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NATURAL INFRASTRUCTURE IN SÃO PAULO'S WATER SYSTEM

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TABLE OF CONTENTS

FOREWORD

Four years after a disastrous water crisis in São Paulo closed schools, blighted crops and drained reservoirs to just five percent of their capacity, Brazil's largest city continues to face risks to the water its 22 million residents depend on. To shore up the main Cantareira Water Supply System, expensive, controversial infrastructure projects are being constructed, while a promising alternative remains untapped: the region's forests have a natural ability to clean and regulate the municipal water supply. This report shows how restoring these forests can reduce São Paulo's water stress and save money.

Healthy forests in São Paulo and around the world filter water, reduce sediment pollution, and buffer against droughts and floods. Yet in the Cantareira System, three-quarters of all forest has been lost, leaving a degraded landscape that sends sediment into São Paulo's drinking water, making it more difficult and expensive to treat, while exacerbating seasonal water stress.

Bringing back even a bit of this native forest can yield significant benefits for São Paulo's citizens, water utility, and industries. Increasing forest cover by eight percent in the Cantareira could cut sediment pollution by 36 percent, for a 28 percent return on investment for the water infrastructure operators over 30 years. This represents an enticing investment opportunity for the Brazilian water sector, just one of the many potential water security benefits that these forests provide. If targeted conservation and restoration efforts expand, these benefits will only increase, and additional benefits to water supply could also be realized.

While many natural infrastructure proponents are already calling for restoration of the Cantareira, the question remains, who will invest? These proponents can use these financial results to build a more investment-ready strategy for the Cantareira System. They can utilize the maps in this report to target the most high-impact areas and use the roadmap to ensure important social and political enabling conditions are in place for their success. Importantly, they must prepare to address the inherent uncertainty in working with natural infrastructure—efficient and wise program design can ensure a return for investors even if improvements to water supply are on the low end of the range estimated in this study.

This report is part of a series of WRI knowledge products in which WRI's Green-Gray Assessment is applied to evaluate new solutions to water management challenges of Latin America. It provides a case study of the Green-Gray Assessment in action, conveying the line of inquiry, data needs, and calculations needed to answer similar questions in other places, anywhere in the world. We hope that water managers, political and business leaders, and civil society groups will use it to spark a renewed effort to restore forests in this region, and beyond.

São Paulo has a character all its own, but the water issues it faces are all too familiar. Cities around the world are looking to new pipes and pumps to address growing water challenges, while ignoring the financial benefits of using critical upstream forests that lie beyond city limits. Natural infrastructure should be considered a water management strategy—in Brazil, across Latin America, and around the world.

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EXECUTIVE SUMMARY

Incorporating natural infrastructure into water management plans can cost-effectively improve infrastructure system performance and resilience. However, decision-makers often lack the tools and data necessary to identify and assess natural infrastructure strategies alongside traditional water management approaches.

This report addresses these needs by evaluating how restoring forests as natural infrastructure can complement and safeguard the Cantareira Water Supply System, São Paulo's primary water source. In so doing, the report demonstrates a replicable analytic approach and pinpoints data needs for such an assessment. The report also makes recommendations for program design to facilitate local investment in natural infrastructure.

HIGHLIGHTS

- Using the World Resources Institute's Green-Gray Assessment, we evaluated natural infrastructure investment opportunities to help achieve two water management objectives in São Paulo's largest water supply system: reduce sediment management costs and secure water flows.
- Targeted restoration of 4,000 hectares of native forest would require an investment of about US$37 million and generate avoided costs of $106 million for a net benefit of $69 million over 30 years.
- Natural infrastructure reduces soil erosion by roughly 36 percent, avoiding sediment pollution costs for a 28 percent return on investment. In general, this return is on a par with the Brazilian water sector's financial performance.
- Reforesting two percent of the watershed for sediment control is only one component of a broader natural infrastructure plan for the Cantareira. Additional natural infrastructure could increase water flow, mitigate flood risk, and enhance rural vitality.
- Local water managers should integrate natural infrastructure into planning to capture these benefits and to contribute to Brazil's growing restoration movement.
- Natural infrastructure programs in the region need additional funding to become fully operational. This report proposes strategies to improve program performance and attract investment.
- For those interested in replicating this approach, the appendices provide the methods and data sources.

Managing Water through Natural Infrastructure

Forests and sustainably managed natural areas play a pivotal role as "natural infrastructure." Nature helps secure urban water supply by controlling erosion, purifying water, mitigating floods, and, in many cases, providing a steady source of water during dry periods. In addition to increased water security, these areas also provide operational and financial benefits to water companies through reduced water treatment costs, avoided operations and maintenance costs, and extended life of the built infrastructure.

In São Paulo, Brazil, much of the natural infrastructure needs to be restored and conserved. With a metropolitan region of 22 million people, São Paulo is the largest city in South America, and the Cantareira Water Supply System (Cantareira System or Cantareira) is its largest and most important water source. The vulnerability of this system became evident in 2014–15, when a water crisis struck São Paulo. In addition, sediment pollution of water sources is a persistent issue that requires constant management in the region. The Cantareira System has only a quarter of its native forest still standing, and this study finds that restoring forest in strategic areas could be part of the solution to these issues.

Rising to this challenge, several programs have begun restoring natural areas to help provide a clean and ample water supply in the Cantareira System. Following a decade of small-scale successes, these natural infrastructure programs—ecosystem restoration or conservation programs directly aimed at improving water security—are increasing their ambition. They aim to secure more funding to increase the scale of their activities by engaging water sector beneficiaries such as São Paulo's water company, Sabesp; the Piracicaba-Capivari-Jundiaí basin committees; and beverage companies and other water-dependent industries. Once funding has been secured, these programs will be able to expand their efforts and produce outcomes at scale.

About This Report

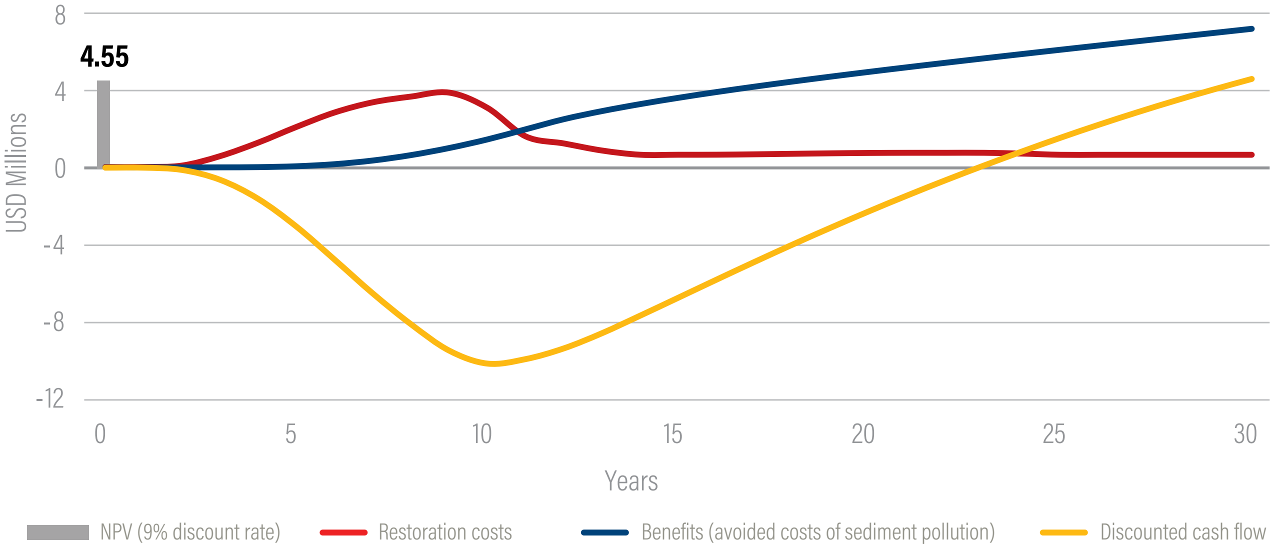
This report has two objectives: inform water managers and related stakeholder groups in São Paulo about natural infrastructure's potential role in sediment management and water security; and demonstrate a process for evaluating natural infrastructure investment opportunities. Water managers such as the local river basin committees, water company, and government water agencies may use this report to understand why, where, and how to invest in natural infrastructure as a water management strategy. Natural infrastructure programs may use the same results to improve program design. At the same time, this report documents a process and provides the data necessary to conduct such an analysis, highlighting a research agenda to help strengthen the analysis in subsequent iterations.

The report details findings of the World Resources Institute's Green-Gray Assessment, a six-step return on investment analysis that evaluates the financial rationale for the water sector to invest in natural infrastructure. Combining geospatial, biophysical, and financial analysis with stakeholder consultation, we estimated some of the direct benefits that would accrue to water infrastructure operators if targeted natural infrastructure strategies were implemented. We paired this Green-Gray Assessment with a review of key enabling conditions that should be put in place to increase the likelihood of natural infrastructure program success. This yielded numerous insights to guide natural infrastructure strategies and investments to success, captured throughout the report.

Natural Infrastructure for Sediment Management: Results

Forest restoration and conservation in priority areas of the Cantareira's watershed can generate substantial savings for water infrastructure operators. Targeted restoration of 4,000 hectares (ha) of native forest could reduce the amount of sediment entering the water system by more than one-third. The reduction in sediment pollution would reduce the costs of sediment management to generate an estimated 28 percent return on investment (ROI) in 30 years (Table ES-1). Figure ES-1 shows the behavior of costs and benefits of the investment scenario over 30 years, which yields a $4.6 million net present value (NPV). This financial return is on a par with the Brazilian water and sanitation sector's financial performance. Net benefits would continue to accrue after 30 years if the natural infrastructure is maintained (e.g., if reforested areas stay forested).

Figure ES-1 | Financial Performance of Targeted Reforestation of 4,000 Hectares (R4000) over 30 Years



Note: R4000 is an investment scenario in which targeted restoration of forest is implemented on 4,000 ha of pasture to reduce sediment pollution. Costs occur during the first 10 years of the project, when forests are restored. The project's benefits (avoided costs of water treatment, dredging, and equipment depreciation) accrue gradually, increasing as the forest matures.
Source: WRI authors.

