

GS-20 Hydrological dynamics in the Winnipeg River basin, Manitoba

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Summary

Because hydrological conditions are the greatest source of risk for hydroelectric production, recent studies describing significant declines in discharge during the 20th century for many Canadian rivers are an understandable cause for concern. The Winnipeg River in northwestern Ontario provides nearly half of the total flow into Lake Winnipeg and the Nelson River, and is the most important component of the hydroelectric system generating power in Manitoba. This study uses a network of long-term discharge gauges to examine the frequency, severity and causes of drought in the basin during the last one hundred years. Extremely low annual flows in the Winnipeg River are the product of widespread reductions in precipitation during the previous summer and autumn, warm temperatures in spring and summer, and very little runoff delivered by spring snowmelt. These conditions are typically associated with circulation similar to the positive mode of the Pacific–North American (PNA) pattern, which may act to inhibit the formation of cyclones in western North America and reduce the amount of precipitation received by northwestern Ontario. A strong, positive PNA-like pattern during autumn and winter appears to be required in order for extreme low flows to occur, but positive PNA anomalies do not always lead to low flows. In contrast to trends observed for other Canadian rivers, annual discharge in the Winnipeg River increased by nearly 60% during the 20th century. Nearly all of this change is due to increases in summer and autumn precipitation and higher discharge during winter. Reports of declining flow for many rivers in the adjacent Canadian Prairies have led to serious concern for the future reliability of water supplies, especially because surface water is the primary source of irrigation for local agriculture. The observed trends toward higher flows suggests that the potential threats to water supply faced by the Canadian Prairie provinces over the next few decades will not include decreasing discharge in the Winnipeg River basin.

Introduction

This study uses a network of long-term discharge gauges to assess how river flow in the Winnipeg River basin (Figure GS-20-1) has behaved during the last one hundred years. Its main goals are to 1) evaluate if river flow increased or decreased during the period of record and investigate the potential causes of such changes; and 2) determine if extreme high or low flows are associated

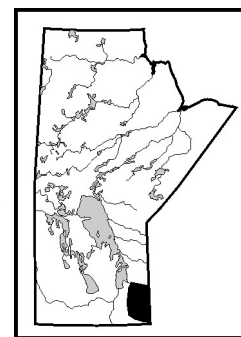
with particular configurations of the synoptic climatology.

