ECONOMIC IMPACT ASSESSMENT OF SILTING-UP AND EROSION PROCESSES: HOW SPATIAL DYNAMIC MODELS COUPLED WITH ENVIRONMENTAL VALUATION MODELS CAN CONTRIBUTE TO SUSTAINABLE PRACTICES IN SUGARCANE FARMING

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Abstract. This chapter approaches the economic valuation of environmental impacts related to soil erosion and silting-up of water streams, designed to allow the transfer of recovery costs to a policy of payment for ecosystem services. The aim of this study is to evaluate the contribution of silting-up mitigation to funding the environmental recovery of riparian areas found in sugarcane farms. The city selected for study is Arealva, located in the Central-West region of São Paulo State, Southeast of Brazil. Spatial dynamic models were conceived to simulate past land cover/land use changes (2005-2010) and future landscape scenarios (2010-2020) in the study area. The main observed changes that took place from 2005 to 2010 were: sugarcane expansion (6,012.71ha (49.68%)), mostly extending over grazing lands, and deforestation (3,107.16ha (22.33%)), predominantly converted into pastures. Three sets of scenarios were defined: i) stationary scenarios, in which the transition rates observed in former years were held constant (business as usual); ii) non-stationary scenarios with a partial recovery of environmentally protected areas along riversides (70% by 2015), and; iii) non-stationary scenarios with a full recovery of environmentally protected areas along riversides (100% by 2015). The regarded impacts are dependent on the estimated amount of lost soil, assessed by means of the Universal Soil Loss Equation (USLE). We also estimated the sediment accumulation rate in order to calculate siltation. The envisaged scenarios for environmental recovery can reduce environmental impacts up to 16% (US$41,479.29 to US$56,789.40) yearly. The riparian and alike vulnerable areas (prone to erosion and silting-up) can be recovered through a financing mechanism, relying either on water use charging or even on a taxation strategy implicitly considering the payment for ecosystem services. The silting mitigation would approximately contribute with US$13.83 to US$18.94 ha^{-}

^{1}.year^{-1}. In this way, sugarcane farms would have a financial incentive to restore and maintain the environmentally protected areas within their domain, reducing the environmental impacts related to silting-up processes. **Keywords**: silting-up; economic valuation; environmental impact; payment for ecosystem services

1 Introduction

The assessment of the landscape changes is key to efficiency in land management, playing an important role in the decision making related to land use and conservation of the environmental and natural resources.

Land-use and land-cover changes (LUCC) are directly translated into changes in marginal revenues, in the ecosystem services and in the environmental impacts generation. In order to assess the cause-and-effect relationship of such changes, it is necessary to consider environmental and socioeconomic aspects. However, it is difficult to compare disparate variables, involving unknown effects, distinct time scales etc.

A suitable strategy for working with this complexity is converting the environmental impacts, the ecosystem services and the profitability into a common basis (monetary values, for example). Thus, it is possible to evaluate if an expansion of a kind of land use compensates for the reduction of a given land cover, i.e., if the marginal revenue increase offsets the environmental impacts associated to the new land use and the ecosystem services reduction associated to the altered land cover.

The environmental impacts and ecosystem services are converted into monetary values through several valuation methods. Among them, there are methods which are responsible for acting in the production function, i.e., they are based on changes in productivity or in production costs. These are simple methods, with high reduction of real phenomena. However, they are appropriate to modeling purposes.

The monetary values for the environmental impacts may be linked to a particular type of land use or land cover. This connection is conducted through a dose-response function. The dose is the magnitude of the LUCC, and the response is the consequence in monetary terms. By connecting them based on a spatial dynamic modeling, it is possible to integrate economic, social and environmental aspects. It is possible, then, to perform an environmental planning that expresses future consequences, enabling the comparison of several alternatives related to conservation, modification or conversion of a certain land use/land cover class, facilitating decision making.

The possibility of performing a spatial assessment of the main environmental impacts, comparing alternatives, emulating useful scenarios for environmental planning and monitoring and, especially, connecting data from different formats, is the motivation of this chapter.

The stated problem is related to the environmental impacts valuation associated to erosion and silting-up, linked to the replacement of pastures and native vegetation by sugarcane. The aim of this study is to evaluate the contribution of the silting-up mitigation in funding the riparian areas restoration.

2 Theoretical Framework

Environmental Impacts

According to Brasil (1986), environmental impact is any change in the physical, chemical or biological properties of the environment, caused by any form of matter or energy, resulting from human activity which directly or indirectly affects:

- health, safety and welfare of the population;
- social and economic activities;
- biota;
- aesthetic and sanitary conditions of the environment;
- quality of environmental resources.

Studies related to environmental impacts are needed when we consider the assessment of some actions and projects consequences, in order to predict or minimize the quality or quantity loss of a specific environmental aspect (Donaire, 1995).

Impact assessment is seen as an environmental policy tool, formed by a set of procedures capable of ensuring that a systematic examination of its aspects and effects – considering alternatives – is adopted. The Environmental Impact Assessment (EIA) is one of the main legal instruments for conducting an evaluating impacts caused by anthropogenic activities (Gilbert, 1996; Romeiro, 2004).

Environmental Impact Statement/Report of Environmental Impact brings different ways of performing an assessment of environmental impacts, such as the approach PSR (Pressure, State, Response); SWOT analysis (Strength, Weakness, Opportunity, Threats); FMEA (Failure Mode and Effect Analysis); TCO analysis (Total Cost of Ownership); cost-benefit analysis; checklist; mathematical models; matrices or interaction diagrams (Leopold, Singer etc.);

matrices of weights; optimization; projections; and scenario planning, etc. (Carvalho, 2002; Romeiro, 2004).

