IMPLICATIONS OF CLIMATE CHANGE FOR FLOOD DAMAGE REDUCTION IN CANADA

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Abstract

Several aspects of recent trends in climate in Canada affect flood magnitude and frequency. On many rivers, the average of snowmelt induced spring floods has been declining with more of the snowpack melting gradually over warmer winters. The Red River is the notable exception. On the other hand, the frequency of high intensity rainfalls affecting small watersheds has been rising at least in southeastern Canada. Projections by latest climate models with recent emission scenarios (IPCC-SRES) are examined to assess whether recent trends are likely to continue. Implications are considered for flood damage reduction programs.

Résumé

Plusieurs aspects des récentes tendances climatiques canadiennes influencent l'ampleur et la fréquence des inondations. Sur plusieurs rivières, la moyenne des inondations printanières induites par la fonte des neiges est en baisse en raison des fontes plus graduelles au cours des hivers plus doux. La Rivière Rouge étant une exception. D'autre part, la fréquence des pluies à haute intensité augmente dans la région sud-est du Canada et a un impact sur les petits basins versant. Les projections des derniers modèles climatiques sont examinées en intégrant les scénarios d'émission (IPCC-SRES) dans le but d'évaluer s'il est probable que les tendances récentes se maintiennent. Les implications pour les programmes de réduction de dommages d'inondations sont prises en considération.

1. INTRODUCTION

One often hears it glibly stated that climate change will bring more floods and more droughts. For floods, this may not be so in many parts of Canada. Yet there are some indications in climate change projections and recent trends of rain and storm intensities, and increased precipitation, especially in the North, that would suggest that for some basins, more flooding may be an outcome of a changing climate. To examine this issue, it is necessary to consider climate projections into the future with increasing forcing of the global system with greenhouse gases and aerosols. The trends over the past 3 or 4 decades are then assessed to see the extent to which these correspond to the modelled projections. Flood damage reduction programs both structural and non-structural may need adjustment in some basins in light of projections and recent decadal trends.

2. CLIMATE PROJECTIONS FOR CANADA

The most recent and reliable climate projections are based upon the global emission scenarios of the Intergovernmental Panel on Climate Change (IPCC) known as the Special Report on Emission Scenarios (SRES). These are based upon different "story-lines" which describe the world's population growth, economic growth rates, and future energy technologies. Two of these, the A_2 and B_2 scenarios have been most frequently used as a basis for modelling future climate by a number of leading modelling groups in the world, including the Canadian Climate Centre for Modelling and Analysis in Victoria. The main differences between these emission scenario story-lines are that in A_2, global population rises to 15 billion and new technology is slower to be adopted than in B2 which has a population projection of 10 billion by 2100. Results of ensembles of these climate projections based on A_2 and B_2 scenarios have been included in the IPCC Third Assessment Report (TAR 2001), Volume I on the Scientific Basis of Climate Change. They suggest for A_2 an average temperature increase of 8°C over Hudson Bay and mid continental Canada and 6°C over most of the rest of Canada, and for B_2 about 1°C less. These are for increases averaged for a 30 year period around 2085, from those experienced in the 30 years centred on 1975 – i.e. a 110 year trend. Greater increases are projected in the far North and less warming in east and west coastal regions.

Precipitation model projections are less reliable than temperature and for both A_2 and B_2 emission scenarios average an increase of less than 5% in total precipitation in southern Canada, graduating to about a 20% increase in the far North. Seasonal modelling (e.g. Hadley Centre, HadCM3, UK) suggest a small decline in the southern Canadian Prairies in summer and a small increase in winter by the 2050's (Gregory et al., 1997).

The IPCC-Third Assessment Report concludes that it is very likely (>90% chance) that there will be higher rain intensities in a warming climate, and the Canadian model suggests that on average over southern Canada, there will be a halving of the return period of high intensity rains, i.e. the 20 year return period event would become a 10 year return period occurrence. (Kharin and Zwiers, 2000)

Sea level rise would be responsible for some coastal flooding, with the 1 to 2 cm per decade rise of the past century becoming a 40 cm rise this century with a range of estimates by 2100 from 9 to 88 cm based on a wide range of SRES scenarios (IPCC 2001). Storm surges with more severe winter storms would add to coastal flooding.

Half of the uncertainty in future climate projections lies in the uncertainties about future emissions (the SRES range) and the rest mainly in the differences in modelling of various climate system processes by the modelling groups in Canada, USA, UK, Germany, Japan and Australia. These models all take account of greenhouse gas forced warming, aerosol cooling, and model the whole atmosphere, ocean, land and vegetation systems, ice and snow.

