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Twentieth-century decline in streamflows from the hydrographic apex of North America

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Abstract

The Rocky Mountain region near the Canada–United States border provides the North American hydrographic apex with headwater streams flowing to the Pacific, Arctic and Atlantic oceans. The area contains numerous national parks and protected areas with relatively pristine watersheds that permit analyses of historic streamflow patterns with minimal human impacts that would alter hydraulic linkages between precipitation and river discharge. Consequently, we analyzed patterns of mean annual discharge (Q_a) from 31 river reaches that were generally free-flowing with hydrologic records typically commencing in the 1910s and extending to about 2002. To maximize the records of six rivers we undertook regression analyses to extrapolate Q_a from sequential hydrometric gauges or from early, summer-only Q data. Spearman ρ and Kendall τ b non-parametric correlations and a parametric approach involving linear regressions combined with analyses of variance were highly consistent in detecting significant historic trends in Q_a and the regression analyses estimated the trend magnitudes. These analyses revealed flow declines (exceeding 0.1%/year over the historic record) for 21 reaches (5 with $p<0.1$, 10 with $p<0.05$), while 10 rivers displayed little change (<0.1%/year and not significant). Flow declines were prominent for the Alberta rivers, which flow to Hudson Bay and the Arctic Ocean, and also observed for some Pacific and Atlantic drainages. Overall, the rivers displayed a mean Q_a reduction of 0.22%/year (median = −0.17%/year) and four rivers had recent decline rates exceeding 0.5%/year. The progressive decline was superimposed on an approximately half-century oscillation in streamflow that was strongly associated with the Pacific Decadal Oscillation. Following from the observed river flow decline over the past century, it is likely that there will be continuing decline in future decades; this prediction contrasts with many current climate change forecasts. Historic and continuing reductions in these streamflows will impact aquatic and riparian ecosystems and diminish water supplies for irrigation, industrial and domestic use, and hydroelectric power generation, with effects extending from these mountain headwaters downstream through other ecoregions.

Keywords: Canada; Climate change; Discharge; Rivers; USA

1. Introduction

Climate change is an ongoing natural process and there is concern that the anthropogenic elevation of atmospheric CO_2 and other 'greenhouse' gasses will

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induce global warming through the twenty-first century (IPCC, 2001). While historic records and climate models are relatively consistent in predicting global warming, precipitation patterns are more complex and regionally variable and much more difficult to model. A common view is that global warming will increase evaporative rates from oceans and thus promote the global hydrologic cycle and generally increase precipitation (IPCC, 2001). Spatial patterns are less certain but global warming is predicted to be more severe at high latitudes and it might be reasonable to expect that other climate patterns, including processes affecting streamflows, would be similar (Nijssen et al., 2001).

Stream flows provide an integration of precipitation over catchment areas and thus reveal regional precipitation patterns. Analyses of stream flows as surrogates for precipitation have particular utility for mountain regions since these areas have limited meteorological monitoring. Also, due to orographic effects, mountain regions have been regarded as continental 'water towers' since they receive major precipitation inputs and often substantial snow-fall that results in gradual water release with melting. Following from the prediction that global warming is associated with increased precipitation, the corollary is that streamflows would have increased in the past and will continue to increase in the future. This prediction is supported by increasing streamflow trends for many United States' rivers for the periods from 1948 to 1988 (Lettenmaier et al., 1994) and 1944 to 1993 (Lins and Slack, 1999), and for some high-latitude Eurasian rivers from 1936 to 1999 (Peterson et al., 2002).

Analyses of historic streamflows for Canadian rivers have provided variable results and indicate differing patterns across geographic regions. Anderson et al. (1991) concluded the hydrologic record was insufficient to confidently detect patterns for the Prairie Provinces. Burn's (1994) study of west central rivers concluded that the prominent streamflow change involved an earlier spring runoff consistent with regional warming and this pattern has been confirmed in subsequent studies (Whitfield, 2001; Zhang et al., 2001; Burn and Hag Elnur, 2002). Westmacott and Burn (1997) detected some declining trends in non-winter streamflow for regions of the Prairie Provinces based on a minimum 30 year record of hydrometric data up to 1991. Zhang et al. (2001) concluded that streamflows of a few southwestern Canadian rivers had declined ($p<0.1$) over the past 30–50 years and Yue and Wang (2002) concluded that between 1967 and 1996, streamflows in some prairie and Pacific regions had decreased ($p<0.1$) while some streamflows had increased ($p<0.1$) in more northerly zones of western Canada. Burn and Hag Elnur (2002) concluded that annual peak flows had decreased ($p<0.05$) from 1950 to 1997 for a number of gauging sites in Alberta and British Columbia but that there was no consistent trend for annual mean flows across Canada as only 11 of 86 stations displayed significant change ($p<0.05$) with approximately equal numbers decreasing and increasing. Most recently, Yue and Pilon (2003) confirmed the trends revealed by Zhang et al. (2001) and Yue and Wang (2002) with the determination that over the past 30 years, regional mean streamflows had declined in southern British Columbia and near the centre of the Prairie Provinces.

These prior studies have been extensive in spatial scope with analyses extending across northern Europe, the United States or Canada. The researchers have generally agreed that non-parametric analyses are appropriate since the data sets are insufficient to verify normality of data distribution that is required for parametric statistics (Yue et al., 2002). The studies recognize the need to discriminate changes in streamflow patterns due to water diversions and water management practices and recognize that land-use impacts can confound the historic analyses. To complement and extend the previous line of investigation, we undertook a study that was geographically intensive rather than extensive. We thus focused on a region that has particular hydrologic relevance for North America and has also been insufficiently investigated in prior studies.

In general shape, North America approximates a large triangle that in three-dimensions represents a massive but shallow tetrahedron with the three faces providing the watersheds for the Arctic, Atlantic and Pacific oceans (Fig. 1). The apex of the tetrahedron represents the continent's hydrographic apex, the location from which adjacent surface waters flow to the three oceans. This hydrographic apex is at Triple-Divide Peak in Glacier Park, Montana near the common border of Montana, USA, and Alberta