Table ES-1 | Financial Performance of Reforesting 4,000 Hectares (R4000) as Natural Infrastructure to Control Sediment Pollution

FINANCIALS OF R4000	$, MILLIONS
AVOIDED WATER MANAGEMENT COSTS	
Water treatment	92.4
Dredging	11.9
Depreciation	1.4
TOTAL	**105.7**
RESTORATION COSTS	
Investments	11.2
Opportunity costs of land	13.8
Operations and maintenance	7.3
Transaction costs	5.0
TOTAL	**37.2**
NET BENEFITS	
Net benefits	68.5
Benefit-cost analysis index (avoided costs/restoration costs)	2.8
Net benefits margin (net benefits/avoided costs)	0.7
FINANCIAL PERFORMANCE (9% DISCOUNT RATE)	
Internal rate of return (%)	12
Net present value ($, millions)	4.6
Payback period (years)	23
Return on investment (%)	28

Notes: Avoided and restoration costs and net benefits are in 2017 values. The costs, benefits, and financial indices are further detailed in Chapter 2 and Appendix C. Numbers may not sum due to rounding.
Source: WRI authors.

Reforestation efforts can be targeted at priority areas that hold the highest potential for aiding in water management goals. Reforesting 2 percent of the watershed at random would reduce sediment pollution by only 8 percent, but targeting reforestation in priority areas could reduce sediment pollution by 36 percent. While the local water company, Sabesp, has planted almost 1,200 ha of trees on its land holdings in the Cantareira, many priority areas for natural infrastructure occur outside the company's fence line, thereby necessitating partnerships with rural landowners to implement an optimal natural infrastructure strategy.

Reforesting 2 percent of the watershed in priority areas for sediment control is only one component of a broader natural infrastructure plan for the Cantareira. As a next step, additional natural infrastructure priority areas should be identified to increase water flow, mitigate flood risk, improve rural livelihoods, or meet other investment objectives.

This study adopts conservative assumptions informed by local data and stakeholders to generate robust, decision-relevant results. Some of these assumptions are uncertain. If we were to adopt other reasonable assumptions, the results would change as well (Table ES-2). The study's sensitivity analysis reveals that the uncertainty around sediment export is the most influential factor on NPV (Figure ES-2). The cost of forest restoration is also uncertain but does not pose risks to the financial viability of the studied investment scenario.

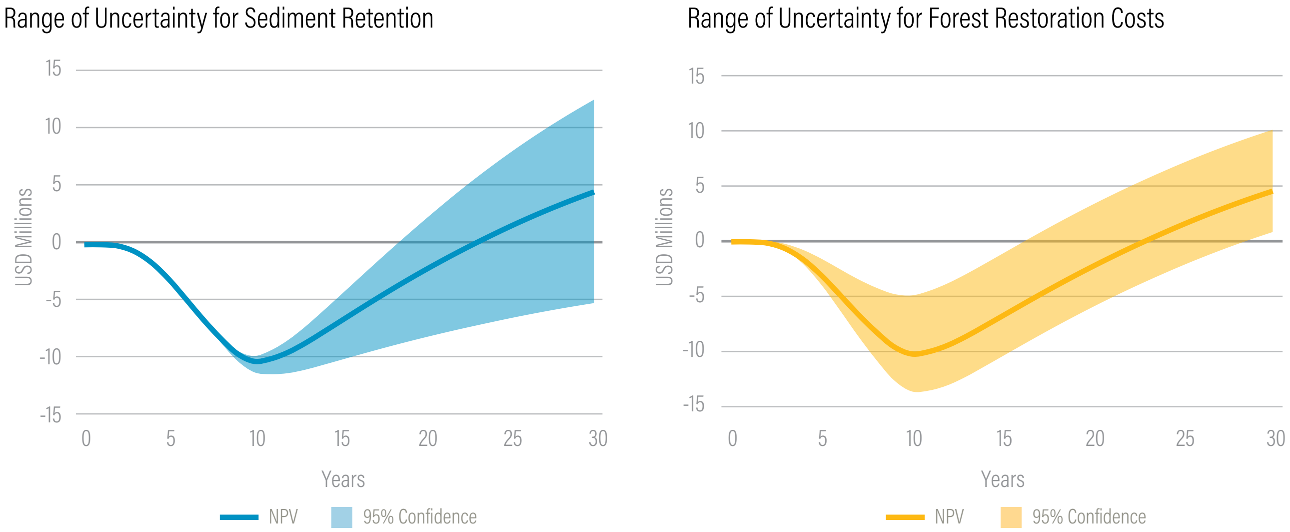
Understanding uncertainty is the first step toward managing it. Natural infrastructure programs can be designed to mitigate investment risks associated with uncertainty. If R4000 were implemented twice as fast as planned, for example, the predicted NPV could nearly double, and significantly reduce the risk of financial losses. Similarly, natural infrastructure financing strategies can be designed to mitigate risk; for example, sharing risk across a pool of investors or blending public and private finance to leverage funds from government programs could improve the financial performance of R4000.

Table ES-2 | Natural Infrastructure's Financial Performance under Alternative Assumptions

IN OUR STUDY, WE ASSUMED/ESTIMATED...	IF WE ASSUME INSTEAD...	NPV ($, MILLIONS)	ROI (%)	PAYBACK PERIOD (YEARS)
It takes **40 years for a forest to reach full maturity,** and sediment retention follows a similar trajectory. However, local stakeholders believe that reforested areas start controlling erosion earlier, with significant results after only a few years.	A forest achieves full erosion control potential **in 20 years**	10	62	19
Forest restoration occurs over 10 years, as currently projected by the São Paulo Water Fund. However, the pace will vary based on how quickly the fund secures investment and the implementation capacity of partners.	The project is implemented **in 5 years**	8	36	19
Restoration costs are $8,000 per hectare on average, including "transaction costs" such as outreach and landowner engagement. But, these transaction costs are typically omitted from similar studies in Brazil.	No transaction costs for restoration (**20% reduction**)	7	47	20
A discount rate of 9% to represent a risk scenario used by Sabesp; however, other investors may use higher or lower discount rates. A 5% discount rate may be suitable for some investors, since government programs are already investing in these activities, and since multiple investors could co-invest in the program to share risk. A 5% discount rate also represents the social discount rate for Brazil calculated by the World Bank.	A **5% discount rate**	18	82	19

Source: WRI authors. See Appendix C for details on these estimates and assumptions.

Figure ES-2 | Possible NPV of R4000 ($, millions)



Notes: Left graph: NPV over 30 years, with uncertainty band based on the possible range of sediment retention performance (95 percent confidence).
Right graph: NPV over 30 years, with uncertainty band based on the possible range of restoration costs (limits based on interviews and literature, described in Appendix C) (95 percent confidence).
Source: WRI authors.

Natural Infrastructure for Seasonal Water Flows: Results

Ensuring sufficient dry season supply is a crucial component of securing total annual water supply. As climate change intensifies seasonal weather in this region, storing water during the rainy season to access in the dry season will become increasingly important. While local conservation groups posit that natural infrastructure could increase dry season water availability, water managers express concern that increased forest cover could reduce overall water availability. We conducted a Green-Gray Assessment to evaluate both of these claims and examine if and how natural infrastructure could support water availability objectives.

Forest restoration is likely to increase dry season flows, but its impact on total annual water availability may be positive or negative, depending on the type of forest restored. Restoring high-altitude forest could increase overall water availability by the forest's ability to generate water supply through fog capture, but increased evapotranspiration by other forest types may slightly counteract these benefits. Although we drew on established science and models for this analysis, scientific data and modeling efforts on interactions between forest and water flows are insufficient in this region. This analysis provides theoretical estimates with large uncertainty bounds (>50 percent) that could be improved through further research.

Our model suggests that forest restoration would have a marginal (likely positive) impact on water availability. In our model, restoring 4,000 ha of forest would result in a change of only +/–0.2 percent total annual flow. As a point of comparison, São Paulo's water supply system loses approximately 20 percent of its water due to leaking pipes. Our model indicates that forest restoration's impact on water availability is unlikely to warrant any changes to water management.

From Analysis to Investment

Natural infrastructure offers an enticing investment opportunity to enhance water management in the Cantareira. Program design, deal structure, and external sociopolitical conditions significantly impact the likelihood of natural infrastructure program success. Actions are needed on the part of natural infrastructure programs, research groups, and water managers to address these success factors.

Water managers stand to achieve lower-cost, more-resilient water supply services by supporting the design and implementation of natural infrastructure strategies. Water managers can refine the assumptions and data underlying this study to inform program design, help identify and incorporate natural infrastructure opportunities within the existing and planned infrastructure mix, and support the development of a coherent long-term natural infrastructure financing strategy that leverages water sector resources. Blended finance approaches that leverage public and private capital could de-risk natural infrastructure strategies, creating even more enticing investment opportunities for the water sector.

Natural infrastructure programs should increase coordination and refine program designs. Stakeholders identified several barriers to scaling up these programs, including the need to

- continue to build monitoring systems to evaluate natural infrastructure performance across programs;
- develop stronger and more detailed watershed plans to guide program activities;
- better engage landowners to enroll more land in natural infrastructure efforts; and
- increase collaboration to achieve outcomes at a system-wide scale while balancing the need for local-level program ownership.

Targeted research will support the advancement of data-driven, high-quality natural infrastructure programs. This study has contributed important data and rules of thumb, especially for calculating natural infrastructure's impacts on water management costs. Additional research is needed to strengthen the analysis in subsequent iterations. For example, expanded hydrological monitoring efforts could increase the certainty and robustness of natural infrastructure's performance on controlling sediment pollution and seasonal water flows, as well as other important services not yet assessed, such as flood control.

> Blended finance approaches that leverage public and private capital could de-risk natural infrastructure strategies, creating even more enticing investment opportunities for the water sector.

CHAPTER I

INTRODUCTION

This report details research and analysis conducted on the Cantareira Water Supply System (Cantareira System or Cantareira), the most important water source for the São Paulo metropolitan area. Our research project examined natural infrastructure investment options as well as opportunities to scale up natural infrastructure financing. We evaluated the financial case for water managers to invest in natural infrastructure and, where applicable, we assessed strategies to enable such investment.

