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Dendrohydrology in Canada's western interior and applications to water resource management

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SUMMARY

Across the southern Canadian Prairies, annual precipitation is relatively low (200–400 mm) and periodic water deficits limit economic and environmental productivity. Rapid population growth, economic development and climate change have exposed this region to increasing vulnerability to hydrologic drought. There is high demand for surface water, streamflow from the Rocky Mountains in particular. This paper describes the application of dendrohydrology to water resource management in this region. Four projects were initiated by the sponsoring organizations: a private utility, an urban municipality and two federal government agencies. The fact that government and industry would initiate and fund tree-ring research indicates that practitioners recognize paleohydrology as a legitimate source of technical support for water resource planning and management. The major advantage of tree-rings as a proxy of annual and seasonal streamflow is that the reconstructions exceed the length of gauge records by at least several centuries. The extent of our network of 180 tree-ring chronologies, spanning AD 549–2013 and ~20° of latitude, with a high density of sites in the headwaters of the major river basins, enables us to construct large ensembles of tree-ring reconstructions as a means of expressing uncertainty in the inference of streamflow from tree rings. We characterize paleo-droughts in terms of modern analogues, translating the tree-ring reconstructions from a paleo-time scale to the time frame in which engineers and planners operate. Water resource managers and policy analysts have used our paleo-drought scenarios in their various forms to inform and assist drought preparedness planning, a re-evaluation of surface water apportionment policy and an assessment of the reliability of urban water supply systems.

1. Introduction

The semi-arid North American Great Plains extend northward into Canada to a latitude of approximately 52° N. The largest contiguous area of low precipitation (200–400 mm; Fig. 1) in the Great Plains is in eastern Montana, southwestern Saskatchewan and southeastern Alberta; in the continental interior and rainshadow of the Rocky Mountains. The lack of rain and snowmelt water in the southern Canadian Prairies is offset by lower rates of evapotranspiration than to the south in the USA. However, unlike in the Great Plains States, there is little use of groundwater in western Canada, even for irrigation, which is extensive. Oil and gas production drives the economy, but surface water sustains it. Demand for surface water generated in the Rocky Mountains is high. While annual precipitation is mostly in the range of 300–400 mm across the Canadian plains, it ranges up to 1500 mm in the mountains. The mountain watersheds yield more than 300 m^3 of water per km^2/yr, an order of magnitude higher than the prairie landscape, which mostly yields less than 10 m^3/km^2/yr.[1]

Rapid population growth, economic development and climate change have exposed this region to increasing vulnerability to hydrologic drought. In 2013, the population of the Province of Alberta surpassed 4 million[2], concentrated in the Calgary–Edmonton corridor. This is larger than the combined 2013 population of three of the four Rocky Mountain States east of the continental divide[3]: Montana, Wyoming and New Mexico. Only Colorado is comparable, in terms of demand for water produced on the eastern slopes of the Rocky Mountains. In southern Alberta, total surface

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[1] http://albertawater.com/water-yield-streamflow-analysis.
[2] Statistics Canada – www.statcan.gc.ca/daily-quotidien/130926/dq130926a-eng.pdf.
[3] U.S. Bureau of the Census – /factfinder2.census.gov/.

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water allocation in the South Saskatchewan River Basin (Fig. 2) has begun to exceed supply in some years. In response, in 2006, the provincial government closed most of the basin to further allocations of surface water, an unprecedented action in the context of Canadian water policy.

Water supply forecasting and management in western Canada is supported by a relatively dense network of water level gauges, reflecting the historical demand for surface water and constraints on the economy imposed by periodic water deficits. This hydrometric network was originally established in the early 20th century to identify and monitor reliable sources of surface water, originally for steam locomotives and irrigation. For these purposes, the number of gauges was more important than the continuity of observations, and thus few gauges have operated continuously for more than 50 years. Based on these short instrumental records, water managers have generally supposed or assumed a sufficient and stationary water supply; however, these gauge data do not capture the full range of variability in the regional hydrologic regime. A longer view, from knowledge of the regional paleohydrology, can provide water resource planners and engineers with (St. George and Sauchyn, 2006; Meko and Woodhouse, 2011):

- A historical context for reference hydrology to evaluate baseline conditions and water allocations.
- Worst-case scenarios: what is possible in terms of severity of excess water and drought.
- Long-term probabilities of exceeding critical hydroclimatic thresholds.
- A historical context for scenarios of water supply under climate change.
- Detection of multi-decadal cycles that exceed the length of short gauge records.
- A much broader perspective on the variability of water levels to assess the reliability of water supply systems under a wider range of flows than recorded by a gauge, and probabilities of simultaneous drought in different river basins.

