Hydrologic model parameters applied to the Brazilian Cerrado

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This document summarizes the values used to parameterize the surface hydrologic models for our study area in southeastern Brazil. For a summary of the models, refer to the The Nature Conservancy (TNC) website provided above and Tallis et al. (2013). The values are based on an extensive literature review, using studies from the Cerrado biome in Brazil whenever possible. The literature search was based on key words for each parameter in Google Scholar and Web of Science. The final parameter values used for modeling were reviewed by hydrology experts at the Natural Capital Project. In all models, we used pixel sizes with 90-meter resolution. The summary statistics are based on the values from published studies (we treated each parameter value as a unique data point).

Parameters that vary by soil type

This section describes the soil types for our study area (Table 1), the parameters and the assumptions used to generate the values for the sediment retention model. The finalized values for soil erodibility are given in Table 2.

Soil classification systems

Nine soil types are found in our study area (Table 1, column 2): Argissolo vermelho-amarelo Distrófico típico, Cambissolo Háplico Tb Eutrófico, Gleissolo Melânico Distrófico Hístico, Latossolo vermelho Distroférrico típico, Latossolo vermelho Distroférrico típico + Nitossolo vermelho Eutroférrico típico, Latossolo vermelho Distrófico típico, textura muito argilosa, Latossolo vermelho Distrófico, textura muito argilosa + Latossolo vermelho-amarelo Distroférrico, textura argilosa, Latossolo vermelho Eutroférrico + Latossolo vermelho Distroférrico, Neossolo quartzarênico Órtico típic. Based on area, the dominant soil type is red latosols, latossolo vermelho distrófico típico, textura muito argilosa, covering 59% of the study area (Table 1). Because of the lack of studies providing values for model parameters, we aggregated the categories into 5 soil types (Table 1, column 3). The reclassification masks differences between the subtypes (e.g., eutrophic latisols and dystrophic latisols), which may differ in productivity. However, the differences between the eutrophic and dystrophic soil types in our study area are expected to be small as the soil property (i.e. dystrophic/eutrophic) is concerned with soil nutrient cations that are not assumed to be primary drivers of the nitrate dynamics. Similarly, because the sediment model does not consider differences in productivity within a soil type, the aggregation of the soil categories does not affect its performance in our analyses. Therefore, ignoring these subcategories is not expected to affect the model results.

Multiple soil classification systems exist in the literature. Because previous studies on the properties of soils in Brazil used different soil classification systems to describe the same soil types, we synchronized the soil categories according to Silva et al. (2011) (Table 1, column 4).

Location of the studies

We narrowed the literature review to studies done in Minas Gerais or the neighboring states of Goiás, São Paulo, Rio de Janeiro, Bahia or Espírito Santo, whenever possible. When parameter values for these locations were not available, we recorded values for the parameters of interest from other locations in Brazil. The location of the original studies which we used to parameterize our models is indicated in the parameter tables.

Special considerations

The InVEST water yield model uses plant available water capacity (PAWC) parameters that vary both by soil type and vegetation (Tallis et al. 2013);[1] PAWC is a function of the Field Capacity and Wilt parameters, the soil depth and the root depth. We were able to find studies with AWC (available water capacity of soils) values for our study area, but they did not report soil and/or root depths. From the AWC values it is not possible to disentangle the soil and vegetation-specific parameters to obtain values for the PAWC for each soil type. Using the PAWC values reported from different studies applicable to our study area is also not optimal as we could not locate values for all soil types (e.g., there are no reported PAWC values for neosols) or could only find values for studies done in global settings (e.g., Nigeria or Turkey).

As a way to circumvent the problem of the AWC parameter not varying by vegetation type, we use different values for the omega (ω) parameter (that also varies per pixel) based on Zhang et al. (2001) for natural vegetation and agriculture.[2] For wetlands, water and developed areas (infrastructure, urban and roads), we use the values for AET (Etk) directly without specifying ω or Z (Allen et al. 1998; Tallis et al. 2013).[3] We summarize the values for ω in Table 3 below and the AET (Etk) values in Tables 4 & 6.

Parameters that vary by land use/land cover (LULC)

This section describes the parameters and the assumptions used to generate the values for parameters in the water yield and nutrient retention models (Table 5). For the finalized values (given in Tables 3-10), whenever possible, we report values from our study area or the states immediately adjacent (Espírito Santo, Bahia, Rio de Janeiro, São Paolo and Goiás). Details on the assumptions and data processing are outlined below. Definitions of the variables used for the water yield and nutrient retention models are given in Table 5.

Land use categories

The land use/land cover (LULC) categories we used in the hydrological models are given in Table 3. Most of the other row crops in our study area appear to be herbaceous annual crops (based on investigation of aerial photos and satellite imagery). Because of the lack of prior studies, we treated the cerradao (broad-leafed forest) as identical to semi-deciduous forests in terms of their LULC parameters and assigned the same values to these two habitat types. We also assigned values reported for "commercial" land use to our "infrastructure" category. We treated "pasture" and

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[1] Note that the InVEST models assume away heterogeneity within a soil or LULC type. See the section on assumptions and limitations for the models in the hydrology model summary.

[2] Note also that we used the older version of the InVEST models (v2.5.5 from 2013) as the newer version (3.0) was not available at the onset of the project. The new version of the models use the values suggested by Donohue et al. (2012), which are different empirical estimates.

[3] Note that the updated versions of the InVEST hydrology models use the values for omega from Donohue et al. (2012), who derive them from a slightly different empirical model.

"grassland" as separate categories; in other words, we did not record parameter values reported for "grassland" in the database.[4] Because values for "roads" were very rarely available, we lumped the category with "infrastructure". We assigned values for disconnected water bodies similar to water bodies with stagnant water (e.g., canals). However, ditches and canals are not common in our study area. The original database distinguished between the two types, whereas the final tables aggregate all water bodies into a single "water" category.