Our analytical approach is based on the World Resources Institute's (WRI's) Green-Gray Assessment (Gray et al. forthcoming; Talberth et al. 2013; Gartner et al. 2013) and Watershed Investment Readiness Assessment (Ozment et al. 2016), which use geospatial, biophysical, and financial analysis as well as stakeholder consultation. We provide the necessary data and methods to conduct this study, and identify data quality issues and information gaps that could be closed to strengthen the analysis.

This chapter describes the Cantareira System and the challenges it faces, and explains how this system could benefit from using natural infrastructure—specifically, native forest conservation and reforestation—as a water management strategy. **Chapter 2** presents a financial analysis to estimate the project's return on investment (ROI) and characterizes the behavior of related costs and benefits across time when using natural infrastructure as a sediment-control measure implemented alongside the existing infrastructure system. **Chapter 3** presents preliminary analysis of natural infrastructure's potential impacts on seasonal water flows to spark further research and discussion. **Chapter 4** discusses options for natural infrastructure programs to finance projects in the Cantareira, details a range of possible financiers, and proposes some necessary actions to facilitate implementation. **Chapter 5** concludes the report by recommending next steps for water managers and natural infrastructure programs in the Cantareira, and highlighting future research needs. This report is also supported by three appendices that disclose the methods, assumptions, and data used in our analysis.

Water Management Successes and Challenges in the Cantareira System

The Cantareira System is the largest of five water supply systems that feed São Paulo, providing almost half of the total water used by the 22 million inhabitants of the metropolitan area. The state water company of São Paulo, Sabesp, operates the system. The Piracicaba-Capivari-Jundiaí (PCJ) basin committees, the Alto Tietê basin committee, and their respective agencies are tasked with managing the 228,000-hectare (ha) drainage area surrounding the water infrastructure system.

The Cantareira System was designed to help guarantee a clean and ample water supply in the face of environmental changes, water stress, and pollution. It has been largely successful since it was built in the 1970s. However, recent events and persistent management challenges have highlighted the system's vulnerability to climate change and environmental degradation, sparking interest in employing new strategies to safeguard the system.

Water supply challenges: The Cantareira was designed with six interconnected reservoirs to

provide a supply of water year-round, despite São Paulo's seasonal climate and geographically heterogeneous precipitation (Figure 1). However, the system failed during a 2014–15 drought, the worst and longest since 1930. The drought caused water produced for the São Paulo metropolitan area to decline by nearly 30 percent, from 71 cubic meters per second (m^3/s) in January 2014 to 50 m^3/s in February 2015. At the apex of this crisis, the Cantareira System reservoirs were at only 4 percent capacity. Sabesp was forced to implement new price structures rewarding conservation, impose stringent regulatory limits on water withdrawals, and install temporary pipes to reach the low water levels. Sabesp lost an estimated US$470 million between 2014 and 2015 as a result of the drought (Sabesp 2015).

Sediment pollution challenges: Like most water supply systems, the Cantareira experiences constant sediment pollution. Sediment enters the water supply system as soil is dislodged from the landscape during intense rain events, which can lead to increased erosion and sediment yield, which in turn increase the need for water treatment. The Cantareira's many reservoirs capture about 87 percent of all sediment that enters the system, thereby reducing sediment pollution downstream (ANA and DAEE 2013). Stakeholders noted that São Paulo's other water supply systems experience even higher levels of sediment pollution and turbidity, suggesting the costs of sediment management in other basins may be even higher than those in the Cantareira.

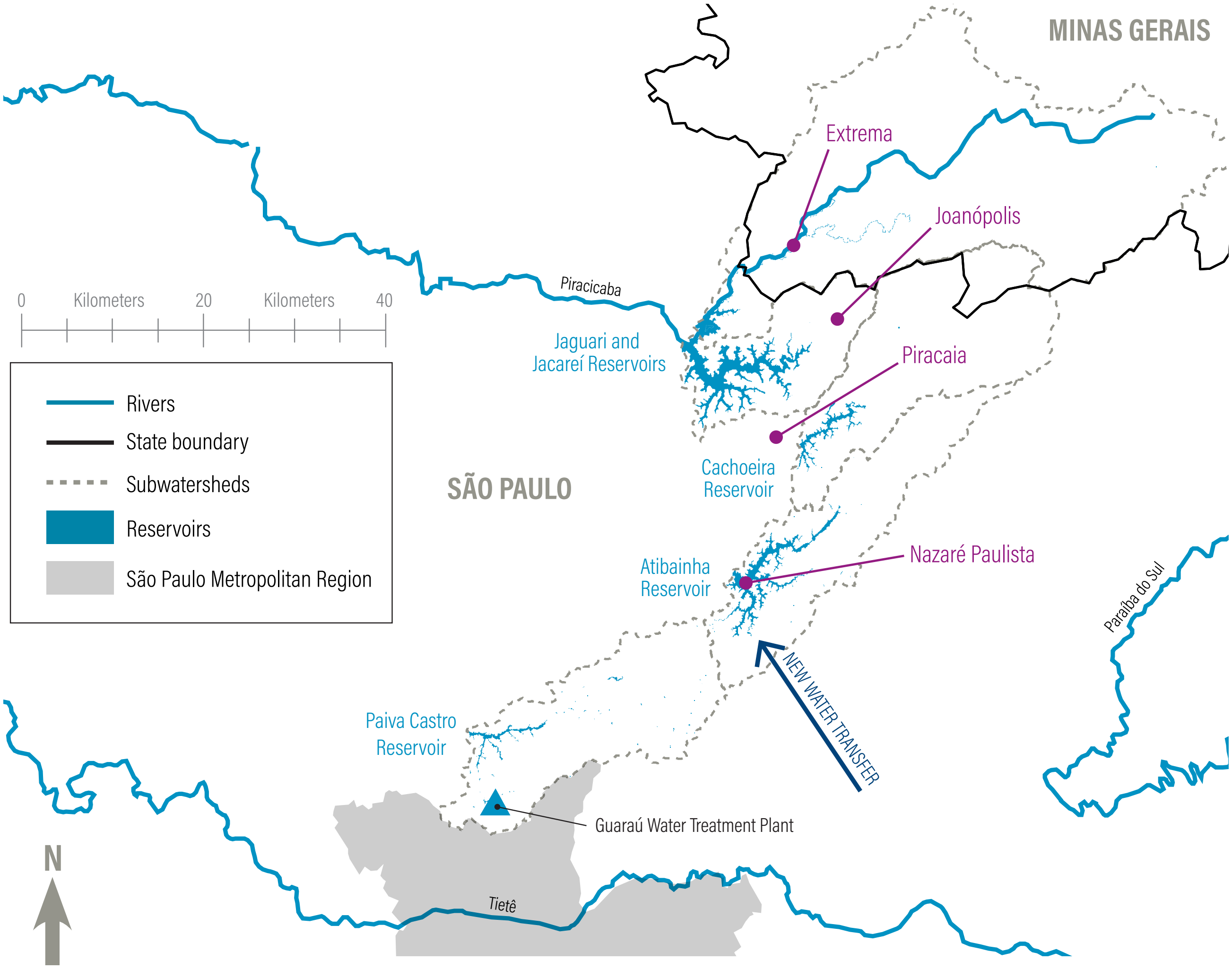
Though turbidity is relatively low here, the system treats and supplies such a high volume of water that the cumulative costs are significant. Sediment impacts the cost of providing clean and ample water in at least three ways:

Water treatment costs: Sediments are the main source of freshwater turbidity (cloudiness in water associated with particulate matter) and increase total-suspended-solids (TSS) levels. Landscape erosion causes sediment to be deposited in water bodies that ultimately flow to the water treatment plant. This in turn impacts the need for chemical inputs, energy, workforce, and maintenance of equipment (Hespanhol 2017).

Dredging costs: Sediment is deposited in reservoirs, either reducing their water storage capacity or creating a need to dredge the reservoir to remove silt. Sediment dredging and removal can be a costly process, though dredged materials can sometimes be sold to recoup these costs.

Depreciation of equipment: Sediment pollution can cause wear and tear on water infrastructure, causing it to be maintained or replaced more frequently. This wear and tear may also influence the depreciation rate of capital equipment (U.S. EPA 2013).

Figure 1 | Schematic of the Cantareira System



Notes: São Paulo's state water company, Sabesp, operates the built infrastructure system; the PCJ and Alto Tietê basin committees govern the 228,000-hectare watersheds that feed the system.
Source: Adapted from ANA 2016a.

These water quality and availability challenges will only grow with climate change. Average annual precipitation is projected to increase by 5 to 20 percent by 2050 (Young and Nobre 2010), and by 2030, about 46 percent more area in southeast Brazil will have an increased risk of flooding (Ferraz et al. 2013). Even so, water stress and scarcity will likely worsen as climate change will also produce prolonged dry periods (Marengo et al. 2013), and it will become increasingly important to capture and store water during intense rainfall and use the excess during the dry season. Sediment pollution and turbidity are also likely to increase, as rainfall and flooding intensify and dislodge more soil from the landscape.

Managing Water Risk

To address these issues, Sabesp's highest priority is to increase resilience and redundancy in the São Paulo water infrastructure systems.

Sabesp's multibillion-dollar plan to extend the system and increase supply involves tapping new reservoirs and expanding infrastructure systems. Projects include the following:

- **Water transfer from Paraíba do Sul to the Cantareira System:** A new 13-kilometer (km) pipe and 6 km tunnel to transfer water from the Paraíba do Sul River Basin's Jaguari Reservoir to the Cantareira System's Atibainha

Reservoir will provide an additional 5.1 m^3/s of water on average, and a maximum of about 8.5 m^3/s, a roughly 15 percent increase in total water supply. The project was originally expected to cost about $170 million and be completed in February 2017 (Lobel 2015). However, due the lack of appropriate environmental permits and other issues, the project took an additional year to complete. (O Globo 2017a). Sabesp will need to pay an estimated $1 million in environmental compensation, according to the environmental impact report. The National System of Protected Areas Law requires that this compensation be applied in the protected areas affected by the project, although it is not clear exactly how it will be invested. Another possible use of these compensation funds is to restore degraded areas and help improve resilience in the system.

- **The São Lourenço water system:** The creation of a new reservoir about 83 km from the São Paulo metropolitan region will provide an additional 4.7 m^3/s of water. The project costs are estimated at $500 million. Originally projected for completion in October 2017, this project faced delays by the São Paulo courts pending further environmental impact studies and was finally completed in April 2018 (O Globo 2017b).

