Ecosystem services modelling as a key input for decision making in the Water for São Paulo Movement

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1. Background

Healthy forests regulate water flows, protect watercourses and maintain water quality by reducing sediment and filtering pollutants. The population that live in large Brazilian urban centers depend on major watersheds, such as the Piracicaba-Capivari-Jundiaí (PCJ). PCJ's headwaters feed the Cantareira Water Supply System, which provides water to 50% of the São Paulo Metropolitan Area population (9 million people). Forest loss has contributed to soil erosion, polluted waterways, change in seasonal water flow, and a decline in water quality. Restoration and protection of ecosystems in these critical watersheds can provide a significant increase of ecosystem services that millions of people rely upon to meet their basic water needs.

The Water Producer Program (WPP) is an original concept developed by the Brazilian Water Agency (Agência Nacional de Águas – ANA) in 2004 and supported by The Nature Conservancy. The WPP is now the Brazilian constituent of the Latin American Water Funds Partnership, an initiative launched by The Nature Conservancy, FEMSA Foundation, Inter-American Development Bank (IDB), and Global Environment Facility (GEF). A water fund is an innovative way to collect money from stakeholders who recognize the value of nature´s services and reinvest that money in conservation. It is based on the notion that the people who benefit from a service, such as clean water, should compensate the provider of that service. Since a healthy watershed minimizes water treatment costs, the funds attract voluntary contributions from large water users downstream, like water utilities, hydroelectric companies, and industries, and financial compensation can come in the form of water user fees, government programs and voluntary payments. Revenue from these investments is directed to recover or preserve key lands upstream that filter and regulate the water supply, as well as to create incentives for sustainable economic opportunities that have a positive impact on local communities.

The WPP is providing financial compensation to farmers living in critical water production areas – such as the Cantareira Water Supply System – in return for reforestation of degraded areas, protection of existing forests, and soil conservation practices. In 2005, the municipality established the first water payment for ecosystem services (PES) scheme in Brazil, Conservador das Águas. The program pays farmers and ranchers $120 per hectare to reforest or terrace their fields, among other strategies to improve water quality. Funding for the program comes from Extrema's budget, the Piracicaba-Capivari Jundiaí (PCJ) watershed committee, and Brazil's federal government. The federal watershed committee collects fees from water users and directs them to farmers and ranchers who protect or restore riparian forests on their lands. TNC has provided technical and financial support since the beginning of the project.

Building on these former initiatives, the Conservancy launched the Water for São Paulo Movement, whose overarching goal is to conserve critical areas for water production and ensure supply in the country's largest city.

2. The Problem

The Cantareira Water Supply System, located northeast of the São Paulo Metropolitan Region, is a complex of 5 headwater watersheds (4 of them being part of the Piracicaba basin). The watersheds are interconnected by tunnels that move 33 $m^3 s^{-1}$ to the Upper Tietê basin, where it is treated and delivered to the 9 million inhabitants of São Paulo, the biggest metropolis in South America. The Cantareira water system supplies nearly half of São Paulo’s water.

These source watersheds cover a total area of 227,950 hectares (551,640 acres), of which little more than 24% was covered by natural vegetation in 2010 (ISA, 2012). Although deforestation rates have significantly decreased in this region in the last 20 years, water quality is impacted by former forest conversion as well as ongoing agriculture and grazing in riparian corridors and on steep slopes. The Cantareira watershed has lost 70% of its original forest cover, aggravating the sedimentation of rivers and dams, and decreasing their ability to supply water. Sediment from eroding hillsides has reached the reservoirs that supply São Paulo, reducing their capacity.

Stream buffers, slopes steeper than 45º, and hill tops – defined by Brazilian Forest Code as “Permanent Protection Areas” (APP in its Portuguese acronym) – cover an area of 36,844 ha of the Cantareira System; by law these areas should retain their natural vegetation. However, a land use assessment (ISA, 2012) showed that only 30% (11,067 ha) of these areas were effectively preserved, while 70% (25,777 ha) of them were deforested and used for economic activities (primarily grazing).

