

PAYMENTS FOR ECOSYSTEM SERVICES TO WATER RESOURCES PROTECTION IN PARAÍBA DO SUL ENVIRONMENTAL PROTECTION AREA¹

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1. Introduction

The vegetation coverage is intrinsically linked to water quality, representing a natural defense that assists in soil maintenance (BERTONI; LOMBARDI NETO, 1985). The ecosystem service of sediment retention provided by natural landscapes is of great interest to water managers, justified by the increase in conflicts over water use and the degradation of water sources (REIS, 2004). Thus, the payments for ecosystem services for ecological restoration in riverbanks is one of the challenges of maintaining public water

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supply (CHAVES, 2004; ATTANASIO et al., 2012; SÃO PAULO, 2014).

The anthropic influence in a watershed, along with the natural characteristics of the subscribed area shapes the sedimentological behavior of the basin (LIMA et al., 2001). Increases in sediment production affect water quality and reservoir management (WALLING, 2009). The forest coverage in river basins contributes to soil retention and, consequently, reduces water treatment costs for public supply and dredging cost in reservoirs (LIMA et al., 2001).

The Fundação SOS Mata Atlântica (2014) points out that the deforestation and the irregular occupation of the watershed areas have contributed to aggravate the impacts of the historic droughts. Thus, it is fundamental to accelerate the recovery actions of these water basins, either by natural regeneration or through forest restoration efforts to protect the springs and riverbanks.

According to Poupeau et al. (2018), one of the main problems faced by the urban water sector is the lack of financing, mainly due to the non-payment culture of the users, as well as the reluctance of governmental authorities in charging adequate rates for political reasons. Urban operators do not have the resources to carry out the necessary investments. Users, particularly the poorest, suffer the consequences of this situation: a poor-quality service characterized by cuts in the supply and a failing sanitation. For effectivity of the watershed restoration and protection, it is necessary that governments act in an integrated manner and draw up plans with clear targets, with instruments of governance and management.

Estimates in monetary units are useful to show the relative magnitude of ecosystem services (CONSTANZA et al., 2014). The implementation of economic instruments, such as Payments for Environmental Services (PES) for the landowners, municipalities and protected areas, is important to preserve these areas (FUNDAÇÃO SOS MATA ATLÂNTICA, 2014). The water valuation is related to watershed protection, where the vegetation stands out for regulating the water cycle, making the maintenance of flow, minimizing floods, controlling erosion and silting, reducing the carrying of sediments, and thus conserving water quality (SILVA et al., 2008).

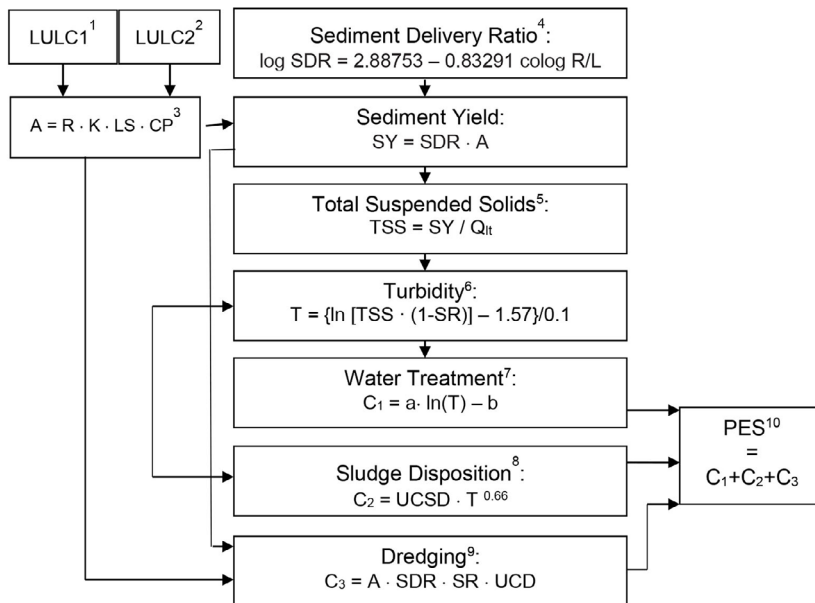
The economic thinking applied to the management of environmental protected areas does not include trivial solutions, it requires the consolidation of analysis criteria compatible with the biological, cultural and historical diversity (CAMPFORA; MAY, 2006). The present study applied a methodological proposal for the implementation of payments for ecosystem services related to the benefits for water supply provided by the protection of water resources through the ecological restoration in riverbanks.

The work innovates by associating the ecosystem benefits of soil retention by restoration with the economic valuation, in order to present a methodological proposal that is feasible for comprehension and reapplication by several actors: companies with environmental liabilities, voluntary financiers, rural landowners and government agencies. The expected result for this financial contribution is the improvement of hydrological conditions and vegetation coverage of the basin (ROSA et al., 2004).

2. Material and methods

The methodological proposal links the ecological restoration in riverbanks to economic incentives, justified by the increase in the water quality for public supply. Adapted from Sousa Júnior (2011), the flowchart (Fig. 1) illustrates the calculations of cost that can be avoided in water treatment, sludge disposal and dredging. These avoided costs are generated by reduction in turbidity, calculated through the methodological approach based on the difference the soil loss between two scenarios: current (status quo) and hypothetical (with the ecological restoration).

Figure 1 - Methodological proposal of quantification and valuation of the ecosystem services associated to the benefits for water supply.



Source: adapted from Sousa Júnior (2011).

Note:

- (1) LULC1 = current scenario
- (2) LULC2 = hypothetical scenario
- (3) A = average annual soil loss (t.ha⁻¹.yr⁻¹)
R = rainfall erosivity factor (mj.mm.ha⁻¹.h⁻¹.yr⁻¹)
K = soil erodibility factor (t.ha.mj⁻¹.mm⁻¹)
LS = topographic factors
CP = cropping management factors
- (4) R = difference between highest and lowest altitude; L = length of main water flow
- (5) Q_{lt} = average long-term flow
- (6) SR = settling rate of the sediments
- (7) "a" and "b" = adjustment coefficients of water treatment

- (8) UCSD = unit cost of sludge disposal (USD.m³)
(9) UCD = unit cost of dredging (USD.m³).
(10) PES = payments for ecosystem services

2.1. Case study

The methodological proposal is presented in the development of the case study in the Paraíba do Sul River Basin Environmental Protection Area (Área de Proteção Ambiental Bacia do Rio Paraíba do Sul – APABRPS, in Portuguese). It is the only federal protected area created with a specific objective associated with the protection of water resources for public supply, by National Decree 87,561/1982 (BRASIL, 1982).

This Decree indicated the following measures for recovery and environmental protection: macrozoning; implementation of urban water supply and sewage treatment systems; industrial pollution control; use of legal instruments and government financial incentives to ensure water pollution control and environmental preservation. Only the State of São Paulo stretch has its boundaries approved by Chico Mendes Institute for Biodiversity Conservation (ICMBio), linked to the Brazilian Ministry of the Environment (MMA). There are discussions about a diagnosis of the APABRPS that includes basins that protect new points and changes in water abstraction, but there is still no official information to use as a reference.

The Paraíba do Sul river basin has a drainage area of 56,665 km²: 39% in Rio de Janeiro, 37% in Minas Gerais and 24% in São Paulo. The basin is responsible for supplying approximately 18.5 million people, including metropolitan regions, industrial complexes and agricultural activities (INSTITUTO OIKOS, 2013). This demand is expected to grow even more due to the planned infrastructure for this region, such as the high speed train, the international cargo airport, the new small hydropower plants, the duplication of the highways and the actions linked to Pre-Salt program.