These projects aim to interlink São Paulo's reservoir systems and increase resilience to seasonal and interannual variability. However, there are some downsides to this approach. These projects proved controversial among regional communities who feel that only the city of São Paulo will benefit or that their own water sources may be threatened. These concerns, along with environmental permitting challenges, caused costly delays. Furthermore, such projects are costly to construct and operate; Sabesp must pay for energy to pump water from distant places and pay taxes on interbasin transfers (PCJ Agency 2015).

Built infrastructure addresses only some of São Paulo's challenges with water insecurity. And new water infrastructure will be just as susceptible to sediment pollution as existing infrastructure.

Built infrastructure addresses only some of São Paulo's challenges with water insecurity. And new water infrastructure will be just as susceptible to sediment pollution as existing infrastructure. While the current plans of interlinking water supply systems and extending reservoir capacity can help address these challenges, questions remain: Are these solutions enough, and could alternative measures help safeguard and enhance system performance?

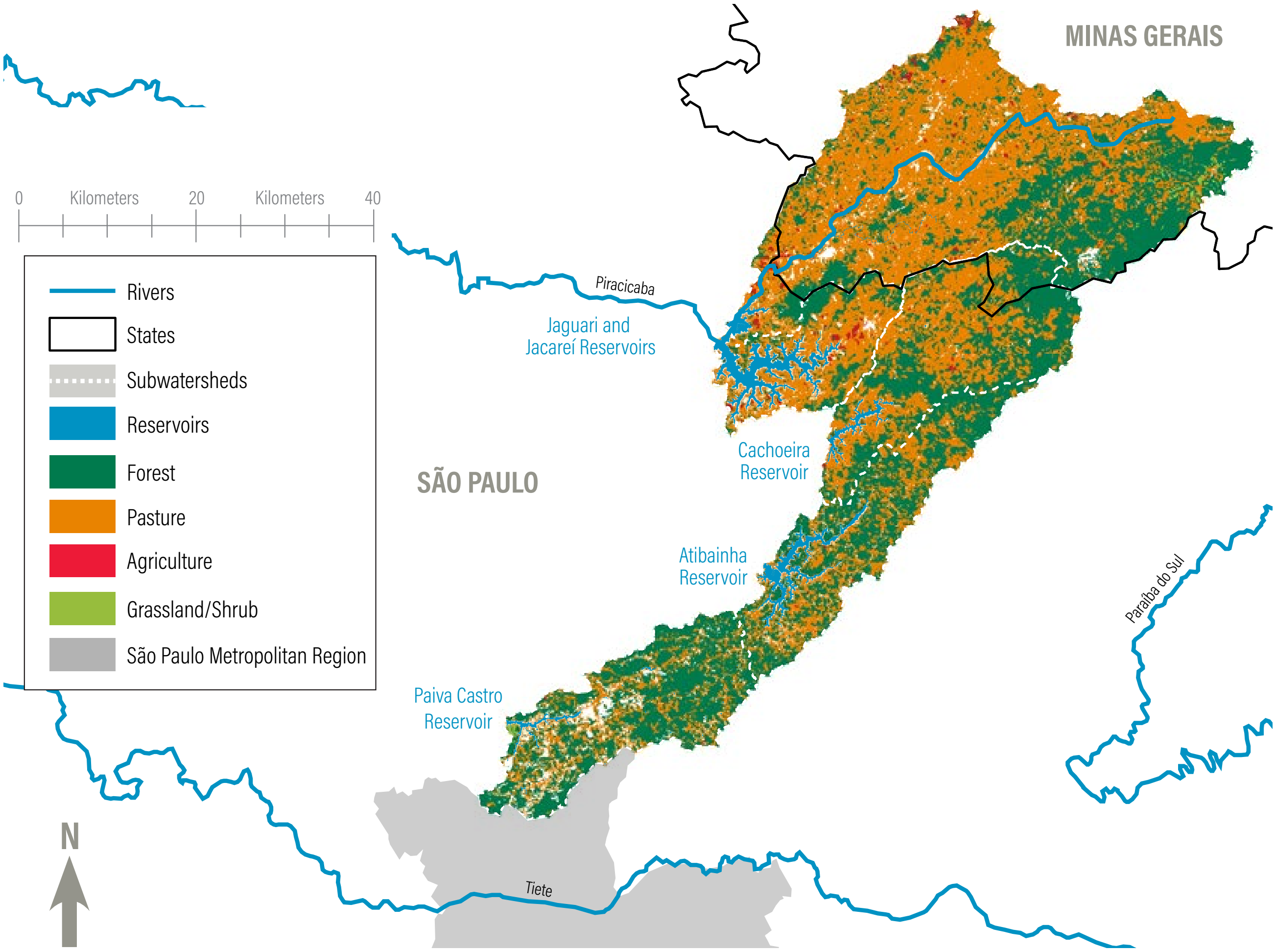
Efforts to Address Water Challenges through Natural Infrastructure

While Sabesp has focused almost exclusively on conventional strategies to water management, the health of landscapes within the 228,000-hectare drainage area surrounding the Cantareira infrastructure system (Figure 2) could significantly impact water stress and sediment pollution.

Sediment management: The main source of sediment pollution in the water system is poorly managed land, especially degraded pastureland, which covers about 30 percent of the basin's land area. Strategic conservation and restoration of native forests can substantially reduce erosion rates compared with other common land uses like pastureland and even plantation forestry. Studies throughout the region have observed and modeled the ability of forests to reduce sediment load (Honzák et al. 2012; Machado et al. 2003; Fujieda et al. 1997), which is consistent with the global literature (Neary et al. 2009). Machado et al. (2003) found that outside of the Cantareira System, in the Piracicaba watershed in São Paulo State, converting a hectare of pasture to native forest decreased sediment yield from that hectare of land by as much as 94 percent.

These hydrologic benefits can reduce water management costs and enhance water system performance. Sousa Júnior (2013) found that reducing the sediment yield in raw water would decrease water treatment costs by almost $3.8 million per year for the São Paulo metropolitan region's source watersheds, including the Cantareira. Kroeger et al.

Figure 2 | Land Cover in the Cantareira System



Source: Data provided by The Nature Conservancy.

(2017) estimated that protecting and restoring the forest in 5 percent (640 ha) of the city of Camboriu's source watershed would reduce concentrations of total suspended solids at the municipal water plant intake by 23 percent and reduce drinking water treatment and dredging costs by $200,000 per year on average over 30 years.

Water availability: Healthy landscapes are also known to help control the timing and flows of water in ways that can enhance water security in seasonal climates. In general, forests possess the ability to absorb and hold water during rain events and slowly release it during dry periods—often called the "sponge effect." Furthermore, the cloud forests that occur along the coastal mountains of southeast Brazil possess a unique ability to generate soil water and streamflow from fog, as tree branches and leaves capture and collect droplets of water that would otherwise remain in the atmosphere. Global literature shows that fog capture can account for up to 30 percent of annual water availability in cloud forests (Ellison et al. 2017), though this is not well studied in Brazil.

In the Cantareira's watersheds, only 24 percent of native forest remains, and it is highly fragmented (Figure 2). Although the recent rate of deforestation has sharply decreased to 0.2 percent per year in this region (Hansen et al. 2013), an additional 1,900 ha of forest (2 percent of currently standing forest) could be lost over the next 30 years. Losing these forests could further degrade water quantity and quality, and would also impact many other important ecosystem services (Box 1).

BOX 1 | THE MANY POTENTIAL BENEFITS OF INVESTING IN NATURAL INFRASTRUCTURE

Although this report focuses on estimating the costs and benefits to the water sector by investing in natural infrastructure, forest conservation and reforestation interventions can generate myriad economic, social, and environmental benefits that could be accounted for in a full cost-benefit analysis. The following are some of the benefits forests provide:

Mitigating climate change through carbon sequestration: Protecting and restoring lands and forests avoids greenhouse gas emissions and sequesters carbon. Complementary mechanisms that could facilitate investments to achieve and enhance this co-benefit include corporate voluntary carbon offsets.

Increasing community resilience to climate change: Ecosystem-based adaptation is one objective of the National Plan for Adaptation in Brazil. Improving watershed health contributes to this objective, especially for those whose livelihoods are tied to ecosystem goods and services, such as rural communities and farmers (Girot 2013; FGB 2015).

Improving human health and well-being: Healthy landscapes and watersheds provide spaces for recreation and underpin vibrant physical and mental well-being, cultural and spiritual fulfillment, and social connections (Abell et al. 2017).

Improving rural economies and livelihoods: Investing in the restoration of rural landscapes can create jobs and new, more sustainable revenue streams for rural landowners. While there is not currently an estimate of how many jobs could be created for natural infrastructure restoration and stewardship in the Cantareira, there is reason to believe these benefits could be significant. For example, Instituto Escolhas (2016) estimates that Brazil's commitment to restore 12 million hectares of forest by 2030 could create 138,000–215,000 jobs.

On-farm productivity: Soil erosion not only negatively impacts water quality, but also jeopardizes farmers' productivity; and soil conservation can help in these areas. Natural infrastructure investments can be designed to enhance pastureland productivity and net income for farmers through crop-livestock-forest integration, as well as agroforestry or silvopastoral systems. Brazil has committed to restoring the productivity of 15 million ha of pasture and promoting crop-livestock-forest integration for 5 million ha by 2030 as part of its nationally determined contribution climate goals (FRB 2015).

Conserving biodiversity: Protecting or restoring natural habitats can improve habitat conditions and connectivity, giving wild species space to roam. Forest conservation and restoration contributes to achieving the Aichi goals related to biodiversity conventions and implementing the National Program for the Conservation of Threatened Species, Pro-Species. Using natural infrastructure to address sediment pollution can improve habitats for aquatic species.

Many local stakeholders across sectors have taken steps toward implementing forest restoration and conservation as a central water management strategy to safeguard the Cantareira System. Notably, the São Paulo Water Fund (previously named the Water Movement for São Paulo, or MApSP in its Portuguese abbreviation), part of the Green-Blue Coalition, aims to serve as an umbrella initiative for the many local efforts active in the region. Led by The Nature Conservancy (TNC), the São Paulo Water Fund targets natural infrastructure efforts in the Cantareira and Alto Tietê water supply systems. For the Cantareira System, the fund set a target of reforesting 9,650 ha and conserving 25,000 ha of native forest in priority areas. In 2013, TNC developed goals for the São Paulo Water Fund to reduce erosion by 50 percent, increase dry season flows by 3 percent, and reduce flood intensity by 5–10 percent (TNC 2013). These targets are currently being revised.