Many techniques depend on weightings, making the assessment dependent on the reliability of the weights involved. As the environment involves physical (biotic and abiotic) and social (socioeconomic and cultural) factors, the impact assessment will be more assertive when involving as many experts as possible (Mirra, 1998; Silva, 2010).

Erosive Processes

The erosion processes are basically classified in natural and anthropic. The first one is related to the natural deterioration, which is responsible for sculpting the geomorphologic aspects of the landscape. The soil cover makes this removal very slow and it is offset by ongoing processes of soil formation. Under natural conditions, the deterioration cycle is usually balanced by the renewal (Bertoni; Lombardi Neto, 1990).

The anthropic erosion processes are fastest than the natural erosion ones. This accelerated erosion process could be technically defined as the removal of soil particles from the higher parts, by the action of rainwater or wind, and the transport and deposition of these particles into the lower parts of the relief, or into the bottom of lakes, rivers and oceans. Its most common variants are: water erosion and wind erosion (IPT; DAEE, 1997).

Water erosion is, in Brazil, more important than erosion caused by winds. It is composed of two stages: breakdown and transport. The breakdown is caused by the impact of raindrops, as well as by the water which flows across the surface. The raindrops touch the surface with a speed calculated in about 5 to 15 miles an hour, while the flood water speed is usually not more than 1 mile/h. The impact of the raindrops in a soil lacking in vegetation generates the particles disruption, the first step to erosion. When the soil surface is properly protected, the cover absorbs most of the kinetic energy of the raindrops (Lombardi Neto; Drugowich, 1995).

A large amount of soil can be removed, since its particles are disaggregated and suspended in the runoff water. The way the particle is transported depends on its size. Clay and silt are most easily carried by water due to the small size of their particles (Lombardi Neto; Drugowich, 1995).

There are, basically, three types of water erosion: the gradual removal of a thin surface layer of uniform thickness, covering pratically all the relief, known as laminar erosion; the erosion in narrow bands along the largest slopes of land is called erosion in furrows; and the displacement of soil mass, forming large cavities or soil landslides is the process known as erosion in gullies (Carey; Silburn, 2006).

Considering these three types, laminar erosion is the most important. Soil losses related to this type of erosion often outweigh the other two forms, those arising from ridges and gullies. All immediately affect the production capacity of the land in a property, while the slow nature of the degradation process causes many problems which are not noticed by farmers before reaching large proportions in order to be corrected (Pierzynski et al., 2000).

The increased pace of erosion has produced noticeable conditions, such as presence of gullies, stunted roots exposed, fallen roadblocks, deep paths in pastures, water reservoir siltation, floods in arable fields, muddy waters in rivers and streams. Dragging of soils and fertilizers to rivers and lakes changes the aquatic micro-fauna and, consequently, the overall fauna, with serious losses.

The greatest or the lowest susceptibility of land to erosion by water depends on a number of factors. Four of these factors are considered the main ones: the climate in the region; the soil type; the terrain slope; and the soil management. The most important climate factors related to erosion are the distribution and the amount and intensity of rainfall. Regarding soils, susceptibility to erosion depends primarily on its physical characteristics, especially its texture, its permeability and its deepness. Flood speed, marked by greater or lesser soil particles dragging, depends on the slopes of the terrain. Finally, the management, or how the land is being used, determines the soil mobility (Sparovek et al., 2007).

Covering the ground with a dense layer of vegetation or debris from previous crops, it is possible to notice that the direct impact of the raindrops is absorbed and there is greater water infiltration. The presence of vegetation minimizes flood. Moreover, the roots are wrapped, holding the ground. The disaggregation and transport of particles vary according to the system of cultivation. Some crops become more susceptible to soil erosion than others. In general, soils with annual crops are more exposed than those grown with perennial or semi-perennial plants (Drugowich et al., 2010).

The way how crops are planted have a great influence. In any culture there are some precautions which must be observed to protect the soil, such as planting level, terracing and no-tillage. These practices could be divided into edaphic, vegetative and mechanical (Almeida et al., 2000):

- edaphic: usability adjustment, burning control or elimination, fertilization, crop rotation;
- vegetative: zoning, forestry, alley cropping with interception of water runoff through vegetation, planting grass on the slopes of roads, windbreakers, adequate control of weeding, mulching, tillage;
- mechanical: soil preparation and contour farming; subsoiling; terraces of the ridge type; terracing, rational arrangement of carriers, and structures for infiltration and deviation of water from the roads, structures to control gullies, retention basins.

In the State of São Paulo (Brazil), there are about 6,700 erosive focuses, and most of them are medium and large (IPT; DAEE, 1997). In rural areas, it is estimated that about 80% of cultivated land is suffering erosion beyond the limits of natural soil recovery. According to Scanavaca Jr. (2011), the State loses 200 million tons of soil per year, with about 50 million being disposed in rivers and streams. This situation generates less fertile soil and silting increasing, as well as it reduces the farm value and increases water treatment costs. The balance between consumption and production is unfavorable, reaching 10kg of soil to 1kg of food. Besides the loss of the resource itself, most of the carbon is fixed in the soil (Bustamante; Oliveira, 2008).

Deposition is the amount of accumulated sediment in a delimited period of time which did not exceed the limit of a given area in question. In order to occur such deposition, there must be transmission or downward movement of water and solids in suspension by superficial flow in the areas between the furrows (Ritter; Shirmohammadi, 2001). This deposition is segmented, with part of the sediment being carried by waterways, part deposited near the source of sediment, and also redistributed in a large extension of the floodplain downstream of the basin or in water reservoirs (Bertolini et al., 1993).