3. RECENT TRENDS IN CLIMATE

So how do recent climatic trends correspond to these climate projections? One issue that must be addressed is the period over which trends are analysed. From analyses in the IPCC-TAR, it is evident that global mean temperature trends up to the 1950's appear to have been influenced as much by changes in solar radiation and volcanic emissions, i.e. natural forcing factors as by greenhouse gas and aerosols. However, since the 60's the greenhouse gas forcing has overwhelmingly dominated, with a rapid rise in global mean temperatures. Thus, to extrapolate from trends in observations to future climates due to greenhouse gas and aerosol increases, it seems prudent to examine observed trends of the last 30 to 40 years. There is an issue with this. Some would argue that 30 to 40 years trend anomalies could be due in large measure to long term ocean temperature anomalies such as in the Pacific Decadal Oscillation rather than greenhouse gas forcing. To complicate matters, others argue that these sea surface temperature patterns of the past four decades are in turn due to anthropogenic forcing. Since in science the simplest explanation is usually the best, it will be assumed that recent trends are mainly due, one way or another, to the increased radiative forcing due to greenhouse gases. Indeed, they are entirely consistent with modelled climate changes with the increasing radiative forcing.

Table 1 summarizes some of the key observational trends and the projections and clearly illustrate the consistency between observed and projected changes.

4. TRENDS IN FLOODS AND HYDROLOGY

In Table 1, a number of hydrologic trends are indicated as well as some climatic trends that should influence the hydrology and, in particular, flood flows. For large basins, the data on changes in southern mid-continent drying, date of spring break-up, snow cover extent, spring snowpack, and glacier retreat south of 60°N, all suggest that in southern Canada peak discharges from snowmelt are likely to decline with climate change. More of the snowpack is melting over winter, leaving less for the spring freshet.

Trends in streamflow measurements summarized by Zhang, et al. (2001), for 30, 40 and 50 year periods to 1997, indicate a general decline in daily maximum flows in the South, with the notable exception of the Red River and some west Coastal streams. Further north – from about 58°N – peak discharges have been generally on the rise. To illustrate more specifically the peak flow declines in southern rivers, Table 2 summarizes for the Mean annual, Minimum and Maximum daily flows, percentage changes from 1970 to 2000 for significant boundary rivers. It will be noted that peak discharges from the St. John River in the East to the Columbia in the West, as measured at border crossings, have been declining. Again the notable exception is the Red River flowing north into Canada at Emerson. This is because in contrast to most regions of southern Canada, the headwater States of the Red River basin, the Dakotas and Minnesota, have experienced a significant increase in annual precipitation, particularly winter snowfall, over the past 30 years. This is also the case for most of Canada north of 58°N. The date of spring break-up is occurring earlier on most Canadian rivers. (Table 1) Thus, there is an observed decline in snowmelt induced average peak flows in most large rivers in southern Canada. There will likely be a continuation of this trend with climate change and more snow melt gradually over winter.

In contrast, small watersheds, susceptible to flash flooding due to heavy rains, are expected to experience more frequent and larger flood events. In addition, increased intensity of winter storms, both observed to date and projected, may well pave the way for occasional very severe floods, especially on watersheds of eastern Canada and the west Coast, with greater potential for heavy rain events combined with snow melt in late winter and spring. The increase in severity of winter storms has resulted mostly in heavy snowfalls and freezing rain events in eastern Canada, but heavy rains and flooding in Europe. European flooding in August 2002 caused damages of $18.5 billion (Schiermeier, 2003). With a warming climate, more of these storms in Canada will likely be accompanied by flood-producing rainfalls in future rather than heavy snowfalls.

5. FLOOD DAMAGE REDUCTION PROGRAMS

Canadians have had to cope with floods in many communities, and have done so in a variety of ways. Structural measures to contain flood waters have been relied upon in a number of cases. Dykes on the lower Fraser River have encouraged the rapid development of Richmond south of Vancouver, the Winnipeg by-pass channel, the floodway, has proven its enormous value several times since being built after the damaging 1950 flood, and in southern Ontario a number of flood control dams and reservoirs and flood-ways have been constructed. Many dams built mainly for hydro-power are also used for flood peak reduction – for example on the Columbia River. Most of these and other flood control works have been constructed in joint provincial-federal programs. In the 1950's and 60's, these were funded federally under the Canada Water Conservation Assistance Act.