One of the biggest challenges for water in the Paraíba do Sul basin is the design of mechanisms that interact management and policy at various levels of decision-making, both federal and state. There is a need to establish a drought and flood risk plan, implementing joint and negotiable actions between users and stakeholders (NEHREN et al., 2018). With the worsening of droughts in water supply systems, the dispute between the states of São Paulo and Rio de Janeiro increased in the concession and transposition of waters of the Paraíba do Sul River (OECD, 2015).

The APABRPS is inserted in the Atlantic Forest domain and its history of land use and occupation has caused a drastic reduction of its original vegetation coverage, intensifying the natural characteristics of high susceptibility to erosive processes (IPT, 2011). The socioeconomic and environmental scenario of the Paraíba do Sul basin, with an increasing water consumption, in contrast to the high level of degradation of the water production areas, presents great potential for the implementation of PES programs.

2.2. Soil losses

The Universal Soil Loss Equation (USLE; Eq. 1), according to Wischmeier and Smith (1978), is a model to estimate the average soil loss due to erosion, over time in a

given area, with specific conditions of cultivation and management. The soil loss potential (A) is the average estimate for the annual soil loss, per hectare, in the studied basin. This equation became the main worldwide reference for the estimation of soil loss by laminar erosion processes, with rainfall activation.

$$A = R \cdot K \cdot LS \cdot CP \quad (1)$$

where,

A = average annual soil loss (t. ha⁻¹.yr⁻¹)

R = rainfall erosivity factor (MJ.mm.ha⁻¹.h⁻¹.yr⁻¹)

K = soil erodibility factor (t.h.MJ⁻¹.mm⁻¹)

LS = topographic factors

CP = cropping management factors

The R factor (rainfall erosivity) is the average annual erosion potential of rainfall, considering the soil erosion as a process of sloping and accelerated trailing of soil particles caused by water (water erosion) in an unprotected area of the vegetation coverage. Rainwater exerts an erosive action by the impact of droplets falling with variable velocity and energy, according to their diameters, and by the runoff (BERTONI; LOMBARDI NETO, 1985).

We used the erosivity map elaborated by Moreira et al. (2006), interpolated by Artificial Neural Network for the State of São Paulo. The erosivity map is represented by a grid of 1030 x 1030 meters.

The K factor (soil erodibility) is a soil intrinsic property. It represents the erosion intensity per unit of water erosion index for a specific soil, which is kept uncovered and prepared in the direction of a slope and 9% in a 25m long plot. According to Bertoni and Lombardi Neto (1985), erodibility refers to the soil susceptibility to erosion, which varies naturally by the physical characteristics of the soil.

The erodibility values were obtained in Mannigel et al. (2002), which they used the Boyoucos equation for the indirect determination. For geospatialization, the values were attributed to the pedological map produced by the Agronomic Institute of Campinas (IAC) and Brazilian Agricultural Research Corporation (EMBRAPA), based on Oliveira et al. (1999).

The intensity of the erosion has a close relationship with length and slope. The LS factor is defined as the expected ratio of soil losses per unit area on any slope to corresponding soil losses of a 25m long unit plot with 9% slope. According to Bertoni and Lombardi Neto (1985), the topographic factors are:

L: the slope length factor is the ratio of the soil losses of an area with any length of slope and another with a slope length of 25m, for the same soil type and slope;

S: the degree of slope factor is the ratio of the soil losses of an area with any degree of slope to slope of 9% for the same soil type and ramp length.

The LS factor was obtained through the method developed by Desmet and Govers

(1996) for a two-dimensional surface. To avoid the overestimation in heterogeneous landscapes, long slope lengths are limited to a value of 333m.

The C factor represents the effect of land use and management on the erosion estimation. The soil loss is calculated by purchasing an area with specific cropping and management and another maintained permanently discovered and with soil preparation in the direction of slope. The C factor had spatially distributed through the LULC map provided by Vieira et al. (2013), available by INPE for the State of São Paulo, in scale 1: 250,000. The C factor value was defined for each LULC class (water resource, forest, pasture, cropland, eucalypt and settlement), based on follow references: Silva et al. (2004), Tomazoni et al. (2005), Farinasso et al. (2006), Ribeiro and Alves (2007) and Martins et al. (2010).

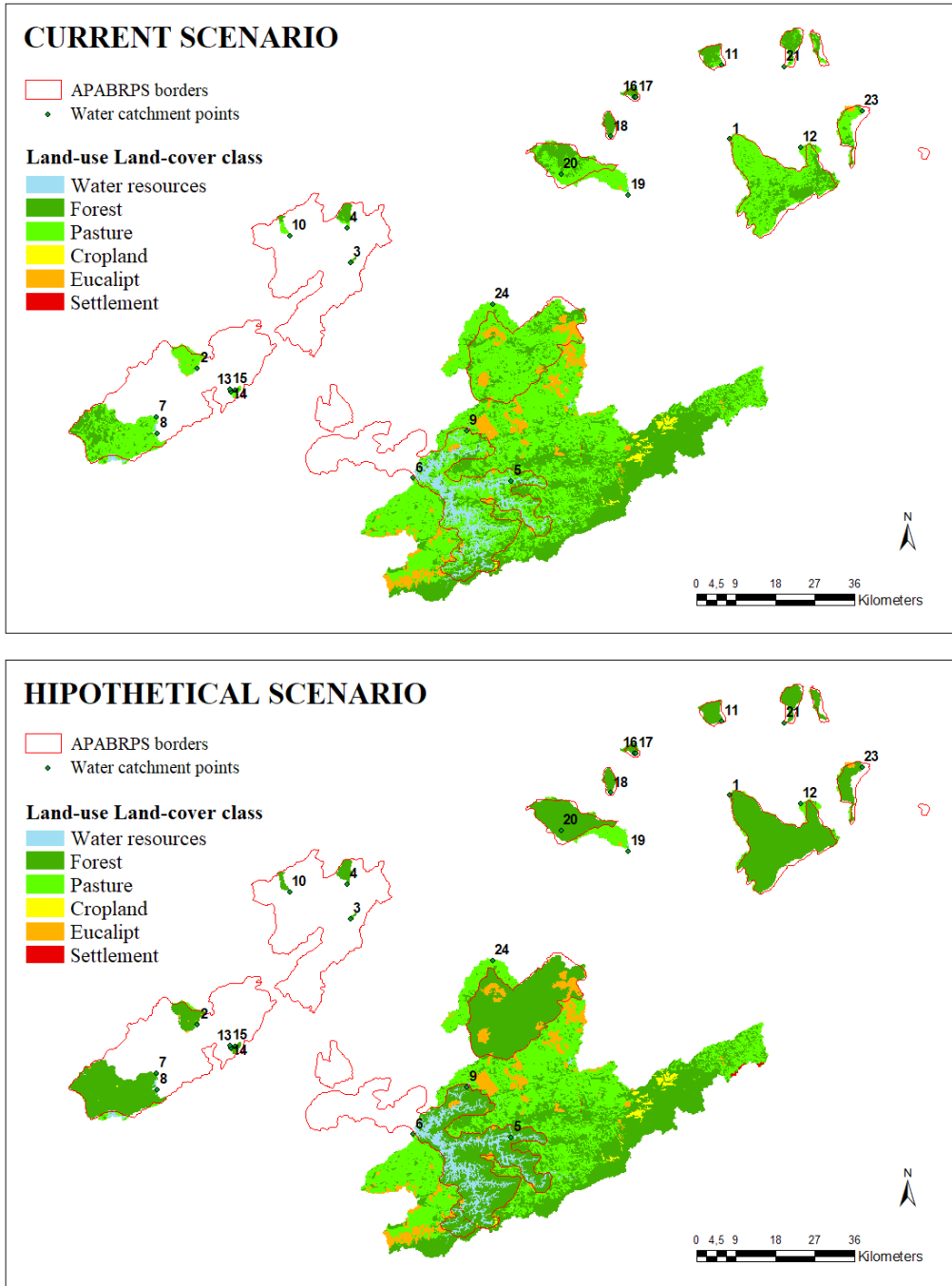
The P factor (conservationist practice) is the relation between the soil losses of an area cultivated with a certain conservationist practice, such as: contour planting and planting in strips (BERTONI; LOMBARDI NETO, 1985). In this study, the P factor is considered 1 in all areas and proximities of the protected areas, indicating that there are no management interventions and conservation practices in land use.