Part of the sediment originated in erosive events is carried downslope and can be placed in the slope itself, while another part can reach waterways (Douglas, 1990). The loose sediment which does not reach watercourses is placed in depressions or in concavities, under vegetation or in other places where the surface flow loses its ability to transport (Rhoton et al., 1982). The sedimentation occurs after and/or during rainfall events, when many soil particles are detached and transported downslope, being retained by plants, depressions or any other obstacle located downstream (Bryan, 2000).

The erosion promotes the generation of sediments which may start processes of turbidity and/or sedimentation of water bodies (Andrade, 2009). Machado et al. (2003) relate erosion and siltation to land use and land cover changes.

Ecosystem Services

Besides the minimization of environmental impacts, there is the possibility of recovering the remaining native vegetation through environmental adaptation. Thus, there could be an increasing of their ecosystem services, those able to support and meet the conditions of human life, such as air purification, protection of soil and natural pest control (De Groot, 1992). Also:

"They are those services that nature provides to absorb, filter and promote water quality; to recycle nutrients and provide soil structure; to maintain climate stability, minimizing disasters such as floods, droughts and storms; to ensure and increase agricultural and industrial production, providing the needed biodiversity and genetic diversity for crop improvement or for drugs, cosmetics or new materials, supplementing processes that human technology does not dominate or replace such as pollination, photosynthesis and waste decomposition" (John, 2008, p 459.).

The characterization of ecosystem services is derived from studies of environmental valuation and inclusion of environmental factors in business negotiations and international agreements. At the beginning, services were considered environmental costs and were associated to evaluations of impacts. This negative characterization related to cost became a positive concept of services and, generally, it was not adequately paid. Costanza et al. (1997) show that, considering the services provided by all existing biomes, the estimated average annual value of these services is US$ 33 trillion, almost the double of the entire world economy GDP.

The Millennium Ecosystem Assessment (MEA, 2003; 2005) suggests the existence of a large number of ecosystem functions and their associated goods and services, gathering ecological functions into four main categories:

- regulatory functions: related to a natural capacity of ecosystems and ecological processes in controling the maintenance of biotic processes through biogeochemical cycles of benefit to living beings, such as clean air, water balance, soil conservation, pollination, sanitary and epidemiological control;
- habitat/support functions: natural ecosystems provide habitat for animal and plant species breeding processes, contributing to biodiversity conservation in situ and genetic diversity. It is the maintenance of ecological and biological processes (nutrient cycling, soil formation, primary production etc.);
- supply functions: corresponding to the processes of photosynthesis and autotrophic processes that convert carbon dioxide, water and nutrients in carbohydrate structures, which are used for generating higher biomass (provision of raw materials, such as water, food, fiber, genetic resources, biochemical, forestry and fisheries etc.);
- information functions: resulting from the moments in which the natural ecosystem contributes to the maintenance of human health by providing active ingredients for the pharmaceutical industry, or when promoting functions of reflection, spiritual enrichment and recreation/tourism.

According to Burstein et al. (2002), there is a basic typology of ecosystem services that differentiate into:

- carbon sequestration, which includes the conservation of existing stocks, as well as the increase of fixed carbon in products from forests and other areas where these stocks exist and where they are increased;

- water services and performance monitoring of watersheds, incorporating services such as water supplying and groundwater aquifers recharging, life extension and hydraulic infrastructure, prevention and mitigation of disasters caused by meteorological phenomena of excess or lack of precipitation;
- conservation of biological diversity, including conservation of niches and reduction of habitat fragmentation in the regional landscape, through the creation of ecological corridors;
- scenic beauty, considered as an enhancement factor of natural properties and as a component of recreation services provision.

The ecosystem services performed by riparian forests are associated with the quantity (permanent) and the quality (purity) of water, such as protecting the soil from raindrop impact, reducing the erosive susceptibility, infiltration, vertical intercept, reducing the risk of flooding, landslides, i.e., all the variables which could affect the hydrological cycle (Tonhasca JR., 2004).

The integrated management should consider the risks of reducing the supply of ecosystem services resulting from changes in land use and land cover, which are related to conversions of ecosystems. The remnants of native vegetation shelter ecosystem functions which originate ecosystem services such as springs and watercourses protection; soil cover; nutrient cycling; retention of soil on steep slopes; food, fiber and energy provision; maintenance of genetic resources for the development of industrial, pharmacological and agricultural products; provision of wood and minerals; climate stabilization; pests and diseases control; air and water purification; regulating the water flow and quality; controlling sedimentation; maintenance of soil fertility and nutrient cycling; decomposition of organic waste; aesthetic and cultural benefits and opportunities for leisure (Vilar, 2009). On the other hand, if the ecosystem is inadequate as a degraded area, with restrict environmental attributes and low resilience, the service scenario performance is inversely shown, and, thus, the ability to generate environmental services is subject to the ecosystem integrity and conservation status (Daily, 1997).

<u>Ecosystem Services Payments</u>

There are many examples of mechanisms for capturing the values related to services provided by nature - environmental taxes, green protocols, green taxes, fines etc. The valuation and policies for ecosystem services payments are strategies for matching economic growth and natural benefits maintenance, adopted by the most relevant environmental agendas (Fearnside, 2004).

Lee and Mahanty (2009) point out that payment for ecosystem service is a political attitude. By adopting the principle of "protector-receiver", the objective is to provide financial incentives for contributing to the maintenance or for increasing the supply of ecosystem services. This policy recognizes the role of protector-receiver and provides the adjustment of the conventional production model to a more sustainable system which ensures both environmental improvements and income generation. This is not compensation, nor the interpretation of environmental conservation as onus (ISA, 2008).

