A planning support tool for sediment management – a case study from central Brazil

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Abstract: Currently, we are developing a sediment management plan for the Federal District of Brasília that aims at the reduction of sediment input into water reservoirs. A central element of this approach is a planning support tool - letsmap do Brazil - that enables the user to test the effects of land use changes on landscape processes and functions (LPF), such as runoff control, sediment input in river network, nitrogen export, and agronomic value. The tool has two principal levels. The upper level contains information on effects of land use on LPF. The parameterized relation between land use and LPF is the core of the system. For each LPF a value specific to land use has been assigned. Values for LPF´s were taken from published research, e.g. C factor from USLE (sediment generation), curve number (water retention), or statistics (agronomic yield). On this level users are allowed to act as land use planer/manager. By changing land uses classes the effect on LPF´s might be tested. The second level contains information on landscape properties and potentials (LPP´s), e.g. potential of runoff control or potential of sediment retention. By linking land use specific values and information on LPP a spatially explicit assessment of effects of land use change on LPF will be achieved.

Keywords: sediment management; Brazil; sediment cascade; landscape functions; landscape properties

Introduction

The Federal District of Brasília is located in the western part of central Brazil. The area belongs to the outer tropics (MAP 1600-1700 mm, MAT 20-21°C) with pronounced dry and rainy season. The area of DF Brasília is 5789 km^2 and population is around 2.3 millions. The population density of the area is rather high (> 400 persons per km^2) and is expected to increase substantially in the future. Urban sprawl and intensification of agriculture are the major drivers for land use change, mostly from (semi)natural savanna vegetation (Cerrado) into urban areas or farmland. A more detailed description of the area can be found in Carvalho et al. (2006), Gonçalves (2009) and Greinert (1992).

Major challenges for water supply of the region are seasonality of rainfall (dry vs. rainy season), increasing water demand due to population growth, collection of surface waters - reservoirs cover 80 % of water supply -, and intense land use in reservoir´s watersheds.

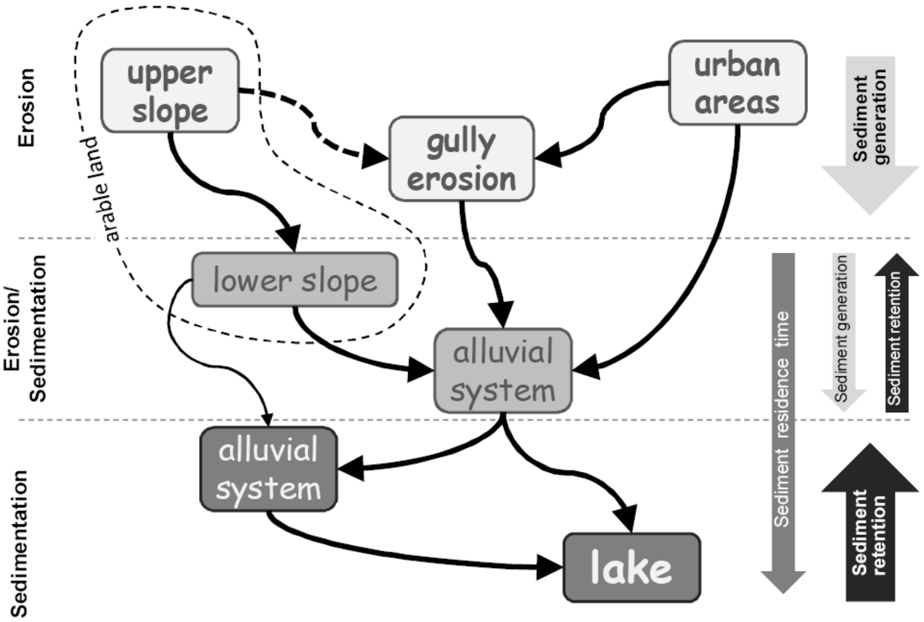

Figure 1. Sediment cascade.

