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Projected Climate Impacts on Snow Depths and Discharges In the Lake Winnipeg Watershed

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Introduction

A number of studies have documented recent trends toward earlier spring snowmelt (e.g. Brown, 2000) and a decline in snow cover extent (Dery and Brown, 2007) across many regions of the Northern Hemisphere in response to enhanced spring warming. Snow cover is anticipated to decrease in the future due to global warming, as snow cover formation and melt are closely related to a temperature threshold of 0ºC. The hydrologic regime of the Lake Winnipeg watershed (LWW), Canada, is dominated by spring snowmelt runoff which accounts for more than 80% of the total annual surface runoff in the region, despite the fact that snowfall only contributes one third of total annual precipitation (Gray and Landine, 1988). Thus, spring snowmelt runoff plays an important role in the agricultural water supply of the region. This study investigated the Canadian regional climate model (CRCM4) future projections of precipitation and temperature as well as maximum snow depth, snow cover duration and snowmelt runoff from the North American Regional Climate Change Assessment Program (NARCCAP) database to assess the potential hydrologic impacts of climate change over the Lake Winnipeg watershed.

Study Area

The Lake Winnipeg watershed extends from the headwaters of the Saskatchewan River in the Rocky Mountains to within about 20 km of Lake Superior. It encompasses portions of four Canadian provinces and parts of four states in the US. The catchment area is about 953,000 km2, which is second in size in Canada after the Mackenzie River Basin (LWSB, 2006). Major drainage systems in the LWW are the Red and Assiniboine, Saskatchewan and Winnipeg rivers flowing into Lakes Manitoba and Winnipeg, while the Nelson River flowing out into Hudson Bay. The LWW experiences a cold continental climate that is typical of the North American central plains. Precipitation in the watershed is greatest in the western edge near the Rocky Mountains (>1000 mm/yr) and to the east (~700 mm/yr) while the remainder of the basin is mostly semi-arid with precipitation ranging between 300 mm to 500 mm/yr. Five river (and lakes) basins are identified in the LWW (see figure below) and snow and runoff analysis are performed and presented for each of these.

The Lake Winnipeg Watershed (LWW) and its river basins

Climate Data

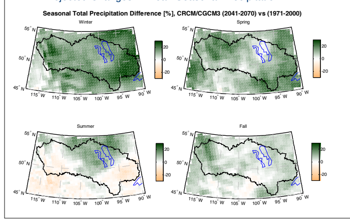
NARCCAP produces climate data based on a set of regional climate models (RCMs) driven by a set of atmosphere-ocean general circulation models (GCMs) over a domain covering the conterminous United States and most of Canada (Mearns, 2004). The RCMs are nested within the GCMs for the current baseline (1971-2000) and future (2041-2070) periods that constitute the two intervals for the climate scenario analysis. They have been forced with the observed emissions for the baseline period and the SRES A2 emissions scenario for the 21st century. Three-hourly precipitation, snow depth (in SWE) and runoff as well as daily maximum and minimum temperature data at 50-km grid resolution from the Canadian CGCM3/CRCM4 (Caya and Laprise, 1999) run, which was readily available at the time of this study, were used to analyze the climate change scenario in the LWW. The projected changes in the hydro-climatic regime were analysed by considering mean monthly and seasonal values of precipitation and temperature over the watershed as well as mean monthly and maximum annual snow water equivalent (SWE), snow cover duration (SCD) and total (surface and sub-surface) runoff values in each river basin for the baseline and future periods, and calculating the corresponding changes between the two.