3 Matherial & Methods

3.1 Study Area

The study area is Arealva, a city located in the state of Sao Paulo, Southeast region of Brasil. Its limitrophe planimetric coordinates are: 22º01'44,40" S, 48º54'39,60" W and its average altitude is 445m. Figure 1 shows the location of the municipality in relation to Brazil and the State of São Paulo, including the biomes, rivers and roads. Arealva has 505km² and 7,842 inhabitants (Macedo et al., 2013).

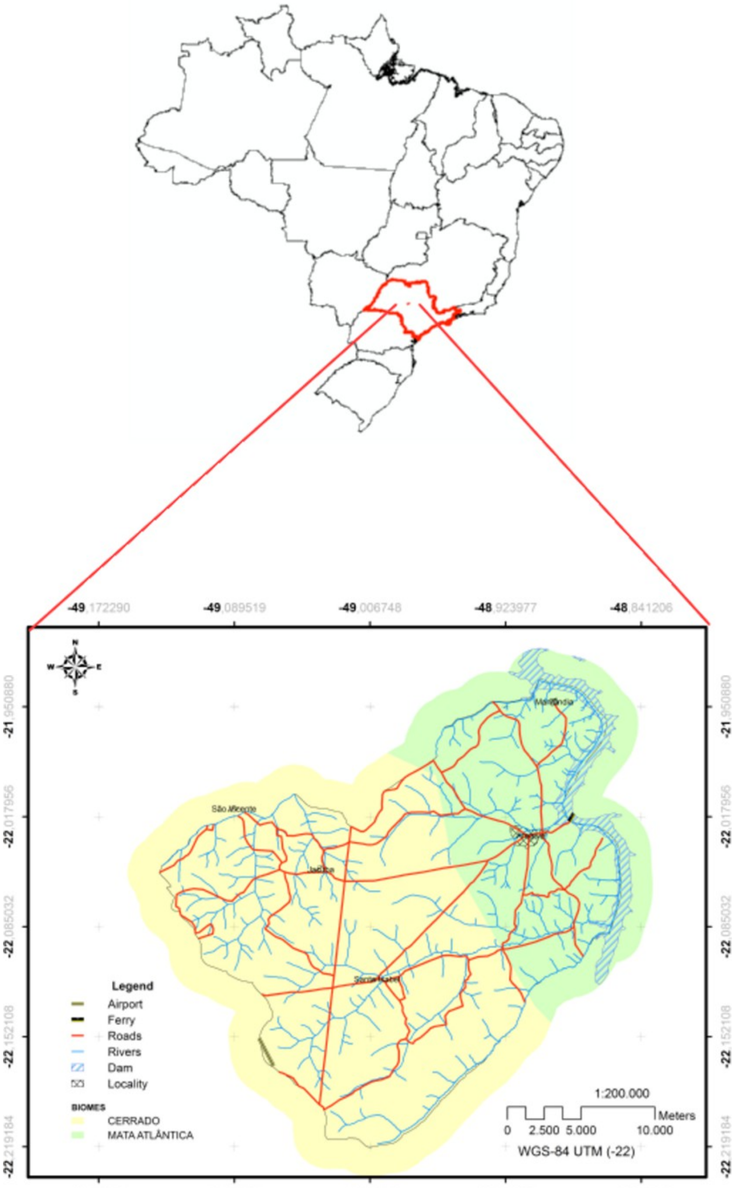

Fig. 1. Study area. The city is in a contact zone of two biomes: Cerrado (orange) and Atlantic Forest (green). It is possible to see the municipality (Arealva) and the regions of Marilândia, Jacuba, Santa Izabel and São Vicente, as well as the roads (in red) and the rivers (in blue), including part of the Ibitinga dam.

The climate is considered high-altitude tropical (Aw), sub humid (C), mesothermal (B'), marked by a dry season during the year. Summer's main features are high humidity and high temperature (~24.3º C). Winter is cold and dry (~18.9º C), not exceeding nine rainy days throughout the season. This climate allows the development of all tropical climate cultures which develop their vegetative growth between September and February. The registered pluviometric average between 2000 and 2010 was 1,500 mm a year (Arealva, 2010).

Regarding the hydrography, Tiete is the main river, to which most of the streams and rivers flow. In general, water used for human consumption and livestock watering comes from common and semi-artesian wells. The irrigation is provided by surface water catchment, mainly from Tiete River (São Paulo, 1983; 2008; Arealva, 2010).

The city is located on the east plateau of Sao Paulo. The relief is slightly hilly, with a predominant declivity of 3-8%, enabling mechanized and semi-mechanized agricultural practices. Its eastern side is flatter, while its western side is marked by the presence of hills with a higher dissection rate (Arealva, 2010).

Considering the geological and pedological aspects, Arealva is inserted in the Bauru Group (Vale do Rio do Peixe formation), a region formed by sedimentary rocks, mainly sandstones. The mineral produced different soil types, such as distrophic red oxysoils, red-yellow oxisoil, red-yellow argisoil and abrupt argisoil. The presence of shallow soil and the slightly hilly relief determine the classification of 75% of the territory as high erosion susceptibility, especially in the western side (São Paulo, 2000).

3.2 PROCEDURES

Table 1 summarizes the data used, including their type, base year, purpose and reference to the generation of land use and land cover maps (2005 and 2010), as well as to the simulations. Table 2 shows the applications used and their main features.

All procedures related to the field survey, to the preparation and validation of land use/land cover maps (2005 and 2010), to the detection of changes which occurred (between 2005 and 2010), to the calibration, to the parameterization and validation of the LUCC model, to the simulation of past scenarios (2006 to 2010) and the generation of future scenarios (till 2020) are described in Macedo et al. (2013), whose methodological procedure is illustrated in Figure 2.