The Water for São Paulo Movement has applied modeling tools to provide a technical basis for supporting decision-making on the best alternatives for land use management, with the goal of ameliorating or preserving hydrological ecosystems services (such as retention of sediments and nutrients by vegetation). One of the tools being used is the model package InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), developed by the Natural Capital Project.

This study presents an application of the InVEST sediment retention model to the Cantareira Water Supply System, with the goal of 1) identifying areas of high erosion and sediment delivery to prioritize for activity implementation, and 2) estimating the total benefit that restoration and conservation activities could have on erosion and sediment delivery. The results provide useful information to the WPP in Cantareira for targeting their activities with a limited budget, as well as demonstrating that investors’ funds can result in positive outcomes for water supply.

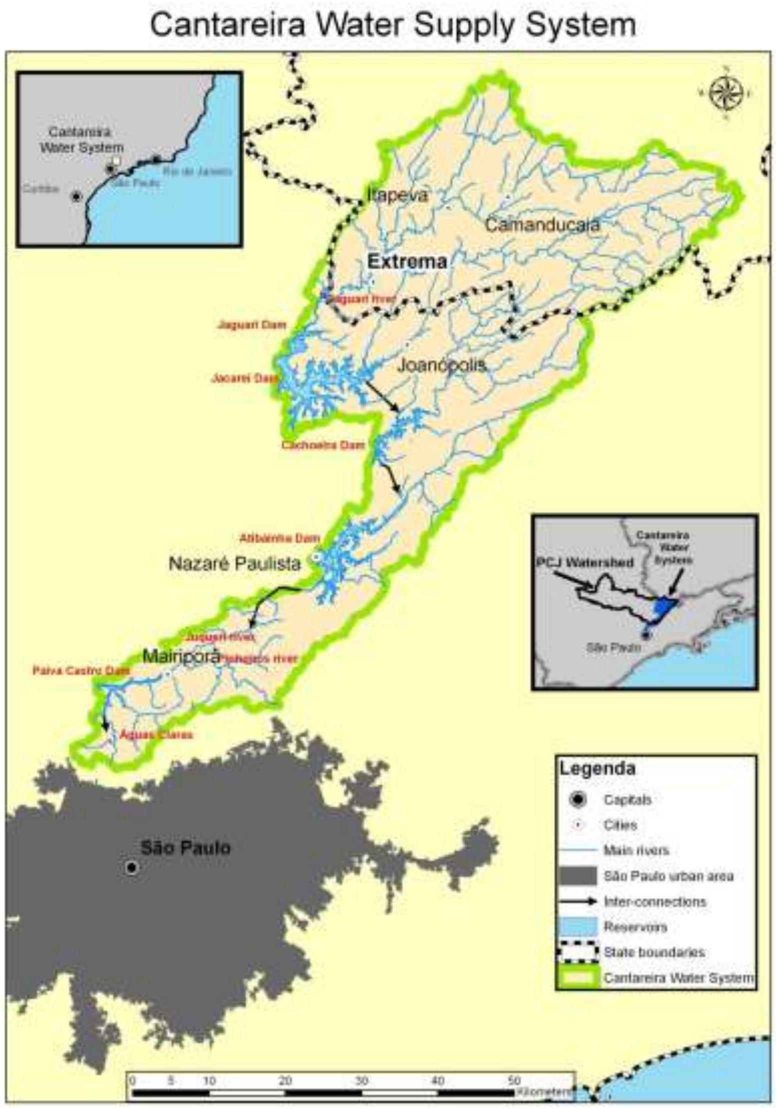

Figure 1: Cantareira Water Supply System, showing also the São Paulo Metropolitan Region

3. Analyses & Methods

We applied the InVEST Sediment Retention model (Figure 1) to estimate the reduction in sediment that could be achieved by restoration and conservation actions in the areas most susceptible to erosion. The InVEST sediment retention model simulates erosion and sediment dynamics for different scenarios of land use, which were built for the study area using GIS tools. This allowed for a comparative analysis of sediment abatement related to different land management approaches and intervention intensities. The goal of this exercise was to develop a prognosis for how much of sediment export could be avoided by restoration activities planned for the Cantareira Water Supply System.