No studies reported values for Eucalyptus for several parameters; in these cases, we assigned it values based on other forest and crop types. Given the small extent of Eucalyptus in our study area (0.1%), this attribution is not expected to introduce a large bias in model outcomes.

Evapotranspiration

Table 6 reports Etk values per LULC type. Note that these values were obtained from separate studies and may not use the same annual reference evapotranspiration (Et0), which may vary by year and location depending on the amount of rainfall, solar radiation and wind speed at a particular location (FAO).[5]

Nutrient loads

The InVEST model conceptually represents the sources (N or P loads) and sinks (capture fractions) of nutrients in the landscape, and computes the nutrient budget to estimate in-stream nutrient loads. No distinction is made between surface and subsurface flow paths, which allows the load and capture fractions to be adjusted to represent both transport processes. Thus, the model output (i.e., exported N) is interpreted as the in-stream nitrate load, under the assumption that most N sources are in the form of nitrate or are transformed during the transport (nitrification process).

In calculating the values of model parameters (Tables 7-9), we excluded studies that reported extreme values (e.g., Verhoeven et al. 2006; Day et al. 2004; Alvarez-Cobelas et al. 2008; Rivera et al. 2007) as those were likely from areas that had high levels of pollutants, thus, would not be representative for our system.[6] In cases where the literature review did not yield credible studies, we used an unpublished global database provided by the Natural Capital Project (NatCap) (http://www.naturalcapitalproject.org/) that summarizes previous published values from around the world.[7]

Reported parameters are annual averages; we did not model the impact of seasonality. The reported values pertain to surface flows and exclude any potential nutrient leaching into the groundwater. The

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[4] The distinction was necessary because of the differences in the plant species composition and management of the two landcover classes. In our study area pastures tend to be dominated by Brachiaria grasses, which are introduced by Africa. In contrast, grassland species are more diverse and include *Tristachya leiostachya Nees, Axonopus pressus (Nees) Parodi, Tristachya chrysothrix Nees, Hyparrhenia rufa (Nees) Stapf, Andropogon lateralis (Spreng.) Nees, A. condensatus H.B.K. and Melinis minutiflora* (Goodland, 1971; Kaufman 1994). Furthermore, pastures are often fertilized to increase their productivity.

[5] Details on estimating the reference evapotranspiration, Et0, can be found here: http://www.fao.org/docrep/x0490e/x0490e06.htm

[6] The studies report values from parts of the US (Louisiana, Mississippi, and the Everglades), Amazonas, or averages for global tropical forests. Because the values reported in these papers were sometimes orders of magnitude higher than the rest of the studies, they were treated as outliers.

[7] A study was deemed credible if it was on the same order of magnitude with other studies. For example, we excluded Brinkman et al, 1985 who reported N loads of 29,000g/ha/year for cerradao in Amazonas, Brazil.

reason is that the InVEST nutrient models do not distinguish between surface and subsurface flows and instead assume that the nutrient load and retention parameters represent both transport processes.

Irrigation

We did not account for potential irrigation when summarizing the parameter values. The usage, frequency and amount of irrigation in our study area were unknown. If irrigation were commonly practiced in our study area, its omission could result in the overestimation of the sediment and nutrient retention. However, this overestimation would be consistent across our modeling scenarios, and, thus, would not bias our conclusions given our results focus on relative comparisons. Note also that the InVEST water yield model assumes that either there is no irrigation, or the irrigation uses water from the study area only.

Capture fractions

The retention coefficients are a lumped representation of the biochemical processes that occur during the nutrient transport to the stream. They are determined empirically based on local studies. While we were able to find local studies that report total nitrogen (TN) and total phosphorous (TP) capture fractions for sugarcane and forests, none were available for the other LULC categories. Thus, for the remaining LULC types we included values based on experimental plots 20 meters in length; the capture fractions were measured by The Nature Conservancy (TNC)-Brazil (Table 10).

As a robustness check we compiled a database of all published studies that report capture fractions by LULC type. The literature reports capture fractions in terms of different Nitrogen (N) and Phosphorus (P) compounds (e.g., nitrates, ammonia, phosphates). While we created a database for all capture fractions using the published literature and the NatCap database, in the final table we report only the values in terms of Total Nitrogen (TN) and total Phosphorus (TP). We classified the available studies in two groups based on the study location: "tropical" if within 36 degrees from the Equator and "non-tropical/global/unstated". The "tropical" locations include the US states of North Carolina, Georgia, Louisiana, Florida, California, Mississippi and Arizona as well as countries like Brazil, Mexico, Australia, Malaysia and China. Whenever possible, we tried to report values from our "tropical" group. When there were no such studies, we reported the global estimates.

We classified the reported LULC categories based on a description of the dominant vegetation. For example, plots covered by fescue, switch grass, orchard grass and Indian grass were considered "pasture", whereas mowed grass, wet meadows and rye grass were not. Combinations of trees and grass were considered "shrubland". We considered any LULC that includes asphalt and mowed grass as "urban"; however, in some cases, the "urban" category includes retention cells, designed to maximize the capture of nutrients. For this reason, the estimates for this LULC class may overestimate the actual capture fractions of urban landscapes; however, "urban" areas made up only 0.2% of the current land cover and did not vary across our scenarios, thus, this overestimate will not bias our conclusions. In summarizing the values from the literature, we ignored negative capture fractions as those are likely the result of short-term events (e.g., nitrification or heavy rainfall that leads to rapid inputs of nitrogen) (Mayer et al, 2007). A summary of the parameter values from published studies is presented in Table 11. Note that the values from this table were used for comparison purposes only and were not input into the final InVEST models.