TABLE 1 Climate change projections and observations

CLIMATE CHANGE PROJECTIONS AND OBSERVATIONS		
Variable	PROJECTED	Observed to Date (2000)
Global mean temperature (IPCC 2001)	1.4 to 5.8°C (1990-2100) (IPCC 2001)	0.6+ or –0.2°C (20th Century) (IPCC 2001)
Canadian mean temperature	2 to 4°C (CGCM – 1975-95 To 2040-60) (Boer et al. 1998)	> 1°C (20th century) (Zhang et al. 2000)
Total Precipitation (2040-2060)	0 to 20% more in north slightly less in mid continent in summer (HadCM3)*	(1950-98) ++ at high altitudes, + at mid latitudes Southern Prairies little change (Mekis & Hogg 1999)
Streamflow (or soil moisture) Mid Continent	-30% by 2050 2 x CO_2** (CGCM) (Boer et al. 2000) (Gregory et al. 1997)	-10% Southern Prairies (1967-1996) (Zhang et al. 2000)
Date of Spring Breakup	Earlier (IPCC 2001)	Earlier 82% of basins (1967-96) Canada
Extreme Rainfall	2 x frequency of heavy rains for 2 x CO_2 (CGCM) (Zwiers & Kharin 1998)	Up to 20% increase in heavy 1-day falls in USA and S.E. Canada (early summer) (Stone et al. 2000, Karl et al. 1995)
Water Vapour in Troposphere (lower atmosphere)	Increase (Boer et al. 2000)	Statistically Significant Increase over N. America except N.E. Canada (Ross & Elliot 1996)
Mean Sea Level Rise	40 - 50 cm (mean IPCC projections) 1990-2100 (IPCC 2001)	10 – 20 cm (1900-1999) (IPCC 2001)
Arctic Sea Ice extent	-21 TO 27% by 2050 (Sarnko et al. 2002)	-3% per decade since 1978 (year round ice extent) (IPCC 2001 – WG II)
Snow Cover extent Dec. Jan. Feb	-15% by 2050 N. America (CGCM) (Boer et al. 2000)	-10% (1972 – 2000) Northern Hemisphere (IPCC 2001 WG II)
Late season snow pack – Rockies – Apr. 1	Less - (more melt over winter)	30% less since 1976 Fraser River Basin (Moore, 1996)
Glacier retreat south of 60°N e.g. Glacier National Park	None left (by 2030) (Boer et al. 2000)	2/3 reduction in numbers (from 150–50) (1850–1990s)
Severe winter storms Frequency and intensity	15% to 20% increase 2x CO_2 (CGCM)*** (Lambert 1995) (Carnell and Senior 1998)	(1959-1997) N of 60°N - Increased frequency and intensity S of 60°N - Increased intensity (McCabe et al. 2001)

* Had CM3 - Hadley Centre (UK) Climate Model version 3
** 2 x CO_2 - Doubled pre-industrial level of CO_2 equivalent (by latter half of 21st century)
*** CGCM - Canadian Global Climate Model (CCCma) (Environment Canada, University of Victoria)

Table 2 Trends in Flows (%) – 1970-2000 (Bruce, et al. 2003)

RIVER	Mean annual	Minimum daily	Maximum daily
St. John (Fort Kent)	-13	71	-16
St. Croix (Baring)	-21	-23	-26
Niagara (Queenston)	-7	-8	-9
Rainy (For Frances)	-22	-12	-27
Lake of the Woods (W)	-21	-59	-29
Red (Emerson)	124	159	63
Souris (Sherwood)	-82	-74	-94
Souris (Westhope)	-42	100	-60
Milk (E. border)	-22	47	-6
Milk (W. border)	-26	59	-41
St. Mary (border)	-7	15	-29
Kootenay (Fort Steele)	3	-4	-12
Columbia (International Border)	4	37	-25

With the passage of the Canada Water Act in 1970, a more flexible approach became possible federally. The federal cabinet, alarmed by the mounting loss due to flood damages across Canada for which the federal government had to pay part of rehabilitation costs, agreed in 1975, under the Canada Water Act, to a Flood Damage Reduction (FDR) Program. Under this program, non-structural measures were promoted. Flood plain mapping and taking of steps to limit developments in the designated flood plains had been pursued successfully in some provinces, for example in Ontario after the devastation of hurricane Hazel (1954). After 1975 Federal-Provincial cost sharing agreements were signed with every province to produce flood plain maps and designated flood plain zones in which both levels of government would use their lending and land use planning powers to limit development. In some cases agreement was reached for cooperation in flood forecasting. The program did provide for structural projects in cases where major developments were already present or unavoidable in the flood plain (Watt, 1995).