Table 1:CRCM4/CGCM3 projected changes in mean annual and seasonal Tmax, Tmin and Precipitation in the LWW

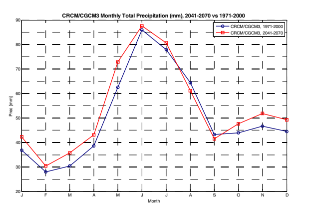
	Tmax (°C)			Tmin (°C)			Precipitation (mm)		
	1971-2000	2041-2070	Difference (°C)	1971-2000	2041-2070	Difference (°C)	1971-2000	2041-2070	Difference (%)
Annual (°C)	**6.8**	**9.3**	**2.5**	**-6.4**	**-3.5**	**2.9**	**605.3**	**644.1**	**6.4%**
Seasonal (°C)									
Winter	-7.8	-4.7	3.1	-19.9	-16.1	3.8	109.4	123.7	13.1%
Spring	7.0	8.6	1.6	-8.0	-5.5	2.5	133.4	153.6	15.2%
Summer	20.3	23.2	2.9	6.4	9.1	2.7	229.2	227.6	-0.7%
Autumn	7.3	9.8	2.5	-4.1	-1.7	2.4	133.2	140.0	5.1%

Projected Change in Precipitation

Projected Changes in Mean Seasonal Precipitation

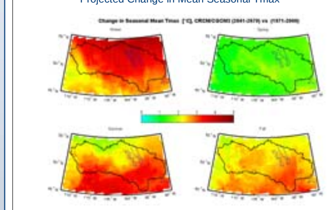


Projected Changes in Mean Monthly Precipitation

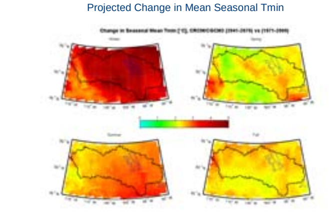


Projected Change in Temperature

Projected Change in Mean Seasonal Tmax

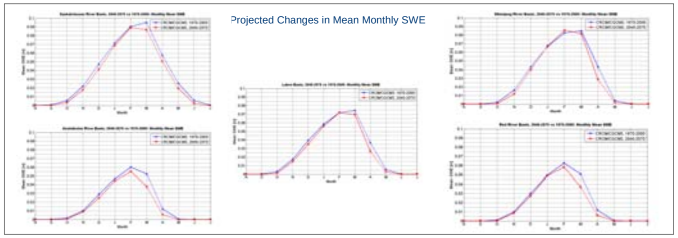


Projected Change in Mean Seasonal Tmin

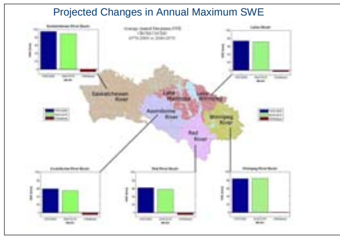


Projected Climate Impact on Snow

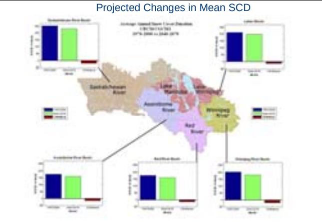
Projected Changes in Mean Monthly SWE



Projected Changes in Annual Maximum SWE

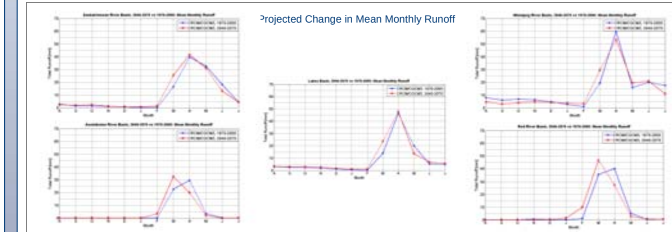


Projected Changes in Mean SCD



Projected Climate Impact on Runoff

Projected Change in Mean Monthly Runoff



Projected Change in Mean Annual Runoff

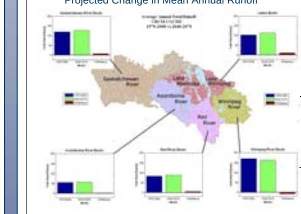


Table 2: CRCM4/CGCM3 projected changes in SWE, SCD and Runoff in the different river basins of the LWW

