Ecological Engineering xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Ecological Engineering

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

Riparian restoration for protecting water quality in tropical agricultural watersheds

Kaline de Mello[a], Timothy O. Randhir[b,*], Roberta Averna Valente[c], Carlos Alberto Vettorazzi[a]

[a] Department of Biosystems Engineering, College of Agriculture, University of São Paulo (ESALQ – USP), Avenida Pádua Dias, 11, Piracicaba, SP, Brazil
[b] Department of Environmental Conservation, University of Massachusetts, 160 Holdsworth Way, Holdsworth Hall, Rm. 326, Amherst, MA, USA
[c] Department of Environmental Science, Federal University of São Carlos, Rodovia João Leme dos Santos, km 110, Sorocaba, SP, Brazil

ARTICLE INFO

Article history:
Received 3 April 2017
Received in revised form 24 June 2017
Accepted 24 June 2017
Available online xxx

Keywords:
Watershed modeling
Land use
Forest restoration
Water resource
SWAT

ABSTRACT

Land use change in riparian zones is one of the most significant threats to water quality in watershed ecosystems. Riparian forests play a major role in protecting water quality, and there is a need to assess the role of riparian restoration in reducing nutrients and sediment loading. This study uses watershed simulation modeling to evaluate impacts of riparian forest restoration on water quality in a tropical agricultural watershed. Soil Water Assessment Tool (SWAT) is used to simulate streamflow, suspended sediment and nutrients of the Sarapuí River watershed, located in southeast Brazil. We observe a spatial and temporal variation in water quality impacts of changes in land use/land cover (LULC) and rainfall patterns. Watersheds with agricultural and some residential areas had a higher sediment and nutrients loads than forest and with pasture land uses, especially during the wet season. Forested watersheds in general had a better water quality than other LULC types. Riparian restoration in the study watershed can reduce suspended sediment (9.26%), total nitrogen (22.6%), and total phosphorus (7.83%). Protecting riparian zone and site-conservation practices is critical to improve water quality. We observe that the simulation model provides a satisfactory baseline of the watershed system to evaluate impacts of land use changes.

1. Introduction

The riparian zone is the interface between terrestrial and aquatic ecosystems, playing an important role on nutrients and sediments transfer (Kuglerová et al., 2014; Ou et al., 2016). Although the riparian forest can contribute to the water quality protection, it is one of the most degraded ecosystems in the world (Nilsson and Berggren, 2000; Kuglerova et al., 2014). Replacing riparian forests by other land uses decreases water quality due to bank erosion, increasing nutrient and sediment loads into the river (Ding et al., 2013; Ou et al., 2016; Yang et al., 2016a). In this context Zhang et al. (2013) and Yang et al. (2016b), emphasizing the importance of understanding the benefits from their restoration.

Riparian forest cover plays a major role in the biogeochemical cycles in watersheds. The vegetation provides protection against erosion, retention of pollutants, excessive nutrients runoff and it have influence in water temperature (Sopper, 1975; Sweeney et al., 2004; Lima and Zakia, 2006; Mingoti and Vettorazzi, 2011; Schilling and Jacobson, 2014; Tanaka et al., 2016) and benefits both the quality of human life and survival of aquatic species (Saalfeld et al., 2012; Ding et al., 2013; Yang et al., 2016a; Tanaka et al., 2016). Particularly in the current context, agriculture and urban growth have been appointed as the primary cause of water quality degradation (Uriarte et al., 2011; Lin et al., 2015; Huang et al., 2016).

Cho et al. (2010) also used SWAT to simulate an intact riparian zone in a watershed, observing that the forested riparian zone reduced 20.5% of sediment loads to the river. In this context, the proximity to surface water has been used as a criterion for prioritizing areas for forest restoration in watersheds (Vettorazzi and Valente, 2016).

Nejadhashemi et al. (2012) used models to evaluate land use change impacts in agricultural watersheds, founding that conversion from forest to urban and agriculture lands lead to greater impact on hydrologic variables than for other land use conversions.

Studies have also reported the impacts of riparian land use on water quality using hydrological models. Gitau et al. (2006) used a model in evaluating a combination of best management practices that include riparian buffers in reducing phosphorus loads. Moriasi

* Corresponding author.
E-mail addresses: kaline.mello@gmail.com (K.d. Mello), randhir@eco.umass.edu, trandhir@gmail.com (T.O. Randhir), roavalen@ufscar.br (R.A. Valente), cavettor@usp.br (C.A. Vettorazzi).

http://dx.doi.org/10.1016/j.ecoleng.2017.06.049
0925-8574/

et al. (2011) used a hydrological model to quantify the effect of riparian forest buffer and Bermuda grass filter strip on sediment yield in a reservoir in USA. Wiseman et al. (2014) and King et al. (2016) also in the USA highlight the relation between management practices in the riparian zone with the decrease the effects of nonpoint pollution in the watersheds.

However, the impacts of riparian restoration in tropical river basins are not well documented. Monteiro et al. (2016) observed that riparian restoration to comply with Brazilian Forest Code could reduce sediment load by 29.4% in a catchment in the Brazilian. Concerning to this condition, we can highlight the Brazil scenario relating with no accomplishment of laws relate to the riparian zone, i.e. the land use in the buffer area is not only with forest; and the fragmentation process the Atlantic Forest, that is a biodiversity hotspot (Mittermeier et al., 2011). Nowadays, it is highly threatened since it has been reduced to only 11% of its original cover (Ribeiro et al., 2009). Considering its relationship with the water quality and, as mention by Strassburg et al. (2016) that the forest reduction affects the water quality and, consequently, water supply, there is a need to understand the importance of tropical forest cover to water quality and how the riparian forest restoration can contribute to the water resources conservation.