The São Paulo Water Fund is aligned and integrated with several governmental and nongovernmental programs, such as:

- **Programa Nascentes**, led by the state government of São Paulo, involves 12 secretariats and coordinates relevant land and water restoration programs from state and municipal agencies (SMA 2015a, 2017). The goal is to optimize and direct public and private resources to the restoration of priority degraded areas. The program enables companies to find projects that meet their habitat mitigation obligations. It has established a weighted scoring system to assign values to projects based on their ecosystem service value (Estado de São Paulo 2014). Programa Nascentes has a state-wide goal of restoring 20,000 ha of riparian forest and has already initiated restoration of 8,700 ha, though very little of this restoration has taken place in the Cantareira (SMA 2017).
- **The PCJ basin committees** (federal, São Paulo State, and Minas Gerais State) are responsible for watershed planning, mediating water conflicts, and establishing water use fee mechanisms (PCJ Agency 2015). Historically, the PCJ committees have invested an estimated 2 percent of their funding in forest restoration as natural infrastructure (Padovezi et al. 2012). Other basin committees responsible for this region, such as the Alto Tietê committee, have the ability to invest in forest restoration as natural infrastructure but have not yet done so.
- The **Extrema Water Producer Program** is led by a municipality in the upstream area of the Cantareira (Extrema, Minas Gerais). Established in 2005, it is one of the more mature and better known natural infrastructure programs in Brazil (ANA 2016b). By 2016, it had reforested 216 ha, conserved 6,378 ha, and engaged 224 farmers (Extrema 2017). The municipality has allocated approximately 3 percent of its municipal budget to supporting natural infrastructure efforts, demonstrating high local commitment.
- **PCJ Water Producer Programs** in Joanópolis and Nazaré Paulista have restored 68 ha of forest and preserved more than 321 ha (ANA 2016).

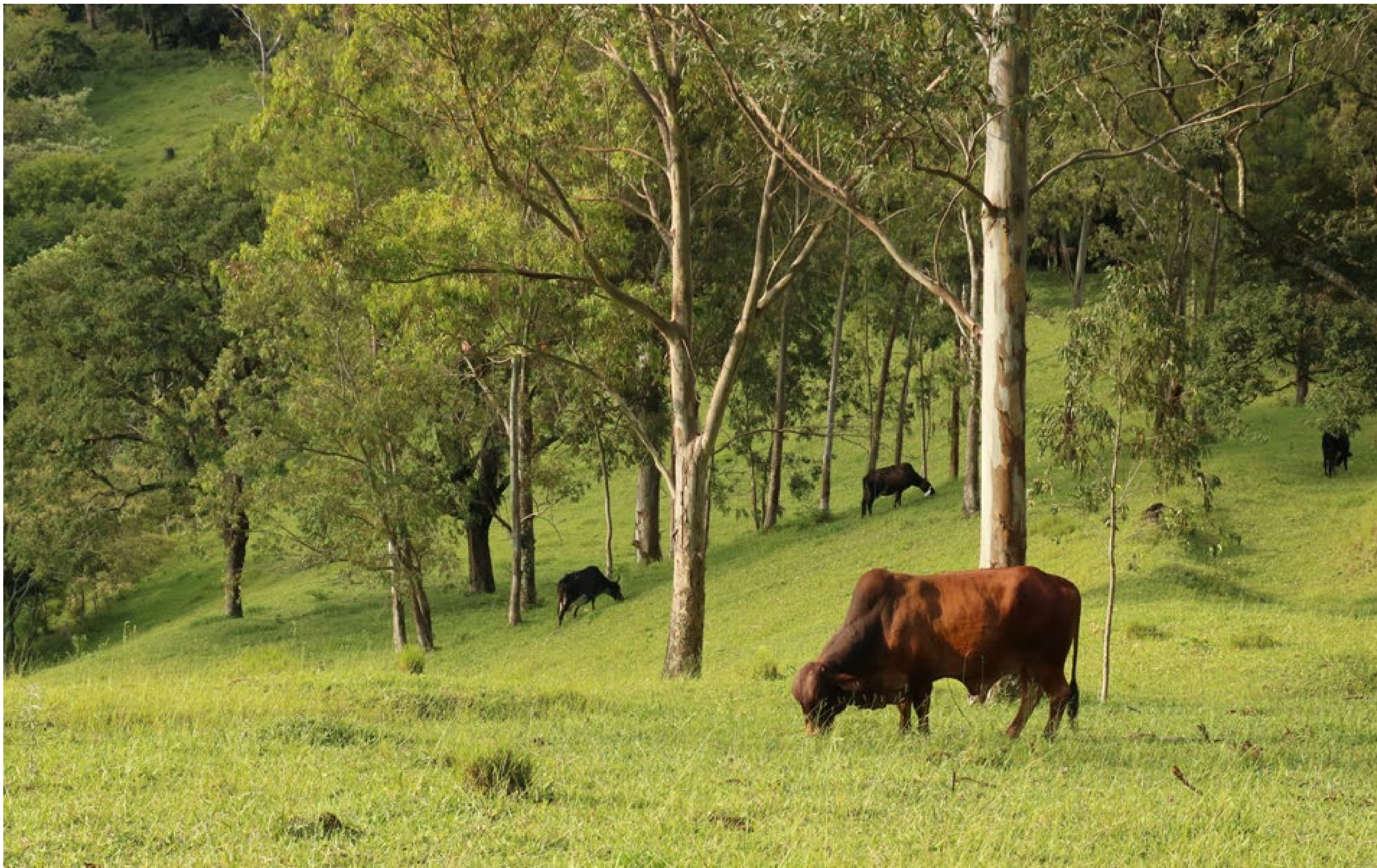
Collectively, these programs have implemented natural infrastructure strategies on about 1,268 ha in the Cantareira System and neighboring Alto Tietê Basin (TNC 2013; SMA 2015a). They have raised about $7.8 million to achieve these outcomes; the resources have mainly gone toward restoring the forest and making payments to landowners for ecosystem services, as well as planning and administering the natural infrastructure strategy.

These early successes and experiences will be key for future growth. Pivoting from demonstration to scale, program operators have expressed interest in growing and diversifying their sources of financial support to expand activities and achieve greater outcomes. Recognizing that water managers stand to benefit from increased natural infrastructure efforts, TNC and partners believe Sabesp and the basin committees are natural partners to scale up operations.

Natural infrastructure efforts are also taking place outside the São Paulo Water Fund. Notably, Sabesp has reforested almost 1,200 ha of forest adjacent to its reservoirs in the Cantareira and has made an additional 880 ha available for nongovernmental organizations (NGOs) or private companies to restore (Sabesp 2017). While this may have some sediment management benefits, it also creates a physical barrier along Sabesp's property line to deter people from entering. It is unclear if Sabesp would entertain the idea of collaborating with the São Paulo Water Fund to implement a landscape-level restoration approach as part of its water management strategy.

If the São Paulo Water Fund is to scale up operations throughout the Cantareira System, some key questions about the role of natural infrastructure in water management will need to be answered:

- To what extent can forest conservation or reforestation as a natural infrastructure approach help address water management challenges facing the Cantareira System?
- How much money should be invested to implement an effective natural infrastructure approach at scale in the Cantareira?
- Which natural infrastructure approaches are most cost-effective or could improve the business case for Sabesp or the basin committees to invest in natural infrastructure?
- What are the trade-offs or limitations of a natural infrastructure approach that water managers should be aware of?
- What are the greatest sources of uncertainty that should be managed to improve confidence in the business case for action?
- What enabling conditions (e.g., managerial, social, legal, financial) have an important impact on the business case and performance of natural infrastructure projects?



CHAPTER II

GREEN-GRAY ASSESSMENT OF NATURAL INFRASTRUCTURE FOR SEDIMENT CONTROL

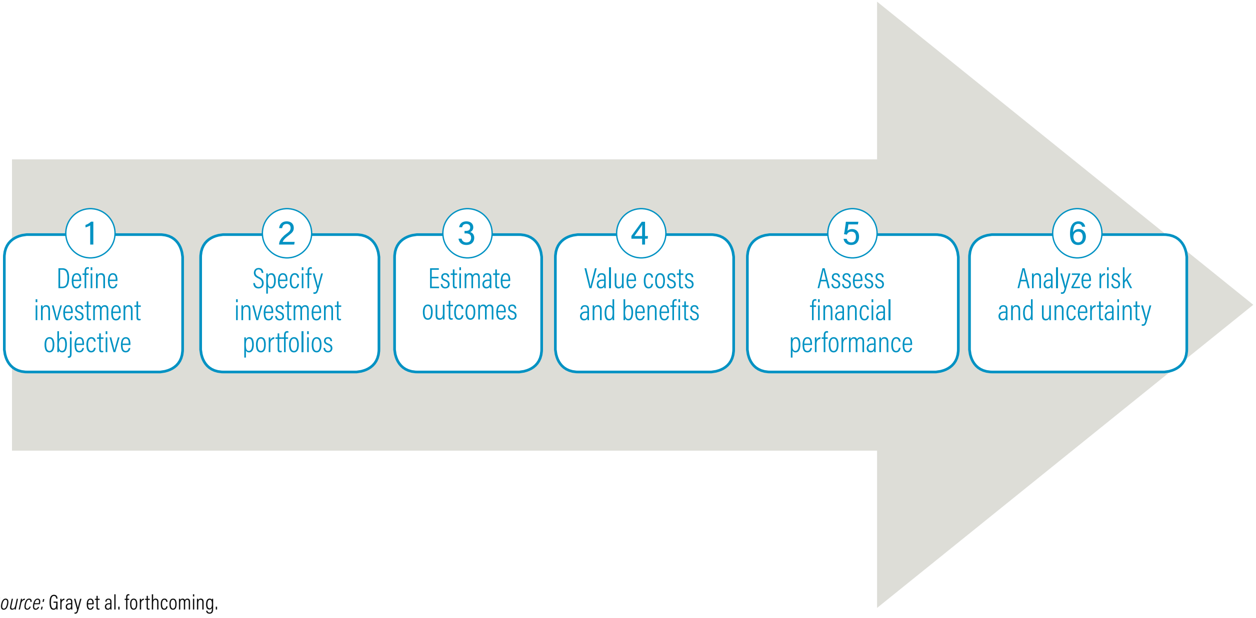
This chapter presents the main results of an assessment that is intended to inform water management and natural infrastructure investments. It summarizes the investment portfolios we evaluated; the estimated biophysical outcomes of each portfolio; and the financial performance in terms of program costs, avoided water treatment costs, and avoided sediment dredging costs. It also highlights several insights from the analysis that could guide natural infrastructure program design and support investment decisions.