	Annual Maximum SWE (mm)			Mean Annual SCD (days)			Mean Annual Runoff (mm)		
River Basins	1971-2000	2041-2070	Difference	1971-2000	2041-2070	Difference	1971-2000	2041-2070	Difference
Saskatchewan river basin	95.0	89.3	-5.8	258	240	-18	119.8	127.2	7.3
Assiniboine basin	60.1	55.4	-4.7	186	170	-16	56.4	58.6	2.2
Lakes basin	74.3	71.8	-2.6	220	206	-14	103.1	113.5	10.4
Winnipeg river basin	84.8	85.7	1.0	212	191	-21	169.6	162.6	-7.0
Red river basin	62.7	58.4	-4.3	185	170	-15	84.2	89.8	5.7

Summary of Results

Projected Changes in Precipitation and Temperature:

- ➢CGCM3/CRCM4 projected an increase in total annual precipitation by 6.4 % for the 2041-2070 compared to 1971-2000
- ➢Seasonally, it projected increases in spring, winter and autumn precipitation by 15.2%, 13.1% and 5.1% respectively, and a decrease in summer precipitation by about 0.7%
- ➢Both mean annual Tmax and Tmin are projected to increase by 2.5 and 2.9 ºC in the future compared to the baseline period
- ➢Seasonally, winter is projected to experience the greatest warming of 3.1 and 3.8 ºC for Tmax and Tmin respectively while spring may experience the smallest increase of 1.6 and 2.4 ºC for Tmax and Tmin respectively
- ➢Change in Tmin is projected to be higher than the change in Tmax

Projected Changes in Snow and Runoff:

- ➢There is an over all reduction in the mean SWE values for the 2041-2070 period compared to the 1971-2000
- ➢The mean annual maximum SWE is expected to decrease in the range of 2.6 to 5.7 mm over most river basins except the Winnipeg river basin which projected a slight increase in the annual maximum SWE of about 1 mm
- ➢The timing of the maximum SWE is projected to be earlier by about a month (from March to February)
- ➢The mean annual SCD is projected to be reduced in all river basins by 14 to 21 days
- ➢The mean monthly runoff plots for the baseline and future climate reveal the shift in spring runoff to earlier periods with increasing runoff in February and March and a corresponding decrease in April for most river basins
- ➢The mean annual runoff is expected to increase in the range of 2.2 to 10.4 mm over most river basins except the Winnipeg River basin which may experience a decrease in mean annual runoff by about 6.9 mm over the basin
- ➢The projected climate also show a slight increase in annual peak monthly flow for most river basins except the Winnipeg River basin which exhibits a slight decrease in annual peak monthly flow

Conclusions

- ➢Analysis of climate projections with CRCM4/CGCM3, corresponding to the SRES's A2 emission scenario, has shown an overall increase in precipitation and temperature in the LWW by 2050s (2041 - 2070) compared to 1980s (1971 - 2000), with seasonal differences in the magnitude of changes
- ➢While the increase in precipitation for the future period means an increase in availability of moisture in the region, at the same time, the corresponding increase in temperature will result in a decrease in the proportion of precipitation falling in the form of snow (instead of rain) and may also increase evapotranspiration in the region
- ➢The future projection also shows an average decrease in the annual maximum snow pack (SWE) by about 4.5% and the mean snow cover duration (SCD) by about 17 days in most parts of the LWW
- ➢While there is an overall increase in total annual runoff projected for most river basins (except the Winnipeg River which shows a decrease in runoff) and an over all shift in spring runoff to an earlier period, only the Assiniboine and Red River basins exhibited significant increases in the annual peak flow and corresponding shift of this peak flow to an earlier month. Note that these RCM runoffs are derived from grid values and are not routed through the river reaches.
- ➢The Winnipeg River basin seems to react differently to the climate change signals compared to the other river basins by exhibiting a slight increase in maximum SWE and a significant decrease in total annual runoff and peak flow for the future period. This may be attributed to increased evaporation from the many lakes covering this river basin, but identifying the exact reason and quantifying the influence needs further investigation

Acknowledgment

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