Catena 147 (2016) 51–60

Contents lists available at ScienceDirect

Catena

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

Effects of wildfire on the catchment hydrology in southwest Alberta

Vinod Mahat [a,*], Uldis Silins [b], Axel Anderson [b,c]

[a] Department of Renewable Resources, University of Alberta, Edmonton, AB, T6G 2H1, Canada
[b] Department of Renewable Resources, University of Alberta, 809 General Services, Edmonton, AB, T6G 2H1, Canada
[c] Water Program Lead, Foothills Research Institute, Hinton, AB, T7V 1X6, Canada

ARTICLE INFO

Article history:
Received 13 January 2016
Received in revised form 27 June 2016
Accepted 28 June 2016
Available online 2 July 2016

Keywords:
Hydrology
Wildfire
Climate elasticity

ABSTRACT

Most wildfire studies focus on the dramatic geomorphic and hydrological effects immediately after a wildfire; however, longer-term effects (5+ years) are also expected and can impact the seasonal availability of water, and annual and peak flows. These changes are especially relevant in regions that rely on water from forested areas. In this study, we present an analysis of (2005–2010) daily climate and streamflow data collected following the 2003 Lost Creek wildfire that burned the majority of the vegetated areas (>50%) of two catchments in the eastern slopes of the Rocky Mountains in southern Alberta, Canada. In the analysis, observed streamflow data showed 1.2 to 2.0 times higher mean annual water yield and 1.4 to 2.2 times higher mean peak flows from burned catchments compared to unburned catchments. The burned catchments did have distinct responses in seasonality, onset of peak and flow recession. Most notable was the recession, which was approximately 40% faster in the burned catchments, compared to the unburned catchments. The differences observed between the burned and unburned catchment behaviors, especially in the annual yield and peak flow, were likely due to the combined impacts of wildfire and variability in climate (precipitation) over the catchments. We used the concept of elasticity commonly applied to climate change problems to account for precipitation variability. This approach suggested an increased annual flow in the burned catchments, but changes in peak flows were not detected. Overall the impact of just wildfire to streamflow was difficult to determine and surprisingly small during this timeframe when precipitation variability over the catchments were accounted for.

1. Introduction

Wildfire is a natural disturbance event that can alter hydrologic and geomorphic processes of catchments that can subsequently impact life, health, property, infrastructure and primary production systems (Bart and Hope, 2010; Elliott and Parker, 2001; Moody and Martin, 2001). A number of ranges of hydrological responses to wildfire have been reported in the literature (e.g. Keizer et al., 2008; Malvar et al., 2015; Prats et al., 2012; Prats et al., 2014; Scott and Van Wyk, 1990, Shakesby and Doerr, 2006). Some of these are increased water repellency (Scott and Van Wyk, 1990; Varela et al., 2005), accelerated bank erosion and sedimentation (Lane et al., 2006; Mayor et al., 2007; Wondzell and King, 2003; Owens et al., 2013), degraded water quality (Emelko et al., 2011; Smith et al., 2012) and increased peak flow and annual water yield (Lane et al., 2006; Malvar et al., 2011; Seibert et al., 2010).

Climate change and changed forest structure due to fire suppression have combined to cause large severe fires in some regions (Marlon et al., 2012). Understanding the potential hydrological change at the catchment scale for the years after a wildfire is important in areas that rely on forested catchments for water supply. However, most of the previous studies focus on the immediate and dramatic changes to the runoff processes. Even in the shorter timeframe the wildfire impacts to catchment hydrology are generally poorly understood and information reported is highly variable. Part of the challenge is the unpredictable nature of wildfire, which makes it impossible to use an ideal sample design to investigate the changes in catchment hydrological response, unless by accident. Although the science of forest change on hydrology, peak flow in particular, has been under debate for decades (Alila et al., 2009; Jones and Grant, 1996; Thomas and Megahan, 1998), the most common experimental design used to understand the hydrological response to forest disturbance relies on a Before-After-Control-Impact (BACI) experimental design where there is pre- and post-disturbance data available for comparison to a reference watershed. Some studies (e.g. Aaronica et al., 2002; Bart and Hope, 2010; Loáiciga et al., 2001; Scott, 1993) compare pre- and post-wildfire hydrological response parameters when a gauged catchment is burned, while other studies (e.g. Britton, 1991; Duncan and Thomas, 2004; Johansen et al., 2001) use prescribed burns. When there are no suitable gauged catchments

