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Tree-ring reconstruction of groundwater levels in Alberta, Canada: Long term hydroclimatic variability

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ABSTRACT

Groundwater could be an increasingly important water supply in the Canadian interior with global warming and declining summer runoff; however, not enough is known about the behavior of groundwater under climatic variability. Groundwater levels at two wells in southern and central Alberta are analyzed in order to document long-term variability of groundwater levels and their sensitivity to climatic events. The instrumental well records span more than 40 years. Strong correlations ($r > 0.7$, $p < 0.01$) between mean annual groundwater levels and tree-ring chronologies suggested the use of regression models to reconstruct historical water levels for more than 300 years. From the estimated groundwater levels several periods with five or more consecutive years of low levels were identified (i.e. periods centered on 1698, 1720, 1855, and 1863 at well 117; 1887 and 1923 at well 159). The application of a regime shift method revealed periods with more than 30 years with below-average water levels. Spectral analyses, wavelet and multitaper methods, suggest dominant oscillation modes in groundwater levels in the 2–8 and 8–16 year bands.

Introduction

Despite the importance of groundwater as a component of the hydrological cycle and source of potable water, especially in arid and semiarid regions, there is a lack of studies of the impacts of climate change on groundwater (IPCC, 2007) and the response of groundwater levels to climate fluctuations such a drought. Groundwater studies are limited by the quantity and quality of the observations available and in particular limitations caused by anthropogenic effects on water table levels.

In Canada groundwater has a major role supplying fresh water for domestic use for almost 9 million Canadians (30.3% of the population). Most of the groundwater is used in rural areas, 67% or 6 million people that rely on groundwater live in rural areas (Statistics Canada, 1996). In Alberta groundwater resources are used by more than 23% of the population through over 500,000 domestic wells. The groundwater allocations are about 3% of the total water allocation in the province and are mostly used in commercial and industrial activities (53%), agriculture (25%), municipal use (18%) and 4% for other purposes (Alberta Environment, 2005).

To date, few studies have modeled or reconstructed future or past groundwater levels in the Canadian Prairies. Chen et al. (2002) used an empirical model to predict groundwater levels, while Ferguson and St. George (2003) used precipitation, temperature and tree rings to reconstruct historical levels of groundwater in the Upper Carbonate Aquifer in central Manitoba back to 1907. Tree rings have been widely used to reconstruct components of the hydrological cycle, such as stream flow and precipitation (e.g. Watson and Luckman, 2001; St. George and Nielsen, 2002; Case and MacDonald, 2003), however Ferguson and St. George (2003) is the only study which has investigated the relationship between tree rings and groundwater within the Prairies.

Tree-ring reconstructions of groundwater levels are based on the common response of tree growth and groundwater levels to effective precipitation, recognizing that these responses are often lagged in time. Tree rings collected at dry sites are a proxy of available soil moisture. In western Canada, spring snow melt and rainfall are the major sources of groundwater and soil moisture (Pomeroy et al., 2007). Summer precipitation has little influence on groundwater levels because it mostly evaporates; mostly from the unsaturated soil water zone where it is available for annual plant growth. Geologic structures and aquifer characteristics are important factors when relating groundwater levels and tree rings. High hydraulic conductivity is an important requirement when studying the effects of climatic variability on groundwater because it represents the capacity of a rock, aquifer, or earth material to transmit water; higher hydraulic conductivity means a faster movement of the water through that media (Fetter, 1994).

