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Hydrological benefits in the context of Brazilian environmental services program

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Abstract The Brazilian program of payment for environmental services (PES) is based on ranges of potential erosion decrease (ED) from soil and water conservation proposals estimated from the Universal Soil Loss Equation. Changes in land use and land cover (LULC) result in many alterations of the basin water balance. Therefore, to contribute to the methodological development of Brazilian PES, this paper proposes a quantification of hydrological benefits based on conservation measures. We propose basing the PES program on adding the potential water storage increase (WSI) parameter estimated from the runoff curve number model. Two LULC change scenarios were run considering conservation measures on degraded areas. We found that indicators of ED and WSI were compatible tools for driving the eligibility of soil and water conservation measures. However, the water storage parameter seems to be better at managing the PES mechanism because it is based on water prices and can contribute to appreciation of the efforts performed by the rural producers. The use of the SCS-CN method presents greater feasibility as a tool for the implementation of PES programs in ungauged basins. Thus, an analysis of the success of the innovation proposal of the Brazilian PES program allows inferences to be made about the quantification and financial valuation of hydrological benefits of the potential storage increase and current water price.

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1 Introduction

Environmental services represent the benefits that human populations derive, directly or indirectly, from ecosystem functions (Costanza et al. 1997). In watersheds, environmental services regulate the quantity and quality of water available for human activities (Locatelli and Vignola 2009). Programs of payment for environmental services (PES) developed by governmental or nongovernmental agencies should improve the relationship between downstream and upstream water users by offering financial compensation for conservation practices performed upstream (Kosoy et al. 2007; Jack 2009; George et al. 2009).

In Brazil, the PES ("Water Producer") program proposes financial support that is proportional to the benefits resulting from water erosion reduction by conservationist practices. This support is not provided to fund farming but rather to fully or partially pay the additional costs that farmers incur from implementing the positive changes proposed (Chaves et al. 2004; ANA 2008). This PES program assumes that PES values per unit area are determined from a proportional reduction of the cropping management factors *C* and *P* (cover management and conservation practices, respectively) from the Universal Soil Loss Equation (USLE) soil erosion model (Wischmeier and Smith 1978).

The *C* factor represents the effect of surface cover and roughness on soil erosion. As surface cover is added to the soil, the *C* factor value approaches zero. The *P* factor reflects the impact of support practices on the average annual erosion rate. *P* is the ratio of soil loss with a support factor to that with straight-row farming up- and downslope. Stripcropping, contouring, and terracing are activities that are considered support practices. The *C* and *P* values are obtained from standard plots (22 m length and 9 % slope) and rainfall series (Wischmeier and Smith 1978; Kinnell 2010).

Hydrological models can be used to evaluate management and conservation plans in watersheds. A widely used method to calculate storm runoff and excess rainfall developed by the Soil Conservation Service (SCS) of the US Department of Agriculture is the NRCS curve number (CN) procedure (SCS 1956; USDA 1986; NRCS 2004). The CN parameter is a quantitative descriptor of the land cover/soil complex and predicts the potential of surface runoff production within a numerical range of 1–100. These values are initially obtained from standard tables related to 4 hydrologic soil groups characterized by their infiltration behavior. The CN parameter can also be obtained from composite series of rainfall-runoff data in hydrographic basins (Shi et al. 2009), and rainfall simulators can be used to calculate CN at specific sites (Elhakeem and Papanicolaou 2009).

Taking into account the fact that nonpoint source pollution can be controlled by direct action on the runoff, this paper proposes a quantification of hydrological benefits of conservation practices through the runoff CN model to contribute to the methodological developments of the Brazilian PES program. The second step would be to compare the original and here proposed methods for quantification and valuation of environmental services. For this step, we studied the effect of two land use and land cover (LULC) change scenarios in erosion and potential water storage within a rural watershed. The economic values of PES were estimated for potential water erosion decrease and potential soil water storage increase.

2 Materials and methods

2.1 Study area

This study was carried out at the 540 km^2 Salobra stream basin (20°12′S to 20°28′S and 54°55′W to 55°16′W, Fig. 1). The Salobra stream is a tributary of the Aquidauana River, an important watercourse for local fisheries and agricultural activities. The altitude of the study area ranges from 200 to 400 m, with an average steepness of 2 %. The climate is tropical and transitional between Cfa and Aw (Köppen classification), with an average annual air temperature of 23 °C and a mean annual precipitation of 1,550 mm.