In this context, we use a watershed hydrological model to simulate the effects of riparian zone restoration on water quality in tropical agricultural watersheds. It presents a comparative evaluation of watershed-wide and riparian zone forest restoration on water quality for policy considerations. This is important in using riparian zone management within the broader context of watershed systems. The specific objectives were: (1) to model hydrological processes for streamflow and water quality in a watershed system; (2) to evaluate the impacts of agricultural and residential lands on sediment and nutrient loadings; and (3) to simulate a riparian zone restoration scenario and its impacts on an agricultural watershed system.

2. Material and methods

2.1. Study area

The study area was the Sarapuí River Watershed (1550 km^2), located in the Sao Paulo State (between the coordinates UTM 23S 195,000 m and 265,000 m; 7,360,000 m and 7,420,000 m), southeast Brazil (Fig. 1).

Sarapuí River is a tributary of Tiete River, one of the main rivers in Brazil, that showed the lowest values of the national water quality index in 2014 (SMA, 2014). Sarapuí River watershed is a particular case of an agricultural watershed close to very high-density urban areas like Sorocaba and Sao Paulo. Sarapuí River supplies four cities in the Sao Paulo State, and its proximity to those areas represents trends for agricultural and urban sprawl due to the demands from large cities. The watershed was originally covered by the Atlantic Rain Forest, which was replaced by agriculture, pasture, eucalyptus and residential (urban) areas. Pasture and farm lands represent, together, 53% of the watershed. Agriculture crops included grains, fruits, and vegetables. Despite the agricultural activities, 37% of the watershed was forest cover.

The main rivers flow from east to west and the drainage network is particularly dense in watershed eastern portion, where there are areas associted with the highest elevation. Thus, the density of the drainage network decreases in the central and west regions. Majority of soil types in the Sarapuí River watershed had red or yellow tropical soils, mainly Latosols, and low-activity clays. However, other soil types also occurred in the watershed, as Gleysols and young soils such as Regosols and Fluvisols. Gleysols occurred more on the central and west portion of the watershed.

The region was under the influence of Cwa climate (humid temperate with dry winters). Annual precipitation was between 1354.7 mm and 1807.7 mm (CEPAGRI, 2014a,b), and with the primarily from October through March. Between December and February were the maximum precipitations (around 200 mm monthly) (CEPAGRI, 2014a,b). Temperatures ranged from 5 °C to 32 °C, with an annual average of 20 °C. January and February were the hottest months (monthly temperature average of 24 °C), and June and July were the coldest months (monthly temperature average of 16 °C).

Six subwatersheds (numbered 1–6) were selected based on physical characteristics and percentage of forest cover to establish the experimental sites (i.e. watershed experimental). We selected subwatersheds of low-order streams (3rd order) with similar area, shape, average slope, and soil types, but varying in forest cover percentage. The three subwatersheds with more than 55% of forest cover (W1, W2 and W5 – Fig. 1) were named "forested", while other three, with 35% or less of forest cover (W3, W4 and W6 – Fig. 1) was named "degraded". According to Vannote et al. (1980), low-order streams (orders 1–3) are strongly influenced by terrestrial inputs.

Subwatershed 5 had 75% of forest cover followed by subwatersheds 1 and 2 (both with 60% of forest cover). Subwatershed 3 represents only 25% of forest cover, 30% of agriculture and the largest residential area (12%). Subwatershed 4 had the largest agricultural area (54%) and 35% of forest cover. Subwatershed 6 was 29% covered by forest, 32% by agriculture and 32% by pasture.

2.2. Conceptual model

The conceptual framework for the Sarapuí River Watershed Model consisted of a system, which included the watershed hydrophysical characteristics, land use/management and conservation actions (riparian restoration), with water quality as the effect (Fig. 2). We used slope, hydrology, climate, soil and land use/land cover (LULC) information to calibrate a hydrological model (SWAT-Soil Water Assessment Tool) for the Sarapuí River to assess the water quality characteristics and their relation to LULC pattern. Then, we created a new LULC map simulating a 100% riparian restoration, i.e. the buffer zone occupied 100% by forest cover. The new scenario was used in the model to simulate water quality responses of riparian forest restoration. The conceptual model presents the overall data flows in this research, of which hydrologic processes are simulated using the SWAT model, described in section below.

2.3. SWAT model development

SWAT (Soil and Water Assessment Tool) model was used to model streamflow, sediment yield (suspended solids) and nutrients load (total nitrogen and total phosphorus). SWAT is a non-point source pollution model created to predict long-term impacts on water and water quality in watersheds with varying soils, land use, and management (Neitsch et al., 2011). It is a continuous-time, semi-distributed, process-based river basin model (Arnold et al., 2012). It has been applied to understand the sediment losses and nutrient loadings in watersheds around the world (Marshall and Randhir, 2008; Reungsang et al., 2009; Wilson and Weng, 2011; Poudel et al., 2013; Lin et al., 2015). It has also been used for simulating riparian processes (Cho et al., 2010; Moriasi et al., 2011; Sun et al., 2016; Monterio et al., 2016).

The model further divides subwatersheds connected by stream networks. The model further divides into hydrologic response units (HRUs) that are unique combinations of different LULC types, soils, and surface slopes. Within each subwatershed, the areas with similar LULC, soil types, and surface slopes are lumped together into a single HRU. The model requires several datasets,