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Stream flow unaffected by *Eucalyptus* plantation harvesting implicates water use by the native forest streamside reserve

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ABSTRACT

Study region: Tropical Atlantic Forest region, Brazil.
Study focus: The temporal and spatial dynamics of soil water, water table depth and stream flow in relation to precipitation and the harvesting and regrowth cycle of a *Eucalyptus grandis* hybrid plantation in a headwater catchment. This landscape contains a mosaic of eucalypt plantation grown for pulpwood on plateau tops and native forest reserves in gullies. Instead of harvesting the native forest to test this effect, we conducted a virtual experiment using a soil and hydrological model (HYDRUS).
New hydrological insights: Plantation harvest had little effect on steam flow, despite a 6–11 m rise in water table level under the plantation area. This result suggests that the native forest reserve intercepted groundwater moving laterally between the plantation and the stream. Measured and simulated runoff coefficients were similarly low (5% and 3%, respectively), but simulated removal of the native forest led to an increase to 38%. Therefore, plantation management in this type of landscape is likely to have little impact on stream flows where there is an intact native rainforest reserve beside the stream.

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1. Introduction

Water use by deep-rooted forests is in some cases higher than shallow-rooted agricultural crops or pasture (Zhang et al., 2001). Prior to European settlement, the Atlantic Forest region of Brazil was predominantly covered by rainforest occupying an area of approximately 150 M ha distributed across large latitude and climatic ranges (Ribeiro et al., 2009). By the late 1900s, however, clearing for agriculture and population growth left only about 11–16% coverage of this native forest (Instituto National de Pesquisas Espaciais, 2011; Ribeiro et al., 2009). During the past four decades, plantation forestry has expanded rapidly in parts of this region mainly by replacing pasture. Eucalypt plantations in Brazil now occupy more than 5.1 M ha with a significant portion in this ecosystem (ABRAF, 2012). This plantation expansion has largely occurred on the plateau part of the landscape away from streams, while rainforest covers areas closest to the streams (gullies). These large-scale changes in vegetation may have affected stream flows, but these effects have not been widely quantified. Despite the mean annual precipitation of around 1200 mm, stream flow is intermittent and low water availability during the dry season probably limits plantation growth (Stape et al., 2008).

Plantation management, particularly harvesting, and the proportional area of and water use by the native forest, could affect stream flow. However, the potential effect of harvesting the native forest has not been measured in this landscape. Such an experiment was not possible as harvesting of streamside native forest is prohibited by the Brazilian forest code (Presidência da República, Lei N° 12.651, 2012), in which it is referred to as the area of permanent preservation (APP).

Generally, stream flow is affected by precipitation amount, distribution and intensity, soil water holding capacity and soil hydraulic conductivity, vegetation interception and water use, and terrain topography. Water use by vegetation depends on plant water demand and actual uptake, which in-turn depends on factors including rooting density and depth, available soil water and climate. The hydrological effects of native forest fragmentation are poorly understood, especially in the tropics in relation to horizontal interactions between land units of vegetation, topography and soils (Giambelluca, 2002). Previous studies in Espírito Santo State of the Atlantic Forest region have quantified many of the aspects of the hydrological cycle in one dimension (plot scale) at plantation and native forest sites, in which water balance simulations generally matched observations (Soares and Almeida, 2001; Almeida and Soares, 2003; Almeida et al., 2007, 2010). A similar capability has become available in two dimensions (e.g. hillslope) using the HYDRUS model (Smethurst et al., 2013), which enabled extension of water balance simulations at the same site to the headwater catchment scale and thereby take into account both vegetation types, i.e. *Eucalyptus* plantation and native forest. Our objectives here were to (1) determine if the HYDRUS model could be used to adequately simulate the hydrology of a headwater catchment in the Atlantic Forest region of Brazil used for plantation forestry with native forest in the APP, and if so (2) use it to understand the potential impacts of harvesting of one or both vegetation types on ground water and stream flow. Our hypothesis was that a quantitative analysis using the HYDRUS model would demonstrate that water use by the native forest APP could prevent an increase in stream flow after harvesting up-slope eucalypt plantations.

2. Methods

The study catchment and measurements are detailed in Soares and Almeida (2001), Almeida and Soares (2003), and Almeida et al. (2007). Briefly, the site is a 286 ha catchment in Espírito Santo State on the eastern coast of Brazil that receives summer-dominant precipitation of 1147 mm year^{-1}. The catchment has undulating plateau tops where *Eucalyptus grandis* hybrid plantations were grown on 6- to 9-year rotation. Steeply incised gullies, to a depth of about 20–40 m, support native forest (30% of total area; Figs. 1 and 2). This native forest had probably had a proportion of trees harvested several decades earlier around the time upper parts of the landscape had been cleared for pasture. At the time of this study the native forest had an appearance (Fig. 2), structure and LAI similar to undisturbed native forest (data not presented). All eucalypt plantations were totally harvested (clearcut) in August to October 1996, and replanted December 1996 to October 1997. Most of the plantation area was totally harvested again in 2004, except two blocks that remained unharvested (11 ha, 6%) after thinning in