Although inserted as an environmental protection area, the historical process of use and occupation of the Vale do Paraíba promoted the elimination of most of the forest coverage of the basin. The low forest coverage of the basin adds to the natural characteristics of the landscape and the relief and the regional climatic conditions, which, when overlapped, impose great vulnerability to erosive processes on large tracts of land. This, together with the conventional methods used in farming practices, results in a great amount of soil loss.

As many pastures are degraded and underutilized, it is suggested the ecological restoration in these areas. Thus, in order to estimate the effectiveness of water resources protection by APABRPS, a second land use and land cover map was designed. In this hypothetical scenario, the pasture areas inserted in the protected area were replacement by forest class (Fig. 2). Consequently, the land-use changes modify the C factor map. For the hypothetical scenario, the C factor of the forest class replaces the factor C for pasture areas. It changes the C factor value from 0.01 to 0.001, indicating the ecological restoration in these areas. The factor C values used to pasture and forest classes can be considered an average and modal value for extensive pasture and forests with dense shrubbery, respectively.

The Atlantic Forest Restoration Pact (RODRIGUES et al., 2009) and the Degraded Areas Restoration Technical Manual (MORAES et al., 2013) point to the 20-year time for secondary vegetation to climax, based on Ferretti et al. (2002). Thus, it can be considered the time for the forest C factor replaces the pasture C factor proposed in the hypothetical scenario.

Figure 2 – Land use and land cover maps for current and hypothetical scenarios.



Source: author's elaboration.

The hypothetical restoration is justified by the lack of care and subsoil of the pastures in many locations into the APABRPS, indicating the need for change and management in land use and land cover, mainly due to the importance of preserving (in this case, restoring) the environmental protected area and, consequently, reestablishment of the benefits provided by the ecosystem, mainly related to the soil retention by the recovery of forest areas.

We used the Sediment Delivery Ratio (SDR) model of the InVEST software - Integrated Valuation of Ecosystem Services and Tradeoffs, version 3.2, developed by the Natural Capital Project. InVEST is a set of models that explore the benefits of ecosystem services among land-use planning scenarios on a regional scale, indicated primarily for application in public policy and decision making.

The model is based on the Revised Universal Soil Loss Equation (RUSLE) (SHARP et al., 2014). It works on the spatial resolution of the input raster of the digital elevation model (30 m). The maps of erosivity, erodibility and land-use were submitted to map algebra operations for InVEST calculations. Therefore, the soil loss potential (A) was calculated to current and hypothetical scenarios. The objective is to map the sediment generation per unit area and its transfer to the water flow. The transfer rate is the proportion of the soil loss that effectively reaches the water withdrawal outlet (BORSELLI et al., 2008).

2.3. Physiographic characteristics

The digital data used in this study were stored and processed in the ArcGIS software version 10.6, by ESRI, for the composition of the database, processing and presentation of analyzes. All digital data were projected in SIRGAS2000 (Geocentric Reference System for the Americas). The territorial limits of each protected area were acquired through the website of the ICMBio.

For the construction of the hydrography networks, we used the Digital Elevation Model (DEM) of the TOPODATA Project of the National Institute for Space Research (INPE) (VALERIANO, 2008), with spatial resolution of 30 m. These models originate from data from the Shuttle Radar Topography Mission (SRTM), provided by the United States Geological Survey (USGS).

From the DEM, it calculated the directions of water flows through the ground surface, the accumulation of water flow and the hydrography. The hydrography was defined considering that from a value of flow accumulation; this accumulation is a water body. The main watercourses were identified as well as their lengths, start (higher altitude) and end (lower altitude) points.

We analyze 24 water catchment points that intersect with the APABRPS, which are granted by Department of Water and Electric Power of the São Paulo State (DAEE). They were used as reference to obtain the watersheds. Each cell was compared to the neighboring cells, establishing the water flows in the direction of the neighboring cell that presented the lowest elevation value. Thus, the drainage maps was created for each watershed.

2.4. Sediment delivery ratio

The physiographic characteristics subsidize the calculation of sediment delivery ratio (SDR), which is the ratio of the soil loss that effectively reaches out the water catchment (WALLING, 1983). It is assumed that a part of the sludge is maintained in suspension in the water column and another part deposits in the rivers and reservoirs. In basins with reduced flow rate of water, the effects of turbulence are smaller, causing the deposition of particles heavier than water. This flow speed depends on the fresh water discharge, the density gradient, the movement along the water body and wind action on the free surface (MIRANDA et al., 2002).

Chaves (2010) compared several equations to calculate the SDR, and found a great disparity in the results. However, if we consider equations involving more than one variable, the results are similar. The author proposes the Equation 2 below, adapted from Roehl (1962):

$$\log \text{SDR} = 2.88753 - 0.83291 \log R/L \quad (2)$$

where,

SDR = sediment delivery ratio

R = difference between the highest and lowest altitude in the drainage area

L = length of main water course in the drainage area

2.5. Sediment yield

The sediment yield (SY) is the sediment discharge through a certain river section per unit catchment area per unit time. Walling (1983) defined it as the relation between the sediment delivery ratio (SDR) and the soil loss potential (A) for the full basin area, being configured as dimensionless and expressed in the following manner (Eq. 3):

$$\text{SY} = \text{SDR} \cdot A \quad (3)$$

where,

SY = sediment yield (t.yr⁻¹)

SDR = sediment delivery ratio

A = soil loss potential (t.yr⁻¹)

The load is the mass transport per unit time. The yield is simply the load normalized for the watershed size. Meade and Parker (1986) have established the great spatial variability of long-term sediment yields at the global scale, controlled by climate, relief, basin size, lithology and damming (MILLIMAN; FARNSWORTH, 2013).

2.6. Hydrosedimentological analyze

The sediment yield is directly correlated to total suspended solids (TSS), varying mainly through water flow and turbidity. Other variables, including relief, basin size, and

occurrence of lakes and lithology, should also be considered (MILLIMAN; FARNSWORTH, 2013). The relation between the TSS and the respective water discharge is (Eq. 4):

$$\text{TSS} = \text{SY} \cdot \text{Q}_{\text{lt}}^{-1} \quad (4)$$

where,

TSS = total suspended solids (mg.L⁻¹)

SY = sediment yield (mg.yr⁻¹)

Q_{lt} = longer-term water discharge (L.s⁻¹)

The suspended sediment delivery usually represents the greater load carried in the flow. In addition, suspended sediment is also considered an important component within the hydrological, geomorphological and ecological processes of the rivers (GAO; JOSEFSON, 2012). The suspended solids in rivers respond quickly to environmental changes. Especially in smaller basins, where the rapid hydrossimetric response modifies suspend solid concentration in time (WALLING; WEEB, 1981).

According Sabesp (2010), the turbidity is the measure of water resistance to light flux, provided by suspended solids in water. In Brazil, the Health Ministry defined that the water produced and distributed to population must be control. The maximum value of turbidity is 5 NTU. The law also indicate the minimum amount and frequency of water tests. The turbidity is also an esthetic parameter to accept or reject the product.