Study area and data

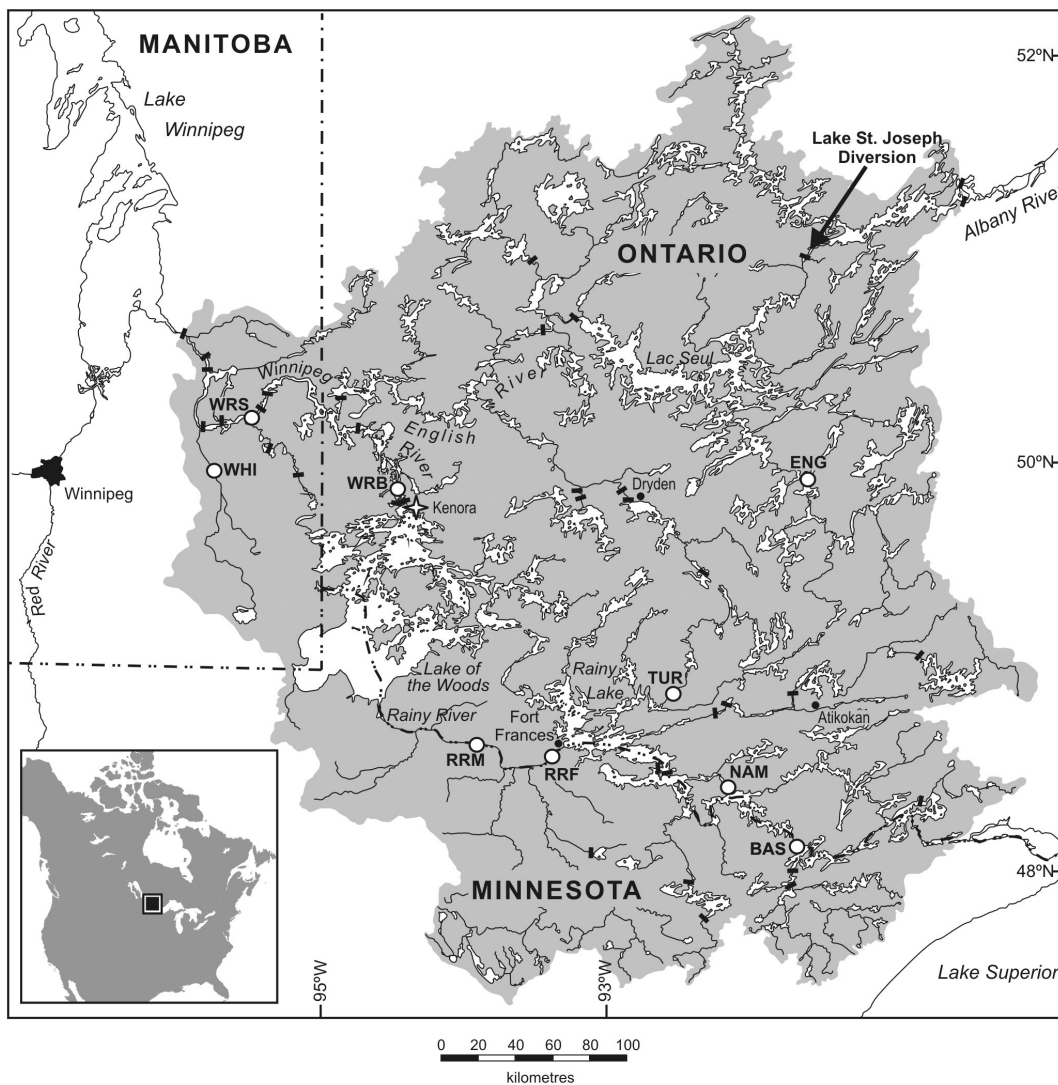
Most of the Winnipeg River basin (WRB) is located at the eastern edge of the Canadian Shield in northwestern Ontario, and can be described as a rugged wilderness area with low, rolling terrain and many large lakes. The Winnipeg River, which also drains a small portion of northern Minnesota, flows westward into Manitoba and empties into the south basin of Lake Winnipeg. The basin has an area of approximately 150,000 km², and supports more than 100 major lakes (including Lake of the Woods) that occupy more than 11,400 km² (Lake of the Woods Control Board, 2002). The basin is largely forested, and serves as a transition zone between the mixed forests of the northern United States and the boreal forest of northern Canada.

Water flow in the WRB has been controlled since the 1880s, when small dams were constructed to aid navigation on Lake of the Woods (Lake of the Woods Control Board, 2002). The first hydroelectric dam in the basin was built on the eastern outlet of Lake of the Woods in 1892, which was followed by a dam on the lake's western outlet in 1925 (Lake of the Woods Control Board, 2002). The Pinawa dam, located on the Winnipeg River, went into operation in 1906 with an initial generating capacity of 8 MW. By 1954, seven additional dams had been built in Manitoba and Ontario, bringing total power production on the river to more than 650 MW. Dams on the Winnipeg River are run-of-river systems, and have limited storage capacity. The only major diversion within the basin transfers water from Lake St. Joseph, which is part of the Albany River basin, into Lac Seul. This channel, built in 1935, adds 80 m³/s of discharge on average into the Winnipeg River system (Lake of the Woods Control Board, 2002).

Daily and monthly streamflow data were obtained from the Water Survey of Canada's HYDAT data archive (Water Survey of Canada, 2005). Gauges within the Winnipeg River watershed were selected for analysis if they had more than 50 years of record, and were still operating at the end of 2003. Nine gauge records satisfied these criteria, with the longest record (Winnipeg River below Lake of the Woods) beginning in 1892.