Funding of this structural part of the FDR program consumed a major part of Canada Water Act funds in the 1970's and early 80's with Fraser River dykes being the largest project. The non-structural flood plain mapping measures which are inherently less costly received about $0.5 to $2 million in federal funds over the 1977-94 period. The mapping program succeeded in designating flood plains in most communities, with special attention to suburban and exurban areas in the path of development. It should be noted, however, that federal funding was reduced to very little by 1995 and disappeared entirely by 1997, with successive budget reductions in Environment Canada (Booth, and Quinn, 1995). A few provinces and municipalities have maintained or updated the mapping, for example, Quebec, but in most areas the program has lapsed, and map revisions with changing conditions are not being undertaken.

Appraisals have been made of the benefits of flood plain mapping and zoning, and where needed, channel improvements. A notable study by Brown et al. (1997) studied floods from a set of four severe rainstorms in 1986 affecting equally south western Ontario and Michigan, but with slightly heavier falls in Ontario. They found that damages were $309 million in Michigan and $0.5 million in Ontario. The authors concluded that the flood plain management and related programs of the basin Conservation Authorities, which administered the FDR Program, was far more effective in reducing losses than the flood insurance program in Michigan. They concluded that "the benefits of non-structural flood plain management measures are cumulative and increase over time" – and tend to be under-estimated by planners and managers.

However, even with declines in peak discharges due to mid-winter snowmelt on many large rivers and the benefits of the flood damage reduction program, flood losses continue to mount in Canada due to severe rainstorms (e.g. Saguenay basin), aging infrastructure, increasing population and structures at risk and, in some areas, relaxation of flood plain zoning.

6. CONCLUSIONS

What can we conclude about floods in Canada, given these trends in government policy, population at risk and climate change?

6.1 In southern Canada, for moderate to large size watersheds (>1000 km^2 approximately) mean annual flood peaks from snowmelt and glaciers will continue to decline for several more decades. However, occasional floods, due mainly to large intense rain storms, may increase. In the longer run, in the latter part of this century with warmer climate, more of the severe storm events will be accompanied by flood producing rains rather than snow.

6.2 In Canada, north of 58°N, mean annual flood peaks and extreme flood events will continue their upward trends. Melting of permafrost and ice jam flooding will complicate the flood frequency and may shift stream-bed locations with land slumps. The Red River in Manitoba may continue to have increased annual and extreme flood peaks.

6.3 Small watershed storm sewers and drainage facilities will experience increased frequency of floods, with floods that exceed design capacity doubling in frequency by the latter part of the century.

6.4 The higher rain intensities affecting small watersheds and urban drainage will increase the frequency of episodes of pollution and high sediment loads. It has been estimated in the USA that a 10% increase in mean annual precipitation, if occurring through increase in precipitation intensities only, would result in an average 24% increase in erosion (Soil and Water Conservation Society 2003).

6.5 Flooding of low-lying coastal regions and erosion of shorelines on Canada's three coasts, will increase in frequency with both sea level rise and larger storm surges. Along the Arctic coastlines, melting of the ice-pack will permit greater wave forces to develop exacerbating this problem (Shaw et al., 1998).

6.6 There has been a decline in attention to flood plain management issues at the federal level and by many provinces, aging infrastructure for drainage facilities, and the mixed effects of climate changes. These three factors suggest a continuing increase in national flood damages.

6.7 Data collection systems and analysis of data, especially for short duration rain intensities and peak flood flows have been reduced by Environment Canada. This makes it difficult to ensure efficient design or adjustments to flood damage reduction measures and drainage facilities, in light of changing circumstances of land development and climate.

7. PROPOSALS FOR ADAPTATION MEASURES

7.1 Through federal-provincial arrangements, restore rain intensity, streamflow and flood measurement programs, to the levels of the 1970's and 1980's.

7.2 Through intergovernmental arrangements, review and revise flood plain mapping in light of:

7.2.1. recent and projected changes in flood flows, with changing climate,
7.2.2. upstream developments in the watersheds that affect flood flows.

7.3 Examine boundary water agreements between Canada and USA and between provinces, for provisions relating to floods and seek appropriate adjustments in such provisions in light of recent trends and projections.

7.4 Document communities susceptible to flooding from the sea, and adjust any set-back rules or shore protection measures in light of sea level rise and storm surge projections.

7.5 Strengthen and expand, in light of recent trends and projections, capacity of culverts, and storm sewers. New facilities should be designed on the basis of revised data and standards.

7.6 New or replacement infrastructure for communities should be designed taking into account recent data and projections, with both climate and development changes.

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