes. Develop integrated adaptation strategies over a broader spatial scale.
Water	The combined long-term effect on water resources of changes in glacier melting, snowpack development and the timing of peak spring runoff volumes is difficult to predict based on current levels of data and uncertain climate change forecasts. Targeted monitoring activities will accelerate the ability to discern climate change trends.	▪ Collect key data specifically aimed at detection of long-term climate change trends including: - glacier terminus positions, - date and depth of peak snow accumulation, - date and volume of peak spring run-off, - annual lake freeze and thaw dates, - minimum summer stream flows. ▪ Collaborate with other jurisdictions on long-term monitoring of climate data and modelling of climate change effects on glaciers, snowpack and hydrology.

Topic	Assessment / Discussion	Draft Management Recommendation
Vegetation	Long-term climate change is likely to impact vegetation in the Park via direct influence on the climatic suitability of areas for different ecosystems and different species. Superimposed on these impacts are those triggered by changes to natural disturbance regimes, most notably a potential increase in the probability of major fires and insect outbreaks. The alpine meadows and vegetation types that comprise them are perhaps most at risk. A future warmer-wetter climate may result in direct loss of area due to forest encroachment, or loss of individual species that are displaced by new invasive species. The management actions that stem from these potential impacts place a higher degree of urgency on some of the long-term vegetation management strategies that have already been identified for the Park.	▪ Potential climate change impacts reinforce the need, and imply a higher degree of urgency on the need for action, on the following vegetation management strategies: - Limit human access to alpine meadows and place firm requirements to stay on maintained trails, - Fire management: mimic landscape-level burn rates, while recognizing that the natural range of variation is likely shifting, - Insect infestations: develop the vegetation management capacity to quickly respond when major outbreak conditions occur utilizing all of the available tools (e.g., prescribed fire, single tree treatments, tree removals) - Invasive species: implement a detection program; develop a protocol to assess and prioritize action around "true" invasives vs. climate adaptation migrations. ▪ Research priorities include: - Monitor for key ecotonal changes as a predictor of climate change effects: species present, physical forms trees take, soil moisture conditions, etc.
Fish and Wildlife	The Park plays an important fish and wildlife refuge role, particularly noting its shared boundaries with two national parks. As terrestrial and aquatic ecosystems respond to a changing climate, so to should we expect fish and wildlife population dynamics to change.	▪ As part of broader fish and wildlife inventory programs, investigate the potential for climate driven changes to population dynamics. Note that listed species may be particularly vulnerable.

Topic	Assessment / Discussion	Draft Management Recommendation
Scientific Research and Education	In many ways the Park is in an ideal position to contribute to and benefit from collaborative research projects. It is physically part of a network of parks and protected areas and through this, strong institutional links with national and neighbouring provincial jurisdictions. From the standpoint of climate change research, the single most important contribution that the park could make would be to establish a program of long-term, high-elevation climate record data. In addition, the Park should collaborate in long-term multi-disciplinary monitoring aimed at the detection of ecological and hydrological trends related to climate change.	▪ Develop an active role in collaborative climate change research, offering the park to serve as the focal point of regional, high-elevation monitoring and study. As noted above, snowpack and glacier assessments offer a logical focal point, as do assessments of ecological change in the alpine meadows. ▪ Over the longer term as baseline inventories are developed, e.g., on red and blue listed species, effort should be focused on targeted impact and adaptation assessments for climate-sensitive species. ▪ Basic climate change education should be provided internally through provision of professional development publications and seminars that are augmented over time with the tangible results of all collaborative research studies.
Outdoor Recreation	As climate change manifests itself over time, it will be important to determine which aspects of outdoor recreation are most vulnerable. Here again, further investigation on an activity or sector basis can inform long-term management decisions. Potential effects on access, safety, infrastructure and the tourism economy should be included for impact and adaptation planning purposes (Suffling & Scott, 2002).	▪ Assess the potential impact of climate change on both winter and warm-season outdoor recreational activities. Consider how changes in primary climate attributes (i.e., temperature and precipitation), and perhaps more importantly trends in season length might impact or benefit different sectors or user groups. ▪ Make the potential for long-term climate change impacts an essentially criterion in all major decisions related to infrastructure and facilities.

Topic	Assessment / Discussion	Draft Management Recommendation
Visitor Experience and Interpretation	Providing information and education to visitors is an important service provided by BC Parks. Given the complexities and mis-information that sometimes surrounds the topic, building improved public awareness and better understanding through climate change interpretation could be an important addition to this service.	▪ Use the climate change information developed through this project (e.g., posters) and elsewhere to build awareness, capacity, and acceptance for climate change adaptation with the public.

Conclusion

This preliminary climate change assessment was undertaken to serve as an addendum to the Mt. Assiniboine Park Management Plan development process that was already underway. We have not undertaken a comprehensive predictive modeling approach to potential climate change impacts in Mt. Assiniboine Park – such an impact assessment process would be a significant undertaking. Instead, we have drawn upon readily available long-term global climate model scenario predictions for key climate variables, drawn from recent research efforts, and applied professional judgments to best understand the potential changes in climate-sensitive management issues facing the Park. This "multiple lines of evidence" approach is expected to be common among climate change adaptation practitioners faced with addressing multiple, inter-related planning issues with limited resources.

In the future, when the Mt. Assiniboine Park (or other) Management Plan is revised, the assessment of climate change impacts should be integrated into the initial terms of reference for the planning process. This will serve to better integrate climate change impact assessment as a standard planning task. Based on the experience gained in this project, we recommend a more thorough approach to these climate change impact assessments. Improved resolution of future climate trends can be achieved by incorporating a range of evolving techniques, including: regional downscaling of GCM predictions, elevation corrections (e.g., using the Climate BC model), enhanced local baseline data using higher resolution datasets, trend analysis using statistical and sensitivity testing.

Climate change challenges some of the basic assumptions on which park management is based. The management goals for Mount Assiniboine Provincial Park include human use and enjoyment, and protection of natural values historically present in the park. Management has ensured that human use and enjoyment of the park does not harm natural values, but has otherwise been relatively 'hands off'. This approach, effective under the relatively stable climate conditions of the past century, may not be as suited to the changing climate conditions projected for the 21st century. Managing Mount Assiniboine and other parks in the face of climate change – and a level of uncertainty about the future – is a challenge that BC is just starting to explore.

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