To evaluate the financial performance of alternative natural infrastructure investment options, we applied a Green-Gray Assessment developed by WRI. This is a conceptual method of analyzing how natural (green) infrastructure can complement and support conventional (gray) infrastructure in producing goods and services for communities (Talberth et al. 2013; Gray et al. 2014; Gray et al. forthcoming) (Figure 3).

In this case, we conducted a financial analysis by comparing the costs and benefits of investing in different natural infrastructure portfolios for Sabesp, São Paulo's state water company, which regulators consider to be the main water user in the Cantareira System. Each step of the Green-Gray Assessment is summarized here and further discussed throughout this chapter:

- **Define the investment objective:** This analysis defined the objective as maximizing the return on investment in sediment control and water treatment strategies for Sabesp over a 30-year timeframe, which reflects typical water management decision-making. We selected this objective because it affects water management costs.
- **Specify investment portfolios:** In this study, we define investment portfolios as one or more activities working in combination to achieve an investment objective. Other studies may refer to these as investment scenarios or alternatives. Working with local stakeholders, we constructed realistic native forest restoration and conservation targets for the basin and identified a reasonable implementation schedule based on the recommendations of local natural infrastructure program representatives. We used InVEST's Sediment Yield Model to identify suitable areas for these interventions (Sharp et al. 2016; see Appendix B for more information).
- **Estimate biophysical outcomes:** We used InVEST's Sediment Yield Model to estimate sediment yield rates under each portfolio. We then converted these sediment yield rates to measures of water quality and volumes of sediment caught in reservoirs.
- **Value costs and benefits:** We calculated the full project costs of each investment portfolio, considering up-front costs, operation and maintenance (O&M) costs, transaction costs, and opportunity costs. We also calculated each portfolio's potential avoided costs (i.e., benefits) in terms of avoided water treatment, dredging, and equipment depreciation.

Figure 3 | The Six Steps of WRI's Green-Gray Assessment



Source: Gray et al. forthcoming.

- **Assess financial performance:** Applying a 9 percent discount rate that reflects the weighted average cost of capital for Sabesp, we examined and compared each investment portfolio's performance in terms of net present value (NPV), ROI, payback period, and internal rate of return (IRR).
- **Analyze risk and uncertainty:** To meet the interests of a range of public and private investors from the water sector, we varied the discount rate from 5 percent to 12 percent, accounting for Brazil's risk premium. We evaluated the sensitivity of our results to some of the most uncertain variables in our analysis, including the sediment avoidance service provided by native forests, the opportunity cost of land, and forest restoration costs. Finally, we examined how the investment portfolios would perform under a projected climate change scenario.

As detailed in the appendices, we collected the necessary data through an extensive literature review and interviews with local stakeholders, including basin committee members, engineers, water utility financial directors and operators, environmental policymakers, investors in forest restoration, NGOs involved in restoration, and watershed program managers in the region.

The current sediment management strategies used by the water utility Sabesp include conventional water treatment and dredging. We compared the costs of conventional infrastructure investments with the costs of investing in alternative green natural infrastructure portfolios. We evaluated the environmental outcomes of reducing erosion and sediment transport into reservoirs to safeguard existing gray infrastructure, reduce O&M costs, and improve the performance of the water supply system.

Investment Portfolios of the Green-Gray Assessment

Working with local stakeholders to identify natural infrastructure strategies that could complement conventional water management systems, we developed an alternative investment portfolio to be compared with the current baseline conditions. Across both portfolios, we assumed that water demand will increase as estimated by the state Department of Water and Electrical Energy, DAEE (2013). Due to a lack of sufficient data on projected land use change and local impacts of climate change, we assumed these conditions would remain constant over 30 years, though we do address these trends in the sensitivity analysis, described below. The portfolios are presented in Table 1.

Forest Restoration Could Reduce Sediment Pollution by 36 Percent

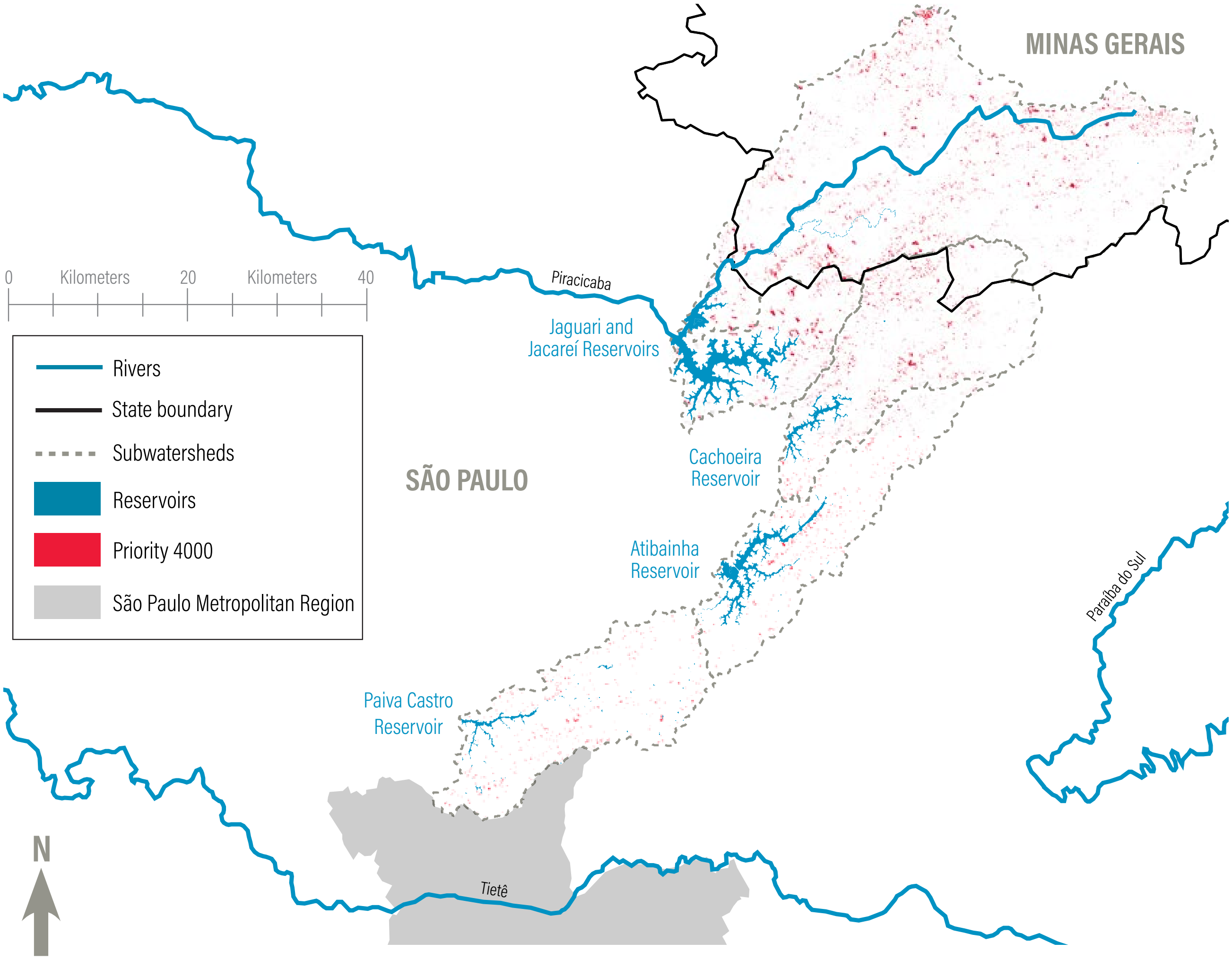
More restoration generally leads to less soil erosion, but restoration has a higher impact in some areas more than others (Figure 4). This is because biophysical factors that influence the rate of soil export—such as soil type, slope, strand side, and proximity to surface water bodies—vary geographically. According to our model, 227,000 tons of sediment are exported across the watershed per year. Restoring 4,000 ha of pastureland randomly distributed in the watershed could avoid 8 percent of the total sediment export. However, if this same 4,000 ha were restored in pasturelands with the highest sediment contribution, the total avoidance could reach 36 percent (Table 2).

Table 1 | Baseline and Alternative Scenarios Constructed for the Green-Gray Assessment

INVESTMENT PORTFOLIO	DESCRIPTION AND ASSUMPTIONS
Baseline	**Conventional infrastructure investments are maintained:** No new conventional sediment control infrastructure investments are made and no new natural infrastructure investments are made. ■ Operation and maintenance of the Cantareira System's six water supply reservoirs continues as usual (Jaguari, Jacareí, Cachoeira, Atibainha, Paiva Castro, and Águas Claras). ■ Operation and maintenance of the Guaraú water treatment plant continues as usual. ■ No investment is made in forest protection or restoration; there is no loss or gain of forest or natural areas (land cover is held constant).
R4000	**Targeted restoration of native forest on 4,000 hectares** ■ **Priority areas:** We used the most recent version of the InVEST Sediment Yield Model to identify the hectares with the highest potential for sediment reduction. The selection of 4,000 ha was inspired by Programa Nascentes, which has a target of restoring forest on 20,000 ha of riparian areas statewide (SMA 2017). Local stakeholders indicated that 4,000 ha of restoration was a reasonable target for the Cantareira region (Carrascosa von Glehn 2017; Bracale 2017; Porto 2017). ■ **Type of restoration implemented:** Overlaying a map of natural regeneration potential with our priority areas shows that 25 percent of priority areas could be restored through natural regeneration (passive forest restoration) and 75 percent through assisted forest restoration (e.g., active planting) (Appendix A). ■ **Overlap with areas of permanent protection:** Overlaying a map of priority areas for sediment control with areas that must be restored to native forest according to the Brazilian Forest Code, about 45% of priority areas should be restored as areas of permanent protection (APPs). ■ **Sequencing of implementation:** We assumed that this restoration plan is implemented in 10 years according to the implementation schedule developed by TNC (2013); see Appendix A for details on this assumption.