* Corresponding author.
E-mail addresses: mahatvinod@gmail.com (V. Mahat), uldis.silins@ualberta.ca (U. Silins), Axel.Anderson@gov.ab.ca (A. Anderson).

http://dx.doi.org/10.1016/j.catena.2016.06.040
0341-8162/

to provide the pre-disturbance data, a logical approach is to gauge burned and reference catchments for post-wildfire data (e.g. Campbell et al., 1977; Mayor et al., 2007; Troendle and Bevenger, 1996). These methods generally involve analyzing post-wildfire data of at least two catchments where one catchment is burned (treatment) and another nearby catchment is unburned (reference). Hydrological modeling (e.g. Lavabre et al., 1993; Seibert et al., 2010) is also becoming a common method to help overcome deficiencies in all types of methods used to investigate the effects of disturbance on catchment parameters; however, these methods can suffer from equifinality and poor model confidence.

This study focuses on the analysis of the post-fire data collected following the 2003 Lost Creek wildfire that burned the majority of the vegetated areas of two catchments in the eastern slopes of the Rocky Mountains in southern Alberta, Canada. No suitable gauged catchments were available to provide the pre-disturbance data in this region. The study area has been the focus of ecohydrology research since the wildfire. Wildfire impacts on soil, sedimentation, geomorphology and nutrients, water quality, and aquatic ecology for this region have been examined in several previous studies (e.g., Bladon et al., 2008; Emelko et al., 2011; Silins et al., 2009. For this region, Silins et al. (2009) report dramatic increase in sediment production in burned catchments immediately after the wildfire, while Bladon et al. (2008) report more than four times higher concentrations of nitrate (NO_3), dissolved organic nitrogen (DON), and total nitrogen (TN) concentrations in burned catchments than those in unburned catchments.

In this study, we examine the wildfire impacts on hydrology using a 1) traditional method, and 2) concept of precipitation elasticity of streamflow. In the traditional method, we report differences in water yield (monthly, seasonal and annual), extreme values (low flows and high flows), peak flow (timing, initiation and recession), and seasonality between the burned and unburned catchments using the post-fire five year data, beginning two years after the wildfire. Quality of the two years data immediately after the wildfire was very poor with erroneous spikes and >50% gaps. Thus, the initial two years data were not included in the analysis. We also investigate the published methods used in the analysis of precipitation and streamflow data and compare the findings with our results in the traditional method. The higher/lower annual or peak flows observed (if any) in the burned catchments are likely to be due to the combined impacts of wildfire and variability in climate (precipitation) over the catchments, but the traditional method does not account for the precipitation variability. We quantify the wildfire only impacts on peak and annual flows by using the concept of climate elasticity of streamflow (magnification or sensitivity of streamflow due to changes in precipitation) following Schaake (1990). We develop elasticity models for both burned and unburned catchments. If the elasticity model shows higher magnification in annual or peak flow for the burned catchment compared to that for the unburned catchments, this indicates that the wildfire has impacts on hydrology irrespective of the precipitation variability over the catchments. The concept of climate elasticity of streamflow has been used in many climate change studies (e.g. Arnell, 2002; Fu et al., 2007; Sankarasubramanian et al., 2001; Schaake, 1990), but we are not aware of any previous studies that have used this concept in land use or forest change analysis.