The study basin has significant ecological relevance because it is located at the highland region surrounding the Pantanal at the Upper Paraguay basin. The Pantanal is a lowland recognized as the largest freshwater wetland in the world (Seidl et al. 2001). The Pantanal is designated as a "national treasure" in the Brazilian constitution and has been awarded high priority for the protective management of its natural resources. Thus, it is very important to perform "best management practices" at the Pantanal upstream area, seeking to avoid problems with siltation, hydrological changes, and organic and toxic pollution at this floodplain (Wantzen et al. 2008).

The land use of the study area is essentially agricultural. Extensive cattle husbandry is the prevailing activity (approximately 73 % of the total area), and a few areas are planted with woody species such as eucalyptus and citrus trees (Table 1). LULC classifications were made using Landsat Thematic Mapper (TM) images (orbit/point 225/74) corresponding to the summer season of 2008 (INPE 2008).

The LULC classification is as follows: poor pasture conditions, with a vegetation cover of less than 50 %; fair pasture, with 50–75 % vegetation cover; dense forest, with advanced stages of vegetation and litter cover; scattered forest, with intermediate levels of vegetation and litter cover; and woody crops, with eucalyptus and citrus trees.

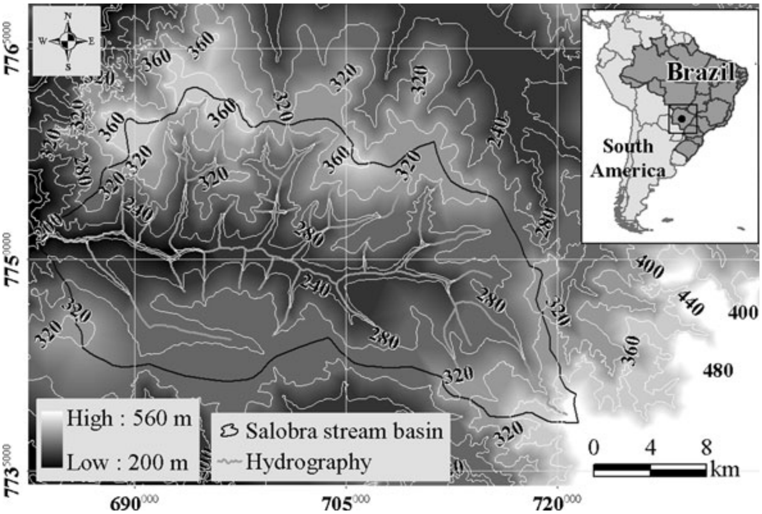

Fig. 1 Study area map

Table 1 Distribution of current LULC at study basin

Land use and land cover (LULC)	Area (ha)	%
Dense forest	7,093	13.1
Scattered forest	5,799	10.7
Poor pasture conditions	18,874	34.9
Fair pasture conditions	20,680	38.2
Water and wet areas	670	1.2
Woody crop	928	1.7

2.2 Determination of land use and land cover (LULC) change scenarios

Two LULC change scenarios, called "Forest Recomposition" and "Pasture Recovery," were designed. These scenarios were based on conservation measures for the recovery of degraded areas on river basins, such as poor pasture conditions (Fig. 2).

The Forest Recomposition scenario integrates the conversion of poor pasture areas to scattered forest by reforestation with native trees. The Pasture Recovery scenario, in turn, considers the recovery of pasture with poor conditions, converting it to fair pasture conditions. These scenarios were analyzed by the percentage of potential erosion decrease (ED) and potential water storage increase (WSI). The data used at this study are standardized from original tables and guidelines.

2.3 Potential erosion decrease (ED)

The USLE model (Wischmeier and Smith 1978) predicts long-term average annual soil loss using six factors that affect soil water erosion. These factors are associated with climate, soil, topography, vegetation, and management (Eq. 1).

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \tag{1}$$

where A is the average annual soil loss per unit of area (t ha^{-1} year^{-1}), R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}), K is the soil erodibility factor (t h MJ^{-1} mm^{-1}), LS is the topographic factor (dimensionless), C is the cover-management factor (dimensionless), and P is the agricultural support practice factor (dimensionless).

