Hydrometric Monitoring Across the Canadian Pan-Arctic Region, 1950-2008

Theo J. Mlynowski, Marco A. Hernández-Henríquez and Stephen J. Déry

Environmental Science and Engineering Program, University of Northern British Columbia, Prince George, British Columbia, Canada

INTRODUCTION

Canada's Network

- Canada's hydrometric network commenced in the 1890's, as a means to develop irrigation plans and reached maximum of 3417 operational hydrometric stations in 1984 (Scott *et al.* 1999).
- Most of the stations are located in the southern half of Canada leaving fewer stations to cover the broad territorial expanse extending north of 60°N latitude (Scott *et al.* 1999).

Arctic

- In comparison to other oceans, the influence of river runoff is more pronounced in the Arctic Ocean because it is the most land-locked (Vörösmarty *et al.* 2001) and shallowest ocean in the world (Jakobsson 2002).
- A disproportionate amount of global surface runoff (11%) flows into the Arctic Ocean that contains 1.2% of the total ocean water (Shiklomanov 2000).
- Déry *et al.* (2009) estimated the average river discharge in northern Canada to be 1153 $km^3\ yr^{-1}$ for 1964-2007 (Information generated by this research is provided online at http://nhg.unbc.ca/ipy).

Previous Studies

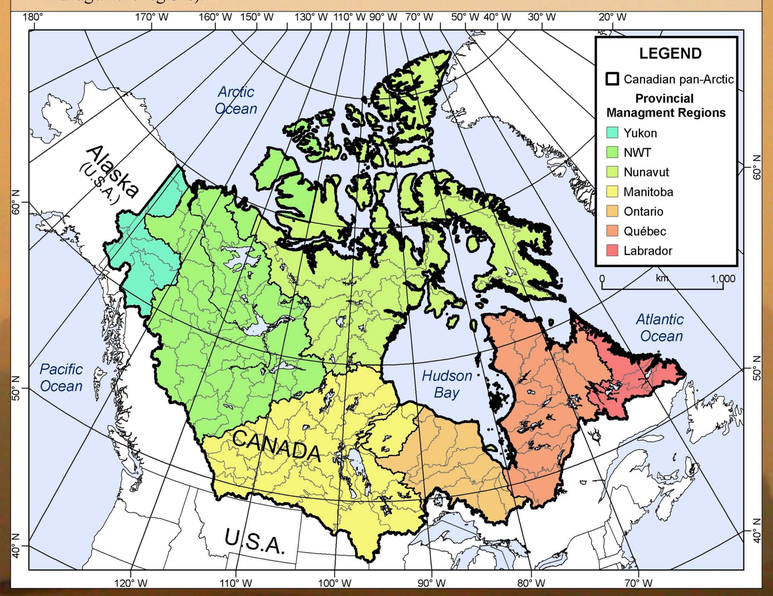
- Lammers *et al.* (2001) and Shiklomanov *et al.* (2002) reported a notable decline in the number of hydrometric stations in gauged area for the pan-Arctic domain of Eurasia and North America after 1985.
- Lanfear & Hirsch (1999) examined the United States Geologic Survey (USGS) stream gauging stations within its management area and revealed long-term records have also been in decline.
- Spence & Burke (2008) highlighted the need to improve the already very sparse hydrometric monitoring network in northern Canada.

Motivation

- In Canada, approximately 60% of river discharge flows to northern latitudes, contributing about 4.2% (1987 $km^3\ yr^{-1}$) of the world's renewable water supply.
- The combination of harsh environmental conditions, lack of infrastructure, and the redirection of government priorities and funds have made it increasingly more difficult to monitor river discharge in northern Canada (Grabs *et al.* 2000; Shiklomanov *et al.* 2002).
- Without an adequate hydrometric network, our understand of the hydrological cycle is limited.
- The goal of this paper is to assess the effectiveness of Canada's monitoring of pan-Arctic river discharge from 1950 to 2008.

STUDY AREA

- The Canadian pan-Arctic region covers an area of $8.23 \times 10^6\ km^2$ or more than three-quarters of Canada
- The study area is defined geographically by rivers flowing into high-latitude oceans, and politically by the hydrometric gauges established within Canada.
- Within the study area, we further grouped hydrometric gauges into management regions defined by the drainage areas of each provincial and territorial boundary (referred hereafter as provincial management regions).