According to Sousa Júnior (2011), the relationship between the suspended solids and the turbidity (T) is well studied and several authors show correlation coefficients between 85% and 95%. In the absence of local empirical data, the author suggests the transfer of functions from similar areas, in order to connect the suspended solids and the turbidity. Teixeira and Senhorelo (2000) estimated a function with correlation coefficient of 92% (Eq. 5):

$$T = \{\ln [\text{TSS} \cdot (1-\text{SR})] - 1.57\}/0.1 \quad (5)$$

where,

T = turbidity (mg/L SiO₂ - NTU)

TSS = total suspended solids (mg.L⁻¹)

SR = settling rate

The sediment settling rate (SR) is an estimate, in percentage, of the amount of material that is separated by solid particles suspended in the water. In basins with reduced water flow velocity, the effects of turbulence are lower, causing the deposition of heavier particles than water. This velocity flow depends on the discharge of fresh water, the density gradient, the circulation along the water course and the action of the wind on the free surface (MIRANDA et al., 2002). The SR is defined in 20%, for basins with long and high watercourses.

2.7. Economic analyze

In order the water use for domestic supply, it used three economic methods to value the benefits generated by the ecological restoration of the watersheds. The first two consider the values associated with the costs avoided, both by chemical cost in the water treatment and by the spending with sludge disposal in the water treatment plant. The last is a mitigation cost method, it sets the dredging costs, calculating the expenses for dredging the sediments from the water reservoir.

The process to produce potable water requests several steps and high level of quality control. The cost with chemical products represents around 60% of the total cost in the water treatment plant (REIS, 2004). The turbidity is fundamental to define the amount chemical products for applying to water treatment. High values of turbidity need high concentration of the chemical products to decant impurities in water treatment plants. In Brazil, the water treatment plants use inorganic coagulants in the process to reduce the turbidity through the Equation 6:

$$C_1 = a \times \ln(T) - b \quad (6)$$

where,

C_1 = water treatment cost

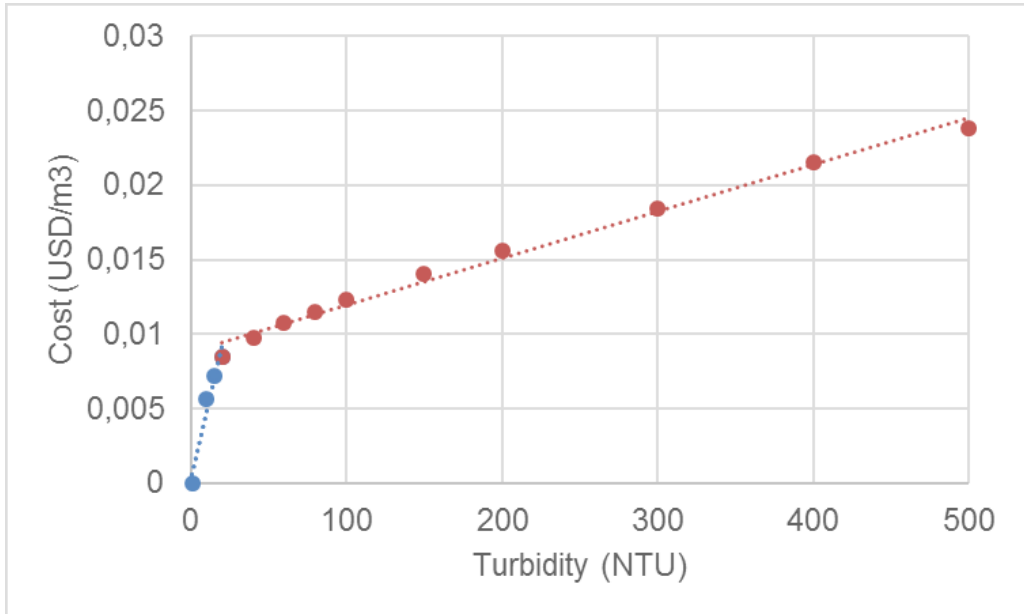
a, b = adjustment coefficients of water treatment

T = turbidity (mg/L SiO_2 - NTU)

In the São Paulo State, Sabesp Company operates most of the water treatment plants. The inorganic coagulant used by Sabesp is the aluminum sulphate. The aluminum sulphate price was of USD 0.2924/kg, according to average price registered by the water supply companies. The price was valued by the National Consumer Price Index (IPCA 2014 – 2018), by Brazilian Institute of Geography and Statistics (IBGE), which reflects inflation in Brazil. The ratio between turbidity and its reduction costs was obtained through the data of a Sabesp standard plant.

□A scatter plot (Fig. 3) relates the chemical products cost (R\$) and the “in natura” water turbidity (NTU), explaining the increase in the treatment cost at high suspended sediment rates. This relation shows the importance of the water quality in the catchment points. The linear trend lines were calculated for the association between turbidity and its reduction cost. They were adjusted in two segments: up to 20NTU (Eq. 7) and from 20NTU (Eq. 8). Therefore, the trend lines express the production cost in the water treatment plants which involves specific expenses to reduce the water turbidity.

Figure 3 - Relation between turbidity (NTU) and water treatment cost (USD.m⁻³), with linear trend lines.



Source: author's elaboration.

If the turbidity is less than 20 NTU:

$$y = 0.0004 * x + 0.0001 \quad (R^2 = 0.9547) \quad (7)$$

If the turbidity is high than NTU:

$$y = 0.00003 * x + 0.0088 \quad (R^2 = 0.99) \quad (8)$$

where,

y = water treatment cost to reduce the turbidity

x = turbidity measured

The high concentration of the chemical products increases the amount of the sludge. This sludge concentrates the impurities of the water treatment in the plant and have a lot of solids, which must receive correct treatment and disposal (REIS, 2004). The sludge disposal cost is considered to Class 2, non-inert, dry matter and centrifuged. According to the calculation report of the service contract of a water supply company in the São Paulo State, the suggested cost for the transportation and disposal of landfill sludge is US \$ 31.78 per ton in the Equation 9 (ODEBRECHT AMBIENTAL, 2015).

$$C_2 = \text{UCSD} \times T^{0.66} \quad (9)$$

where,

C_2 = sludge disposal cost

UCSD = unit cost of sludge disposal

T = turbidity (mg/L SiO_2 - NTU)

The definition of the costs associated with the dredging or de-loading works is not trivial and involves the costs of different dredging equipment, their maintenance, the dredged volumes and the distance from the point of discharge of waste (SOUSA JÚNIOR, 2011). The relative values increase when the scale of the activity is reduced and the access of the machines. The cost of USD 6.62 per ton of dredged material is adopted in Equation 10, corroborating with the costs of sediment removal in desorption activities (BIDONE et al., 2009; SECRETARIA DE PORTOS DA PRESIDÊNCIA DA REPÚBLICA, 2017).

$$C_3 = \text{NPE} \times \text{SDR} \times \text{SR} \times \text{UCD} \quad (10)$$

where,

C_3 = dredging cost

NPE = natural potential for erosion (t.yr^{-1})

SDR = sediment delivery ratio

SR = settling rate

UCD = unit cost of dredging (USD.m^{-3})

The supply of the good quality water to water supply company is an ecosystem service provided by the forest coverage. This benefit is generated by protection of the vegetation and the soil in the watershed, avoiding the suspended sediments in water. In theory, the total economic value of the soil loss can be represented by the sum of the values associated, directly or indirectly, to the loss of well-being in the several activities affected by erosive processes. These activities begin with the productivity loss in the rural areas and extend the chain of impacts on water and its users.