Silting of reservoirs is a major problem in the Federal District of Brasília and has already resulted in the loss of some smaller reservoirs and in the reduction of volume and area of larger reservoirs. Since silting is a serious threat to drinking water provision of the region, we focus on the process of sediment generation/retention in the landscape and measures to prevent or minimize sediment input in reservoirs. Although we are not yet able to quantify the sediment fluxes, we assume major sources to be soil erosion from arable land, gully erosion in context of ill maintained infrastructure and urban erosion from areas without vegetation, e.g. construction sites (Carvalho et al., 2006; Greinert, 1992). We adapted the idea of sediment cascade (Houben et al., 2009; Hoffmann et al., 2007) for the investigation area (fig. 1). The position in the cascade, i.e. in the landscape, is closely linked to the dominance of processes, i.e. erosion or sedimentation. Sediment generation occurs mostly in upper slopes, gullies, and urban areas, while alluvial plains in the upper reaches of river networks and lower slopes act as temporary sinks for sediments. However, these zones will be also sediment sources, e.g. due to lateral erosion of alluvial sediments. Alluvial sediments in the inflow zone of reservoirs and in the reservoirs are considered as final sink.

In our contribution we will present a planning support tool as major element of a sediment management plan (SMP) that aims at minimizing the sediment input into reservoirs. A crucial part of the SMP is prevention of sediment generation by land use management and land use planning. Therefore, we used a modified version of a planning support tool, *letsmap do Brazil*, to simulate the effects of land use change on sediment input into river networks and reservoirs.

Our contribution might be of wider interest because (i) silting is a frequent phenomenon in semi-humid environments, (ii) the tool *letsmap do Brazil* allows for initiating participatory processes and (iii) the development of a planning tool for integrated land use is a general methodological approach.

1. Material and Methods

The planning support tool *letsmap do Brazil* was developed to facilitate the evaluation of different land use scenarios regarding the effect of land use pattern on landscape processes and functions (LPF) (for details see Fürst et al., 2009 or www.letsmap.de). The web based tool was adapted to the specific demands of our study.

The basic idea of the tool is a cellular structure that considers land use and its effect on LPF, i.e. soil erosion, runoff control, nitrogen export and agronomic value. To each LPF a land use specific value is assigned (fig. 2 a, tab. 2). We will apply the tool *letsmap do Brazil* to support decision and participation processes in planning and management of land use. The simulation of land use change is focused on soil erosion from non-urban areas and thus reducing generation and transport of sediments into the river network. However, urban erosion and gully erosion were not considered so far, but will be subject of future research.

