Journal of Environmental Management 84 (2007) 245–256
Journal of Environmental Management
www.elsevier.com/locate/jenvman

Predicting streamflow response to fire-induced landcover change: Implications of parameter uncertainty in the MIKE SHE model

Christine E. McMichael[a,*], Allen S. Hope[b]

[a]Institute for Regional Analysis and Public Policy, Morehead State University, 150 University Boulevard, Morehead, KY 40351-1689, USA
[b]Department of Geography, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182-4493, USA

Received 30 August 2005; received in revised form 21 March 2006; accepted 2 June 2006
Available online 9 August 2006

Abstract

Fire is a primary agent of landcover transformation in California semi-arid shrubland watersheds, however few studies have examined the impacts of fire and post-fire succession on streamflow dynamics in these basins. While it may seem intuitive that larger fires will have a greater impact on streamflow response than smaller fires in these watersheds, the nature of these relationships has not been determined. The effects of fire size on seasonal and annual streamflow responses were investigated for a medium-sized basin in central California using a modified version of the MIKE SHE model which had been previously calibrated and tested for this watershed using the Generalized Likelihood Uncertainty Estimation methodology. Model simulations were made for two contrasting periods, wet and dry, in order to assess whether fire size effects varied with weather regime. Results indicated that seasonal and annual streamflow response increased nearly linearly with fire size in a given year under both regimes. Annual flow response was generally higher in wetter years for both weather regimes, however a clear trend was confounded by the effect of stand age. These results expand our understanding of the effects of fire size on hydrologic response in chaparral watersheds, but it is important to note that the majority of model predictions were largely indistinguishable from the predictive uncertainty associated with the calibrated model—a key finding that highlights the importance of analyzing hydrologic predictions for altered landcover conditions in the context of model uncertainty. Future work is needed to examine how alternative decisions (e.g., different likelihood measures) may influence GLUE-based MIKE SHE streamflow predictions following different size fires, and how the effect of fire size on streamflow varies with other factors such as fire location.

Keywords: Fire; Uncertainty; Streamflow; Modelling

1. Introduction

A key challenge in water resources planning and management is to determine how hydrological processes are affected by landcover change (Badhuri et al., 2001; Croke et al., 2004; Tang et al., 2005; Tong and Chen, 2002). Wildfire is a major agent of land surface transformation in large areas of the western United States. Fire-induced landcover changes are a particular concern in many central and southern California semi-arid shrubland (i.e., chaparral) watersheds as development expands from urban cores into the surrounding fire-prone foothills. Predicting the hydrological impacts of fire-induced land surface change is an increasingly important problem in these water-limited areas. Mounting anthropogenic pressures and future climate change are expected to alter the current size, timing and frequency of wildfires in semi-arid shrublands (Davis and Michaelsen, 1995; Keeley et al., 1999; Lenihan et al., 2003; Moreno and Oechel, 1995; Ryan, 1991) and, subsequently, streamflow dynamics (Loaiciga et al., 2001).

Most research that has examined the hydrologic impacts of fire in chaparral shrublands has focused on small experimental watersheds involving fire treatments covering an entire watershed (Crouse, 1961; Hoyt and Troxell, 1932; Keller et al., 1997; Lewis, 1968; Pitt et al., 1978; Rowe, 1963; Turner, 1985). This constraint makes it difficult to

*Corresponding author. Tel.: +1 606 783 5442; fax: +1 606 783 5092.
E-mail addresses: c.mcmichael@moreheadstate.edu (C.E. McMichael), hope1@mail.sdsu.edu (A.S. Hope).

0301-4797/$ - see front matter
doi:10.1016/j.jenvman.2006.06.003

extrapolate research findings to larger watersheds which are most relevant to water resource managers. Fires that occur in larger chaparral watersheds generally do not burn the entire watershed, such that only a sample of watershed attributes (e.g., vegetation type and age, slope, and soil type) is usually modified by a given fire. Consequently, post-fire streamflow in larger chaparral watersheds is usually impacted by a combination of the newly regenerating area and the unburned portion of the landscape. The unburned area is also a complex mosaic of vegetation types in different stages of post-fire recovery and with different fire histories.