3. Results

The soil loss potentials (A) calculated to current and hypothetical scenarios are presented in Table 1 for 24 watersheds that intersect with the APABRPS. The watersheds Rio Una and Rio Bocaina are the greatest difference of the soil loss between the current and hypothetical scenarios, respectively 817.530 and 680.543 t.year^{-1} . Rio Paraibuna, Represa Jaguari 0, Rio Bananal, Ribeirão Gomerai and Rio Guaratinguetá present great savings in soil loss, all more than 100.000 t.year^{-1} . Other watershed instead of did not present large soil loss, they have good savings in relative soil loss. Represa Jaguari 1/2, Represa Jaguari 3, Córrego da Couve, Rio do Braço, Rio do Entupido, Ribeirão Araraquara point from 20 a 65 $\text{t.ha}^{-1}.\text{year}^{-1}$ saved with the ecological restoration.

Table 1 - Soil loss potential in current and hypothetical scenarios for the watersheds.

ID	Watershed	Current scenario		Hypothetical scenario		Difference	
		t.year ¹	t.ha ⁻¹ .year ¹	t.year ¹	t.ha ⁻¹ .year ¹	t.year ¹	t.ha ⁻¹ .year ¹
1	Rio da Bocaina	863.305	32	182.762	7	680.543	25
2	Ribeirão das Palmeiras	57.864	17	24.087	7	33.777	10
3	Córrego da Serrinha	625	5	292	2	333	3
4	Ribeirão dos Souzas	23.748	19	13.337	11	10.411	8
5	Represa Paraibuna	434.096	31	383.639	27	50.457	4
6	Rio Paraibuna	7.723.931	18	7.347.581	17	376.350	1
7	Represa Jaguari 0	318.678	19	58.510	4	260.168	15
8	Ribeirão Araraquara	57.344	31	9.646	5	47.698	26
9	Rio do Entupido	68.438	70	21.069	22	47.369	48
10	Reservatório Paraibuna	234.799	58	234.100	58	699	0
11	Córrego da Couve	33.808	75	4.421	10	29.387	65
12	Ribeirão Batedor	65.329	35	31.197	17	34.132	18
13	Córrego Fundo	18.169	11	9.418	6	8.751	5
14	Represa Jaguari 3	8.651	38	1.073	5	7.578	33
15	Represa Jaguari 1/2	4.805	28	519	3	4.286	25
16	Córrego Coura	12.967	33	8.256	21	4.711	12
17	Córrego Prata+Cristo	7.015	37	5.387	29	1.628	8
18	Ribeirão Lemes	19.990	17	19.621	17	369	0
19	Rio Guaratinguetá	205.960	15	93.548	7	112.412	8
20	Ribeirão Gomerai	239.729	67	61.852	17	177.877	50
21	Rio do Braço	89.168	40	43.497	20	45.671	20
22	Rio Bananal	321.776	50	139.695	22	182.081	28
23	Ribeirão Vermelho	76.044	20	48.653	13	27.391	7
24	Rio Una	2.806.457	62	1.988.927	45	817.530	17
Total		13.693.272	836	3.328	1	13.689.944	835

Source: author's elaboration.

The payments for ecosystem services are calculated through the difference of the potential soil loss between the scenarios. The empirical economic model, according to the proposed methodology, valuate this benefit by the sum of the three costs: savings in water treatment, savings in sludge disposal and savings in dredging.

The greatest savings in the water treatment are to Represa Jaguari 3, Rio Una, Rio Guaratinguetá, Represa Jaguari 1/2 and Rio Paraibuna, respectively. The same watersheds

also have the biggest savings in sludge disposal. They show annually savings from 111 to 646 thousands of dollars for water treatment and from 9 to 25 thousands of dollars for sludge disposal. This sludge disposal indicates the contempt of the product that is associated with the water treatment, but one must analyze the process individually in each case.

These watersheds indicated present large variation in the dredging savings, ranging from a few hundred to millions of dollars. The watersheds that reach millions of dollars are: Rio Paraibuna and Rio Una. By adding the avoided values, the PES improve very high values. It demonstrates the importance of the replacement from the pasture to planted forests, which has direct effect in the sediment retention by vegetation and, consequently, lower deposit sediments at the bottoms of reservoirs. These dredging analyzes depend on the feasibility of the PES implementation, aiming at the need to remove accumulated sediments in the reservoirs of each water catchment.

The table 2 shows the avoided costs calculated in this study. Adding the three avoided costs, the Represa Jaguari 3 and Represa Jaguari 1/2 are the greatest savings per protected hectare in the sediment retention services: USD 3,014 and 1,691, respectively. The development of the PES project is justified by the values that would be collected by the avoided costs in several watersheds, such as Córrego da Couve, Rio do Entupido, Ribeirão Gomerál, Ribeirão Araraquara and Córrego Prata+Cristo.

Table 2 - Economic valuation (USD.year⁻¹) for the Payments for Ecosystem Services at watersheds.

ID	Watershed	Water Treatment	Sludge disposal	Dredging	Absolut PES (USD.year ⁻¹)	Relative PES (USD.ha ⁻¹ .year ⁻¹)
14	Represa Jaguari 3	646,643	25,539	9,521	681,703	3,014
15	Represa Jaguari 1/2	270,436	9,495	2,010	281,942	1,691
11	Córrego da Couve	2,482	453	34,085	37,020	83
9	Rio do Entupido	4,764	859	70,795	76,418	79
20	Ribeirão Gomerál	282	44	204,213	204,538	57
8	Ribeirão Araraquara	71,634	3,867	22,378	97,878	54
17	Córrego Prata+Cristo	603	111	8,838	9,552	51
3	Córrego da Serrinha	4,799	239	530	5,568	47
19	Rio Guaratinguetá	462,406	24,695	122,693	609,794	47
21	Rio do Braço	9,137	1,698	84,809	95,644	43
16	Rio Una	537,603	32,544	1,223,442	1,793,589	40
24	Córrego Coura	503	87	14,928	15,518	40
22	Rio Bananal	7,429	1,327	225,999	234,755	37
12	Ribeirão Batedor	16,833	3,442	38,445	58,719	32
1	Rio da Bocaina	44,894	4,983	484,272	534,148	20

23	Ribeirão Vermelho	29,665	1,749	40,064	71,478	20
18	Ribeirão Lemes	7,755	1,248	12,931	21,934	19
4	Ribeirão dos Souzas	93	15	20,079	20,186	17
2	Ribeirão das Palmeiras	26,299	1,501	19,806	47,606	15
5	Córrego Fundo	7,673	454	11,077	19,204	12
7	Represa Jaguari O	45,818	3,163	144,251	193,232	12
13	Represa Paraibuna	1,351	237	159,095	160,683	12
6	Rio Paraibuna	111,327	9,865	2,373,046	2,494,237	6
10	Reservatório Rio Paraibuna	18,070	1,176	100,149	119,396	-
Total		2,328,498	128,789	5,427,456	7,884,743	14

Source: author's elaboration.

In order the public supply, the savings total more than USD 7.8 million for water treatment, sludge disposal and dredging costs. Considering the 24 watersheds within the APABRPS, the annual average value estimated for PES is USD 226.89 per hectare, ranging from USD 6 to 3,014 depend on the watershed. This average value is greater than all opportunity costs of land calculated for the cities under APABRPS influence. The average opportunity cost is USD 81.58, ranging from USD 29.16 to 125.89 for 23 cities in studied area, based on Young (2016).

The comparative analysis of land-use decisions between farming and forestry allow to reanalyze the competition for land, as well as the substitution of inputs and other factors of production. Concentrating investments in restoration hotspots, which landscapes have high benefits and feasibility, it would maximize the potential to mitigate anthropogenic impacts and improve human well-being (Brancalion et al., 2019). The reforestation in highly productive agricultural lands in southern Chile contributed to increase it (TORRES-SALINAS et al., 2016).