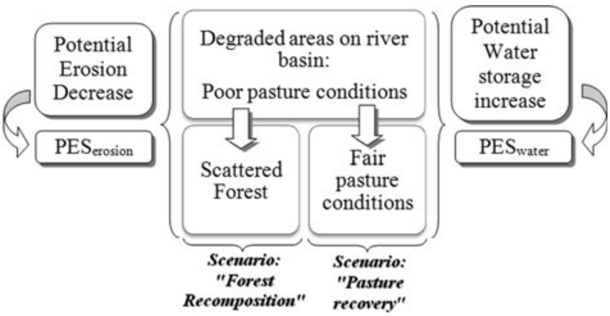

Fig. 2 LULC change scenarios from the degraded pasture areas in the study basin

The ED indicator is defined as the evaluation of conservation scenarios considering the temporal variation of the anthropic factor of the USLE model (the product of the C and P factors) (Eq. 2).

$$\mathrm{ED}\,(\%) = 100\left(1 - \frac{A_{\mathrm{final}}}{A_{\mathrm{initial}}}\right) = 100\left(1 - \frac{CP_{\mathrm{final}}}{CP_{\mathrm{initial}}}\right) \quad (2)$$

where ED = the potential erosion decrease indicator for each LULC scenario; CP_{final} = the product of factor C and factor P after conservation plan implementation, and CP_{initial} = the product of factor C and factor P before conservation plan implementation.

The values attributed to the anthropic factor (CP) for conventional or conservationist land use and management are listed in the Operational Guide of the Water Producer program (ANA 2008) and by the authors in Chaves et al. (2004) (Table 2).

The PES valuing at the "Water Producer" program (called $\mathrm{PES}_{\mathrm{erosion}}$) was based on the additional cost of production for the participating producer to implement conservation practices. The values definition process used the mean deployment cost of direct seeding as a starting point, which is an economically and environmentally efficient and widely used conservation practice in Brazil. Thus, the conversion of a conventional agricultural system to direct seeding costs approximately USD 57 ha^{-1} and reduces erosion by approximately 90 % (Chaves et al. 2004).

According to the "Water Producer" program, the $\mathrm{PES}_{\mathrm{erosion}}$ should be proportional to the environmental performance. In this manner, the ED values were categorized by ranges to define $\mathrm{PES}_{\mathrm{erosion}}$ for the farmers (Table 3). A minimum ED value of 25 % was assumed to provide the payment for conservation practices, considering a minimum threshold for environment service efficiency (Chaves et al. 2004; ANA 2008).

2.4 Potential water storage increase (WSI)

The SCS-CN method was adopted here to quantify the hydrological effects from conservation practices in United States. The SCS-CN method comprises a semiempirical model that estimates runoff caused from individual rainfall events, and it considers the physical characteristics of the basin (SCS 1956; USDA 1986). This method is based on the water balance and two fundamental hypotheses that can be expressed by Eqs. (3), (4), and (5).

Table 2 Variation of the parameter CP of USLE model at LULC change scenarios

Scenario	Current LULC	CP_{initial}	LULC change	CP_{final}
Forest recomposition	Poor pasture conditions	0.25	Scattered forest	0.03
Pasture recovery	Poor pasture conditions	0.25	Fair pasture condition	0.12

Table 3 Definition of payments for environmental services from potential erosion decrease (ED) ($\mathrm{PES}_{\mathrm{erosion}}$)

ED (%)	25–50	51–75	76–100
$\mathrm{PES}^{a}_{\mathrm{erosion}}$ (ha^{-1})	USD 24.58	USD 36.87	USD 49.16

Source: modified from Chaves et al. (2004)

[a] 1 USD = 2.0343 BRL (July 17th, 2012)

The cumulative precipitation is expressed as:

$$P = I_a + F + Q \quad (3)$$

$$\frac{Q}{P - I_a} = \frac{F}{S} \quad (4)$$

$$I_a = \lambda S \quad (5)$$

where P = cumulative precipitation (mm), I_a = initial abstraction (mm), F = cumulative infiltration excluding I_a (mm), Q = direct runoff (mm), S = potential maximum soil moisture retention after the onset of runoff (mm), and λ = the initial abstraction ratio.

Combining Eqs. (3), (4), and (5) gives the following expression for Q (Eq. 6).

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}, \quad \text{if} \quad P > I_a \quad (6)$$

Equation (6) is valid for $P > I_a$; otherwise $Q = 0$. The parameter S is defined by Eq. (7):

$$S = 254\left(\frac{100}{\text{CN}} - 1\right) \quad (7)$$

where S is in mm and the runoff CN is dimensionless.