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| WRS Winnipeg River at Slave Falls | ENG English River at Umfreville | ○ Flow gauging stations |
| WRB Winnipeg River below Lake of the Woods | BAS Basswood River near Winton | ● Communities |
| RRM Rainy River at Manitou Rapids | TUR Turtle River near mine centre | ■ Dams |
| RRF Rainy River at Fort Frances | WHI Whitemouth River | ★ Climate station |
| NAM Namakan River at outlet of Lac La Croix | | |

Figure GS-20-1: Map of the Winnipeg River basin showing the locations of the climate station and stream gauges used in this analysis. Base map provided by the Lake of the Woods Control Board.

Increasing streamflow during the 20th century

Mean annual flows of the Winnipeg River have increased substantially since 1924. At the Slave Falls gauge, annual flows have increased by 4.8 m³/s/a; relative to mean flows at the beginning of the record, this cumulative change corresponds to an increase of 58%. Results for the monthly flow series suggest that the shift to higher annual flows has been driven by large increases in discharge during the winter (Figure GS-20-2). Statistically significant ($p = 0.05$) increases are observed for flows from November to April, ranging between +61 to +110%. There are no significant changes in discharge during the summer months.

The tendency toward higher winter flows is repeated

throughout the watershed at gauges upstream from Slave Falls, with seasonal flow increasing by 44 to 128% (not shown). For the Turtle River, significant positive trends in monthly discharge from November to March led to a 46% increase in annual flow. Increasing winter and spring flows were also observed on the Basswood River and the English River at Umfreville, indicating that these seasonal changes occurred over a wide geographic area. However, in the case of the Basswood and English rivers, these seasonal increases were not large enough to cause a significant rise in annual discharge. The trend analysis results also suggest that the English River basin has experienced larger increases in winter flows than have basins in the Lake of the Woods–Rainy River watershed.