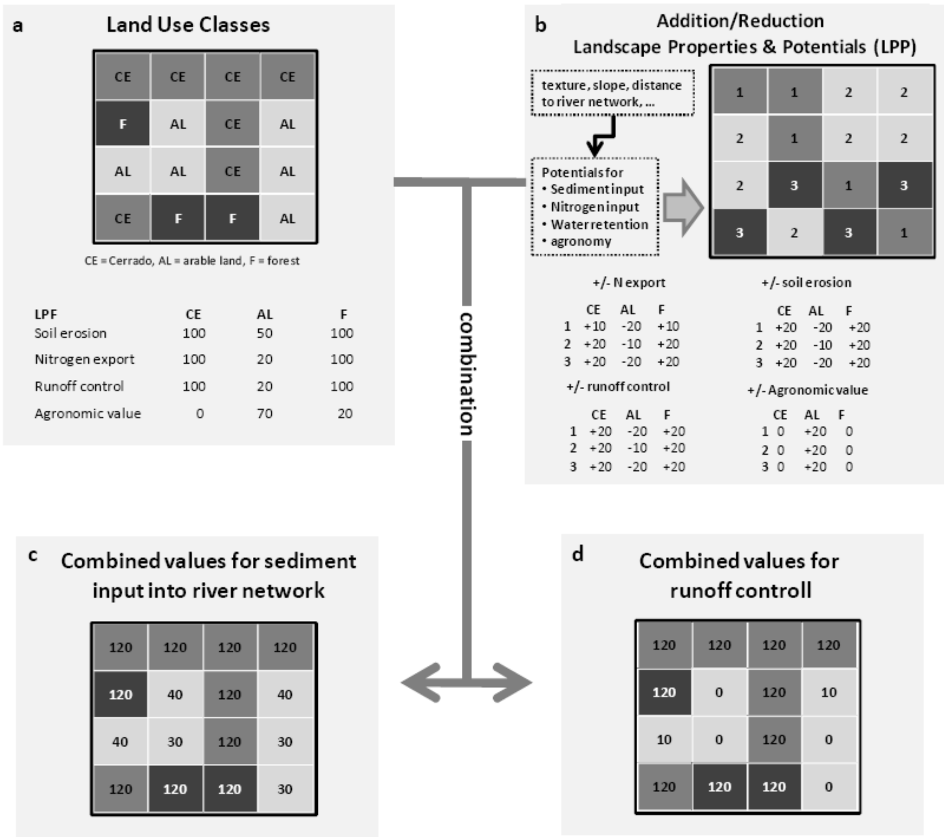

Figure 2. Approach of the planning support tool letsmap do Brazil.

A second layer contains information on landscape properties and potentials (LPP´s) (fig. 2 b) which were obtained from spatial data available for the DF Brasília. We used simple standard methods (tab. 3) to assess LPP´s influence on effects of land use on LPF. The parameterization of LPP´s, e.g. runoff control, was carried out using simple methods widely used in assessment of LPP´s. For example, from a DEM we obtained slope and from a soil map we took texture and water capacity (fig. 3). These parameters were used to assess runoff control according to Zepp (in Marks 1992). In a similar way, LPP´s for N export and soil erosion were calculated. All spatial data was processed using ArcGIS 9.3.

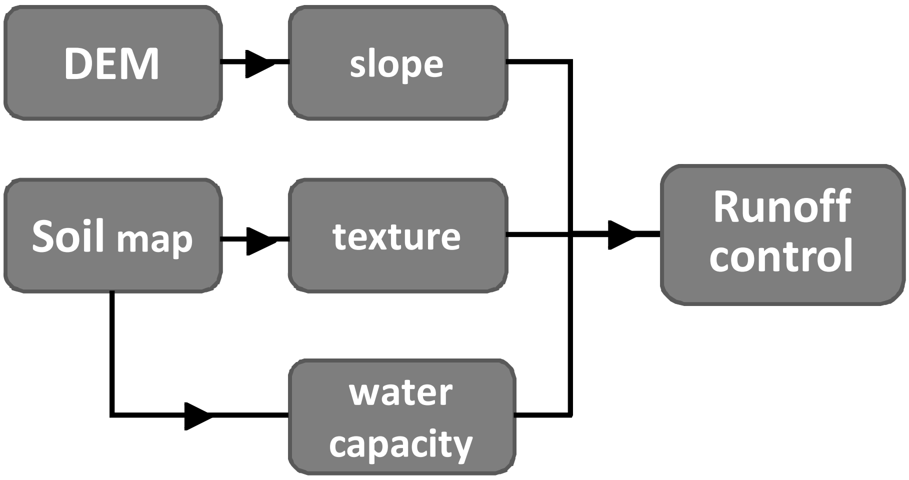

Figure 3. Procedure for estimating runoff control

The combination of information allows for a site specific assessment by taking LPP and land use class into account. The assessment results in a combined value of land use class and site conditions for LPF, i.e. nitrogen export, soil erosion, runoff control, and agronomic value (fig. 2 c and d).

2. Results

We defined land use classes focusing on land management and crop cultivation using statistic data (IBGE, 2009) and - to a lesser extent - expert knowledge. We excluded urban areas, since no reliable data for erosion exist. Land use types were further distinguished into land use classes compromising information on soil management influencing soil erosion (tab. 1).

The land use classes “arable land, soy” and “arable land, corn” cover large parts of the region. These land use classes were subdivided into no-tillage and tillage practice. From the list of land use classes (tab. 1) users of *letsmap do Brazil* may choose their desired land use and test the effect of a changed land use pattern on LPF.

The core of the tool *letsmap do Brazil* is the assignment of LPF values for each land use class (tab. 2). The results of simulations of land use change effects depend to a large extent on this relation. We used information from published research or from official statistics. Only for land use class pastures and meadows we estimated the agronomic value.