Table 1. Used data, format, reference date and purpose.

Data	Format	Base Year	Purpose	Source
Land use and land cover maps	Raster	2005 and 2010	Obtain land use/cover classes.	Macedo et al., 2013
Watersheds	Polygon	2010	Calculating the rate of sediment delivery.	Ana, 2010
Slope – degrees	Raster	2000	Calculating the Topographic Factor.	Valeriano, 2008; Valeriano; Rossetti, 2011
Elevation (Topodata)	Raster	2000	Calculating the Catchment Area.	Valeriano, 2008; Valeriano; Rossetti, 2011
Pluviosity	Table	1990-2010	Calculating the Erosivity.	Ciiagro, 2013; DAEE, 2013
Pedological map	Polygon	1982	Calculating the Erodibility.	Almeida et al., 1982
Silting-up events	Table with information based on water body/stream	2005-2010	Water quality monitoring.	CETESB, 2012; SABESP, 2012
Values related to dredging and alike silting-up mitigation actions	Table	2004-2013	Value related to the cost of silting-up mitigation.	Nóbrega, 2004; Bigaran; Tizato, 2009; Moreira, 2011

Table 2. Applications used.

Software	Purpose
ARCGIS v. 10	Variables standardization, tables, datum and projection; vector editing; rasterization; raster editing; accumulation area assessment.
Erosividade Brasil	Calculating the erosivity.
Erodibilidade Brasil	Calculating the erodibility.
IDRISI v. 14 (Kilimanjaro)	Calculating the soil loss for comparative purposes.
USLE-2D	Calculating the topographic factor, for comparative purposes.

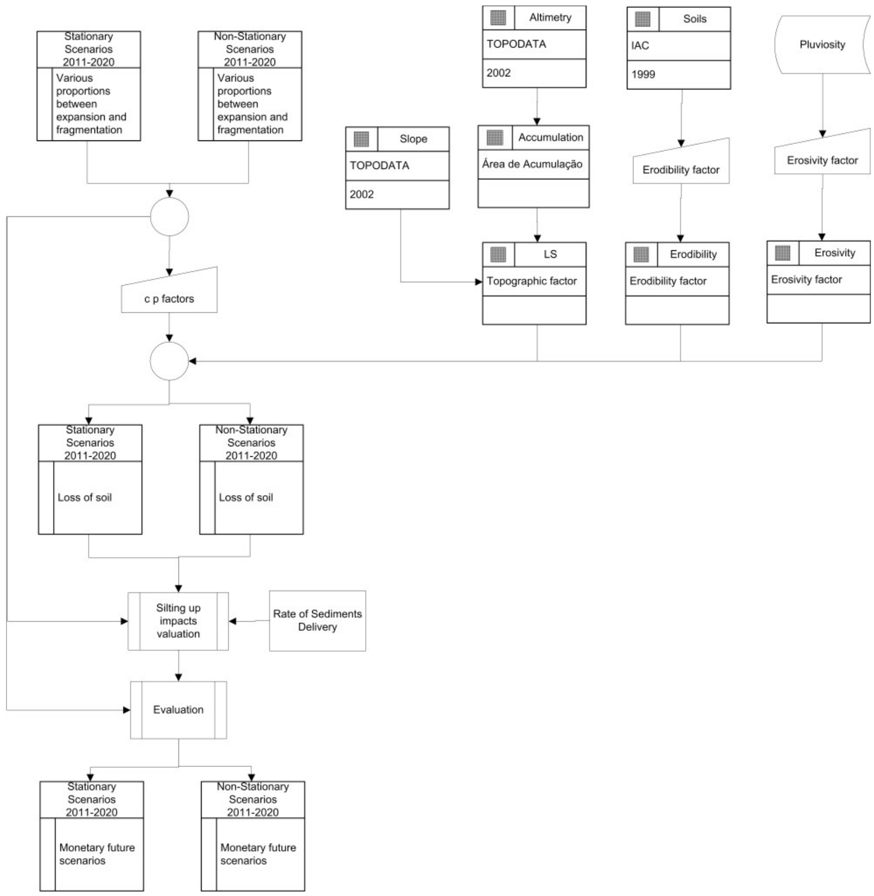

Fig. 2. Methodological procedure for generating future land cover/land use scenarios and its valuation of environmental impacts produced by the silting-up process.

The scenarios were proposed considering the revegetation of riparian areas as a strategy for minimizing environmental impacts and for recovering environmental services which have been already committed. According to São Paulo (2011), the riparian area of Arealva is about 3,000 inhabitants. It is estimated that around 35% of this area is irregularly occupied. Moreover, there are no remaining areas under recovery.

Two sets of scenarios were defined:

- Stationary scenarios, which maintained the transition rates and reproduced the features detected (business as usual). The historical trend is the replacement of pasture by sugarcane;

- Non-stationary scenarios of readjustment of riparian areas. In this scenario, two rates of revegetation were simulated: i) 70% by 2015 and; ii) 100% by 2015.

Non-stationary scenarios of environmental readjustment simulated the increasing native vegetation and the reduction of the other classes in the riparian area. Outside them, the stationary transition rates were maintained, i.e., the detected changes (historical trend), including the reduction of native vegetation were kept for calculations.