In summarizing the capture fraction values for our study area, we did not consider the area of the field that is the source for runoff, the irrigation and rainfall amounts, the duration of the studies and seasonality, soil type, the slope and the age of the buffers (Zhang et al, 2010). We also ignored storm frequency, rainfall amounts and the hydrological conditions at the site. These factors, along with climate, are likely to impact the capture fractions (Zhang et al, 2010; Mayer et al, 2007; Arora et al, 2010). For the sediments, the particle size and soil type are also likely to impact the retention or capture fraction (Dosskey, 2001).

Rescaling capture fractions

The summary capture fraction parameter values also do not distinguish buffer widths. Because of the rather coarse resolution at which we performed the analysis (90-meter resolution), we did not rescale the parameters obtained from the literature review or experimental designs. The reason is the reported thresholds of 25-50m for the capture fractions, such that capture fractions are found to level off once the threshold has been reached (Zhang et al, 2010). Below we expand on this point and present evidence for similar threshold effects using the database of previous studies we have compiled from various sources (Fig. 1 & 2).

To date, very few studies have looked at the relationship of capture fractions and buffer width systematically (Dosskey, 2001; Zhang et al, 2010). The existing evidence on the relationship of capture fractions and buffer widths pertains to grass and forest only (e.g., Zhang et al, 2010). Furthermore, because of the limited number of studies, the meta-analyses lump all nutrient compounds by Phosphorus- or Nitrogen-based (e.g., they treat total nitrogen, nitrates and ammonia as similar compounds) and do not consider individual thresholds for each of the compounds.

Previous studies have indicated a positive relationship between the nutrient capture fractions and the width of a buffer for small buffer widths (Lee et al, 2003; Zhang et al, 2010). For example, Lee et al (2003) find that increasing the buffer width from 7m to 16.3m results in a 20% increase in capture fractions for a soluble nutrient. Performing a meta-analysis of published studies, Zhang et al (2010) find that the efficiency initially increases with the buffer width, but levels off at a maximum of 25-40m regardless of the slope. Similarly, Dosskey (2001) shows that most of the nitrate retention (or capture) occurs within 10-30m of the buffers. Mayer et al (2007) find that wider buffers (>50m) removed more N than narrower buffers (<25m), but also find evidence of threshold effects: The marginal increases in the surface capture fractions appear very small past 30-40m (e.g., Fig. 1 in their paper); the subsurface removal of nitrogen did not appear to be affected by the buffer width. They predict nitrogen removal efficiencies of 65-75% and 80-90% for wetland buffers of 15 and 30m, respectively, for nitrates.

Dealing with missing values for erosion susceptibility

Studies reporting values for the land management factor, P, were not available for cerrado, infrastructure, wetlands and Eucalyptus LULC categories. For this reason, we assigned them a value of 1.00. Doing so implies that management does not affect the susceptibility to erosion factor, C (Note, that P values smaller than 1 mitigate the impact of C, making the LULC category less susceptible to erosion). For the missing value for C for the infrastructure category, we assigned a value of 0.06, which is the same as for urban residential category. For the phosphorus and nitrogen capture fractions for Eucalyptus, we used the values from the other row crops.

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References

Allen RG, Pereira LS, Raes D, Smith M, Ab W (1998) Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56 By: 1–15.

Allen RG, Tasumi M, Morse A, Trezza R, Wright JL, et al. (2007) Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC) — Applications. J Irrig Drain Eng 133: 395–406.

Alvarez-Cobelas M, Angeler DG, Sánchez-Carrillo S (2008) Export of nitrogen from catchments: a worldwide analysis. Environ Pollut 156: 261–269.

Alves JS, Gomes I, Machado ML, Vieira EM, Simao MLR, et al. (2009) Levantamento dos fatores da Equação Universal de Perdas de Solo (Eups) para o delineamento de áreas com potencial erosivo da Bacia do Rio Paranaíba (PN1 – IGAM).

Arora K, Mickelson SK, Helmers MJ, Baker JL (2010) Review of pesticide retention processes occurring in buffer strips receiving agricultural runoff. Journal Am Water Resour Assoc 46: 618–647.

Barbiero L, Neto JP, Ciornei G, Sakamoto AY, Capellari B, et al. (2002) Geochemistry of water and ground water in the nhecola pantanal of mato grosso , brazil : variability and associated processes. Wetlands 22: 528–540.

Beskow S, Mello CR, Norton LD, Curi N, Viola MR, et al. (2009) Soil erosion prediction in the Grande River Basin, Brazil using distributed modeling. Catena 79: 49–59.

Brinkman WL (1985) Studies on hydrobiogeochemistry of a tropical lowland forest system. GeoJournal 11: 89–101.

Cabral OMR, Rocha HR, Gash JH, Ligo M a. V., Tatsch JD, et al. (2012) Water use in a sugarcane plantation. GCB Bioenergy 4: 555–565.

Chuquipiondo IGV (2007) Avaliacao da estimava do potencial de erodibilidade de sols nas margens de cursos de agua: Estudo de case trecho de vazao reduzida capim branco I araguari Minas Gerais Escola de Engenharia da Universidade federal de Minas Gerais.

Day JW, Ko J-Y, Rybczyk J, Sabins D, Bean R, et al. (2004) The use of wetlands in the Mississippi Delta for wastewater assimilation: a review. Ocean Coast Manag 47: 671–691.

Donohue RJ, Roderick ML, McVicar TR (2012) Roots, storms and soil pores: Incorporating key ecohydrological processes into Budyko's hydrological model. J Hydrol 436-437: 35–50.

Dosskey MG (2001) Toward quantifying water pollution abatement in response to installing buffers on crop land. Environ Manage 28: 577–598.

