Journal of Hydrology: Regional Studies 19 (2018) 17–24

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

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

Hydrological effects of forest plantation clear-cut on water availability: Consequences for downstream water users

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ARTICLE INFO

Keywords:
Clear-cut proportion
Flow duration curve
Eucalyptus forest
Low flow indices
Forest age mosaic
Hydrological model

ABSTRACT

Study Region: São Paulo State, Brazil.
Study Focus: This study assessed the influence of forest plantations on streamflow in a gauged catchment (85 ha), covered with fast-growing *Eucalyptus* sp. plantations. One strategy for reducing the effects of plantations on streamflow is to reduce the area of a catchment occupied by forest, and in this context, our objectives were to simulate the effects on streamflow of different proportions of forest cover (70%, 50% and 0% of the forest cover). Moreover, we used low-flow indices (Q90 and 7Q10) to examine the effects of such scenarios on water availability for downstream users.
New Hydrological Insights: Fast-growing forest plantation areas have been expanding globally, with simultaneously increasing concerns about the water consumption of these forests, especially in water-limited regions with consequences for downstream users. Simulations of scenarios with varying forest cover proportions showed an annual streamflow increase of 90% when clear-cutting had removed the forest cover in the catchment. The 100% forest cover scenario produced rates of streamflow below the low flow indices, resulting in less water availability for downstream water users. The reduction in forest cover proportion at the catchment scale promoted an attenuation of water use. Therefore, forest plantation management should adopt management strategies such as regulating the forest cover proportion to minimize the effects on water supply for downstream water users.

1. Introduction

The area occupied by fast-growing forest plantations is expanding in several parts of the world (Payn et al., 2015); at the same time, the area of forest plantation in Brazil currently exceeds 7.5 million hectares (IBA, 2016). These expansions are accompanied by a parallel increase in concerns regarding water use (Jackson et al., 2005; Calder, 2007). Such concerns are mainly related to the decrease in water availability to downstream users (van Dijk and Keenan, 2007; Guzha et al., 2018) and the effects on low flows (Farley et al., 2005; Beck et al., 2013).

The effects on streamflow are high evapotranspiration rates associated with fast growing/highly productive forests, which are typical characteristics of *Eucalyptus* forest plantations (Scott, 2005). These effects are characterized by an observed decrease in

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https://doi.org/10.1016/j.ejrh.2018.06.007
Received 2 October 2017; Received in revised form 2 June 2018; Accepted 22 June 2018
2214-5818/

streamflow following reforestation (Bosch and Hewlett, 1982; Guzha et al., 2018) accompanied by an increase in streamflow following forest clear-cutting (Scott, 2005). Due to this relationship, one way to minimize the effects of forest plantations on streamflow might be to control the proportion of forest cover at the catchment scale, which has the potential to modify the streamflow regime (Zhang et al., 2012). For this reason, it is important to understand the relationship between streamflow and forest cover proportion in order to better manage forest plantations and avoid water-use conflicts (Brown et al., 2013). This is especially necessary in regions where fast-growing forest is the predominant land use (Swanson et al., 2000; DeFries and Eshleman, 2004), as well as in water-limited regions (van Dijk and Keenan, 2007) since decreases in streamflow related to forest expansion can reduce water availability and consequently may enhance water-use conflicts (Farley et al., 2005; Scott, 2005; van Dijk and Keenan, 2007).

In this context, alternative forest management strategies may minimize the effects on streamflow in a catchment(Vanclay, 2009). Some alternative forest management strategies include (i) increasing the rotation cycle to allow the recovery of streamflow to original levels (Scott and Prinsloo, 2008); (ii) choosing species with higher water-use efficiency to increase wood production without increasing water use (Forrester et al., 2010); (iii) establishing forest stands with different ages to minimize the peak water consumption (Vertessy et al., 2003; Ferraz et al., 2013), and (iv) choosing forest plantation locations relative to the stream network for reaching the potential areas in catchment planning (Kalantari et al., 2014). However, some of these management practices are costly, which may hinder their practical implementation.