Table 1. Land use classes

land use type	land use class	
arable land	• arable land, general • arable land, soy (tillage) • arable land, soy (no tillage) • arable land, corn (tillage) • arable land, corn (no tillage)	• arable land, bean • arable land, sorghum • arable land, wheat • arable land, cotton
Horticulture	• coffee • fruits	• vegetables
grassland	• pastures and meadows	
(semi)natural vegetation	• Campo (grass savanna) • Cerrado (tree savanna)	• Mata Galeria (gallery forest) • bush land
Other	• afforestation (eucalyptus, pine) • burned areas • bare soils	

Table 2. Land use classes and values for landscape functions (Goldbach, 2010)

Landscape processes and functions (LPF)	value/parameter	Source
Sediment retention/soil erosion	C factor (USLE)	Morgan, 1995; Silva ,2007; Roose, 1976; Halbfaß & Grunewald, 2008; Wischmeier & Smith, 1978b; Collinet & Valentin, 1984
Agronomic value/yield	€ ha^{-1} a^{-1}	IBGE 2009
Water retention/runoff	CN value	US SCS, 1972; Gonçalves, 2007; Franke, 1994a, 1994b, 1995
Nitrogen retention/applied fertilizer	N kg ha^{-1} a^{-1}	FAO 2010

Examples, numbers in ( ) are standardized LPF values (0-100)

	Arable land, soy (tillage)		**Coffee**	
C factor	0.35	(65)	0.22	(78)
agronomic value	504 € ha^{-1} a^{-1}	(7)	1226 € ha^{-1} a^{-1}	(18)
CN value	72	(11)	66	(23)
N fertilizer	7 kg N ha^{-1} a^{-1}	(94)	115 kg N ha^{-1} a^{-1}	(0)

All values were standardized on a scale from 0-100, where 100 is highest fulfillment of LPF. For estimating the effect of land use on soil erosion we used the Cover-Management factor or C factor of the Universal Soil Loss Equation (Wischmeier & Smith, 1978). The C factor describes the complex effect of plant cover and tillage practice on soil erosion.

Agronomic values were taken from the official statistics of the Instituto Brasileiro de Geografia e Estatística (IBGE, 2009) on yield for the Federal District of Brasília. Per ha values were calculated from area and total value of agricultural products. The effect of land use on runoff control was assessed using the curve number method by the US Soil Conservation Service (US SCS, 1972). The CN value gives the runoff/precipitation ratio for each land use class. We standardized the CN value for the hydrologic condition "fair" and the "hydrologic soil group A", both are most common in the study area. For the impact of land use on water quality we used the amount of applied nitrogen fertilizer. Amounts were taken from a study on Brazilian fertilizing practice by the Food and Agriculture Organization of the UN (FAO 2010) (tab. 2).

In a second step we mapped landscape properties and potentials (LPP´s) (fig. 2 b) which control land use effects on LPF`s. We used simple methods that have been developed in landscape assessment and that are based on site properties, e.g. texture, slope and other (tab. 3). The final step will be the implementation of values of land use classes (fig. 2 a) and values of LPP´s (fig. 2 b) into the tool letsmap do Brazil.

Table 3. Landscape properties and potentials (LPP´s).

Landscape processes and functions (LPF)	**Landscape property and potential (LPP) & method**
Sediment retention/soil erosion	Sediment input into river network [erodibility (Hennings, 1994) & distance to river network (buffer 100 m)]
Water retention/runoff	Runoff control after Zepp (in Marks, 1992)
Agronomic value/yield	Suitability for agricultural use (Spera et al. 2004)*
Nitrogen retention/applied fertilizer	N export (Müller 2004)*

* not yet implemented

For test simulations we used a scenario that is based on real land use (fig. 4 a) and three non-realistic test scenarios of dominance of fruit plantations, afforestation, or savannah vegetation (Cerrado) (fig. 4 b-d). The average values for LPF´s are low for agronomic value for the scenarios real land use, afforestation, and Cerrado. However this is an effect of averaging and does not present the total agronomic value of all arable land.

For the scenarios Cerrado and afforestation an increase in retention of sediment, water, and nitrogen is to notice, since this land use classes imply a better protection of soil surfaces against erosion, no or only little fertilizer application, and higher infiltration rates. A contrasting scenario is the total change of arable land into fruit plantations, which results in a substantial increase of agronomic value, a decrease of N retention, i.e. higher fertilizer amounts, and lower soil erosion/sediment input. However, these scenarios are only thought to present the basic idea and the function of letsmap do Brazil and have only a very limited background in the real world.