Filoso S, Martinelli LA, Howarth RW, Boyer EW, Dentener F (2006) Human activities changing the nitrogen cycle in Brazil. Biogeochemistry 79: 61–89.

Furquim SAC, Graham RC, Barbiero L, de Queiroz Neto JP, Vallès V (2008) Mineralogy and genesis of smectites in an alkaline-saline environment of Pantanal wetland, Brazil. Clays Clay Miner 56: 579–595.

Guenni O, Marin D, Baruch Z (2002) Responses to drought of five Brachiaria species. I . Biomass production, leaf growth, root distribution, water use and forage quality. Plant Soil 243: 229–241.

Hamilton SK, Sippel SJ, Melack JM (1995) Oxygen depletion and carbon dioxide and methane production in waters of the Pantanal wetland of Brazil. Biogeochemistry 30: 115–141.

Lathuillière MJ, Johnson MS, Donner SD (2012) Water use by terrestrial ecosystems: temporal variability in rainforest and agricultural contributions to evapotranspiration in Mato Grosso, Brazil. Environ Res Lett 7: 024024

Lewis WM (1986) Nitrogen and Phosphorus Runoff Losses from a Nutrient-Poor Tropical Moist Forest. Authors: William M . Lewis , Jr . Published by: Ecological Society of America Stable

Martins CA (2011) Estimativa da evapotranspiração no estado de São Paulo com o modelo da biosfera SiB2 Universidade de Sao Paulo.

Martins JD, Rodrigues GC, Paredes P, Carlesso R, Oliveira ZB, et al. (2013) Dual crop coefficients for maize in southern Brazil: Model testing for sprinkler and drip irrigation and mulched soil. Biosyst Eng 115: 291–310.

Martins SG, Avanzi JC, Silva MLN, Curi N, Norton LD, et al. (2010) Rainfall erosivity and rainfall return period in the experimental watershed of Aracruz in the coastal plain of Espirito Santo, Brazil. R Bras Ci Solo 34: 999–1004.

Mayer PM, Reynolds SK, McCutchen MD, Canfield TJ (2007) Meta-analysis of nitrogen removal in riparian buffers. J Environ Qual 36: 1172–1180.

Mello CR, Viola MR, Norton LD, Silva AM, Weimar FA (2008) Development and application of a simple hydrologic model simulation for a Brazilian headwater basin. CATENA 75: 235–247.

Quesada CA, Hodnett MG, Breyer LM, Santos AJB, Andrade S, et al. (2008) Seasonal variations in soil water in two woodland savannas of central Brazil with different fire history. Tree Physiol 28: 405–415.

Reckhow KH, Beaulac MN, Simpson JT (1980) Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficients. Washington, DC.

Rivera EC, de Queiroz JF, Ferraz JM, Ortega E (2007) Systems models to evaluate eutrophication in the Broa Reservoir, São Carlos, Brazil. Ecol Modell 202: 518–526.

Ruhoff AL, Souza BSP, Giotto E, Pereira RS (2006) Avaliacao dos processos erosivos atraves da equacao universal de perdas de solos, implementada com algoritmos em legal. Geomatica 1: 12–22.

Santos CR, Rosa R (2011) Anais XV Simpósio Brasileiro de Sensoriamento Remoto - SBSR, Curitiba, PR, Brasil, 30 de abril a 05 de maio de 2011, INPE p.1153. Anais XV Simposio Brasileiro de Sensoriamento Remoto. Curitiba, PR. pp. 1153–1160.

Santos RS., Oliveira IP, Morais RF, Urquiaga SC, Boddey RM, et al. (2007) Componentes da parte aérea e raízes de pastagens de Brachiaria spp. Em diferentes idades após a reforma, como. Pesq Agropec Trop 37: 119–124.

Sao Paolo Environmetal Agency (2010) Governo do estado de Sao Paulo SMA/CPLA.

Silva AM, Mello CR, Curi N, Oliverira PM (2008) Simulacao da variabilidade espacial da erosao hidrica e uma sub-bacia hidrografica de latossolos no sul de Minas Gerais. R Bras Ci Solo 32: 2125–2134.

Soares J V, Almeida AC (2001) Modeling the water balance and soil water fluxes in a fast growing Eucalyptus plantation in Brazil. J Hydrol 253: 130–147.

Sparovek G, Schnug E (2001) Temporal Erosion-Induced Soil Degradation and Yield Loss. Soil Sci Soc Am J 65: 1479.

Stape J., Binkley D, Ryan MG (2004) Eucalyptus production and the supply, use and efficiency of use of water, light and nitrogen across a geographic gradient in Brazil. For Ecol Manage 193: 17–31.

Tallis, H.T., Ricketts, T., Guerry, A.D.,Wood, S.A., Sharp, R., Nelson, E., Ennaanay, D.,Wolny, S., Olwero, N., Vigerstol, 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., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., and Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M. (2013). InVEST 2.5.5 User's Guide. The Natural Capital Project, Stanford.

Tasumi M, Allen RG, Trezza R, Wright JL (2005) Satellite-Based Energy Balance to Assess Within-Population Variance of Crop Coefficient Curves. J Irrig Drain Eng 131: 94–109.

Verhoeven JT a, Arheimer B, Yin C, Hefting MM (2006) Regional and global concerns over wetlands and water quality. Trends Ecol Evol 21: 96–103.

Wilcke W, Lilienfein J (2005) Nutrient Leaching in Oxisols Under Native and Managed Vegetation in Brazil. Soil Sci Soc Am J 69: 1152.

Williams MR, Melack JM (1997) Solute export from forested and partially deforested catchments in the central Amazon. Biogeochemistry 38: 67–102.

Zhang L, Dawes WR, Walker GR (2001) Response of mean annual evapotranspiration to vegetation changes at catchment scale. Water Resour Res 37: 701–708.