The selected environmental impacts were related to erosion and silting-up. They are influenced not only by the type of land use and the management practices performed, but also due to the topography. Therefore, we estimated the potential soil loss based on the universal soil loss equation (USLE), considering the annual stationary and non-stationary scenarios (Equation 1).

$$A = R * K * LS * CP$$

USLE
A = rate of erosion per unit area, in $t.ha^{-1}.year^{-1}$;
R = erosive power of the rain, in $MJ.mm.ha\text{-}1.h\text{-}1.year^{-1}$;
K = soil erodibility, in $t.h.MJ^{-1}\ mm^{-1}$;
LS = land slope and length, dimensionless;
CP = degree of soil cover (C) and conservation practices (P), dimensionless.

Considering the average rainfall in the last 20 years and the erosivity data presented in the Erosividade-Brazil database (Silva, 2004; Silva et al., 2006), we measured the erosivity (R) for the entire municipality, since there is no significant spatial variation in the annual rainfall height in the study area (Cataneo et al., 1992).

According to each type of soil, we adopted the erodibility factor suitable for the observed features (Bertoni; Lombardi Neto, 1990; Marques, 1996). Table 3 shows the respective values.

The equation used in the Erodibilidade-Brasil application (Silva; Alvares, 2005) is cited in Mitchell and Bubenzer (1980), converted into the international system, according to Foster et al. (1981).

Table 3. Erodibility factor by soil class.

Class	Erodibility (K)
Dystrophic red latosoils + dystrophic red-yellow oxisoils, A moderate, medium texture, flat and slightly-wavy relief.	0.042
Eutrophic red-yellow argisoils + dystrophic and eutrophic red argisoils, both sandy / medium texture, mild slightly relief .	0.02
Dystrophic red latosoils + dystrophic red-yellow and red argisoils, A moderate, medium texture, flat and slightly-wavy relief.	0.0162
Eutroferric and dystroferric red latosoils, A moderate, clayey, flat and slightly-wavy relief.	0.013

Table 4. Land use factors (C) and the conservation practices (P) land use/land cover class.

Class	C	P
Urban	0	0
Water body	0	0
Sugarcane	0.18	0.5
Other cultures	0.25	0.7
Grassland	0.3	0.5
Silviculture	0.1	0.2
Riparian area (non-vegetated)	0.26	0.06
Native vegetation	0.05	0.2
Riparian area (vegetated)	0. 012	0.1

The topographic factor (LS) was calculated based on Equation 2 (Azim-Zade, 2010), using the digital elevation model resampled to 20m of spatial resolution (Cowen, 1993; Desmet; Govers, 1996; Salgado, 2011 , Salgado et al., 2011;. Salgado et al., 2012).

$$\frac{\sin(d*0.01745)}{0.09}$$

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¿

$$LS=\left(\frac{CA*PS}{22.13}\right)^{0.6}*¿$$

LS = Topographic factor;
CA = Catchment area;
PS = Pixel Size;
d = Slope.

We calculated the land use factors (C) and conservation practices factors (P) (Bertoni and Lombardi-Neto, 1990; Lepsch et al., 1991), as shown in the Table 4.

The desilting costs are proportional to the amount of suspended matter, which is related to the erosion processes. In Arealva, both the company which is responsible for the local hydroelectric power plant and the company which holds the concession of the Alcohol Waterway carry the costs of dredging, estimated at around US$9.00.t-1 (Nóbrega, 2004; Bigaran; Tizato, 2009; Moreira, 2011). The amount of sediments depends on several factors, including the watershed area and the length of rivers (Sousa Jr., 2011). It is necessary to estimate the rate of sediment delivery (RS), described in Equation 3 (Roehl, 1962).

$$RS = \log 2.88753 - 0.83291 . colog \frac{R}{L}$$

RS = rate of sediment delivery, dimensionless;
R = range between the highest and the lowest elevation in the basin, in meters;
L = length of the main stream of water from the basin, in meters.

We considered the watersheds for estimating the RS. Based on it, we calculated the environmental impact related to siltation (Equation 4) (SOUSA Jr., 2011).

$$ISILT = A * RS * 0.5 * PDRED$$

ISILT = Impact related to siltation, in US$.$ha^{-1}$.$year^{-1}$;
A = Soil loss, in t.ha^{-1}.$year^{-1}$;
RS = Rate of sediment delivery;
PDRED = Average price of dredging and desilting, in US$.$t^{-1}$.

The coupling of the environmental impacts valuation in LUCC models allows the design of several scenarios which integrate not only plausible future landscape patterns, but mainly the derived consequences in terms of environmental impacts.

Assessment of the Environmental Impacts Resulting from Erosion and Silting-Up for the Envisaged Land Use/Land Cover Scenarios.

3 Results

The environmental impacts derived from erosion and silting-up, caused by the replacement of grassland and native vegetation by sugarcane culture, are dependent on the estimated amount of lost soil. This estimate can be seen in Figure 3.

There is a clear reduction of soil loss in the scenarios of environmental readjustment. In the stationary scenario, there is a reduction in soil loss due to the replacement of grasslands by sugarcane, since the sugarcane fields own a c factor accounting on average for half of the c factor belonging to the other land use/cover classes. Scenarios with environmental readjustment presented lower values than stationary scenarios, ranging from 1 to 16%. Even with the recovery of riparian areas, there will be an erosive potential, since it is also conditioned by erosivity, erodibility and topographic factors, which are the most relevant ones in calculating soil loss (Valeriano, 2003; Chaves, 2010; Salgado, 2011).