For the conservation of nature through ecological restoration, the average costs with fencing and forest recovery are very high, reaching USD 2,358 ha⁻¹.year⁻¹ when included in transportation of inputs and administration (YOUNG, 2016). Although the restoration costs are not considered, the results indicate benefits (avoided costs) higher than the opportunity costs of the several degraded areas that intersect with the protected area (YOUNG, 2016). On other hand, the low economic values showed for some watersheds may not be sufficient to justify the land-use change: from degraded pasture to forest, because the cost of the project implementation tends to be higher than the collection.

Costa Rica's national program pays landowners who cooperate with forest plantations at USD 550 ha⁻¹ for 5 years (PAGIOLA, 2008). Financing comes from fossil fuel sales tax rates, the World Bank, the Global Environment Facility (GEF), and others. Pagiola et al. (2013) indicates that government-funded programs generally cover much larger areas, but are less likely to be efficient because they lack direct information about the

value of the service or the quality of its supply, and the government's need to respond to numerous pressures that are often oblivious to the objectives of the program. The user-funded programs are more likely to be efficient, with users not only providing funding but also observing the value and quality of the service received.

4. Conclusions

This paper presents a methodologic proposal for the economic valuation to be used in the implementation of Payments for Ecosystem Services programs associated with the water resources protected under the ecological restoration inside the APABRPS. The PES mechanism is proposed to encourage farmers to restore their underutilized pastures, promoting new forest areas. This will overcome some constraints and obstacles to ecological restoration and agroforestry, mainly linked to the lack of initial funding and the sustainability of the investments made.

As there was no explicit calibration of the data for insertion in the model, it recognizes a weakness in the estimation of soil loss and turbidity, and the data should be used after cautious comparison with empirical data or other references. Despite the uncertainties of the estimates of soil loss and avoided costs, all analyzes were made regarding the difference between land use scenarios, which reduces the error of the estimates, and the results can be considered qualitatively, but they should still be cautious for quantitative values.

The sediment retention service provided by natural landscapes is of great interest to managers of water resources. The knowledge of the areas where the sediments are produced and transferred allows the creation of better strategies to reduce the sediment load. The accuracy of sediment retention value is mainly limited by two factors: quality of information of sediment removal costs and the user's ability to calibrate it with real sedimentation data. The size of the drainage basin and the percentage of the protected area also influence the PES value.

Farther, the public water supply may be compromised if the protection of upstream watersheds does not occur. Charging for the use of the benefit may be necessary for financing the management and provision of the natural resource. In the case of water, for example, the management costs of the supplying area can be associated with water availability or pollution control. Thus, it is justified the charging on those who benefit from the protection of water resources, whereas these values should be passed on to those who help to restore the ecosystem services. The expected result of this financial contribution is the improvement of hydrological conditions of the Paraíba do Sul river basin.

The PES is an instrument for sustainable development at the local level that combines forest restoration objectives with economic incentive objectives. This will increase investment in the development of alternative sources of income for communities in areas of forest recovery. If the water policy do not give priority to economic criteria, it would generate depletion of the resource and inequalities in water access.

The ecosystem service of freshwater quality maintenance is one of the main highlights in the studies and projects of PES in Brazil and the world. It indicates the need for

water supply, as well as other unaccounted water uses: electric power generation, animal consumption and producing, cropland, industrial processes, among others. In addition to multiple-use water, the reforestation and the forest conservation may improve other ecosystem services, such as climate regulation, disease regulation, genetic resources, nutrient cycling and recreation. Thus, the PES project implementation recognizes the importance of these benefits generated by the ecosystem.

References

- ATTANASIO, C.M.; GANDOLFI, S.; ZAKIA, M.J.B.; VENIZIANI JUNIOR, J.C.T.; LIMA, W.P. A importância das áreas ripárias para a sustentabilidade hidrológica do uso da terra em microbacias hidrográficas. **Bragantia**, v. 71, nº 4, p. 493-501, 2012.
- BERTONI, J.; LOMBARDI NETO, F. **Conservação do solo**. Livroceres, Piracicaba, 368p., 1985.
- BIDONE, E.D.; SILVEIRA, R.P.; FIORI, C.S.; RODRIGUES, A.P.C.; ARY PIRES, M.F.; CASTILHOS, Z.C. Custo sócio-econômico de dragagens portuárias. In: BOLDRINI, E. B.; PAULA, E. V. (Orgs). **Gestão ambiental portuária**. Ademadan, Antonina, 2009.
- BORSELLI, L.; CASSI, P.; TORRI, D. Prolegomena to sediment and flow connectivity in the landscape: A GIS and field numerical assessment. **Catena**. n. 75, p. 268-277. 2008.
- BRANCALION, P.H.S.; NIAMIR, A.; BROADBENT, E.; CROUZEILLES, R.; BARROS, F.S.M.; ZAMBRANO, A.M.A.; BACCINI, A.; ARONSON, J.; GOETZ, S.; REID, J.L.; STRASSBURG, B.B.N.; WILSON, S.; CHAZDON, R.L. Global restoration opportunities in tropical rainforest landscapes. **Science Advances**., v. 5, n. 7, 2019.
- BRASIL (País). **Decreto nº 87.561**, de 13 de setembro de 1982. Dispõe sobre as medidas de recuperação e proteção ambiental da Bacia Hidrográfica do Rio Paraíba do Sul, e dá outras providências. Diário Oficial da União, Brasília. 1982.
- CAMPHORA, A. L.; MAY, P. H. A valoração ambiental como ferramenta de gestão em unidades de conservação: há convergência de valores para o bioma Mata Atlântica? **Megadiversidade**, v. 2, nº 1-2, 2006.
- CHAVES, H.M.L.; BRAGA, J.B.; DOMINGUES, A.F.; SANTOS, D.G. Quantificação dos benefícios ambientais e compensações financeiras do “Programa do Produtor de Água” (ANA): II. Aplicação da Metodologia. **Revista Brasileira de Recursos Hídricos**. 2004.
- CHAVES, H.M.L. Relações de aporte de sedimento e implicações de sua utilização no pagamento por serviço ambiental em bacias hidrográficas. **Revista Brasileira de Ciência do Solo**, v. 34, p. 1469 – 1477, 2010.
- COSTANZA, R.; DE GROOT, R.; SUTTON, P.; VAN DER PLOEG, S.; ANDERSON, S.J.; KUBISZEWSKI, I.; FARBER, S.; TURNER, R.K. Changes in the global value of ecosystem services. **Global Environmental Change**, vol. 26, n. 1, pp. 152-158, 2014.

DESMET, P.J.J.; GOVERS, G. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. **Journal of Soil and Water Conservation**, n. 51.5, p. 427-433, 1996.

FARINASSO, M.; CARVALHO JÚNIOR, O.A. de C.; GUIMARÃES, R.F.; GOMES, R.A.T.; RAMOS, V.M. Avaliação qualitativa do potencial de erosão laminar em grandes áreas por meio da EUPS - Equação Universal de Perdas de Solo, utilizando novas metodologias em SIG para os cálculos dos seus fatores na região do Alto Parnaíba-Pi-MA. **Revista Brasileira de Geomorfologia**, ano 7, n.2, p.73-85. 2006.

FERRETI, A. R. Fundamentos ecológicos para o planejamento da restauração florestal. In: GALVÃO, A. P. M.; MEDEIROS, A. C. de S. (eds.). **Restauração da Mata Atlântica em áreas de sua primitiva ocorrência natural**. EMBRAPA Florestas, Colombo, p. 21-26, 2002.

FUNDAÇÃO SOS MATA ATLÂNTICA. **Desmatamento nos mananciais acentua crise de abastecimento de água em São Paulo**. 2014. <http://www.sosma.org.br/101269/desmatamento-nos-mananciais-acentua-crise-de-abastecimento-de-agua-em-sp/> Accessed in 01 nov. 2014.