Zhang X, Liu X, Zhang M, Dahlgren R, Eitzel M (2010) A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. J Environ Qual 39: 76–84.

Figures

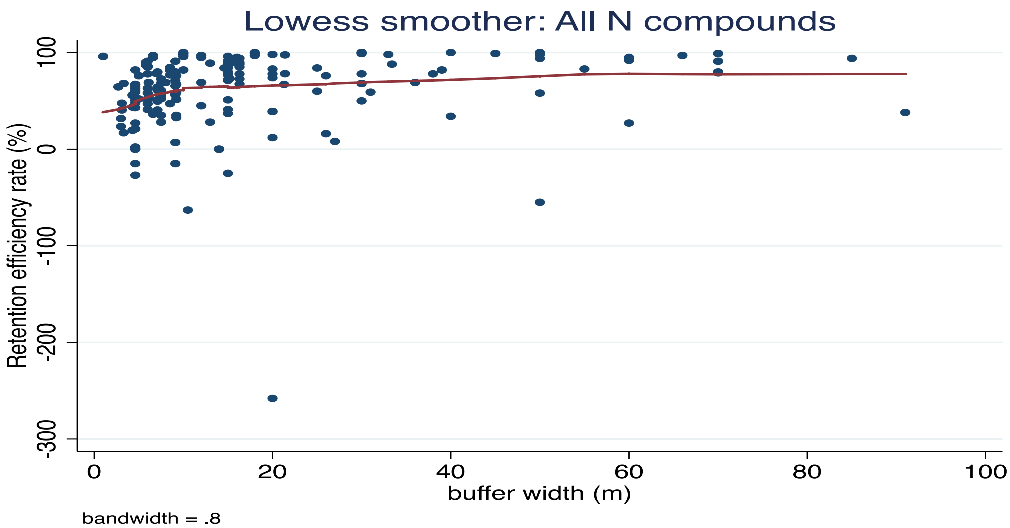

Figure 1. Nitrogen retention as a function of buffer width (n=183). Because of the relatively small numbers of studies distinguishing between TN, TKN, NH_4, NO_3-N, and NO_3, we lump all N compounds. The graph does not distinguish between the LULC types. Separate graphs on the relationship of Total Nitrogen (TN) and buffer width and TN and buffer width by grass and forest cover are available upon request.

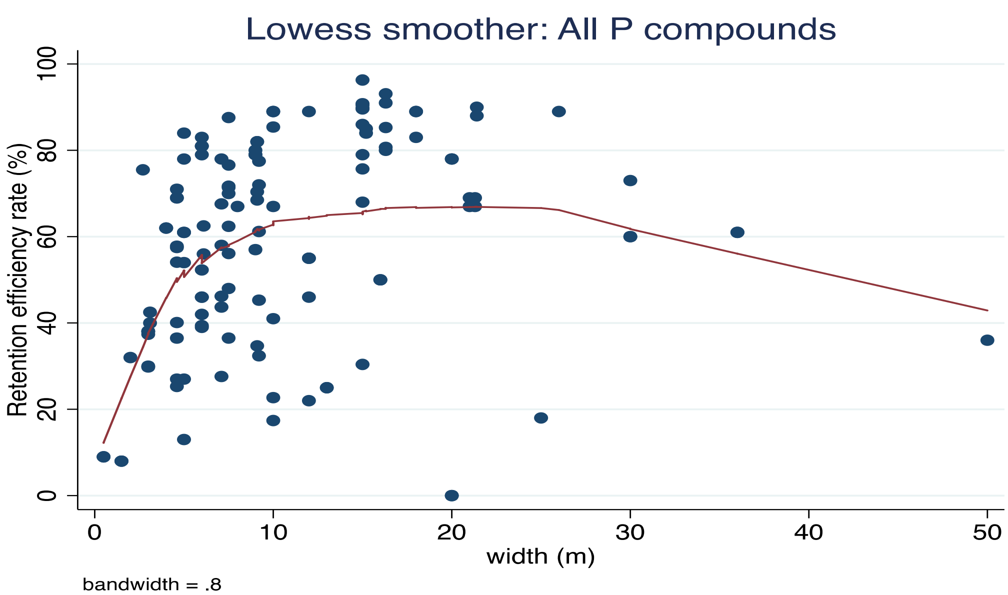

Figure 2. Phosphorus retention as a function of buffer width (n=128). Again, the graph lumps all Phosphorus compounds and does not distinguish between LULC types (grass vs. forest or a mixture thereof).Separate graphs on the relationship of Total Phosphorus (TP) and buffer width and TP and buffer width by grass and forest cover are available upon request.

Tables

Table 1. Soil types in our area according to the different soil classification systems. The categories according to the Brazil soil taxonomy are given in (3) and their USDA counterparts in (4). Columns (5) & (6) are in reference to the total area of our study watershed.