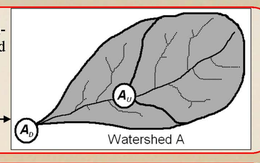


METHODS

- Hydrometric gauges for this study are selected on the basis of two criteria:
  1) Hydrometric gauges must be near the river's outlet.
  2) Rivers need to have a relatively long period of hydrometric record.
- The study period (1950-2008) is limited to 59 years since data availability and quality, particularly in northern regions, degrades substantially prior to 1950.
- Hydrometric Data for the period 1950 –2008 are extracted (when and where available) from:
  1) **Water Survey of Canada's** (WSC) hydrometric database (HYDAT; available online at http://www.wsc.ec.gc.ca/).
  1) **Ministère de l'Environnement du Québec** (http://www.cehq.gouv.qc.ca/suivihysro/default.asp (Only for Québec).
  1) **Hydro-Québec** (Only for the intensively dammed La Grande Rivière in Québec).
  2) **United States Geologic Survey** (http://waterdata.usgs.gov/nwis) (Only for the Yukon River).
- For compiling hydrometric time series for the 91 rivers, different equations where used depending on the location of gauges and completion of their hydrometric records. For instance:

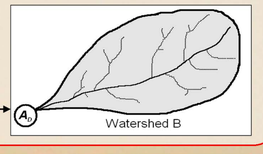
If a watershed has a complete hydrological record then we use,

$$A_t = \frac{t_D A_D}{D}$$



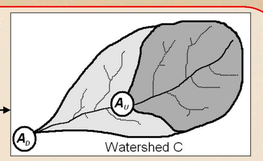
If there is only one gauge (i.e. with an incomplete or complete hydrological record) then we use,

$$A_t = \frac{t_D A_D}{D}$$



If a watershed has multiple gauges with incomplete hydrometric records

$$A_t = \frac{t_D A_D + t_U A_U}{D}$$



*However, t_D and t_U are the number of non-overlapping days when data are available at the downstream and upstream gauges (i.e., $t_D + t_U \leq D$). This process is repeated if more than two gauges with partial records are available.

For a given management region then, the overall gauged area A_O is the sum of all n contributing watersheds (e.g., sum of watersheds A, B and C in Fig. 2), i.e.,

$$A_O = \sum_{i=1}^{n} A_{ti}$$

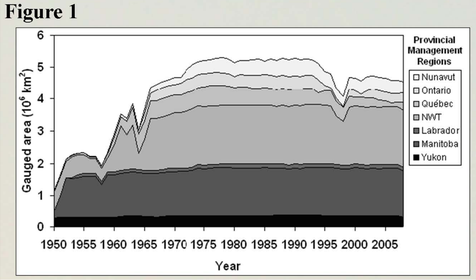
Abbreviation Legend

- A_t = Total gauged area
- T_D = Number of days for the downstream gauge
- A_D = Downstream gauged area
- D = Number of days for that year (i.e., 365 or 366)
- T_U = Number of days for the upstream gauge
- A_U = Upstream gauged area

- This procedure is repeated for the years spanning 1950 to 2008, providing annual time series for the entire Canadian pan-Arctic and for each provincial management region.

RESULTS

Figure 1



Keypoints:

1) General trend increases, levels off, then decreases.
2) Since 1992 Canada's maximum gauged area of the pan-Arctic has declined by 15%.
3) The Mackenzie and the Nelson River systems contribute to a large portion of the Northwest Territories and Manitoba management regions, respectively.

Keypoints:

1) Manitoba management region is responsible for 79% of the decline in 1958.
2) NWT management region is responsible for 98% of the decline in 1964.
3) All management regions decline throughout the period 1993–1998.
4) NWT and Ontario management regions are responsible for the increase in 1999.

Figure 2

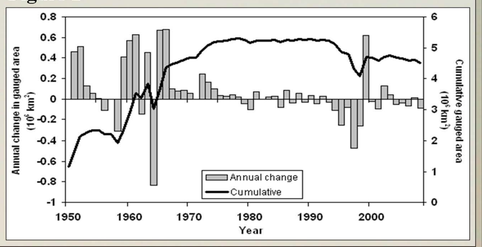
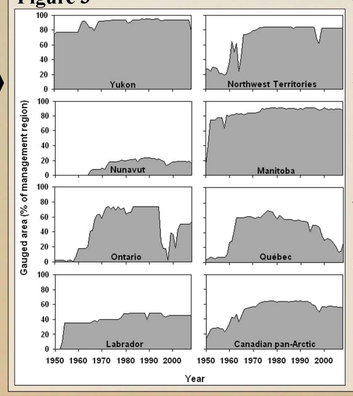


Figure 3



Keypoints:

1) Yukon, Manitoba, Labrador have relatively constant monitoring.
2) NWT has a series of downward "spikes" in 1962, 1964, 1997.
3) Nunavut does not commence monitoring until 1964 and gauged area does not exceed 25%.
4) Québec and Ontario's gauged area declines dramatically in recent history.
5) No more than 65% of the Canadian pan-Arctic is ever monitored.