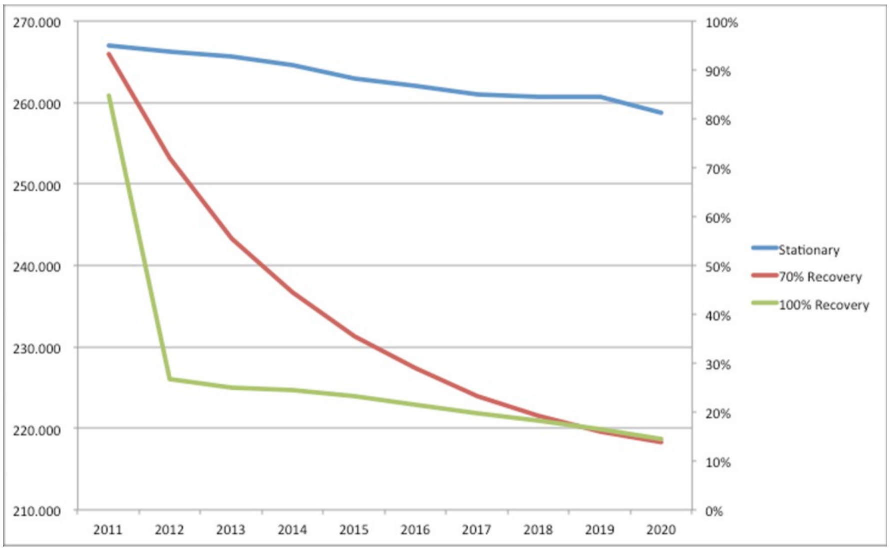

Fig. 3. Dynamics of the soil loss estimate related to the considered scenarios, from 2011 to 2020 (t.year-1).

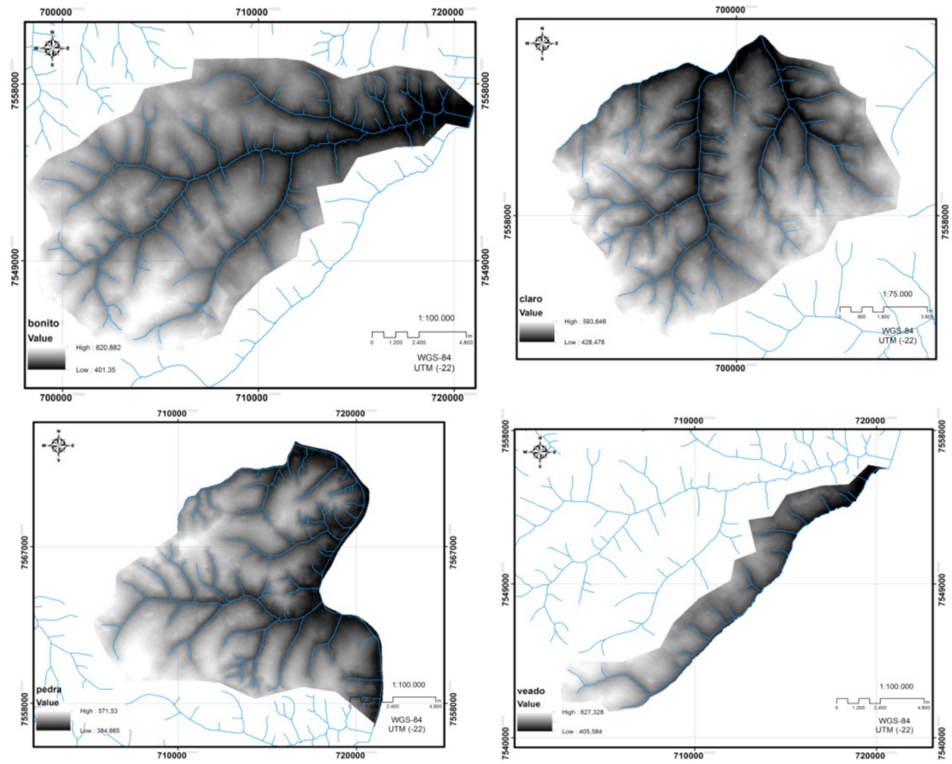

Fig. 4. Watersheds considered for the calculation of the rate of sediment (RS) delivery in Arealva.

From time to time (nearly in a one-year span), investments associated with dredging for reducing sediments are made in the Ibitinga reservoir, so as to enable the continuity in electrical energy generation and also to minimize the risk of low flow and draughts in the Tietê River, which could jeopardize the operationality of the Alcohol Waterway. These investments can be transferred to the final consumer, but they are presently regarded as a control measure against a situation of widespread environmental impact, although such impact is in fact largely originated upstream and unfairly beared by the agricultural sector.

In the particular case of dredging, the estimated cost depends on the rate of sediment delivery. This rate was calculated by assessing the proportional area of all watersheds partially or entirely contained within the municipal boundaries of Arealva, as it can be seen in Figure 4 and in Table 5.

Table 5. Calculation of the sediment delivery rate (RS), altimetric range, name and lenght of the main watercourse and the watersheds area of Arealva.

Watershed	Area (ha)	Main waterstream	Length (m)	Elevation range (m)	RS
Soturninha Brook (1)	15,771.09	Soturninha Brook	14,521.70	186.86	0.272248022
Claro River	10,866.10	Claro River	13,121.62	165.17	0.266164605
Bonito Creek	19,241.34	Bonito Creek	26,333.29	219.53	0.144882799
Veado Creek	4,652.99	Veado Creek	24,316.37	221.74	0.172569649

Considering that 50% of the sediments will have to be effectively dredged, it can be observed in Figure 5 that the dynamics of the economic impacts related to dredging expenses are directly proportional to soil loss.

