First-order verification of hydrologic model predictions for the Brazilian Cerrado

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The InVEST hydrologic models were designed to represent the dominant processes of sediment/nutrient delivery and retention by land use/ land cover (LULC). Since they are not standard rainfall-runoff models, classical calibration and testing methods are not always applicable. Testing and calibration were particularly difficult in our study region due to: i) the absence of local data (e.g. in-stream sediment or nutrient concentration time series, contributions from point sources) to calibrate the model or a more sophisticated model, and ii) the existing uncertainties in nutrient/sediment dynamics in this region of Brazil (Thomas et al., 2004; Moreno-seceña et al., 2011; Filoso et al., 2006; Maillard & Santos, 2008) (e.g. magnitude of nutrient leaching from sugar cane fields, effect of cattle ranching).

InVEST sediment and nutrient model predictions, however, were checked against the local and global literature to confirm that their order of magnitude was credible.

Nutrient loads

We found that the InVEST model predictions for nitrogen loads were in the lower range of estimates derived from the literature: the range for Brazil studies was 0.05-4.667 ton N km^{-2} y^{-1} in a recent global synthesis (Supplementary information in Alvarez-Cobelas et al., 2008). Given the spatial and temporal variability of nutrient export, we then compared predicted annual loads with local studies reporting annual nitrogen and phosphorus loads from natural and anthropogenic sources for catchments in the Bahia State (de Paula et al., 2010) and Sao Paulo State (Cunha et al., 2011). This comparison was performed for two scenarios: (a) when 100% of our study watershed was comprised of natural habitat and (b) when 100% of our watershed was comprised of agriculture (mixture of sugarcane and pasture).

de Paula et al. (2010) directly reported average annual nutrient loads from natural and anthropogenic sources in Bahia State. For the comparison with the100% natural scenario in our study, we used the sum of the loads for all natural sources (atmospheric deposition and natural soil leaching) reported in that paper. For the comparison with 100% agriculture scenario, we used the sum of the natural sources and the weighted average of the loads for agricultural crops and cattle ranching. These values were found to be in the same order of magnitude as InVEST

results (Table 1). Because no confidence intervals were reported in the original study, these values should only be used as a rough estimate of the absolute loads.

Cunha et al. (2011) reported median concentrations for 319 sampling sites in agricultural and reference (natural) catchments for the Cerrado area of the Sao Paulo State. To convert concentrations into annual loads, we used the average annual flow from InVEST for our study catchment, which was equal to c. 400 mm for the natural catchment, and c. 700 mm for the agricultural catchment.[1] We note that the procedure to convert concentrations into annual loads comprises uncertainties, since the sampled days may not be representative of the whole range of flow rates. However, for the purpose of this exercise, these uncertainties are deemed reasonable (and their impact is quantified through the examination of the 10^{th} and 90^{th} percentiles of the data reported by Cunha et al. 2011). The InVEST nitrogen and phosphorus model predictions for both scenarios fell within the range reported in Cunha et al. (2011) (Table 1).

Table 1. Comparison of InVEST nutrient loads with local literature. Ranges denoted by [ ], when available, represent the 10^{th} and 90^{th} observed values reported in the original study.

Study	Natural (ton/km^2/yr)		Agricultural (ton/km^2/yr)	
	N	P	N	P
State of Bahia	0.073	0.003	0.160	0.060
State of Sao Paulo	0.125 [0.041; 0.543]	0.016 [0.004; 0.117]	0.638 [0.212; 3.331]	0.063 [0.014; 0.354]
InVEST output for our study area in Minas Gerais	0.063	0.004	0.268	0.022

Sediment loads

The sediment load predictions based on the InVEST model were within the order of magnitude of estimates for Latin America (reported range from 1 to 6,000 ton/km^2/yr) (de Araújo & Knight, 2005). We further compared the InVEST output for the 100% natural and 100% agricultural scenarios to values from two local studies that reported turbidity or total sediment loads.

First, we used turbidity estimates reported by a study of 14 streams in central Brazil (Fonseca et al., 2014). Streams were classified into four categories ranging from Natural (1) to Very Impacted (4), with category 3 representing mainly rural watersheds that were not dramatically impacted by urbanization. We used categories 1 and 3 to represent the 100% natural and 100% agricultural scenarios, respectively. We converted turbidity estimates into sediment concentrations using the relationship provided by work done in Brazil by Sousa (2013):

$$S = 4800e^{0.1T}$$

where S is the amount of suspended solids, given in mg/m^3, and T is turbidity in NTU (Nephelometric Turbidity Units). We note that this relationship is only valid for low levels of turbidity, so we assumed a linear relationship between turbidity and suspended solids for values

[1] Note: these values are in line with our expectations, given the average annual precipitation of c. 1250 mm, and a runoff ratio of 30% expected for the natural state in this climate (Zhang et al., 2001).

higher than 10 NTU (Teixeira & Caliari, 2005). We then converted sediment concentrations into loads based on the annual average water yield, as implemented in the nutrient calculations (described above). Since 10^{th} and 90^{th} percentiles were not reported, confidence intervals were obtained from the minimum and maximum values, respectively, for each category.

Second, we compared InVEST results for the 100% agricultural scenario with a comprehensive study of sediment dynamics conducted in an agricultural catchment in the neighboring Goias State (Strauch et al., 2013).

We found that InVEST sediment estimates fell within the range as reported by Fonseca et al. (2014) and fell slightly below that reported by Strauch et al. (2013) for an agricultural catchment in Goias State (Table 2).

Table 2. Comparison of InVEST sediment loads with local literature. Ranges denoted by [ ], when available, were obtained from the minimum and maximum observed data reported in the original study.

	Natural (ton/km^2/yr)	Agricultural (ton/km^2/yr)
Central Brazil	2.6 [2.0; 8.5]	7.8 [4.2 ; 74.4]
State of Goias	n.a.	[10; 26]
InVEST output for our study area in Minas Gerais	3.0	4.3

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