Soil code (1)	Name (Portuguese) (2)	Aggregated soil type (3)	Translated soil types (4)	Area (in km^2) (5)	% of Total Area (6)
CXbe8	Cambissolo Háplico Tb Eutrófico	Cambisols (CAMBISSOLO HÁPLICO)	Inceptisols	31.25	1.13
GMd4	Gleissolo Melânico Distrófico Hístico	Gleisols (GLEISSOLO MELÂNICO)	Entisols	43.54	1.58
LVd1	LATOSSOLO VERMELHO Distrófico típico, textura muito argilosa	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	1635.64	59.26
LVd11	LATOSSOLO VERMELHO Distrófico típico, textura muito argilosa	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	171.74	6.22
LVd2	LATOSSOLO VERMELHO Distrófico, textura muito argilosa + LATOSSOLO VERMELHO-AMARELO Distroférrico, textura argilosa	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	70.91	2.57
LVd6	LATOSSOLO VERMELHO Distrófico típico, textura muito argilosa	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	31.55	1.14
LVdf1	LATOSSOLO VERMELHO Distroférrico típico + NITOSSOLO VERMELHO Eutroférrico típico	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	219.19	7.94
LVdf2	LATOSSOLO VERMELHO Distroférrico típico	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	64.95	2.35
LVef1	LATOSSOLO VERMELHO Eutroférrico + LATOSSOLO VERMELHO Distroférrico	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	83.55	3.03
LVef2	LATOSSOLO VERMELHO Eutroférrico + LATOSSOLO VERMELHO Distroférrico	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	36.27	1.31
PVAd7	ARGISSOLO VERMELHO-AMARELO Distrófico típico	ARGISSOLO VERMELHO-AMARELO	Red-yellow ultisols	313.64	11.36
RQo1	NEOSSOLO QUARTZARÊNICO Órtico típico	NEOSSOLO QUARTZARÊNICO	Quartzipsamment	57.85	2.10

Table 2. Values for the soil erodibility parameter (K). It captures susceptibility to erosion according to soil physical properties.[8] Values denoted by the symbol †are from non-local studies (i.e. outside Minas Gerais, Rio de Janeiro, Bahia, Espírito Santo, Goiás or São Paolo).

	K (erodibility), in t ha MJ^{-1} mm^{-1}					
Soil type	**Count**	**Average**	**Std dev**	**Min**	**Max**	**Source**
Argissolo vermelho-amarelo	2	0.03	0.00	0.03	0.03	Alves et al, 2009; Santos & Rosa, 2011
Cambisols (Cambissolo háplico)	5	0.02	0.01	0.01	0.02	Alves et al, 2009; Silva et al, 2008; Beskow et al, 2009
Gleisols (Gleissolo melânico)	3	0.04	0.03	0.00	0.07	Alves et al, 2009; Chagas et al, 2011; Silva et al, 2011
Latisols (latossolos vermelho)	31	0.01	0.01	0.00	0.02	Alves et al, 2009; Chagas et al, 2011; Silva et al 2008, 2011; Santos & Rosa, 2011; Beskow et al, 2009
Neossolo quartzarênico	2†	0.08†	0.04†	0.05†	0.12†	Silva et al, 2011; Chagas et al, 2011

[8] It can also be calculated using the percent sand, clay and silt for each soil type.

Table 3. Values for omega (ω) for the landcover/landuse (LULC) classes in our study area based on empirical estimates from Zhang et al (2001). Note that because of the vegetation in wetlands, we do not use the Etk values directly for that LULC category.

Original LULC Class	Reclassified LULC Class	ω
Cerradão (Broad leaf Forest)	Cerradao	2
Cerrado (Shrubland)	Cerrado	2
Semideciduous Forest	Forest	2
Riparian forest	Forest	2
Wetland	Wetland	2
Pasture	Pasture	0.5
Sugarcane	Sugarcane	0.5
Row Crops (annual herbaceous)	Other cultivated	0.5
Eucalyptus Plantation	Other cultivated	2
Urban Development	Development	NA
Industrial/Commercial	Development	NA
Roads	Development	NA
Water bodies	Water	NA

Table 4. AET (Etk) values for the land cover/land use types that do not require a calculation of ω or Z. Note that these are the reported values from the literature (i.e., we did not obtain the Kc which we multiplied by an Et0 coefficient). The values are copied from Table 6.

LULC	AET (Etk) (in mm)
infrastructure	127.33
urban	554
water	937.5

Table 5. List of parameters and definitions to be used in the water yield and nutrient retention models.

Parameter	Code	Parameter description	unit
Land use-specific evapotranspiration[9]	Etk	Land cover-specific evapotranspiration Etk (PET)=Et0*Kc	mm
Load P		Phosphorus loading coefficient for each LULC	g/ha/yr
Load N		Nitrogen loading coefficient for each LULC	g/ha/yr
P Capture (%)		vegetation's Phosphorus filtering efficiency	% per m^2
N Capture (%)		vegetation's Nitrogen filtering efficiency	% per m^2
C (Land cover factor)	C	Susceptibility to erosion according to protection given by each LULC	unitless
P (Land management Factor)	P	Susceptibility to erosion according to protection given by management type	unitless
Sediment Capture (%)		vegetation's sediment filtering efficiency	% per m^2

[9] Note there is some confusion in the InVEST manual v2.5.5 as to the vegetation-specific constant is listed: it appears both as Kc and Etk. In our model we clarify the distinction. In the InVEST manual Etk is referred to as "potential evapotranspiration" for each land cover type.

Table 6. Values for the evapotranspiration and root depth parameters using ***only local*** studies (from Minas Gerais, Bahia, Espírito Santo, Rio de Janeiro, Goiás and São Paolo), whenever possible (studies from outside our study area are indicated with †; values based on expert review -with ‡). These are the final values we used in the hydrology models.