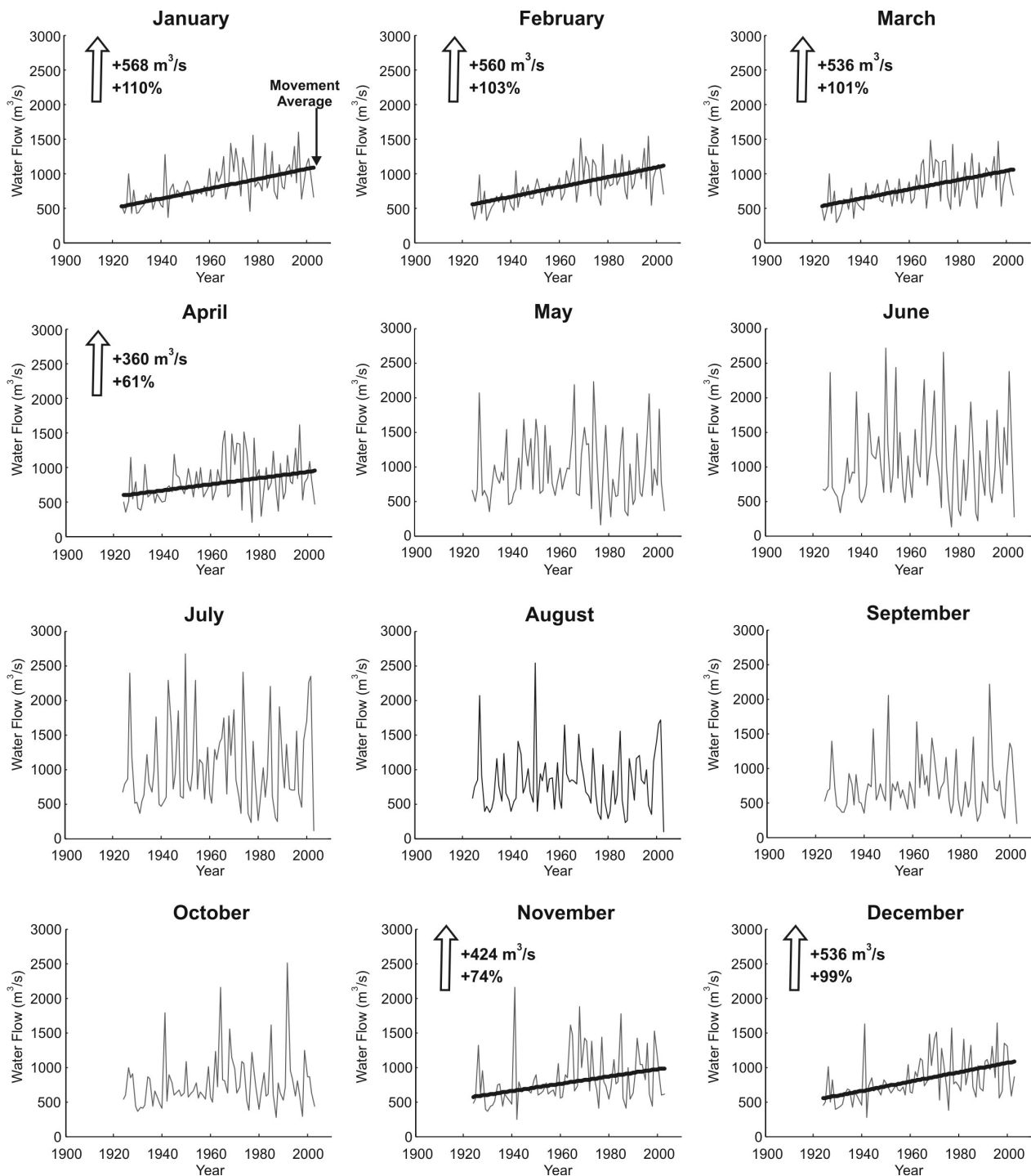


Figure GS-20-2: Linear trends in monthly streamflow for the Winnipeg River at Slave Falls from 1924 to 2003. Statistically significant increases in flow are highlighted with a heavy line. Total and percent changes are expressed relative to the beginning of the trend line. Discharge is expressed in m^3/s .

Annual and winter discharge also increased on the Big Fork, Sturgeon and Roseau rivers in northern Minnesota after 1960, indicating that trends in the WRB are not artefacts caused by changes in techniques used by Canadian agencies to measure discharge. Although some increases are observed on WRB rivers that are affected by regulation and diversion, the presence of similar trends at

upstream gauges demonstrates that direct anthropogenic interference in the hydrological system is not the primary cause of these changes. However, the possibility that some fraction of the trends in flow at the downstream gauges is due to regulation effects cannot be excluded.

Rising winter discharge across the basin has coincided with increasing annual and seasonal precipitation. Total

annual (October to September) precipitation at Kenora has increased by approximately 108 mm (15.5%) since 1924. This change largely reflects increases in summer (May to July) and autumn (August to October) precipitation, as no significant trends were observed for winter (November to January) precipitation, and precipitation during spring (February to April) decreased by 25%. No significant trends were identified in annual, monthly or seasonalized temperature records from Kenora. The changes observed at Kenora are part of a general increase in precipitation across much of northwestern Ontario.

Causes of severe low flows

Extremely low flows are typically preceded by widespread reductions in the amount of precipitation received by the WRB in the previous year. Dry conditions become established over northwestern Ontario in summer, and by autumn expand to affect southern Manitoba and northern Minnesota as well. The largest negative precipitation anomalies are centred over the Rainy River basin. Winter snow is also reduced, with most of the basin receiving about 20 mm (~25%) less than average. Spring and summer conditions appear to be less critical to the development of low flows, as mean precipitation anomalies over the basin are close to average during spring and slightly above average in summer. The lowest flows in the smaller, unregulated watersheds (the Basswood, English, Namakan and Turtle rivers) also follow large reductions in precipitation during the previous autumn (not shown), but dry conditions are typically restricted to those individual sub-basins, rather than extending over the entire WRB.