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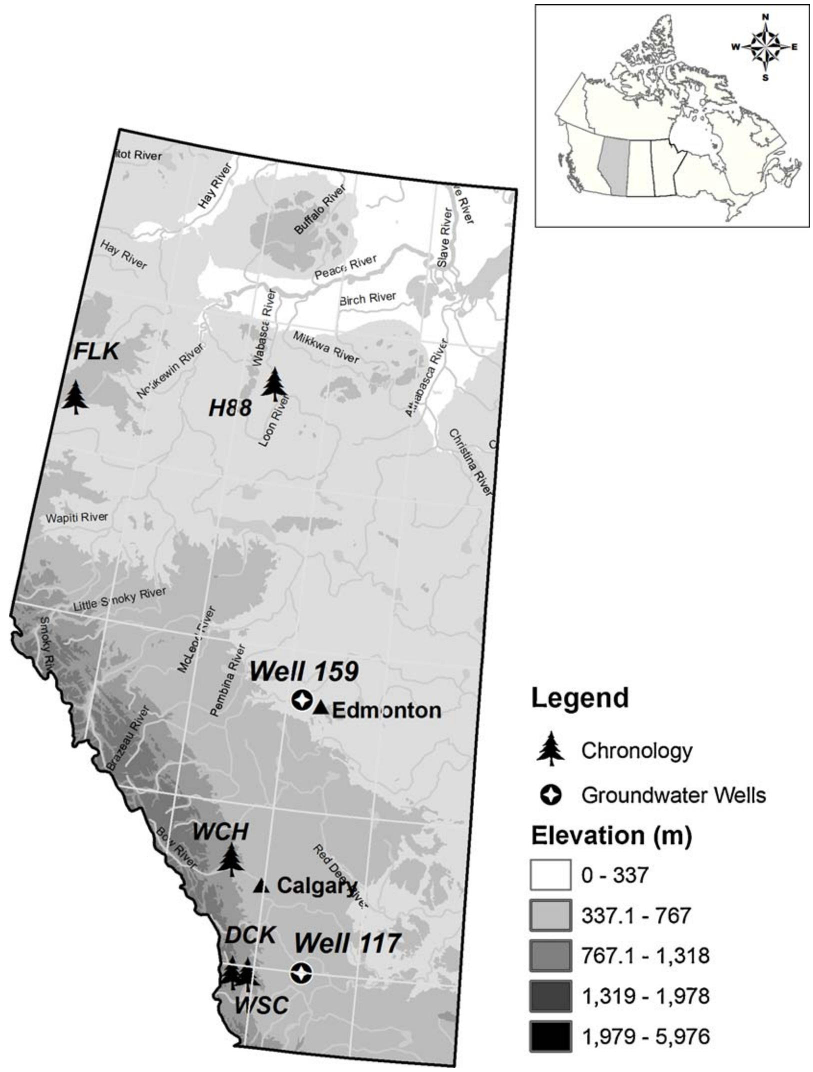

Fig. 1. Study area and location of the tree-ring chronologies and groundwater wells.

This study aims to relate water table variations to climate variability at inter-annual and inter-decadal time scales. Using tree-ring chronologies we reconstruct mean annual groundwater levels, apply regime shift techniques (Rodionov, 2004) to detect discontinuities in mean water levels, and apply spectral analysis, wavelet (Torrence and Compo, 1998) and multitaper (Ghil et al., 2002) methods, to identify the dominant oscillation modes.

Data and methods

Study area

The study area is between 49° and 58° latitude and 120° and 110° longitude in the Canadian Province of Alberta (Fig. 1). The tree-ring sites are in the headwater regions of major river basins in the southwestern foothills of the Rocky Mountains and the boreal forest of north-central Alberta. The two groundwater wells selected for this study are located in the central and southern part of the Province. The Prairie Provinces have a cold and sub-humid climate with a difference of more than 30 °C between the coldest and warmest month. Mean annual temperature increases from north to south and east to west. Mean annual precipitation ranges from just over 300 mm in southeastern Alberta to about 600 mm in the boreal forest and to over 900 mm in the Rocky Mountains.

Tree-ring chronologies

The five tree-ring chronologies, from two species (*Pseudotsuga menziesii* (Mirbel) Franco, *Pinus banksiana* Lamb.) (Fig. 1) in the foothills and boreal forests of Alberta, are part of a larger network spanning the Northwest Territories, Alberta, Montana and Saskatchewan. These moisture-sensitive tree-ring chronologies contain annual and seasonal moisture signals spanning more than 800 years. The wood and tree-ring data were processed in the Tree Ring Laboratory of the University of Regina using standard dendrochronological methods (Stokes and Smiley, 1968; Fritts, 1976; Cook, 1985; Cook and Kairiukstis, 1990). Conservative detrending (negative exponential or a 67% smoothing spline) was used to remove growth trends. The chronologies were cross-dated to detect missing or false rings and verified with COFECHA (Holmes, 1983). They range in length from 147 to 664 years and all of them end in 2003 or later (Table 1).