		Etk (in mm)				
LULC category	**Count**	**Mean**	**St dev**	**Min**	**Max**	**Source**
Cerradao (Broad leaf forest)	2	1103.75	245.72	930.00	1277.50	Martins (2011); Mello et al, (2008)
Cerrado (Shrubland)	1	949.00	N/A	N/A	N/A	Martins, 2011
Eucalyptus plantation	3	1208.50	241.20	930.00	1350.50	Martins, 2011; Soares & Almedia, 2001; Mello et al, 2008
Forest (Semi-deciduous forest)	2	1103.75	245.72	930.00	1277.50	Martins (2011); Mello et al, (2008)
Infrastructure	1†	127.33†	N/A	N/A	N/A	Allen et al, 2007
Other cultivated	4	1057.50	360.54	604.5	1351	Mello et al, 2008
Pasture	1	912.50	N/A	N/A	N/A	Martins, 2011
Sugar cane	3	733.67	119.22	279.00	930.00	Martins, 2011; Cabral et al, 2012, Mello et al, 2008
Urban (including residential)	1	554.00†	N/A	N/A	N/A	Allen et al, 2008
Water	4	937.50†	151.30†	730.00†	1050.00†	FAO/InVEST; Allen et al, 2007
Wetlands	7	1275.71†	160.09†	1000.00†	1300.00†	Hamilton, 2002; Furquim et al, 2008; Allen et al, 2007; Barbiero et al, 2002

Table 7. Values for the Phosphorus (P) and Nitrogen (N) loads using ***only local*** studies (from Minas Gerais, Bahia, Espírito Santo, Rio de Janeiro and São Paolo), whenever possible (studies from outside our study area are indicated with †; values based on expert review with ‡). These are the final values we used in the hydrology models.

		P load (g/ha/year)				
LULC category	**Count**	**Mean**	**St dev**	**Min**	**Max**	**Source**
Cerradao (Broad leaf forest)	1	142.57	N/A	N/A	N/A	São Paulo Env Agency 2010
Cerrado (Shrubland)	4†	115.00†	62.43	50	200	TNC-NatCap database
Eucalyptus plantation		1262.75‡	N/A	N/A	N/A	
Forest (Semi-deciduous forest)	1	142.57	N/A	N/A	N/A	São Paulo Env Agency 2010
Infrastructure	1†	296.34†	N/A	N/A	N/A	São Paulo Env Agency 2010
Other cultivated	1	1262.75	N/A	N/A	N/A	São Paulo Env Agency 2010
Pasture	1	101.84	N/A	N/A	N/A	São Paulo Env Agency 2010
Sugar cane*	1	1262.75	N/A	N/A	N/A	São Paulo Env Agency 2010
Urban (including residential)	1	216.08	N/A	N/A	N/A	São Paulo Env Agency 2010
Water	8†	161.37†	249.51†	0.00†	650.00†	Lewis (1986)l NatCap database
Wetlands	5†	86.00†	150.27†	10.00†	130.00†	NatCap database

		N load (g/ha/year)				
LULC category	**Count**	**Mean**	**St dev**	**Min**	**Max**	**Source**
Cerradao (Broad leaf forest)	1	2190.00	N/A	N/A	N/A	São Paulo Env Agency 2010
Cerrado (Shrubland)	1	1500.00	N/A	N/A	N/A	Wilke& Lilienfein, 2005
Eucalyptus plantation		10767.50‡	N/A	N/A	N/A	
Forest (Semi-deciduous forest)	1	2190.00	N/A	N/A	N/A	São Paulo Env Agency 2010
Infrastructure	1†	6510.14†	N/A	N/A	N/A	São Paulo Env Agency 2010
Other cultivated	1	10767.50	N/A	N/A	N/A	São Paulo Env Agency 2010
Pasture	2	5412.50	5073.49	1825.00	9000.00	São Paulo Env Agency 2010; Filoso et al, 2003
Sugar cane*	1	10767.50	N/A	N/A	N/A	São Paulo Env Agency 2010
Urban (including residential)	1†	5812.63†	N/A	N/A	N/A	São Paulo Env Agency 2010
Water	7†	2601.42†	3485.15†	0.00†	9980.00†	Lewis, 1986; NatCap database
Wetlands	4†	1620.00†	4285.47†	550†	2330.00†	NatCap database

Table 8. Values for “developed” LULC cover, which combines roads, infrastructure and urban/residential.

Parameter	Count	Mean	St dev	Min	Max
Etk (in mm)	2	340.67	301.70	127.44	554.00
P load (g/ha/year)	2	256.21	56.75	216.08	296.34
N load (g/ha/year)	2	6161.39	493.21	5812.63	6510.14

Table 9. Values for erosion susceptibility parameters using ***only local*** studies (from Minas Gerais, Bahia, Espírito Santo, Rio de Janeiro and São Paolo), whenever possible (studies from outside our study area are indicated with †; values based on expert review-with ‡). These are the final values we used in the hydrology models.

	C (unitless)					
LULC category	**Count**	**Mean**	**St dev**	**Min**	**Max**	**Source**
Cerradao (Broad leaf forest)	5	0.01	0.0044	0.0001	0.01	NatCap database, Chquipiondo (2007); Beskow et al, 2009
Cerrado (Shrubland)	2	0.04	0.0000	0.04	0.04	Chquipiondo (2007); Alves et al, 2009
Eucalyptus plantation	1	0.01	N/A	N/A	N/A	Alves et al, 2009
Forest (Semi-deciduous forest)	6	0.01	0.0045	0.0001	0.01	NatCap database, Chquipiondo (2007); Beskow et al, 2009
Infrastructure	2‡	0.06‡	0.09‡	0.0010‡	0.12‡	
Other cultivated	7	0.27	0.17	0.02	0.55	NatCap database, Alves et al, 2009; Chquipiondo (2007); Beskow et al, 2009
Pasture	7	0.03	0.06	0.01	0.16	NatCap database, Beskow et al, 2009; Alves et al, 2009; Chuquipiondo (2007); InVEST USLE
Sugar cane	2	0.26	0.09	0.17	0.31	Alves et al, 2009; NatCap database
Urban (including residential)	2†	0.06†	0.09†	0.0010†	0.12†	NatCap database, Chuquipiondo (2007)
Water	2	0.07	0.10	0.0000	0.14	NatCap database, Chuquipiondo (2007)
Wetlands	1	0.0010	N/A	N/A	N/A	Chuquipiondo (2007)