Low-flow years in the WRB are associated with upper-air circulation patterns that cause air masses to move in a north-south trajectory. On average, circulation over western North America is characterized by a 'ridge' of high pressure over the Rockies, and a 'trough' of low pressure that extends over eastern Canada. In the autumn prior to severe drought years in the WRB, the high-pressure ridge over British Columbia becomes strengthened, which forces Pacific air masses to be deflected to the north before moving southeastward across the Prairies. This pattern intensifies through the winter, with the centre of the ridge moving eastward to occupy a position above the northern Rocky Mountains. The ridge's eastward shift is particularly evident prior to the occurrence of low flows in 1977 and 2003. This arrangement of unusual atmospheric conditions is very similar to the positive phase of the Pacific-North American (PNA) pattern (Wallace and Gutzler, 1981). As noted above, precipitation from February to July is not unusually low, but anomalously warm temperatures suggest that increased evaporation during spring and summer acts to reduce runoff and streamflow toward the end of the water-year. Spring and summer temperatures across

the basin (not shown) are roughly 2 to 3°C warmer in low-flow years as compared to high-flow years.

Potential connections to the Pacific-North American pattern

As noted, extreme low flows in the Winnipeg River are associated with autumn and winter circulation patterns that resembles the PNA pattern. Many of the lowest flows in the Winnipeg River (1961, 1977, 1981, 1988, 1998 and 2003) followed years when the PNA index was strongly positive (above 0.8). The PNA is also significantly ($p = 0.01$) correlated with annual ($r = -0.36$) and spring ($r = -0.46$) flow at Slave Falls. These results suggest that the state of the PNA may act as an important control on streamflow in the WRB. The index was negative during most of the 1960s and early 1970s, which indicates that this mode may also have contributed to persistently high flows during this period. However, the PNA index was also positive prior to high flows in 1970 and 2001. The geopotential height fields for these two years show the typical PNA pattern over western North America, but also includes regions of anomalous high pressure centred over northern Quebec, the Labrador Sea and southern Greenland. These patterns suggest that the apparent relationship between the PNA and streamflow in the Winnipeg River basin may be modulated by conditions in the North Atlantic sector.

Conclusion

Long-term records indicate that streamflow in the WRB increased significantly during last 80 years, with winter streamflow going up by 44 to 128% at both upstream and downstream gauges over the entire basin. Changes in annual and winter streamflow are observed in records from both regulated and unregulated portions of the watershed, which point to an underlying cause related to climate. Comparisons with long-term meteorological records suggest that the basin hydrology has served to amplify coincident, but smaller, increases in precipitation during summer and autumn.

Extreme low flows in the Winnipeg River are the product of a series of unusual hydroclimatic conditions within the watershed, principally widespread reductions in precipitation during the previous summer and autumn, warm temperatures in spring and summer, and very little runoff delivered by spring snowmelt. These conditions are typically associated with the circulation similar to the positive mode of the PNA pattern, which may act to inhibit the formation of cyclones in western North America and reduce the amount of precipitation received by northwestern Ontario. A strong, positive PNA-like pattern during autumn and winter appears to be required in order for extreme low flows to occur, but positive PNA anomalies do not always lead to low flows. The apparent relationship between streamflow in the WRB and the PNA

may be influenced by other competing or complementary factors and these interactions should be investigated in future work.

Reports of declining flow for many rivers in the adjacent Canadian Prairies (Westmacott and Burn, 1997; Yulianti and Burn, 1998; Rood et al., 2005; Déry and Wood, 2005) have led to serious questions about the future reliability of water supplies, especially because surface water is the primary source of irrigation for local agriculture (Gan, 2000). These concerns have been exacerbated by suggestions that a doubling of atmospheric CO₂ could increase the severity and frequency of droughts in the region (Burn, 1994). The results of this study show that the hydrological trends in the WRB during the 20th century are different from those observed on other Canadian rivers, and imply that projections made for the rivers in the Canadian Prairies may not be valid for this watershed. A recent review of results from an ensemble of climate models projects that runoff in the Winnipeg River region and northern and central Manitoba will increase 20 to 30% by the middle of the 21st century (Milly et al., 2005). Because of these projections, and the observed trends toward higher flows, it seems likely that the potential threats to water supply faced by the Canadian Prairie provinces over the next few decades will not include decreasing streamflow in the WRB.