GAO, P.; JOSEFSON, M. Event-based suspended sediment dynamics in a central New York watershed. **Geomorphology**, n. 139, p. 425-437, 2012.

INSTITUTO DE PESQUISAS TECNOLÓGICAS DO ESTADO DE SÃO PAULO. IPT. **Plano da Bacia Hidrográfica do Paraíba do Sul**, Trecho do Estado de São Paulo (UGRHI 02), 2011- 2014. Relatório Final. Relatório Técnico nº 122 707-205, São Paulo, v. 1, 223p., 2011.

INSTITUTO OIKOS DE AGROECOLOGIA. OIKOS. **PSA Água: Um Programa de Pagamento por Serviços Ambientais para o Trecho Paulista da Bacia Hidrográfica do Paraíba do Sul**. Resumo Executivo. 6p, 2013.

LIMA, J.E.F.W.; SANTOS, P.M.C.; CHAVES, A.G.M.; SCILEWSKI, L.R. **Diagnóstico do fluxo de sedimentos em suspensão na bacia do rio São Francisco**. ANEEL/ANA/Embrapa, Brasília, 108p, 2001.

MANNIGEL, A. R.; CARVALHO, M. P.; MORETI, D.; MEDEIROS, L. R. Fator erodibilidade e tolerância de perda dos solos do Estado de São Paulo. **Acta Scientiarum Agronomy**, Maringá, v. 24, n. 5, p. 1335-1340, 2002.

MARTINS, S.G.; SILVA, M.L.N.; AVANZI, J.C; CURTI, N.; FONSECA, S. Cover-management factor and soil and water losses from eucalyptus cultivation and Atlantic Forest at the Coastal Plain in the Espírito Santo State, Brazil. **Sci. For.** Piracicaba, v. 38, n. 87, p. 517-526, 2010.

MEADE, R.H.; PARKER, R.S. Issues in sediment research in rivers of the U.S. **Proceedings 4th Interagency Sedimentation Conference**. n. 1: 4, p. 162-168, 1986.

MILLIMAN, J.D.; FARNSWORTH, K.L. **River discharge to the coastal ocean: a global synthesis**. Cambridge University Press, 2013.

MIRANDA, L.B.; CASTRO, B.M. DE; KJERFVE, B. **Princípios de oceanografia física de estuários**. São Paulo: EDUSP, 414p, 2002.

MORAES, L.F.D.; ASSUMPÇÃO, J.M.; PEREIRA, T.S.; LUCHIARI, C. **Manual técnico para a restauração de áreas degradadas no Estado do Rio de Janeiro**. Rio de Janeiro: Jardim Botânico do Rio de Janeiro, 84p, 2013.

MOREIRA, M.C.; CECÍLIO, R.A.; PINTO, F.A.C.; PRUSKI, F.F. Desenvolvimento e análise de uma rede neural artificial para a estimativa da erosividade da chuva para o Estado de São Paulo. **Revista Brasileira de Ciências do Solo**, n. 1, p. 1069–1076, 2006.

NEHREN, U.; SCHLUTER, S.; RAEDIG, C.; SATTTLER, D.; HISSA, H. Strategies and Tools for a Sustainable Rural Rio de Janeiro. **Springer Series on Environmental Management**. Springer International Publishing. 2018.

ODEBRECHT AMBIENTAL – LIMEIRA S.A. **Memória de cálculo** – engenharia. Contrato de concessão do município de Limeira – SP. 2015. <http://www.arespcj.com.br/arquivos/46126_Custos_Sistema_Terci%C3%A1rio.PDF> Accessed in 20 ago. 2018.

OECD. Water Resources Governance in Brazil. **OECD Studies on Water**. Paris: OECD Publishing. 2015.

OLIVEIRA, J.B.; CAMARGO, M.N.; ROSSI, M.; CALDERANO FILHO, B. **Mapa pedológico do Estado de São Paulo**: legenda expandida. Campinas, Instituto Agrônomico; Rio de Janeiro: Embrapa Solos. 64p: mapa, 1999.

PAGIOLA, S. Payments for environmental services in Costa Rica. **Ecological Economics**, vol. 65, 712 p, 2008.

PAGIOLA, S.; VON GLEHN, H.C.; TAFFARELLO, D. **Experiências de Pagamentos por Serviços Ambientais no Brasil**. São Paulo, SP: SMA/CBRN. 2013.

POUPEAU, F.; RAZAFIMAHEFA, L.; ROBERT, J.; MERCIER, D.; MASSARDIER, G.; JACOBI, P.R. **Water Conflicts and Hydrocracy in the Americas**. Coalitions, Networks, Policies. São Paulo: IEE-USP. 2018.

REIS, L.V.S. **Cobertura Florestal e Custo do Tratamento de Águas em Bacias Hidrográficas de Abastecimento Público**: Caso do Manancial do Município de Piracicaba. Tese de doutorado (Doutorado em Recursos Florestais) □ Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo. Piracicaba. 215 p, 2004.

RIBEIRO, L.S.; ALVES, M.G. Quantificação de perda de solo por erosão no município de Campos de Goytacazes/RJ através de técnicas de Geoprocessamento. In: SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO, 13, 2007, Florianópolis. **Anais**. Florianópolis, p.3039-3046, 2007.

RODRIGUES, R.R.; BRANCALION, P.H.S.; ISERNHAGEN, I. **Pacto pela restauração da mata atlântica**: referencial dos conceitos e ações de restauração florestal. São Paulo: LERF/ESALQ: Instituto BioAtlântica, 256p., 2009.

ROEHL, J.W. Sediment source areas, delivery ratios and influencing morphological factors. **International Association of Hydrological Sciences**. n. 59, p. 202-213, 1962.

ROSA, H.; KANDEL, Z.; DIMAS, L. **Compensación por servicios ambientales y comunidades rurales**: lecciones de las Américas y temas críticos para fortalecer estrategias comunitarias. SEMARNAT/INE/PRISMA/CCMSS, México/DF, 2004.

SABESP. COMPANHIA DE SANEAMENTO BÁSICO DO ESTADO DE SÃO PAULO. **Tratamento de Água**. 2010.

SÃO PAULO (Estado). Secretaria do Meio Ambiente – SMA. **Resolução SMA nº 32**, de 03 de abril de 2014. Estabelece as orientações, diretrizes e critérios sobre restauração ecológica no Estado de São Paulo, e dá providências correlatas. 2014.

SECRETARIA DE PORTOS DA PRESIDÊNCIA DA REPÚBLICA – SEP/PR. **Acórdão 179/2017** – Plenário. Processo 030.958/2014-8. 2017.

SHARP, R.; TALLIS, H.T.; RICKETTS, T.; GUERRY, A.D.; WOOD, S.A.; CHAPLIN-KRAMER, R.; NELSON, E.; ENNAANAY, D.; WOLNY, S.; OLWERO, N.; VIGERS-TOL, K.; PENNINGTON, D.; MENDOZA, G.; AUKEMA, J.; FOSTER, J.; FORREST, J.; CAMERON, D.; ARKEMA, K.; LONSDORF, E.; KENNEDY, C.; VERUTES, G.; KIM, C.K.; GUANNEL, G.; PAPPENFUS, M.; TOFT, J.; MARSIK, M.; BERNHARDT, J.; GRIFFIN, R.; GLOWINSKI, K.; CHAUMONT, N.; PERELMAN, A.; LACAYO, M.; MANDLE, L.; HAMEL, P.; VOGL, A.L. **InVEST 3.1.1 User's Guide**. Stanford: The Natural Capital Project. 2014.

