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The impact of Best Management Practices on simulated streamflow and sediment load in a Central Brazilian catchment

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ABSTRACT

The intense use of water for both public supply and agricultural production causes societal conflicts and environmental problems in the Brazilian Federal District. A serious consequence of this is nonpoint source pollution which leads to increasing water treatment costs. Hence, this study investigates in how far agricultural Best Management Practices (BMPs) might contribute to sustainable water resources management and soil protection in the region. The Soil and Water Assessment Tool (SWAT) was used to study the impact of those practices on streamflow and sediment load in the intensively cropped catchment of the Pipiripau River. The model was calibrated and validated against measured streamflow and turbidity-derived sediment loads. By means of scenario simulations, it was found that structural BMPs such as parallel terraces and small sediment basins ('Barraginhas') can lead to sediment load reductions of up to 40%. The implementation of these measures did not adversely affect the water yield. In contrast, multi-diverse crop rotations including irrigated dry season crops were found to be disadvantageous in terms of water availability by significantly reducing streamflow during low flow periods. The study considers rainfall uncertainty by using a precipitation data ensemble, but nevertheless highlights the importance of well established monitoring systems due to related shortcomings in model calibration. Despite the existing uncertainties, the model results are useful for water resource managers to develop water and soil protection strategies for the Pipiripau River Basin and for watersheds with similar characteristics.

1. Introduction

Land use and land management practices can adversely affect natural resources and ecosystems. In the fast growing urban area of the Brazilian Federal District (Distrito Federal = DF) in Central Brazil, urban sprawl and intensive agriculture have caused severe losses of native savanna vegetation (Cerrado) and an enormous pressure on the region's water resources (Felizola et al., 2001; Fortes et al., 2007; Lorz et al., 2012). The metropolitan area of the city of Brasília, the federal capital of Brazil, showed the most rapid growth of all the large Brazilian cities and spread beyond the DF region (Martine and Camargo, 1997).

Serious societal conflicts and environmental problems arise in catchments of the DF, where water is used for both public supply and agricultural production. This is also the case for the Pipiripau River Basin (PRB). Recently, DF's water supply company (CAESB) is observing an increase in water treatment costs in the PRB due to soil erosion and nutrient runoff from surrounding agricultural areas (Buric and Gault, 2011).

Best Management Practices (BMPs) can be a useful strategy to mitigate nonpoint source pollution resulting from agricultural activities (Schwab et al., 1995). The PRB is part of the Water Producer Program (Programa Produtor de Água) launched by Brazil's National Water Agency (ANA). This program aims at the implementation of BMPs based on the concept of Payments for Environmental Services (PES). The practices to be supported comprise the restoration and conservation of native vegetation in priority areas such as riparian zones but also BMPs such as terraces,

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sediment retention basins or sustainable crop management (BRASIL, 2010). The BMPs aim at improving water quality by reducing sediment and nutrient inputs without considerably reducing water quantity. These measures can have a positive effect on water availability during dry seasons, because they improve water infiltration into the soil and thus groundwater recharge. Watershed models are useful tools to study the impact of various BMP implementations on hydrology and nonpoint source pollution. By effectively capturing site-specific characteristics, i.e. climate, topography, and soil, comprehensive watershed models can limit labor, time, and financial expenses that are associated with intensive field studies (Koch and Grünewald, 2009). The Soil and Water Assessment Tool (SWAT) is such a model and has been used for a wide range of environmental conditions across the globe to predict flow, sediment and nutrient load from watersheds of various sizes (Gassman et al., 2007). Numerous studies have used SWAT to evaluate the impact of BMPs on water quality for watersheds in the US and in Europe, e.g. Vaché et al. (2002), Arabi et al. (2006), Bracmort et al. (2006), Gassman et al. (2006), Secchi et al. (2007), Tuppad et al. (2010), Lam et al. (2011), and Maringanti et al. (2011). A recent SWAT BMP application for a watershed in Brazil (São Bartolomeu Stream, Minas Gerais) was reported by Rocha et al. (2012). In general, these studies showed that BMPs, such as conservation tillage, no-till, contouring, filter strips, terraces, or grassed waterways, can lead to significant reductions of sediment and nutrient loads depending on catchment properties and the type and extent of the BMPs considered. Several studies included sensitivity analysis of BMP implementation parameters (Arabi et al., 2008, 2007a; Ullrich and Volk, 2009; Woznicki and Nejadhashemi, 2012), and very few studies incorporated probabilistic uncertainty analysis of BMP effectiveness (Arabi et al., 2007b; Sohrabi et al., 2003). Uncertainty considerations are particularly important when model results are supposed to support decisions regarding water resource policy, regulation, and program evaluation (Shirmohammadi et al., 2006).