Economic considerations

In Manitoba, hydropower provides nearly 95% of total electricity production (Manitoba Hydro, 2005). Although most of its watershed is in Ontario, the Winnipeg River is the most important component of the hydrological system used to generate power in the province. The river supports six hydroelectric generating stations operated by Manitoba Hydro, which collectively produce 585 MW of electricity (roughly 14% of total provincial production). Furthermore, the river provides nearly half (45%) of the flow into Lake Winnipeg and the Nelson River (despite comprising only 12% of the Nelson River watershed), and has an important influence on the production of nearly 4000 MW at downstream stations on the Nelson River. Widespread drought affecting most of the WRB was cited as the main factor responsible for reducing energy production and sales during the 2003/04 fiscal year (Manitoba Hydro, 2004). Conversely, a return to wetter conditions in 2004 and 2005 was credited with greatly improved hydroelectric conditions in Manitoba (Manitoba Hydro, 2005). Understanding the dynamics of the WRB, including the causes of severe droughts and long-term trends, is critical to developing accurate estimates of future hydroelectric power production in Manitoba.

Acknowledgments

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References

- Burn, D.H. 1994: Hydrologic effects of climate change in western Canada; *Journal of Hydrology*, v. 160, p. 53–70.
- Déry, S.J. and Wood, E.F. 2005: Decreasing river discharge in northern Canada; *Geophysical Research Letters*, v. 32, no. 10, L10401, doi: 10.1029/2005GL022845.
- Gan, T.W. 2000: Reducing vulnerability of water resources of Canadian prairies to potential droughts and possible climate warming; *Water Resources Management*, v. 14, p. 111–135.
- Lake of the Woods Control Board 2002: Managing the water resources of the Winnipeg River drainage basin; Lake of the Woods Control Board, Ottawa, Canada. 20 p.
- Manitoba Hydro 2004: 2003/04 annual report and 2004/05 first quarter financial results; Manitoba Hydro, URL <http://www.hydro.mb.ca/news/releases/news_04_08_11.shtml>, news release, August 11, 2004.
- Manitoba Hydro 2005: 2004/05 annual report; Manitoba Hydro, URL <http://www.hydro.mb.ca/about_us/ar_2004/ar_2004_report.shtml> (October 2005).
- Milly, P.C.D., Dunne, K.A. and Vecchia, A.V. 2005: Global patterns of trends in streamflow and water availability in a changing climate; *Nature*, v. 438, p. 347–350.
- Rood, S.B., Samuelson, G.M., Weber, J.K. and Wywrot, K.A. 2005: Twentieth-century decline in streamflows from the hydrological apex of North America; *Journal of Hydrology*, v. 306, p. 215–233.
- Wallace, J.M. and Gutzler, D.S. 1981: Teleconnections in the geopotential height field during the Northern Hemisphere winter; *Monthly Weather Review*, v. 109, p. 784–812.
- Water Survey of Canada 2005: Archived hydrometric data; Environment Canada, URL <<http://www.wsc.ec.gc.ca/hydat/H2O/>> (September 2005).
- Westmacott, J.R., and Burn, D.H. 1997: Climate change effects on the hydrologic regime within the Churchill-Nelson River Basin; *Journal of Hydrology*, v. 202, p. 263–279.
- Yulianti, J. and Burn, D.H. 1998. Investigating links between climatic warming and low streamflow in the Prairies region of Canada; *Canadian Water Resources Journal*, v. 23, p. 45–60.