Another major outcome from this study is the identification of most sensitive areas (in terms of sediment production) inside this region. With this information, the WPP can concentrate their restoration efforts on the most critical areas, given that the benefits of sediment reduction would be proportionally bigger, and require proportionally smaller investment, if interventions are targeted effectively.

3.1. Data and analysis

As a baseline scenario, we used the best available land use map of this region, developed by Instituto Socioambiental (ISA, 2012), that reflects the land use condition in 2010. We simulated the ecological restoration of these areas by developing a hypothetical land use map that represents the 2010 land use scenario plus restoration of the most degraded (greatest potential sediment production) parcels.

To create this Land Use Intervention Map, we first ran the InVEST sediment retention model using the "current" land use, i.e. the 2010 map. Then, we analyzed the output raster of sediment export rate by pixel and we selected all pixels that showed a potential sediment production bigger than 0.28 ton $pixel^{-1}$ (7 ton ha^{-1}, since pixel area is 400 m^2). We used a majority filter for pixel clumping to select only patches inside pasture, bare soil, mining or agriculture land uses. Next, we replaced these patches in the original land use map with forest cover and its associated model parameters (in the case of restoration), or with agriculture with soil conservation practices, according to the practice and the former land use (e.g. forest restoration in pasture, mining or bare soil; soil conservation in agricultural areas).

The sediment model was then run on the two land use scenarios: 1) 2010 land use ("before") and 2) 2010 land use considering restoration or soil conservation in degraded areas ("after").

4. Results

According to the screening criteria related above, we identified a total of 9,815.7 ha as land with high sediment delivery potential (>7 ton ha^{-1} $year^{-1}$; Table 1). The vast majority of these fragile areas are occupied by grazing activities, which can increase the risk of further erosion.

Eligible land use for interventions	Priority areas (ha)	Interventions	% of total area
Pasture	9,314.5	Forest Restoration	4.09%
Agriculture	255.6	Agriculture with Soil Conservation	0.11%
Bare Soil	165.3	Forest Restoration	0.07%

Mining	80.3	Forest Restoration	0.04%
TOTAL	**9,815.7**		**4.31%**

Table 1 – Land use areas identified as priority for interventions in Cantareira Water Supply System.

We also calculated the sediment delivery rate for the Cantareira Water Supply System as a whole, and for the highest sediment-producing areas identified in Table 1. The sediment delivery rate was calculated by dividing the average sediment export (*s_export* output from InVEST) by the average erosion rate (*USLE* output from InVEST). The results of running the "before" and "after" land use scenarios are the following (Table 2):

- The current average erosion rate (*USLE*) for the Cantareira System was estimated at 18.1 ton ha^{-1} $year^{-1}$, and the calculated sediment export (*s_export*) was 2.6 ton ha^{-1} $year^{-1}$, indicating a sediment delivery rate of 14.4%.
- Considering forest restoration or soil conservation within the highest sediment-producing areas (equivalent to 9.8 thousand hectares, or 4.3% of total area), we estimated an erosion rate (*USLE*) of 15.7 ton ha^{-1} $year^{-1}$ and sediment export (*s_export*) of 1.2 ton ha^{-1} $year^{-1}$, which corresponds to a sediment delivery rate of 7.6%.
- Comparing the Intervention Land Use Scenario's sediment delivery ("after") with that of the 2010 Land Use Scenario ("before"), we estimate a hypothetical reduction of 11.4% in erosion rates, and a reduction of 52.5% in average sediment delivery (ton yr^{-1}).

Cantareira Water Supply System					
AREA (Ha)	**Scenario**	**Total Erosion (ton yr^{-1})**	**Average Erosion (ton ha^{-1} yr^{-1})**	**Total Sediment Delivery (ton yr^{-1})**	**Average Sediment Delivery (ton yr^{-1})**
227,893	Current Land Use (2010)	4,122,730	18.1	591,928	2.6
227,893	Intervention Land Use (2010 plus restoration/ conservation in priority areas)	3,568,198	15.7	281,415	1.2
	ABSOLUTE REDUCTION	469,360	2.1	310,513	1.4
	PERCENT REDUCTION	11.4%	11.4%	52.5%	52.5%

Table 2 – Erosion and Sediment Delivery estimated for the Cantareira Water Supply System for current and post-intervention scenarios.