The parameter S is the potential maximum retention or storage (mm) measured after runoff begins. According to Mishra and Singh (2004), the direct participation of the watershed in runoff production depends mainly on parameter S. The parameter CN defines the potential for runoff production numerically. The CN values were provided by reference tables that combine physical characteristics of the landscape, such as soil type, LULC, and antecedent moisture condition (AMC). The AMC considers precipitation in the 5 days before the rainfall event analyzed (USDA 1986). Three AMC levels are considered: AMC I, dry soil (but not to the wilting point); AMC II, average case; and AMC III, saturated soil (Gabellani et al. 2008).

The SCS-CN method also includes initial abstraction (I_a) by vegetation interception, soil infiltration, and accumulation in landscape depressions. I_a comprises the rainfall required for the initiation of runoff (Shi et al. 2009) and is linearly related to S (Gabellani et al. 2008).

The soil types in the basin are dark red alic latosol (oxisol) (sandy loam), alic quartz-arenic neosol (sandy loam), dystrophic purple latosol (silty loam), and dystrophic low humic gley (Tb) (silty loam). According to the descriptions and soil texture specifics defined by the SCS-CN method for hydrologic soil groups (USDA 1986), we classified the first two soil types belong to hydrologic soil group A and the other two to group B. The spatial distribution of the hydrologic groups of the prevailing soils and the respective land use are shown in Fig. 3.

The CN values were determined according to CN table specifications for "Pasture, grassland, or range—continuous forage for grazing" and "Woods" categories, while taking into account AMC II conditions (USDA 1986). The CN values applied to the current LULC and LULC change scenarios are presented in Table 4.

The variation of potential water storage (S) during the simulation of conservation measures scenarios and the price of water charged for use in the rural sector (ANA 2009) were used for the PES valuation (called $\text{PES}_{\text{water}}$) (Eq. 8). The water price adopted was BRL 0.03 m^{-3}, or approximately USD 0.01 m^{-3}.

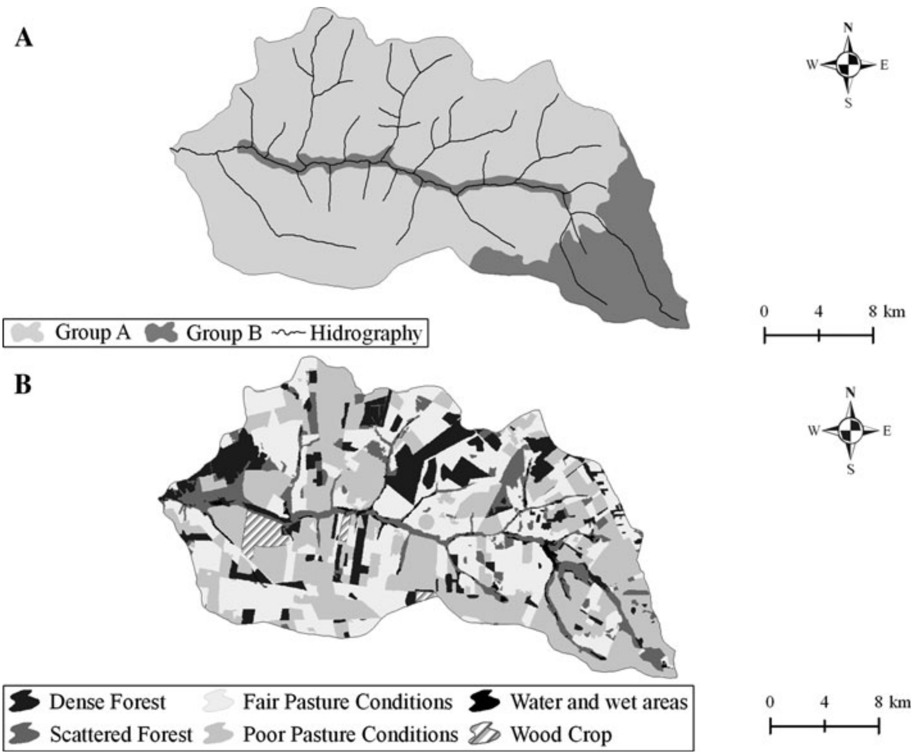

Fig. 3 **a** Hydrologic soil group; **b** current LULC

Table 4 Variation of CN values at LULC change scenarios, in according to hydrologic soil groups

Scenario	Current LULC	$CN_{initial}$ (hydrologic soil group)	LULC change	CN_{final} (hydrologic soil group)
Forest recomposition	Poor pasture conditions	68 (A) 79 (B)	Scattered forest	36 (A) 60 (B)
Pasture recovery	Poor pasture conditions	68 (A) 79 (B)	Fair pasture condition	49 (A) 69 (B)

The letters (A) and (B) refer to hydrologic soil group A and B, respectively (see USDA 1986)

$$PES_{water} = \frac{(S_2 - S_1)}{1,000} \cdot A \cdot P_{water} \quad (8)$$

where $PES_{(water)}$ = payment for environmental services from the increase of water storage in the basin (USD); S_1 = potential water storage in the soil profile before the conservation measure, in mm; S_2 = potential water storage in the soil profile after the conservation measure, in mm; A = area of LULC change, m^2; P_{water} = the price of water in the rural sector, in USD m^{-3}; and 1,000 = factor of unit conversion.