SILVA, A.M.; SCHULZ, H.E.; CAMARGO, P.B. **Erosão e Hidrossedimentação em Bacias Hidrográficas**. São Carlos: **RiMa**. 140p, 2004.

SILVA, T.B.; SANTOS, R.M.; AHNERT, F.; MACHADO JUNIOR, J.A. Projeto Produtores de Água: uma nova estratégia de gestão de recursos hídricos através do mecanismo de pagamento por serviços ambientais. **Olam: Ciência & Tecnologia**. Rio Claro, v. 8, n. 3, p. 48-67, 2008.

SOUSA JÚNIOR, W.C. **Pagamento por Serviços Ecosistêmicos**: Mata Ciliar, Erosão, Turbidez e Qualidade de Água. Produtos Técnicos. Projeto de Recuperação de matas ciliares, Secretaria do meio ambiente do estado de São Paulo, SP. v. 34, n. 1, 2011.

TEIXEIRA, E.C.; SENHORELO, A.P. Avaliação de correlação entre turbidez e concentração de sólidos suspensos em bacias hidrográficas com uso e ocupação diferenciada. In: XXVII CONGRESSO INTERAMERICANO DE ENGENHARIA SANITÁRIA E AMBIENTAL. **Anais**. 2000.

TOMAZONI, J.C.; MANTOVANI, L.E.; BITTENCOURT, A.V.L.; ROSA FILHO, E.F. A sistematização dos fatores da EUPS em SIG para quantificação da erosão laminar na bacia do rio Anta Gorda (PR). **Estudos Geográficos**, Rio Claro, v.3, n.1, p.1-21, 2005.

TORRES-SALINAS, R.; GARCÍA, G.A.; HENRÍQUEZ, N.C.; ZAMBRANO-BIGIARINI, M.; COSTA, T.; BOLIN, B. Forestry development, water scarcity, and the

Mapuche protest for environmental justice in Chile. **Ambiente & Sociedade**. n. 19(1), p. 121-144, 2016.

VALERIANO, M.M. **Topodata**: guia para utilização de dados geomorfológicos locais. São José dos Campos, SP: INPE: Coordenação de Ensino, Documentação e Programas Especiais (INPE-15318-RPE/818). 72p, 2008.

VIEIRA, R.M.S.P.; ALVALÁ, R.C.S.; CUNHA, A.P.M.A.; SESTINI, M.F.; CARVALHO, V.C.; VALERIANO, D.M.; SILVA, J.S.V.; ABDON, M.M.; PONZONI, F.J.; CANAVESI, V.; SANO, E.; DAMBRÓS, L.A.; HASENACK, H.; FERRAZ NETO, S.; BARBOSA, A.A. **Mapa de uso e cobertura da terra do território brasileiro para uso em modelagem climática e meteorológica**. INPE, São José dos Campos, 33 p., 2013.

WALLING, D.E. The sediment delivery problem. **Journal of Hydrology**. n. 65, p. 209-237, 1983.

WALLING, D.E. **The impact of global change on erosion and sediment transport by rivers**: current progress and future challenges. Unesco, 2009.

WALLING, D.E.; WEBB, B.W. The reliability of suspended sediment load data. **IAHS Publication**. v.133, pp. 177-94, 1981.

WISCHMEIER, W.H.; SMITH, D. Predicting rainfall erosion losses: a guide to conservation planning. **Agriculture Handbook**. Washington, DC: USDA-ARS. 1978.

YOUNG, C.E.F. (coord.). **Estudos e produção de subsídios técnicos para a construção de uma Política Nacional de Pagamento por Serviços**. Relatório Final. Instituto de Economia, UFRJ, Rio de Janeiro, 93 p, 2016.

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PAYMENTS FOR ECOSYSTEM SERVICES TO WATER RESOURCES PROTECTION IN PARAÍBA DO SUL ENVIRONMENTAL PROTECTION AREA

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PAYMENTS FOR ECOSYSTEM SERVICES TO WATER RESOURCES PROTECTION IN PARAÍBA DO SUL ENVIRONMENTAL PROTECTION AREA

Abstract: One of the benefits of forest and reforestation is linked to the erosion control and reduction of the amount of sediments suspended in water. This study proposes a methodology for Payments for Ecosystem Services associated to these benefits in 24 water supply watersheds, under influence of the Paraíba do Sul River Basin Environmental Protected Area, in Brazil. In order to estimate the water resources protection through the reforestation, the current scenario was compared to a hypothetical scenario, in which degraded pasture are replaced by forest. The avoided soil erosion could reach around $40t \cdot ha^{-1} \cdot yr^{-1}$. Reforestation can avoid expenditures in water treatment, sludge disposal and dredging around USD 7.8 million per year. Annual values for PES range from USD 6 to 3,014 per hectare of reforested area. The results highlight the importance of valuing the benefits of the ecosystem services rescued.

Key-words: Payments for ecosystem services; environmental economic valuation; water supply; soil loss; reforestation.

PAGAMENTOS POR SERVIÇOS ECOSSISTÊMICOS PARA PROTEÇÃO DE RECURSOS HÍDRICOS NA ÁREA DE PROTEÇÃO AMBIENTAL DA BACIA DO RIO PARAÍBA DO SUL

Resumo: Um dos benefícios da floresta e do reflorestamento está ligado ao controle da erosão e redução da quantidade de sedimentos em suspensão na água. Este estudo propõe uma metodologia de Pagamentos por Serviços Ecosistêmicos associada a esses benefícios

em 24 bacias de abastecimento de água, sob influência da Área de Proteção Ambiental da Bacia do Rio Paraíba do Sul, no Brasil. Para estimar a proteção dos recursos hídricos por meio do reflorestamento, o cenário atual foi comparado a um cenário hipotético, no qual pastagens degradadas são substituídas por florestas. A erosão evitada do solo pode atingir cerca de $40\text{t}\cdot\text{ha}^{-1}\cdot\text{ano}^{-1}$. O reflorestamento pode evitar gastos com tratamento de água, disposição de lodo e dragagem em torno de US \$ 7,8 milhões por ano. Os valores anuais para PSE variam de US \$ 6 a 3.014 por hectare de área reflorestada. Os resultados destacam a importância de valorizar os benefícios dos serviços ecossistêmicos resgatados.

Palavras-chave: Pagamentos por serviços ecossistêmicos; valoração econômica ambiental; abastecimento de água; perda de solo; reflorestamento.

PAGOS POR SERVICIOS ECOSISTÉMICOS PARA LA PROTECCIÓN DE LOS RECURSOS HÍDRICOS EN EL ÁREA DE PROTECCIÓN AMBIENTAL DE PARAÍBA DO SUL

Resumen: Uno de los beneficios del bosque y la reforestación está relacionado con control de erosión y reducción de cantidad de sedimentos suspendidos en el agua. Este estudio propone una metodología para Pagos por Servicios de Ecosistemas asociados a estos beneficios en 24 cuencas hidrográficas, bajo la influencia del Área Protegida Ambiental de la Cuenca del Río Paraíba do Sul, en Brasil. Para estimar la protección de recursos hídricos a través de la reforestación, el escenario actual se comparó con un escenario hipotético, en que los pastos degradados son reemplazados por bosques. La erosión del suelo evitada podría alcanzar $40\text{t}\cdot\text{ha}^{-1}\cdot\text{ano}^{-1}$. La reforestación puede evitar gastos en tratamiento del agua, eliminación de lodos y dragado de alrededor de USD 7,8 millones por año. Los valores anuales para PSE varían de USD 6 a 3,014 por hectárea de área reforestada. Los resultados destacan la importancia de valorar los beneficios de servicios ecossistémicos rescatados.

Palabras-clave: Pagos por servicios ecossistémicos; valoración económica ambiental; suministro de agua; pérdida de suelo; reforestación.