Taking this difficulty into account, the use of hydrological models can be an alternative tool for providing responses to the effectiveness of alternative strategies for forest management (DeFries and Eshleman, 2004; Guzha et al., 2018). In this study, we used a simple conceptual hydrological model developed by Brown et al. (2006) and widely used by Shao et al. (2009) and Zhang et al. (2012) to predict the effects of forest plantations on streamflow following a change in the proportion of forest cover. Increases in forest plantation area can lead to low flow reduction (Brown et al., 2005), which will affect water availability at the catchment scale and, consequently, water availability for downstream water-users (van Dijk and Keenan 2007). Therefore, understanding these changes in a streamflow regime is necessary to the development of strategies for water resources management (Zhang et al., 2012).

The aim of this study is to simulate the hydrological effects of different forest cover scenarios and discuss forest plantation occupation planning as a tool for water conservation and implementation of the hydrosolidarity concept in forestry activities.

2. Material and methods

2.1. Study area

Aiming to best represent the climatic conditions and management practices under which fast-growing planted forests are distributed in Brazil, we used a gauged catchment located in the State of São Paulo (23°02′01″ S; 48°37′30″ W) (Fig. 1). This region is representative of the climatic conditions and management practices of fast-growing plantation forests in Brazil.

The catchment area is 85.8 ha with 95% forest cover (85% fast-growing forest plantations - in which *Eucalyptus* spp. and *Pinus* spp. occupy 76% and 9% of the catchment area, respectively - and 10% native vegetation buffer along the stream) and 5% of the area consisting of roads.

The mean annual temperature in the region is 19.4 °C, with a mean annual precipitation of 1319 mm, with rainfall mostly concentrated in the summer period (October to March), based on a 40-year time series – 1950–1990 (Alvares et al., 2013).

Soil types are both Typic Hapludox and Rhodic Hapludox (Gonçalves et al., 2012), which are typical tropical soils.

2.2. Datasets

Streamflow was measured using an H-flume equipped with an automatic stage recorder (Thalimedes Shaft Enconder sensor) with a 15-minute resolution, coupled with a datalogger.

Precipitation was measured with an automatic rain gauge (TR-525I, Texas Electronics) and recorded at 30 min intervals by a data logger located 1 km from the stream gauge. The streamflow and rainfall data used in this paper are from August 2009 to December 2016 (Fig. 2).

Potential evaporation (PET in mm. h^{-1}) was estimated using Penman's formulation, as given in Shuttleworth (1993). For this estimation, the meteorological data of net radiation (MJ. m^{-2}.d^{-1}), air temperature (°C), relative humidity (%) and wind speed at 2 m height (m.s^{-1}) were obtained from an automatic station located 1 km from the streamflow gauge, with a 30 min recording interval.

2.3. Forest cover change simulations

To simulate the effects of forest cover changes (by forest cover proportion) on streamflow, we used the Forest Cover Flow Change (FCFC) model (Brown et al., 2006), which is based on a downward approach (Sivapalan et al., 2003). This model uses streamflow observations to simulate the effects of forest cover due to management (Podger et al., 2005) and requires few inputs, such as daily precipitation, daily flow, and daily potential evapotranspiration. In addition, the proportion of the catchment area under forest cover before and after changes is required, input as a percentage (Brown et al., 2006).

The effects of forest cover changes on the Flow Duration Curve (FDC) were simulated by linking the area under the curve parameters (five parameters of the FDC that capture the key components of the curve, see Best et al., 2003) and mean annual streamflow, as predicted by Zhang's curve (Zhang et al., 2001). The FDC parameters are optimized to fit observed and predicted data. The CTF (cease to flow percentile) and Q_{50} parameters were derived directly from measured data, while the other three parameters