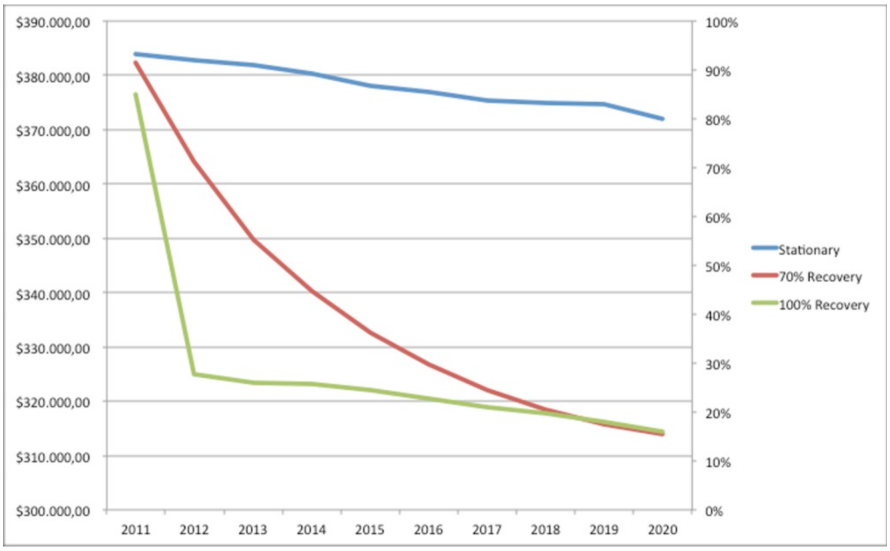

Fig. 5. Dynamics of the environmental impact estimate related to the dredging and desilting of the watersheds in Arealva for the considered LUCC scenarios, from 2011 to 2020 (US$.year^{-1}).

In the analyzed period, the environmental readjustment scenarios can reduce the impacts related to dredging and desilting in 16%, being US$41,479.30 (70% recovery) and US$56,789.50 (full recovery). If we consider the total riparian area (about 3,000 ha), the mitigation of environmental impacts could sum up approximately US$13.83 ha^{-1}.year^{-1} or US$18.94 ha^{-1}.year^{-1}. These values are lower than the reported payment of main environmental services, but these financial resources could certainly be allocated for the recovery of riparian areas.

A reduction in profitability was noticed, despite there was a reduction in the selected environmental impacts, since the environmental readjustment includes the replacement of certain types of land use that are not in compliance with the current legislation (Brasil, 2012). However, if we consider that all sectors must be in accordance with the laws and that many ecosystem services and environmental impacts were not considered, reducing profitability should not be taken as a hindrance to the recovery of riparian areas. Moreover, some agricultural activities such as dairy and cattle production are underpaid and cause severe and large extent environmental impacts. This requires investments in infrastructure, such as drilling wells, for example.

Therefore, the environmental impacts reduction coupled with an increased productivity compensates for any decrease in a productive area caused by environmental readjustment initiatives.

4 Conclusion

The assessment of environmental impacts related to agricultural activities and ecosystem services in wild environments by LUCC monitoring is essential for an integrated and comprehensive analysis. The economic variables coupled with the spatial variables enable more representative models, allowing greater effectiveness in their applications.

The environmental readjustment in riparian areas is not only a legal issue. Ecosystem services are important for the sustainability of agricultural activities. Any reduction in terms of aggregate profitability should be offset by an increase in the ecosystem services provision and by a reduction in the risk of environmental impacts.

Environmental readjustments normally reflect in reduced profitability (sacrificed income). However, it brings a dual benefit: it increases the supply of ecosystem services and decreases the risk of negative environmental impacts. Both benefits are external to the market and difficult to be detected by the agents.

The environmental readjustment scenarios are able to reduce environmental impacts in up to 16% (US$41,479.29 - US$56,789.40) annually. This calculation is exclusively related to the selected study area. Such scenarios are also able to increase the wealth of the concerned municipality, depending on a two-fold strategy of: i) assigning the due importance to ecosystem services, including actions for rendering environmental resources readily available; and of ii) internalizing environmental impacts, including a fair reallocation of dredging costs upstream, where sediment delivery predominantly takes place.

The provision of an economic tool designed for the valuation of ecosystem services, coupled with the internalization of potential environmental impacts, is able to render the environmental readjustment feasible and competitive. The riparian and other fragile areas (prone to erosion and silting-up) could be recovered through a funding mechanism, which could be based on procedures of charging for water use and/or even on a strategy for ecosystem services payment. Such mechanism could also rely on a progressive discount on rural property taxes proportional to the percentage of recovered riparian area inside the property. The mitigation of silting-up would approximately account for savings of US$13.83 - US$18.94 $ha^{-1}.year^{-1}$.

Obviously, there are other impacts that could be mitigated, such as plagues, diseases, biodiversity loss, fire etc., what would contribute to the reduction of the total value associated with them. It is worth highlighting that this particular work concerns a reduced analysis as to its geographical, temporal and thematic dimensions. The span of time considered for this analysis ranges from 2005 to 2010 for the purpose of calibration, and from 2010 to 2020 for the sake of prediction. Furthermore, the considered environmental impacts do not regard further implications in the medium- and long-run and neither do they take into account a geographical extent beyond the Arealva municipality boundaries. In other words, we can state that the erosion and silting-up processes produced in Arealva will have implications outside this municipality, and this has not been taken into account in our analyses. Lastly, we must clarify that the land cover and land use classes adopted in this work comprise a wide range of environmental impacts and ecosystem services, which could not be dealt with in a thorough manner, since this would make this research unfeasible in view of constraints related to the lack of technical and financial resources, human capital, data availability, computational processing capacity and execution deadlines. Nevertheless, we strong recommend that local stakeholders promote further valuations of environmental impacts and ecosystems services as comprehensive as possible in the future, what would certainly result in more substantial savings derived from the mitigation of other environmental impacts found in the study area.

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