Table 5 Main characteristics of the two PES options

PES option	$PES_{erosion}$	PES_{water}
Environmental service	Potential Erosion Decrease (ED)	Potential Water Storage Increase (WSI)
Indicator	Variation of the anthropic factor (*CP*) of USLE model	Variation of the parameter *S* of SCS-CN method
Financial valuation	Incentives based on initial investments for practices improvement, adjusted in accordance with ranges of potential erosion reduction	Incentives based on benefits from practices improvement, quantified by potential water storage increase and local water price

Despite the PES_{water} valuing being based on the difference between potential water storage in the soil profile before and after conservation measures, we estimated an index of potential WSI only for comparison with the potential erosion reduction index (ED, Eq. 2) under the same LULC scenarios (Eq. 9).

$$\mathrm{WSI}\,(\%) = 100\left(1 - \frac{S_1}{S_2}\right) \tag{9}$$

where WSI = potential water storage increase; S_1 = potential water storage in the soil profile before the conservation measure, in mm; and S_2 = potential water storage in the soil profile after the conservation measure, in mm.

In brief, both the PES Brazilian program ($PES_{erosion}$) and the proposal here (PES_{water}) are based on a specific relationship between land use and ecosystem service provision, but the difference between the two methodologies refers, essentially, to the specific environmental services quantified, the physical indicators, and the principles for financial incentive valuations (Table 5).

3 Results and discussion

We found similar results from ED and WSI for the different scenarios simulated (Fig. 4). The conversion of poor pastures to scattered forest ("Forest Recomposition" scenario) has a greater impact on soil loss (88 % of ED) and water storage (72 % of WSI) than does the

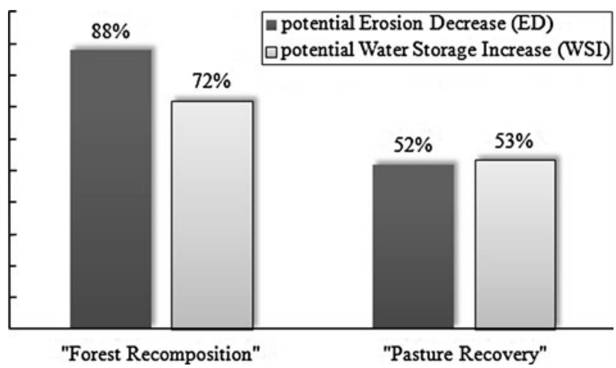

Fig. 4 ED and WSI for the different scenarios simulated

Table 6 Definition of payments for environmental services (PES) from potential erosion decrease (ED), $PES_{erosion}$, and potential water storage increase (WSI), PES_{water}, for two scenarios

Scenario	$PES_{erosion}$ (USD ha^{-1} $year^{-1}$)	$PES_{erosion}$ on all basin (USD $year^{-1}$)	PES_{water} (USD ha^{-1} $year^{-1}$)	PES_{water} on all basin (USD $year^{-1}$)
Forest Recomposition	$49.16	$927,783.88	$45.49	$858,606.50
Pasture Recovery	$36.87	$695,837.91	$19.88	$375,166.67

1 USD = 2.0343 BRL (July 17th, 2012)

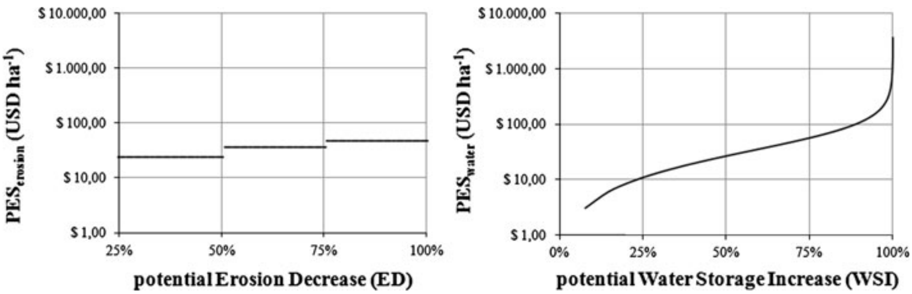

Fig. 5 PES from erosion decrease (*left*) and potential storage increase (*right*)

recovery of poor pastures ("Pasture Recovery" scenario), with a range of approximately 50 % for both ED and WSI. Therefore, WSI indexes such as ED are able to value the impact of LULC changes and can be a tool to drive the eligibility of soil and water conservation measures.

