Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Hydrology 319 (2006) 282–294
Journal of Hydrology
www.elsevier.com/locate/jhydrol

Trends and variability in the hydrological regime of the Mackenzie River Basin

Omar I. Abdul Aziz, Donald H. Burn*

Department of Civil Engineering, University of Waterloo, Waterloo, Ont., Canada N2L 3G1

Received 15 September 2004; revised 15 June 2005; accepted 28 June 2005

Abstract

Trends and variability in the hydrological regime were analyzed for the Mackenzie River Basin in northern Canada. The procedure utilized the Mann–Kendall non-parametric test to detect trends, the Trend Free Pre-Whitening (TFPW) approach for correcting time-series data for autocorrelation and a bootstrap resampling method to account for the cross-correlation structure of the data. A total of 19 hydrological and six meteorological variables were selected for the study. Analysis was conducted on hydrological data from a network of 54 hydrometric stations and meteorological data from a network of 10 stations. The results indicated that several hydrological variables exhibit a greater number of significant trends than are expected to occur by chance. Noteworthy were strong increasing trends over the winter month flows of December to April as well as in the annual minimum flow and weak decreasing trends in the early summer and late fall flows as well as in the annual mean flow. An earlier onset of the spring freshet is noted over the basin. The results are expected to assist water resources managers and policy makers in making better planning decisions in the Mackenzie River Basin.

Keywords: Water resources; Mackenzie river basin; Mann–Kendall test

1. Introduction

Most water resources projects are planned, designed and operated based on the historical pattern of water availability, quality and demand assuming constant climatic behaviour. It is therefore important to investigate present and probable future climatic change patterns and their impacts on water resources so that appropriate adaptation strategies may be implemented. Almost all the processes in the biosphere are influenced in some way by climate change phenomena . Of great concern are the climate change impacts on the environment and water resources.

Cunderlik and Burn (2002) summarized some of the recent literature on the analysis of hydrological trends and variability. Burn and Hag Elnur (2002) described the development and application of a procedure to identify trends in hydrological variables by utilizing the Mann–Kendall non-parametric test, a permutation approach and a vector resampling approach. Kundzewicz and Robson (2004) reviewed commonly applied methodologies for conducting

* Corresponding author. Tel.: +1 519 888 4567; fax: +1 519 888 4349.
E-mail address: dhburn@civmail.uwaterloo.ca (D.H. Burn).

0022-1694/$ - see front matter © 2005 Elsevier Ltd All rights reserved.
doi:10.1016/j.jhydrol.2005.06.039

trend analysis studies. Burn et al. (2004a) investigated trends and variability in hydrological variables for natural streamflow gauging stations for the Liard River Basin in northern Canada. Lindstrom and Bergstrom (2004) analyzed time series of annual runoff volumes and annual as well as seasonal flood peaks in Sweden. Burn et al. (2004b) compared trend results for two watersheds within the Mackenzie River Basin, namely the Liard River Basin and the Athabasca River Basin. The interested reader is referred to these publications, and references contained therein, for further details on past trend analysis work.

This paper explores hydrological trends and variability for the Mackenzie River Basin in the Canadian north. Previous studies (e.g. IPCC, 2001) have hypothesized that northern basins will be particularly sensitive to the impacts of climatic change. IPCC (2001) predicted probable changes in flood frequencies and increases in runoff due to increased precipitation in northern latitudes. However, comparatively little research has been conducted on trends and variability in northern basins partially because of the lack of sufficient data for pristine rivers in the remote areas that characterize much of the far north (Woo and Thorne, 2003; Burn et al., 2004a). The Mackenzie River Basin is chosen in this study for exploring climatic impact on hydrological trends and variability because the basin has been subject to few human interventions (e.g. hydroelectric development) while being representative of the climatic regime in the Canadian north. The paper consists of a description of the approach used to investigate hydrological and meteorological trends, results of application of the techniques to data from the Mackenzie River Basin and a summary of the results and conclusions.

2. Methodology

The methodology used for exploring hydrological trends and variability is described in greater detail in Burn et al. (2004a). The procedure started with the evaluation of trends in hydrological variables for individual stations using the Mann–Kendall non-parametric trend test (Mann, 1945; Kendall, 1975). The Mann–Kendall test is a rank-based method that has been applied in many previous studies for identifying trends in hydrological variables. The results of the trend test can be used to determine whether the observed time series for a variable from a collection of sites exhibit a number of trends that is greater than the number that is expected to occur by chance. All the trend results in this research have been evaluated at the 10% level of significance to ensure an effective exploration of the trend characteristics of the study area.

It is also necessary to consider the correlation structure of the data. The correlation structure consists of the serial, or auto, correlation of the data series and the cross-correlation between hydrological variables at different locations. Following Burn et al. (2004a), the data were corrected for serial correlation through a modified version of the Trend Free Pre-Whitening (TFPW) approach developed by Yue et al. (2002). The TFPW involves estimating a monotonic trend for the series, removing this trend prior to pre-whitening the series and finally adding the monotonic trend calculated in the first step to the pre-whitened data series. In essence, the TFPW approach attempts to separate the serial correlation that arises from a (linear) trend from the remaining serial correlation and then only removes the latter portion of the serial correlation. Note that although the TFPW procedure involves fitting and removing a linear trend, the overall Mann–Kendall trend detection procedure does not make any assumptions about the nature of the trend in a data set. The cross-correlation was incorporated by evaluating the global (or field) significance of the trend results using a bootstrap resampling technique from Burn and Hag Elnur (2002). The resampling method determines the critical value for the percentage of stations exhibiting a trend by chance. Based on this critical value, it is possible to determine whether the observed number of trends exceeds what is expected to occur by chance.

The relationship between hydrological variables and meteorological variables was explored using correlation analysis to better understand the origins of observed hydrological trends and variability. Data for a group of meteorological variables were investigated for significant trends by applying the Mann–Kendall test, while the strength of the relationship between meteorological variables exhibiting a trend and hydrological variables exhibiting