5. Discussion

Our results show that the change in sediment delivery can be significantly larger than the erosion rate reduction, because we are locating restoration interventions at relatively small but strategic places in the watershed. Despite the fact that the erosion rate is not being dramatically reduced on average, targeting interventions to critical areas means that sediment delivery to streams can be significantly improved. This is because riparian areas and places with steep slopes, if covered with forests or other natural vegetation, would trap most of the soil detached locally and upslope and prevent it from reaching water bodies below. By doing this prioritized kind of intervention, we can obtain impressive gains in terms of sedimentation reduction and water quality increase, with smaller efforts of restoration (Figure 2).

Although calibration of the InVEST Sediment Retention model using observed values from the field (which are very hard to find in Brazil) would improve the model performance, this analysis gives us a very informative picture about the expected benefits of restoration: improvement in water quality and increasing reservoir storage by reducing erosion and sediment delivery. Besides that, the model has proven to be a powerful tool for the Cantareira Project restoration activities, by helping to define the highest priority areas in which to expand our efforts for water ecosystem services improvement.

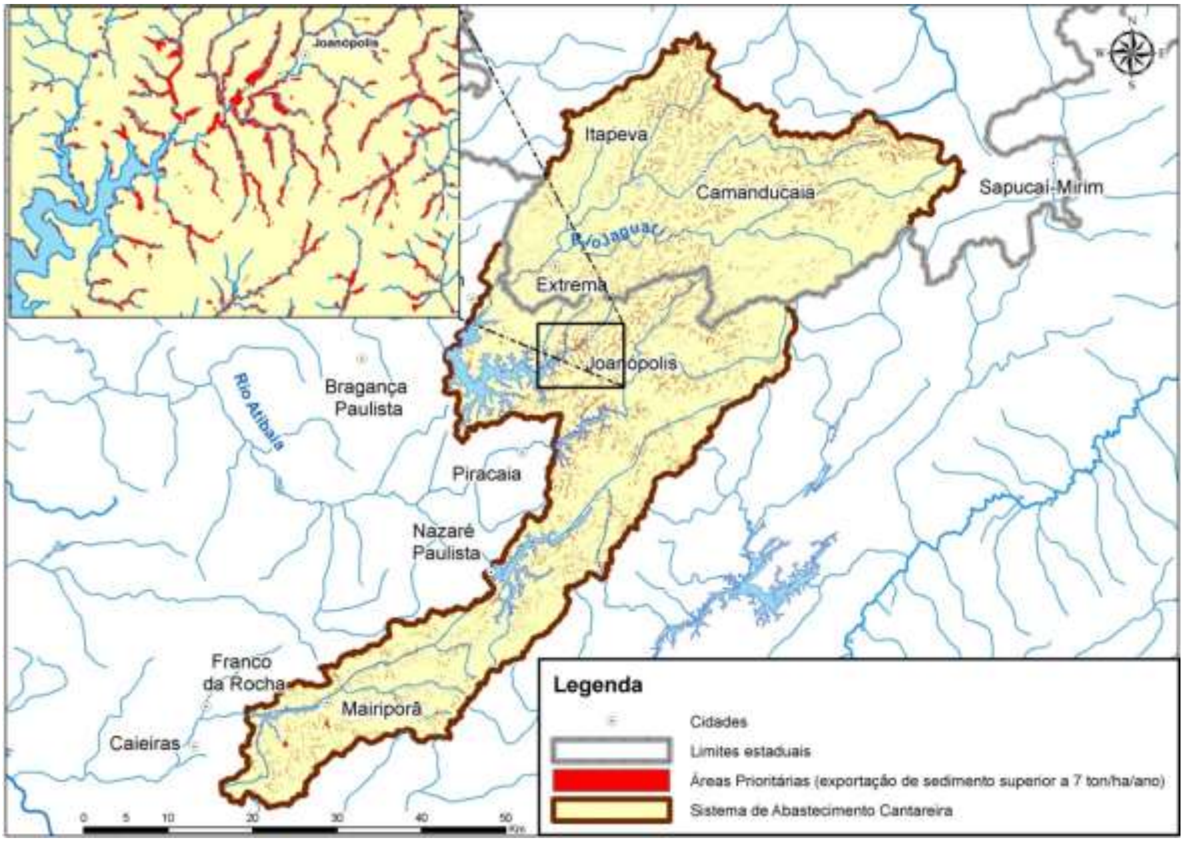

Figure 2: Priority areas for intervention in Cantareira water supply system

6. Use of InVEST results by decision makers and stakeholders at Cantareira Water Supply System

Each cubic meter of storage is increasingly important to Brazil's largest city – which represents 20% of the country's GDP – currently suffering the worst drought on record. Pitiful rainfall and high rates of evaporation in scorching heat have caused the volume of water stored in the Cantareira system to dip to less than 10% of capacity. As an emergency stopgap to provide water to the city, the government of São Paulo spent US$36 million on emergency constructions to allow access to water stored below the level of the pumps. Known to water managers as "dead volume," this water was never intended to be part of the water supply, and the reservoirs are now, essentially, operating at a deficit. This situation is of serious concern to the residents of São Paulo, and industry and large-scale agriculture face fundamental risks to their businesses as water supplies dwindle.