Tree-ring measurements from stands of long-lived moisture-sensitive trees are the source of proxy hydroclimatic data and a chronology of absolute annual resolution. Dendro-hydrology is a well-established and well-documented field of research (Meko and Woodhouse, 2011; Meko et al., 2010). One of seminal studies in dendrohydrology was the Stockton and Fritss (1973) 158-year

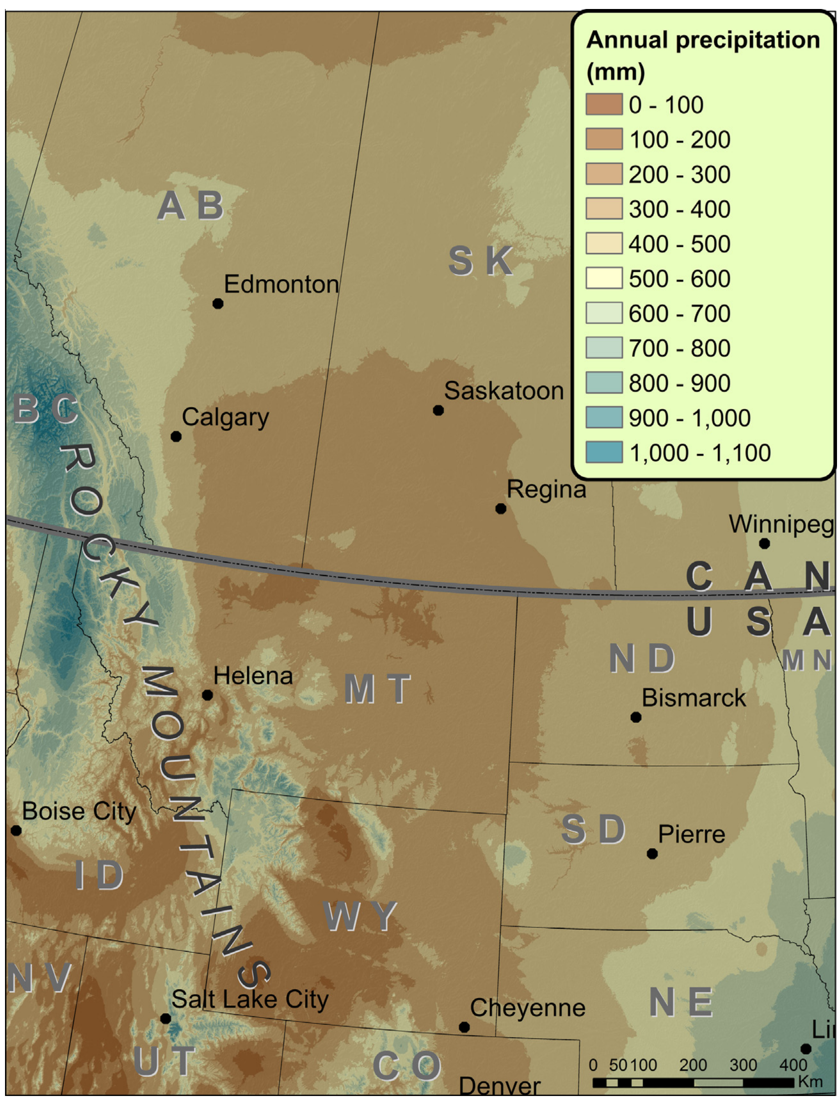

Fig. 1. Mean annual precipitation in the western interior of North America. East of the Rocky Mountains, in the Great Plains, the largest area of low precipitation (200–400 mm) is in eastern Montana, southwestern Saskatchewan and southeastern Alberta. *Source:* North American Environmental Atlas <http://www.cec.org/atlas/map/?lang=en>.