In this study, the SWAT model is utilized to evaluate the impact of BMPs on streamflow and sediment loads in the PRB. Among the catalog of possible BMPs supported by the Water Producer Program, we selected (i) terraces, (ii) small sediment retention basins ('Barraginhas'), and (iii) a multi-diverse crop rotation system for impact analysis. SWAT is capable of accounting for these types of BMPs (Arabi et al., 2008; Waidler et al., 2011). The analysis is based on a previous SWAT case study conducted for the PRB by Strauch et al. (2012), where it was shown that using an ensemble of precipitation input data can lead to improved streamflow predictions in this region. They also found that uncertainty in 'goodness of fit' parameterization of the SWAT model increases when spatial data on precipitation is limited. Therefore, the evaluation of BMP effectiveness presented in this study follows this approach by considering that precipitation data ensemble. The study is part of the IWAS-ÁGUA-DF project (http://www.iwas-sachsen.ufz.de/) which supports the development of an integrated water resources management for the DF (Lorz et al., 2012). IWAS-ÁGUA-DF includes three major complexes: (1) catchments and water bodies, (2) waste water (Aster et al., 2010), and (3) drinking water (Vasyukova et al., 2012). This paper is addressing complex (1) by investigating to what extend BMPs might contribute to sustainable water resources management in this region.

2. Materials and methods

2.1. Study area

The PRB is located in the Brazilian Central Plateau. From the headwaters in the state of Goiás to its mouth into the São Bartolomeu River (DF), the Pipiripau River drains an area of about 235 km^2. This study focuses on the part up to stream gauge Montante Captação which covers an area of 188 km^2 (Fig. 1). The terrain is gently undulating with predominantly nutrient-poor and well-drained Ferralsols EMBRAPA (1978). Characterized by semi-humid tropical climate, rainfall is unevenly distributed throughout the year. Over the period 1978–2007, nearly 85% of the catchment's annual rainfall (1350 mm) occurred during the rainy season from November to April. The temperature varies slightly around 20.5 °C throughout the year.

During the rainy season, more than 50% of the study area is intensively cropped with soybean and corn, mainly in monoculture (cf. "large-scale cropping" in Fig. 1). Brachiaria pasture covers 23%,

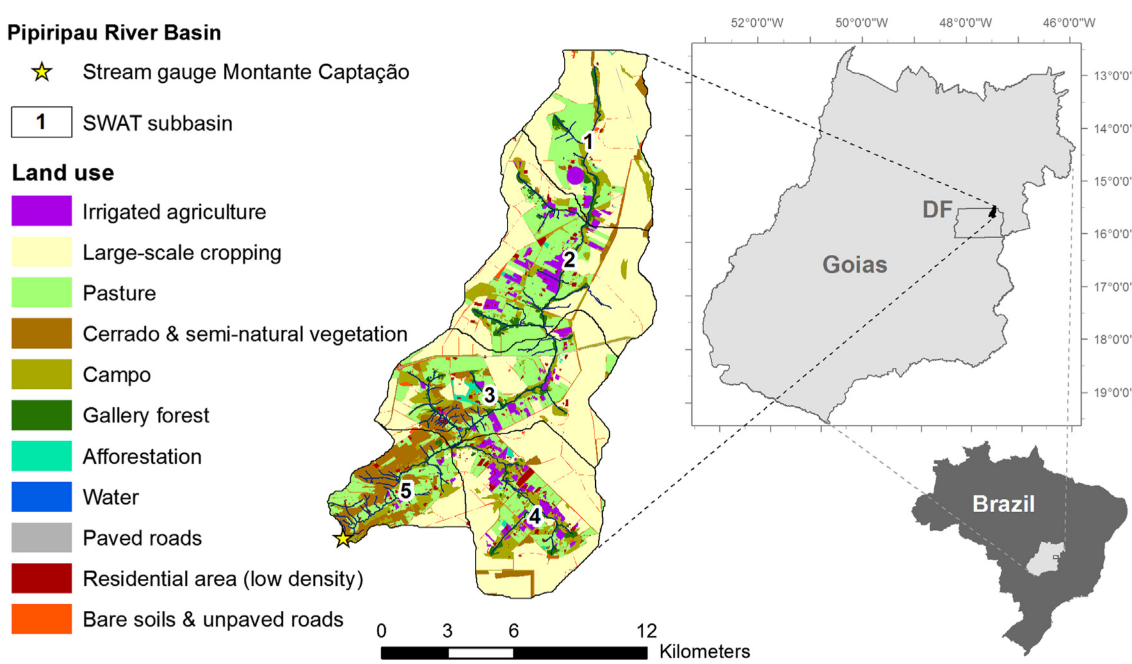

Fig. 1. Location and land use map of the Pipiripau River Basin.