DISCUSSION

- As far as we know, the details of our methods for assessing the effectiveness of hydrometric monitoring is the first of its kind and different than previous studies (e.g., Lammers *et al.* 2001; Shiklomanov *et al.* 2002).
- This study provides supporting evidence for the deterioration of Canada's river discharge monitoring network in the pan-Arctic region. In particular, since 1988 Canada's gauged area has declined from 64% to 56 % (or $0.70 \times 10^6\ km^2$ in area), which is the equivalent of losing the monitored area of Alberta.
- The primary reason for the network decline in Canada can be attributed to the reduction of government funds for water monitoring networks. In 1995, a government program review targeted Environment Canada with an overall budget reduction of approximately 35% (Pilon *et al.* 1996). As shown by our study, this resulted in an immediate decline in the total gauged area for the Canadian pan-Arctic region.
- Significant declines in gauged area are apparent for the Ontario, Québec, and Nunavut management regions.
- Because this study focuses on the most downstream gauges, a single decommissioned or malfunctioned gauge could potentially have an adverse effect on the total gauged area. For example, the decommissioned gauge at Arctic Red River (station 10LC014) on the Mackenzie River in 1997 reduced the total gauged area by 14% (or 448,200 km^2 in area).
- The Nunavut management region has the shortest hydrometric period and the worst gauged area representation in Canada due to the harsh environmental conditions, remoteness, large area, and small population. In general, the Arctic Archipelago has less than 1% of its surface area gauged (Déry & Wood 2005).
- As inferred by Spence & Burke (2008), the lack of effective monitoring reduces our ability to accurately predict the state and dynamics of freshwater flux from the Arctic Archipelago.

REFERENCES

Déry, S. J. & Wood, E. F. 2005, *Geophys. Res. Lett.* 32, L10401, doi:10.1029/2005GL022845.

Déry, S. J., Hernández-Henríquez, M. A., Burford, J. E., and Wood, E. F. 2009, *Geophys. Res. Lett.*, **36**, L13402, doi: 10.1029/2009GL038852.

Grabs, W. E., Portmann, F. & de Couet, T. 2000, In: *The Freshwater Budget of the Arctic Ocean.* Kluwer Academe Publishers, Dordrecht, Netherlands, pp. 249-268.

Jakobsson, M. 2002, *Geochem. Geophys. Geosyst.* **3**(5), 1028, doi:10.1029/2001GC000302.

Lammers, R. B., Shiklomanov, A. I., Vörösmarty, C. J., Fekete, B. M. & Peterson, B. J. 2001, *J. Geophys. Res.* **106(4)**, 3321–3334.

Lanfear, K. J. & Hirsch, R. M. 1999, *Eos. Trans. AGU.* **80**(50), 605–607.

Pilon, P. J., Day, T. J., Yuzyk, T. R. & Hale, R. A. 1996, *Can. Water-Resour. J.* **21**, 157–163.

Scott, D., Yuzyk, T. R. & Whitney, C. 1999, In: *Proceedings of the CWRA 52nd annual conference on Partnerships in Water Resource Management*, June 1999, Nova Scotia.

Shiklomanov, A. I., Lammers, R. B. & Vörösmarty, C. J. 2002 *Eos. Trans. AGU.* **83**(2), 13-16.

Shiklomanov, I. A. 2000, *Water International* **25**(1), 11-32.

Spence, C. & Burke, A. 2008, *J. Hydrol.* **362**, 247-259.

Vörösmarty, C. J., Hinzman, L. D., Peterson, B. J., Bromwich, D. H., Hamilton, L. C., Morison, J., Romanovsky, V. E., Sturm, M. & Webb. R. S. 2001, Arctic Research Consortium of the U.S., Fairbanks, Alaska, p.84.

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