Note: For R4000, we assumed that restoration would occur over the first 10 years, and we evaluated the resulting costs and benefits across a 30-year time horizon, including the 10 years needed to implement green infrastructure.
Source: WRI authors.

Figure 4 | Sediment Export in the Cantareira System



Note: This map identifies non-forested hectares that are large sources of sediment, which we deem to be priority areas for reforestation.
Source: InVEST Sediment Yield Model (Sharp et al. 2016; see Appendix B).

Biophysical modeling results for sediment reduction and estimated changes in system turbidity levels are presented in Table 2. The baseline conditions of 227,000 tons of sediment yield per year amount to about 6.8 million tons of soil lost over 30 years. We assumed less than 3 percent of all eroded sediment in the water system arrives at the treatment plant because much is deposited in reservoirs along the way (Sousa Júnior 2011; Appendix C). This amount generates an inflow average turbidity at the treatment plant of around 7.9 nephelometric turbidity units (NTU), which is quite close to values observed by São Paulo's environmental regulatory agency, CETESB (Moreno et al. 2014).

We found that reforesting 4,000 ha (R4000) could reduce average turbidity at the water treatment plant from 7.9 to 4.0 NTU.

An important caveat is that this model represents the change in only one source of sediment (soil loss from the landscape) and simplifies other sources and methods of sediment transport (i.e., legacy sediment, channel erosion). While this may overestimate the reduction in sediment yields, the model results give a first approximation of the magnitude of change possible with a targeted restoration strategy that focuses on areas with the highest sediment yields. We provide details on model results and a discussion of modeling uncertainties in Appendix B. Poorter et al. (2016) have estimated that it takes about 44 years for a restored tropical forest, including the Atlantic Forest in Brazil, to fully recover its structure. Based on this finding, we assumed that erosion control services will develop following a similar "S curve" trajectory and not level out (reaching 100 percent of their full potential) until Year 44. The benefits of natural infrastructure continue to build beyond the typical timeframe for water management projects in Brazil. Some studies have found that sediment control services can be achieved within only a few years after reforestation and local stakeholders also highlighted anecdotal evidence of sediment retention occurring much earlier in restored forests, suggesting the big changes brought about by the "S curve" may occur earlier than we assume.

Tabela 2 | Impacts of Forest Restoration on Sediment and Turbidity

BIOPHYSICAL OUTPUT	BASELINE SCENARIO	R4000	CHANGE
Sediment yield (total tons input to the system over 30 years)	6,797,561	4,382,372	**-36%**
Turbidity level (NTU) in year 30	7.9	4.0	**-49%**

Source: WRI authors.

Financial Performance of Gray and Green Infrastructure Strategies

To understand the financial impact of natural infrastructure, we must first estimate the baseline costs of sediment management in terms of the following:

- **Water treatment**, which involves removing turbidity from the water supply through various technologies such as coagulation, flocculation, and sludge removal.
- **Dredging**, which refers to excavating sediment that has settled at the bottom of the reservoir and must be removed periodically to maintain the reservoir storage capacity. In this chapter, we present dredging costs as an annual value for simple communication.
- **Depreciation of equipment**, which addresses the natural process by which equipment wears out and needs to be replaced. However, less sediment in the system reduces wear and tear on the water utility's equipment, prolonging its useful life and reducing the need for infrastructure repairs, replacements, and upgrades.

Sediment Management in the Cantareira System Currently Costs About $22 Million per Year

Using regression models based on aggregated quarterly data from financial reports covering 16 years (detailed in Appendix C), we estimated operational costs of water treatment in the São Paulo metropolitan region to be about $0.44/m³. Based on interviews with key stakeholders and a literature review, we estimated water treatment costs due to current levels of turbidity to be around $0.02/m³ in our baseline, or 3.9 percent of total operational costs. We estimated dredging costs for all six reservoirs (including machinery, labor, and disposal of sludge) to be $10.13/m³ of sediment on average, or $5.10 per ton (Sousa Júnior 2011; Hespanhol 2017), and depreciation at about $0.001/m³/year (Sampaio 2017). See Appendix C for a breakdown of unit costs used as inputs for these calculations.

The total costs of water treatment in the baseline were estimated to be about $21.8 million per year, while dredging costs were $3.4 million per year (if they occur annually) and depreciation $1.3 million per year. This amounts to about $26.5 million per year to meet an average water demand of 30.01 m³/s. To calculate these water treatment costs at the water treatment plant, we assumed an increasing water demand rate of 0.3 percent per year, based on projections from the São Paulo State Department of Water and Hydropower Energy (DAEE 2013).

Forest Restoration Requires a $37 Million Investment over 10 Years

To determine the cost of implementing each green infrastructure investment portfolio, we considered several cost components:

- **Costs of implementing green infrastructure**, which include all investments needed to put restoration in place, including seedlings, chemical inputs, labor, and fencing to keep cattle out.
- **Green infrastructure operation and maintenance costs**, which include all expenses necessary to promote restoration processes over time and minimize seedling mortality/ecological failures. Based on the recommendations of São Paulo State's Secretariat of Environment (Carrascosa von Glehn 2017, SMA 2013), we assumed that these O&M costs are incurred annually for three years following the restoration. We also assumed that fence repairs occur every 14 years after restoration, considering that SMA (2013) estimates regular fence depreciation at around 5 percent per year.
- **Transaction costs**, which are expenses incurred to engage landowners in the restoration projects, design and monitor the program, and administer contracts and payments. We assumed these costs amount to 20 percent of the total program costs based on input from the São Paulo State Secretariat of Environment and similar studies from the region.
- **Opportunity costs**, which are the loss of potential benefits from likely alternative uses of the land. To entice landowners to implement a natural infrastructure strategy, the investor must meet or surpass the landowner's estimated opportunity cost. In this study, we assumed the opportunity cost to be the pasture rental value, an average annual $171/ha. We assumed a payment to cover this opportunity cost is made each year over 30 years. We also assumed that all restoration taking place in APPs had an opportunity cost of zero because there is no legal alternative activity for those areas. To address the various approaches to estimating the opportunity cost of land and questions of whether the Forest Code law will be enforced, we used alternative assumptions in the sensitivity analysis presented later in this chapter.

The total cost of restoring forests was estimated to be $37 million for the R4000 portfolio (Table 3).

Table 3 | Estimated Costs for Forest Restoration

	ASSISTED RESTORATION ($/HA)	NATURAL REGENERATION ($/HA)	R4000 (THOUSANDS)
INVESTMENTS IN ASSISTED RESTORATION (75% OF PRIORITY AREAS)			
Fence	1,028	N/A	3,092
Soil preparation	109	N/A	328
Ant control	37	N/A	112
Chemical inputs	140	N/A	422
Seedlings transportation	16	N/A	47
Seedlings	730	N/A	2,197
Seedlings plantation	325	N/A	979
Irrigation	280	N/A	843
Workforce	685	N/A	2,131
TOTAL	**3,350**	**N/A**	**10,151**
INVESTMENTS IN NATURAL REGENERATION (25% OF PRIORITY AREAS)			
Fence and workforce	N/A	1,110	1,010
TOTAL	**N/A**	**1,110**	**1,010**
OPERATIONS AND MAINTENANCE COSTS, ASSISTED RESTORATION (3 YEARS)			
Ant control	354	N/A	1,066
Cleaning of seedlings	1,196	N/A	3,598
Replanting (seedlings, transportation, and planting)	421	N/A	1,266
Fencing repairs (year 15)	185	N/A	557
TOTAL	**2,156**	**N/A**	**6,487**
OPERATIONS AND MAINTENANCE COSTS, NATURAL REGENERATION			
Fencing repairs (year 15)	N/A	823	816
TOTAL	**N/A**	**823**	**816**
TRANSACTION COSTS			
Transaction costs	1,101	165	4,990
TOTAL	**1,101**	**165**	**4,990**
OPPORTUNITY COST OF LAND			
APPs (44.5% of priority areas)	0	0	0
Other areas (55.5% of priority areas)	6,250	6,250	13,750
TOTAL	**6,250**	**6,250**	**13,750**
TOTAL COSTS (2017 VALUES)	**12,857**	**8,348**	**37,204**

Source: WRI authors.

Sediment Management Cost Savings of R4000 Are Significant

We found that R4000 would avoid $106 million in sediment management costs over 30 years (Table 4; Figure 5). The largest source of savings is related to water treatment; R4000's estimated reduction in turbidity at the water treatment plant could result in an annual savings of about 14 percent. The methods for calculating these avoided costs are detailed in Appendix C.

Table 4 | Average Water Turbidity and Related Management Costs over 30 Years (present value)

	BASELINE	R4000	SAVINGS	% CHANGE
Average water turbidity inflow at treatment plant (NTU)	**7.9**	**4.0**	**N/A**	**49**
WATER TREATMENT COSTS ($, MILLIONS)				
Workforce	305.8	269.2	36.6	12
Chemical products	78.1	55.1	23.0	29
Sand replacement (10% per year)	1.0	0.7	0.3	30
Anthracite replacement (10% per year)	56.3	54.1	2.2	4
Sludge removal	34.7	22.4	12.3	35
Energy	176.6	158.6	18.0	10
TOTAL	**652.5**	**560.1**	**92.4**	**14**
DREDGING COSTS ($, MILLIONS)				
Workforce	1.2	1.1	0.1	8
Machinery	92.0	81.7	10.3	11
Disposal	8.8	7.3	1.5	17
TOTAL	**102.0**	**90.1**	**11.9**	**12**
TOTAL DEPRECIATION ($, MILLIONS)				
Depreciation	40.3	38.9	1.4	3
TOTAL	**40.3**	**38.9**	**1.4**	**3**
TOTAL COSTS ($, MILLIONS)	**794.8**	**689.1**	**105.7**	**13**

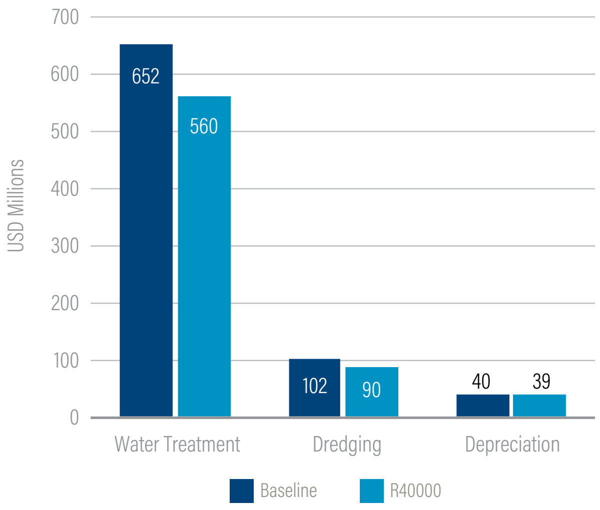
Source: WRI authors.