In face of this crisis, modelling work done in the Cantareira system has been a key input to stress the importance of natural infrastructure for water sustainability in São Paulo. In addition to the modelling described here, TNC did a similar exercise for the Alto Tiête system which is also key for São Paulo water provision. With these studies, TNC brought a new evidence that suggests that investing in 14,276 hectares of natural infrastructure within the basins of the Piracicaba, Capivari, Jundiaí (Cantareira System) and Alto Tietê rivers would decrease the level of sediments that clog the rivers by 50%. This represents 9,816 hectares in Cantareira system (4.3% of total area) and 4,460 of Alto Tiête system (1.7% of total area). Reducing erosion would increase the capacity of water reservoirs and simultaneously decrease the cost for the removal of sediments. Implementation of this strategy is expected to have a cost of US 66,9 millon in 10 years, and the benefits expected in terms of reduction of treatment and drainage costs is of US 6 million per year. The actions that are been implemented on the ground are guided by the prioritization and results of the study.

Such strategic investment can bring enormous benefits to more than 20 million inhabitants of the São Paulo Metropolitan Region while helping farmers and ranchers to stay on their land. This initiative shows that one of the highest priorities for securing São Paulo's water supplies is strengthening natural infrastructure by restoring the degraded Atlantic Forest, as well as conserving existing forest remnants. This type of solution, when well-managed, minimizes the risk of extreme events and reduces the vulnerability of populations to floods and prolonged droughts.

The Nature Conservancy presented this study to several key stakeholders in São Paulo, it has been cited by several authors, and taken up by various organizations who have disseminated the results and implemented new environmental guidelines. These include the State Government of São Paulo; the Watershed Basins Committees in Piracicaba, Capivari, Jundiaí (where environmental guidelines and payment for ecosystem services have been approved); the Alto Tietê Committee, who has recently convened a group to identify guidelines and actions; and organizations of civil society ("Aliança pela Água"). Also, using science-based studies to support watershed management has been key in attracting the interest and support of the private sector in collaborative watershed partnerships.

In the future, TNC aims to apply this type of analysis in other watersheds important to the water supply of São Paulo, which have been gaining importance in face of the water crisis: Guarapiranga and the Rio Grande. In addition, these results and new applications will help TNC to expand the WPP strategy to 12 most at-risk cities (in terms of water provision) in Brazil.

REFERENCES

CAMPAGNOLI, F. The production of the sediment from South American: propose of mapping of the erosion rates based on geological and geomorphological aspects. Revista Brasileira de Geomorfologia. Uberlândia: UFU. ano 7, n.1, 2006, p. 3-8.

ISA (Instituto Socioambiental) 2012 – Cantareira System Land Use Map – 2012 Imagery.

Natural Capital Project – InVest 2.4.2 Beta User's Guide, 2012.