Despite the similar changes in environmental variables for the same scenarios, the compensation mechanisms from potential erosion reduction ($PES_{erosion}$) and potential WSI (PES_{water}) produced different PES values (Table 6).

The difference between the valuation of water price, defined by water charge on basins, and the financial support for soil conservation practices, defined by the Brazilian PES program, influenced the different PES value results. The ED values were categorized by discrete-empirical ranges to define $PES_{erosion}$, while the PES_{water} is here proposed as a semi-conceptual, with continuous behavior associated with WSI index (Fig. 5). Taking account, the smaller values of ED, such as those obtained in Pasture Recovery scenario, the minimum value of $PES_{erosion}$ can be greater than PES_{water} because of the large range incorporated. However, the PES_{water} is more sensitive to change in the environmental variable (parameter *S*), so it can further appreciation of the efforts performed by the rural producers.

Both $PES_{erosion}$ and PES_{water} have small values compared with other countries. In Colombia, the average payments to landholders are approximately US\$136 ha^{-1} for diminishing water sedimentation and facilitating stream-flow regulation, which are based on a previous opportunity cost study (Moreno-Sanchez et al. 2012). In Munich, Germany, the city offered an annual payment of USD 292–355 ha^{-1} $year^{-1}$ to farmers as a financial incentive to switch to organic farming (Grolleau and McCann 2012). However, small PES values are important in countries in development, considering the feasibility for governmental agencies to disseminate the PES program throughout the territory.

The use of SCS-CN parameters makes evaluation models for the implementation of PES programs in ungauged basins more feasible. The CN data are available in tables and are used as guidelines for many LULC conditions in Brazil. However, these data can be calibrated for any region for accurate evaluations of PES programs. Considering ungauged basins, the calibration of the CN parameter could be easier than factors *C* and *P* because portable rainfall simulators can be used to calibrate the CN parameter at specific locations (Elhakeem and Papanicolaou 2009).

The PES_{water} option is based on a simple and straightforward assumption about the relationship between land use and ecosystem services. This proposal can be useful during political decisions about water resource management due to the reduction in the complexity of environmental process knowledge (Muradian and Rival 2012). In general, ecosystem service projects already have the "missing quantities problem" as well the "missing prices problem" (Boyd 2008).

A greater integration of concepts, methods, and the latest results as well as attention to context specificity is required to generate policy-relevant insights (Lele 2009). It is important to analyze the relevance of conservation projects within the context of the watershed by focusing on sensitive areas (Rodrigues et al. 2011), which can lead to the greater participation of watershed users and the establishment of progressive goals for soil and water conservation. In addition, upstream and downstream communities should recognize that conservation practices have long-term benefits besides the PES (George et al. 2009).

4 Conclusion

This study presents simulations in an ungauged basin while considering effective conservation strategies through the analysis of two different LULC change scenarios with a focus on the establishment of PES values from hydrological benefits (PES_{water}). This PES option considered a simple and straightforward assumption about the relationship between land use and ecosystem services.

Considering that the indicators of potential soil erosion reduction and potential WSI showed similar evaluations for the scenarios simulated, these methodologies are compatible tools for driving the eligibility of soil and water conservation measures. The parameter *S* of the SCS-CN method indicates the potential storage increase. This parameter is suitable for application in hydrological evaluations of proposed conservation measures that include the implementation of PES in ungauged watersheds. Considering that the SCS-CN method is preferable over the USLE model because the calibration of parameter CN is easier than factors *C* and *P*, the use of the CN parameter presents greater feasibility for PES implementation in Brazilian river basins.

The PES mechanism that takes into account the water storage is an improvement because it is based on water prices and can contribute to appreciation of the efforts performed by the rural producers. Thus, the analysis of the innovation proposal of the Brazilian PES program allows inferences to be made about the quantification and financial valuation of hydrological benefits from a potential storage increase and current water prices.

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