2. Materials and methods

2.1. Study site and data collection

The study site consists of two unburned (reference) catchments: Star Creek and North York Creek (Star Ck. and North York Ck.) and two burned catchments: South York Creek and Lynx Creek (South York Ck. and Lynx Ck.) in the Rocky Mountain region of southwest Alberta (Fig. 1). These catchments are located immediately south of the Crowsnest Pass and includes the northern tip of the Flathead mountain range marking the British Columbia border on the western portion and stretches east across the Blairmore range including Willoughby and Hastings ridges to Turtle and Hillcrest mountains on the eastern edge. These catchments are adjacent and have similar slope, aspect, soils, and vegetation (pre-wildfire); drainage area differs slightly between the catchments. The catchments are characterized by Cretaceous shale and sandstone surficial geologic deposits. Soils are well to imperfectly drained (Eutric or Dystric Brunisols) with weak horizon development, which is a characteristic of higher elevation northern environments (Bladon et al., 2008; Silins et al., 2009). Physical characteristics of the study area with mean elevation, elevation range, and catchment and channel slopes of burned and unburned catchments are given in Table 1.

The study catchments are tributaries of the Oldman River, which is an important river for a regional water supply and has seen periods where demand has exceeded supply (Emelko et al., 2011; Silins et al., 2009). The majority (50 to 70%) of the total annual precipitation falls as snow from October to April. Streamflows in the study area are dominated by snowmelt and peak flows are driven by spring snowmelt or rain on snow melt events. Spring snowmelt (approximately mid-March until early June) produces the highest continuous streamflows (mean daily discharges of ~5–10 mm day^{-1}). Rain-on-snow or mid-winter melt events are a common occurrence, producing some of the larger flows, with mean daily discharge in excess of 30 mm day^{-1}. Base flow in the late summer and the over winter period is generally near 0.5–2 mm day^{-1}.

Prior to the wildfire in 2003, all the catchments had similar forest dominated by Lodgepole pine (*Pinus contorta* Dougl.ex Loud. Var. latifolia Engelm.); at lower and mid elevations, subalpine forest dominated by Engelmann spruce (*Picea engelmannii* Parry ex Englem.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and alpine at higher elevations characterized by alpine meadow vegetation and exposed rock. In July–August of 2003, the Lost Creek wildfire burned 21,000 ha of nearly contiguous forests and the organic forest floor in South York Ck. and Lynx Ck. catchments. The fire was particularly severe in that it consumed nearly all forest cover and forest floor organic matter. However, the alpine areas did not have adequate fuel to burn, so the extent of burn was 53% and 67% for South York Ck. and Lynx Ck., respectively (Table 1).

Southern Rockies Catchment Project (SRWP) started monitoring of climate and streamflow of these catchments immediately after the fire in order to capture the 2004 freshet and to investigate the hydrological responses to wildfire. Hourly temperature, relative humidity, precipitation and snow depth were recorded from multiple meteorological stations located in the study catchments (Fig. 1). Universal precipitation gauges equipped with alter shields were installed in the upper end of Star Ck., North York Ck., and South York Ck., and tipping bucket rain gauges were installed at each of the five gauging sites. In the fall of 2004, tipping bucket rain gauges were fitted with an *anti*-freeze overflow system to allow them to function as universal precipitation gauges through the fall and early winter of 2004/05. Precipitation data were collected at 2–3 week intervals during the summer-fall and in 1–2 month intervals during winter depending on snow pack conditions and access.

Instantaneous stream discharge was determined using standard velocity area techniques with either a Swoffer current meter (Model 2100, Swoffer Instruments Incorporated, Seattle, WA, USA) or a Sontek acoustic doppler velocity meter (Flow Tracker ADV, Sontek/YSI, San Diego, CA, USA). Stage-discharge relationships were derived for each stream and applied to continuous stage measurements recorded using either gas bubblers (Waterlog Model H-350 Lite and H-355, Design Analysis Associates Inc., Logan, UT, USA) or stand-alone pressure transducers (HOBO U20, model U20-001-01, Onset Computer Corporation, Pocasset, MA, USA). These relationships were used with continuous stage data to calculate the continuous streamflows. No attempt was made to measure soil properties (i.e. soil water repellency or hydrophobicity).