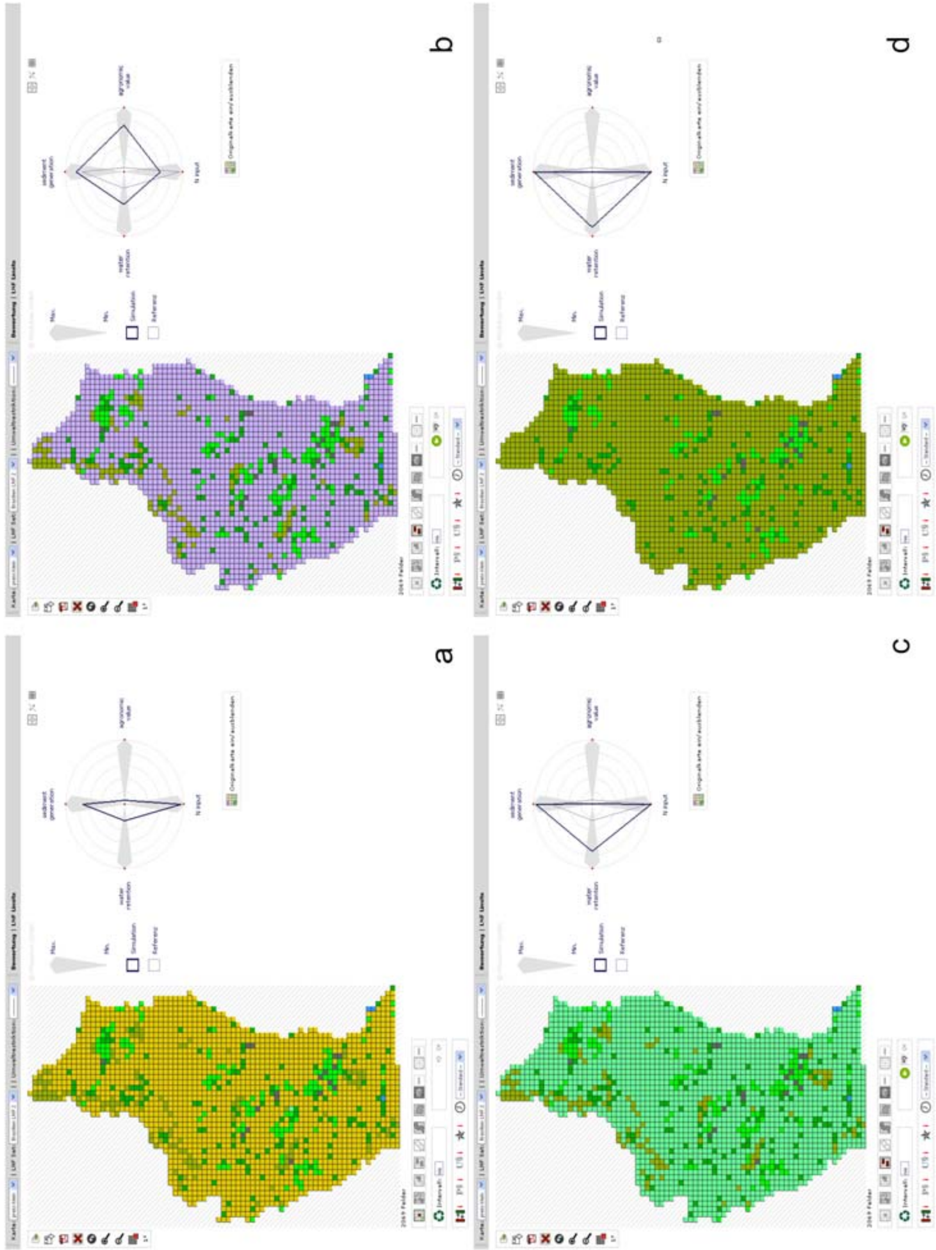

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Figure 4. Test simulation with letsmap do Brazil for catchment with (a) scenario arable land (real land use), (b) scenario fruit plantation, (c) scenario afforestation, (d) scenario Cerrado

The final step will be the implementation of landscape properties to make the tool spatially explicit. For the LPP runoff control we produced a map (fig. 5) after the method by Zepp (in Marks, 1992) (fig. 3). The map shows a more or less even distribution of mapping units. Areas with a low potential of water retention have mostly soils with low infiltration rates, while areas with high potential of water retention belong to hydrologic groups A and B with high to moderate infiltration rates (Gonçalves, 2009).