	P (unitless)					
LULC category	**Count**	**Mean**	**St dev**	**Min**	**Max**	**Source**
Cerradao (Broad leaf forest)	2	0.55	0.64	0.10	1.00	NatCap database, Ruhoff et al, 2006
Cerrado (Shrubland)		1.00‡	N/A	N/A	N/A	
Eucalyptus plantation		1.00‡	N/A	N/A	N/A	
Forest (Semi-deciduous forest)	2	0.55	0.64	0.10	1.00	NatCap database, Ruhoff et al, 2006
Infrastructure		1.00‡	N/A	N/A	N/A	
Other cultivated	1	0.70	N/A	N/A	N/A	Ruhoff et al, 2006
Pasture	2	0.85	0.21	0.70	1.00	
Sugar cane	4	0.73	0.25	0.50	1.00	NatCap database
Urban (including residential)	1†	0.98†	N/A	N/A	N/A	NatCap database
Water	1	1.00	N/A	N/A	N/A	NatCap database
Wetlands		1.00‡	N/A	N/A	N/A	

Table 10. Capture coefficients adapted to our study area for sediment, total Phosphorus (TP) and total Nitrogen (TN) used for our models. Except for the urban areas, the values come from model calibration using local data for buffers of width 20m; these were carried out by The Nature Conservancy-Brazil. The footnotes for the cerradao also pertain to the semi-deciduous forest category.

Row Labels	Sediment Capture (%)	P Capture (%)	N Capture (%)	Source
Cerradao (Broad leaf forest)	80[10]	80[11]	80[12]	TNC Brazil
Cerrado (Shrubland)	50	50	50	TNC Brazil
Urban (including residential)	7.58[13]	6.38[14]	4.96[15]	TNC –NatCap database
Commercial/infrastructure	5	5	5	TNC Brazil
Eucalyptus	80	75	75	TNC Brazil
Forest (Semi-deciduous forest)	80	80	80	TNC Brazil
Other cultivated	50	50	50	TNC Brazil
Pasture	70	25	25	TNC Brazil
Sugar cane	50	25	25	TNC Brazil
Water	95	5	5	TNC Brazil
Wetlands	90	80	80	TNC Brazil

[10] Spavorek et al. (2002) found a capture fraction of 54% for riparian forests for a 52-meter wide buffer in Piracicaba, SE Brazil. This value was excluded from the table above.
[11] This estimate excluded the values from Brinkman et al (1985) who find a caption fraction of 91.78% in Manaus.
[12] Brinkman et al. (1985) also find a nitrogen capture fraction of 80% for Manaus.
[13] We used the global value from the TNC-NatCap nutrient retention database for urban sediment capture fractions given for a vegetated area within an urban setting and rescaled it using the proportion of urban area within our study region that is vegetated. Given the aerial photos, we decided on 10%.
[14] We rescaled the capture fractions using 10% vegetation cover within the urban areas within our study region.
[15] We rescaled the capture fractions using 10% vegetation cover within the urban areas within our study region.

Table 11. Capture fractions for sediment, total P and total N from the literature. Even though a very small number of studies were from Brazil, we tried to report values from tropical locations, whenever possible (the values from the non-tropical locations are indicated by †). Note, the urban capture fractions are given for vegetated patches within large urban areas. Sources: NatCap database and references therein. This table is used for comparison purposes only

Sediment capture (%)					
Land cover/land use	**Count**	**Average**	**St. dev**	**Min**	**Max**
Cerradao (Broad leaf forest)	21	71.29	17.44	22	98
Cerrado (Shrubland)	10	61.20	13.77	45	91
Urban (including residential)	5†	75.80†	21.09†	54†	99†
Commercial/infrastructure					
Eucalyptus	1	100.00	NA	NA	NA
Forest (Semi-deciduous forest)	21	71.29	17.44	22	98
Other cultivated	8†	81.25†	8.45†	70†	94†
Pasture	14	88.36	13.88	56	98
Sugar cane[16]	3†	94.33†	5.51†	89†	100†
Water					
Wetlands	18	71.50	28.69	9	100
Phosphorus capture (%)					
Land cover/land use	**Count**	**Average**	**St. dev**	**Min**	**Max**
Cerradao (Broad leaf forest)	2	75.39	23.18	59	91.78
Cerrado (Shrubland)	14†	66.12†	26.56†	18†	96†
Urban (including residential)	4	63.75	7.37	53	69
Commercial/infrastructure	2†	66.50†	2.12†	65†	68†
Eucalyptus	1	95.60		NA	NA
Forest (Semi-deciduous forest)	2	75.39	23.18	59	91.78
Other cultivated	16†	56.94†	28.83†	0†	98†
Pasture	2	86.50	6.36	82	91
Sugar cane	2	61.50	9.19	55	68
Water	1	61.00	NA	NA	NA
Wetlands	19	60.23	27.92	3	95
Nitrogen capture (%)					
Land cover/land use	**Count**	**Average**	**St. dev**	**Min**	**Max**
Cerradao (Broad leaf forest)	1	80.00			
Cerrado (Shrubland)	10†	63.57†	25.18†	28†	96†
Urban (including residential)	5	49.60	10.83	40	65
Commercial/infrastructure					
Eucalyptus	1	86.40	NA	NA	NA
Forest (Semi-deciduous forest)	1	80.00	NA	NA	NA
Other cultivated	6†	69.50†	32.03†	8†	98†

[16] These values appear to be rather large compared to our estimates for Minas Gerais. One explanation for the observed discrepancy may be the different sugarcane species and location (the values reported above pertain to Giant Cane (*Arundinaria gigantea*) grown in Illinois, USA).

Pasture	15†	52.89†	26.06†	0†	95†
Sugar cane	2	70.00	28.28	50	90
Water	7†	7.43†	6.97†	2†	22†
Wetlands	8†	41.00†	31.91†	6†	100†