2. Objectives

Since it is not practical to conduct field experiments with varying proportions of a watershed burned, it is necessary to conduct 'experiments' using hydrological models. While it may seem intuitive that bigger fires will have a greater impact on streamflow response than smaller fires in larger chaparral watersheds, the actual nature of this relationship has not been documented. Therefore, the primary objective of this research was to establish the relationship between streamflow response and area burnt for a moderately sized chaparral watershed in central California. Bosch and Hewlett (1982), summarizing data from 94 paired-catchment studies conducted in forested, scrub and grassland regions around the world, found that changes in annual streamflow were generally proportional to the amount of change in vegetation cover. It was expected that a similar relationship would be found between streamflow response and fire size in the study watershed.

Since the purpose of investigations such as this is often to assist with watershed planning and management, model predictions should be evaluated in the context of predictive uncertainty (Beven and Freer, 2001). If hydrological predictions of streamflow response to modified watershed conditions cannot be differentiated from the uncertainty inherent in the calibrated model, then such predictions may have little practical value for watershed managers. Consequently, our second objective was to reevaluate the results obtained in the first phase of this study in the context of predictive uncertainty—defined here as the uncertainty associated with model predictions. More specifically, we aimed to identify those simulated streamflow responses to fire size that exceeded the predictive uncertainty associated with the calibrated model. These responses were considered to be the most 'reliable' predictions.

3. Materials and methods

In this study we utilized a physically based, spatially distributed hydrological model to investigate the effects of fire size on streamflow response for a medium-sized chaparral watershed in central California under both wet and dry weather regimes. Daily flow predictions were aggregated to three temporal scales selected to gauge the longer-term effects of fire size on hydrological conditions in the study watershed, namely, cumulative (for the simulation period), annual and seasonal flows. The uncertainty in model predictions at each daily time step was established using a Bayesian Monte Carlo-based approach for model calibration and uncertainty estimation.

3.1. Study site

Jameson is a medium size watershed (34 km^2) located in the San Rafael mountains approximately 12 km north of Santa Barbara, CA, USA (Fig. 1). The semi-arid climate of this region is characterized by cool, wet winters and warm, dry summers. Annual average precipitation and streamflow in Jameson are 780 and 233 mm, respectively. This non-urbanized watershed is dominated by evergreen chaparral shrubs, followed by drought-deciduous sub-shrubs (coastal sage scrub), oak woodland, conifer forest and grassland (Franklin et al., 2000). Sandy-loam soils cover the generally rugged terrain where elevation ranges from 677 m at the watershed outlet to 1771 m at the highest point along the ridge.

3.2. Hydrological model

Fire size simulations were implemented using a modified version of the physically based, spatially distributed MIKE SHE model (Andersen et al., 2001). The MIKE SHE model is a derivative of the Système Hydrologique Européen, SHE, (Abbott et al., 1986a, b) and is capable of representing all major phases of the hydrologic cycle. It has been widely used to study a variety of water resource and environmental problems under diverse climatological and hydrological regimes (Refsgaard and Storm, 1995). The major differences between the original (MIKE SHE) and modified (MSHE_m) versions of the model occur in the representations of flow in the unsaturated and saturated zones. The decision to use a modified version of MIKE SHE was necessitated by the lack of detailed knowledge and limited data regarding the groundwater environment in the study watershed. The reader is referred to Refsgaard and Storm (1995), DHI Water and Environment (2000), and Andersen et al. (2001) for a complete description of the model structure and setup.

Spatial variation in watershed characteristics is represented in MSHE_m using equally sized grid cells, each of which is vertically discretized into a number of sub-layers to represent the soil profile. Following Tague et al. (2004) and McMichael et al. (2006), model grid cell size in this study was fixed at 270 m. This spatial scale was selected to allow for the most accurate representation of watershed attributes without placing excessive demands on computer run time required for the Monte Carlo-based simulations. Model predictions of streamflow were made at a daily time step and aggregated to monthly values for comparison with observed streamflow data. Observed values of monthly streamflow were obtained from the United States