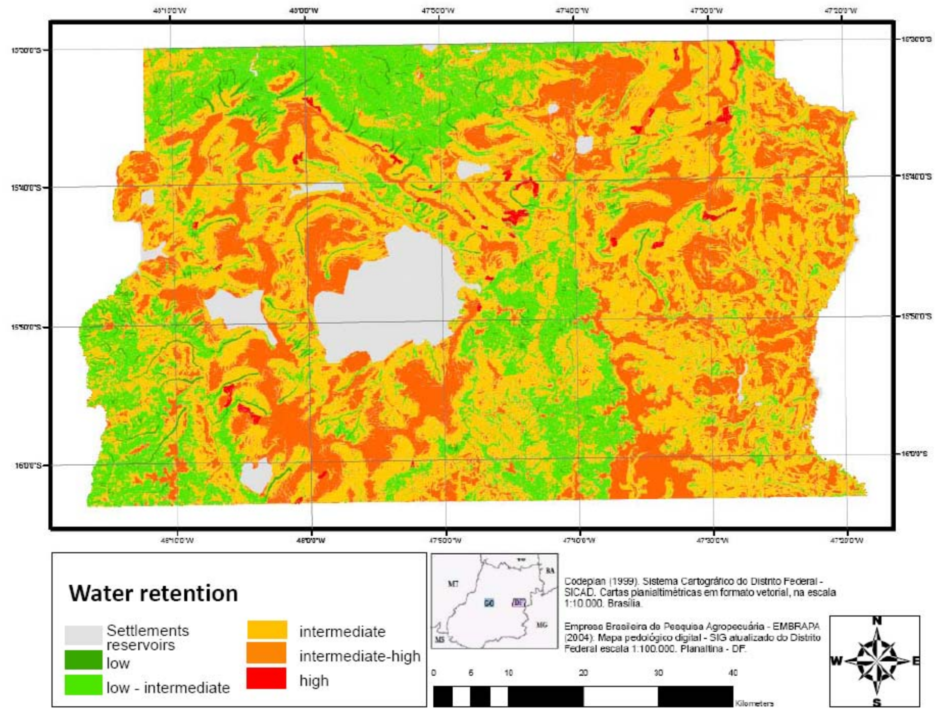

Figure 5. LPP runoff control (water retention) (Goldbach, 2010).

However the assessment of runoff control is complex. During the dry season the surface runoff should be at maximum to add water to the reservoirs. In contrast, during the rainy season an increased infiltration is desirable, since the recharge of groundwater stores water that will be the major source for surface waters during dry season.

Discussion and Conclusion

A major challenge in preventing silting of reservoirs and sediment transport into river networks is the involvement of land users and their activities in a sediment management plan. With *letsmap do Brazil* we have developed a planning support tool that is able to integrate different aspects of land use that might be contradicting. With *letsmap do Brazil* we will be able to show the effects of land use change on the LPF´s soil erosion (sediment input into river network), runoff control (water retention), nitrogen export and agronomic value.

An additional, future step is the implementation of LPP´s to make the system spatially explicit. An example is the effect of runoff concentration in channel networks (hydrologic connectivity) and its effect on sediment input into the river network. LPP´s will provide in combination with values specific to land use classes a more realistic assessment of land use effects. However, this will be a major challenge, both in terms of technology and intellectual input, for our future work.

We see a great potential to support an integrating view on landscapes, e.g. in watershed management, and to provide a base for trade-offs by using the tool *letsmap do Brazil.* Visualization of land use change, transparency and user friendly handling of the system will enable stakeholders with different backgrounds to participate in planning and management processes.

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