Journal of Hydrology (2008) **359**, 141–149

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jhydrol

The impact of large-scale forest harvesting on hydrology in the Willow watershed of Central British Columbia

Yong Lin, Xiaohua Wei *

Department of Earth and Environmental Sciences, University of British Columbia, 3333 University Way, Kelowna, British Columbia, Canada V1V 1V7

Received 6 September 2007; received in revised form 16 June 2008; accepted 24 June 2008

KEYWORDS
Large-scale watershed hydrology;
Forest harvesting;
Time series analysis

Summary Availability of long-term hydrological and climatic data from 1953 to 2005, along with large-scale cumulative forest harvesting in the Willow watershed (2860 km^2) situated in the central interior of British Columbia, Canada provided us a unique opportunity to study the impact of large-scale forest disturbance on hydrology. Various statistical techniques including time series analysis and non-parametric tests were applied to analyze the impacts of forest harvesting on peak, mean and low flows over annual and other periods (spring, summer and winter). The results showed that forest harvesting in the Willow watershed significantly increased mean and peak flows over annual and spring periods. However, the mean and peak flows in the summer and winter periods were not significantly affected. The impacts of forest harvesting on low flow for all studied periods were either not statistically significant or inconclusive. In addition, we specifically tested the relation between the spring peak flows and timber harvesting with consideration of climate variables by regression model analysis. Our regression analysis further confirmed that spring peak flows were significantly altered by forest harvesting in this large-scale watershed.

Introduction

The impact of timber harvesting on watershed hydrology has been the subject of considerable study and debate (Jones and Grant, 1996; Sun et al., 1998; Post and Jones, 2001; Andréassian, 2004; Cosandey et al., 2005; Wei et al., 2005; Calder, 2007). Previous studies have used the paired watershed or replication (with treatments randomly assigned) approaches (i.e. Golding, 1987; Eberhardt and Thomas, 1991; Jones and Grant, 1996; Brown et al., 2005) for evaluation of timber harvesting impacts on small-scale watersheds (less than 100 km^2). It is well recognized that

* Corresponding author. Tel.: +1 250 8078750; fax: +1 250 8078005.
E-mail address: adam.wei@ubc.ca (X. Wei).

0022-1694/$ - see front matter
doi:10.1016/j.jhydrol.2008.06.023

the results from small-scale watersheds are difficult to apply to large-scale watersheds (>1000 km^2). Lack of information regarding hydrological impacts of large-scale forest disturbance greatly constrains our ability to develop forest and watershed management strategies on a large spatial scale.

Although the need to understand cumulative impacts of land use change on hydrology for relatively large watersheds is widely recognized, research at this scale is limited and the reported results are various and inconsistent. Many studies showed that the hydrological responses to alteration of forest covers are not significant in large-scale basins. For instances, the study in Northeastern Ontario, Canada by Buttle and Metcalfe (2000) found limited stream flow response in some large-sized watersheds (ranging from 401 to 11,900 km^2) to land cover changes (5–25%) and no definitive changes in annual peak flows. The research in the Pasak River watershed (14,500 km^2) by Dyhr-Nielsen (1986) also showed similar results, even though the forest cover change was much greater (50%). Wilk et al. (2001) did not find any significant hydrological change in the Nam Pong River basin (12,100 km^2) in Northeast Thailand after a reduction of forest cover from 80% in 1957 to 27% in 1995. Robinson et al. (2003) reviewed the hydrological results from 28 basins across Europe sampling different spatial scales of watersheds, and concluded that changes in forest cover at a regional scale will be likely to have a relatively small effect on peak and low flow.

In contrast, some studies showed that streamflows were significantly affected by deforestation in large-scale watersheds (Matheussen et al., 2000; Siriwardena et al., 2006). According to Siriwardena et al. (2006), forest harvesting in the Connet River watershed (16,440 km^2), Central Queensland, Australia led to an increase of 78% in runoff. Costa et al. (2003) examined the impacts of land use in the Tocantins River basin (175,000 km^2) in Southeastern Amazonia and found that land clearing for pasture and crops resulted in an increase of 24% in mean annual discharge in the post-harvesting period. A numerical simulation study in the Interior of Columbia River basin (USA and Canada) showed 4.2–10.7% increase of annual average runoff following deforestation (Matheussen et al., 2000). In addition, there were some case studies showing reduction of water yield after deforestation (Ring and Fisher, 1985) or no detectable hydrological change following deforestation (Siriwardena et al., 2006).

In large-scale watersheds or basins, the coexistence of various types of land features such as wetlands, ponds, lakes, often dilute the effects of land use change (Robinson et al., 2000). Variations in land use, vegetation regeneration of different ages, and spatial and temporal variations in rainfall are some of the factors that prevent consistent conclusions from large catchment data (Siriwardena et al., 2006).

Paired or replication approaches are not feasible for large-scale watersheds (>1000 km^2) as it becomes difficult to find suitable controls (Fohrer et al., 2005). Without paired watersheds, alternative approaches must be explored to assess the impacts of land use changes on hydrology in large-scale watersheds. Time series analysis, a useful tool for analyzing un-replicated and serially correlated data (Goldman et al., 1989), can be an alternative approach to assess impacts of forest disturbance or land use change on hydrology in large-scale watersheds. It can be applied in a single, un-replicated watershed. Time series analysis has been widely used in environmental assessment (Chatfield, 1989; Box et al., 1994). Jassby and Powell (1990) provided a useful review on methods of detecting changes in ecological time series, and they recommended a cross-correlation technique for inference of causation between two time series and intervention analysis for evaluation of impacts of unusual events.

In watershed hydrology, land use or forest cover change and climate interactively affect hydrological processes, making it difficult to separate the effect of forest cover change on hydrology. Conceptual or physical based hydrological models are useful in studying the impact of forest harvesting on hydrological processes, where precipitation, temperature and other climatic variables are main input variables. However, the input requirements for detailed watershed characteristics and hydrological parameters are sometimes difficult to meet when modeling large-scale watersheds. In contrast, a simple regression model, which has relatively fewer demands on input data, can be a useful alternative for describing the relations between hydrology and other climate and land use change variables in large watersheds (Wiens, 1989; Schulze, 2000).

The Willow watershed in the interior of British Columbia, Canada has been substantially harvested over the past half century (the total forest clear-cut area accounting for 31.92% of the total watershed). Availability of harvesting data, together long-term hydrological and climatic records provided us a unique opportunity to examine the impacts of forest harvesting on hydrology in this large-scale forested watershed. Our research hypothesis was that forest harvesting significantly increased mean, peak and low flows in the Willow watershed. The findings from this study can provide useful information for understanding watershed sensitivity and resilience to large-scale disturbance in the BC interior.

Materials and methods

Study area

The Willow watershed is located in the central interior of British Columbia and has an elevation ranging from 572 to 2418 m. The Willow River is about 278 km in length and flows north into the Fraser River. Although some of the tributaries originate in high-elevation mountains, the majority of the watershed consists of a long, broad valley at low to medium elevations and gentle to moderate slopes. The watershed area above 1500 m accounts for 8.2% of the total area while that below 1000 m is 55.6%.

Soils are dominated by loamy glaciofluvial materials along the broad valley bottoms with the moderate to steeply sloping valley sides blanketed by a variable layer of till and colluvium. The river terraces are characterized by flat to gently sloping topography with each successive terrace separated by a steep escarpment. Considerable portions of the low-lying areas have been draped with glaciolacustrine sediments composed of gravely sands to cobbly gravels. The inherent nature of fine textured surficial materials, such as glaciolacustrine and sandy glaciofluvial deposits,