Chemical product costs are very sensitive to variations in turbidity levels. While estimated costs in the baseline scenario were \$0.07/m^3 of water treated, in R4000 the values dropped to a weighted average of \$0.04/m^3 of water treated (Figure 6). Other water treatment costs are directly proportional to the level of TSS in the water.

Unlike the nonlinear relationship between turbidity and water treatment, dredging costs are proportional to the total amount of sediments deposited in the reservoirs. The less sediment deposited in the reservoirs, the less dredging costs to maintain the water storage capacity. R4000 decreases dredging costs by 12 percent.

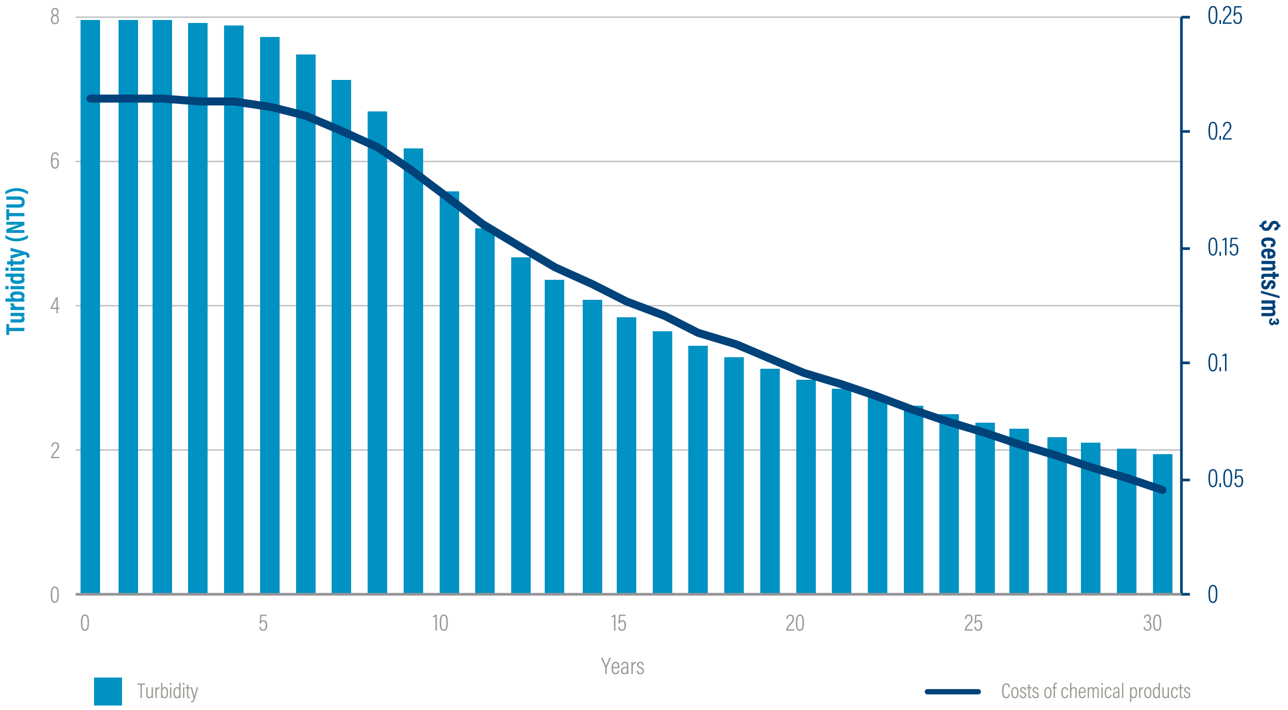
Depreciation, on the other hand, is related to the infrastructure and equipment of the water treatment plant. Because the depreciation rate is time cumulative, as sediments flowing to the treatment plant decrease, the rate becomes progressively lower. In this study, depreciation is calculated only on equipment directly affected by sediments and turbidity. Total depreciation savings are 3.4 percent.

Figure 5 | Costs of Water Management across Investment Portfolios ($, millions, in 30-year timeframe)



Source: WRI authors.

Figure 6 | Estimated Turbidity and Costs of Chemical Products by Year across Investment Portfolios



Note: The cost of chemicals decreases more than proportionally as turbidity decreases because of the amount of chemicals that must be used to treat various densities of suspended solids.
Source: WRI authors.

Sensitivity Analysis

We applied a sensitivity analysis to address uncertainties, varying one parameter at a time to measure its impact on the overall financial performance of the project (Ittelson 2009; Assaf Neto 2010). The three largest sources of uncertainty were restoration costs, opportunity costs, and the level of sediment reduction.

We also varied the discount rate. While our benchmark discount rate was 9 percent, we also considered a "low-risk scenario" of 5 percent which also represents the social discount rate for Brazil (Lopez 2008), and a "high-risk scenario" of 12 percent. More information on the sensitivity analysis and full results are provided in Appendix C.

Table 5 shows that the uncertainty of these variables can pose some risk to the financial performance of R4000.

To understand the impact of sediment retention on R4000's financial performance, we first conducted a statistical analysis (Monte Carlo simulation) based on the results of InVEST's uncertainty analysis and found a wide 95 percent confidence interval of 20–43 percent of sediments retained. Assuming the lowest possible sediment retention, R4000's payback period is 57 years, with losses of $5.9 million by Year 30. On the other hand, If R4000 achieves the upper limit of expected sediment retention, the investment would achieve a payback within 20 years with an NPV of around $10.6 million.

The other available local studies on this topic have estimated restoration costs to range from 51 percent cheaper to 35 percent more expensive than the assumptions in our analysis. We used these studies to craft alternative assumptions about the cost of forest restoration (Benini and Adeodato 2017).

Table 5 | Outputs from Sensitivity Analysis for R4000 Investment Portfolio

ALTERNATE ASSUMPTIONS	DESCRIPTION	IRR (%)	PAYBACK (YEARS)	ROI (%)	NPV ($, MILLIONS)
Benchmark analysis (9% discount rate)		**12**	**23**	**28**	**4.6**
INVESTOR RISK-REWARD AND FINANCING OPTIONS					
5% discount rate		12	19	82	18.4
12% discount rate		12	30	0.4	0.05
IMPLEMENTATION FACTORS (9% DISCOUNT RATE)					
APPs have opportunity costs	Assumes APPs are not enforced, or that for other reasons smallholder farmers need incentives to restore in these areas	11	26	14	2.6
Cost of restoration is 35% higher	If assisted restoration costs are the maximum found in literature for Atlantic Forest	9	30	0.1	0.02
Cost of restoration is 51% lower	If assisted restoration costs are the minimum found in literature for Atlantic Forest	16	18	65	8.2
BIOPHYSICAL FACTORS (9% DISCOUNT RATE)					
20% of sediments are retained	Sediment retention performs at lower limit of normal distribution (within 2.5% of the lowest values)	4	57	–36	–5.9
43% of sediments are retained	Sediment retention performs at upper limit of normal distribution (within 2.5% of highest values)	15	19	65	10.6

Source: WRI authors.

R4000 is still financially viable when restoration costs are 35 percent higher than the costs used in our analysis.

R4000 shows a high sensitivity to the intrinsic risk represented in discount rates. Under a low-risk scenario represented by a 5 percent discount rate, the NPV increases by $13.8 million. Even under a higher-risk scenario represented by a 12 percent discount rate, the project would be viable.

Water managers have always faced uncertainty, and these results are arguably within the realm of normalcy. Chapter 4 discusses some ways that the São Paulo Water Fund and other natural infrastructure programs can address these sources of uncertainty to reduce perceived risks around natural infrastructure, and make this project more financially appealing to water managers.

Forest Conservation Has a Relevant Role

While previous sections discussed the costs and benefits of *restoring forests* for sediment control, *conserving existing forest* is also relevant. The cost to conserve forest is typically lower than the cost of restoration (Soares-Filho et al. 2014) because it requires fewer upfront investments (e.g., no seedlings or workforce to plant trees) (Rodrigues et al. 2011). Standing mature forest already provides sediment retention, whereas a restored forest needs time to mature before its sediment retention benefits reach their full potential. Standing forest can also reduce the cost of reforestation by supporting natural regeneration. Forest conservation, therefore, could complement restoration activities, ultimately enhancing natural infrastructure's sediment control services in the region.

Table 6 | Impacts of Forest Conservation on Sediment and Turbidity

BIOPHYSICAL OUTPUT	D1900	C1900
Sediment export (tons over 30 years)	6,969,657	6,797,561
% change in sediment export	+2.5%	0
Turbidity level in year 30 (NTU)	8.2	7.9
% change in turbidity in year 30	+3.8%	n/a

Source: WRI authors.

The Cantareira System does not seem to be under immediate threat of deforestation because most forest conversion took place decades ago. The 16-year historical rate of deforestation in the Cantareira tracked by Hansen et al. (2013) recorded a deforestation rate of less than 0.1 percent per year. Projecting this rate into the future, the watershed may lose 1,900 ha of forest over a 30-year time horizon (about 2 percent of current forest cover).

However, no robust projection of future land cover has been made for this region, so it is difficult to know whether current land use change trends will continue, and which areas are most at risk of deforestation. This has bearing on our estimates of the potential biophysical impacts and costs of conservation.

We analyzed two scenarios to estimate the costs and benefits of forest conservation for sediment management. We maintained the same counterfactual assumptions as in our restoration investment portfolios (current reservoirs and the water treatment plant are operated and maintained as usual and no new infrastructure investments are made):

- The “Deforestation” scenario (**D1900**) assumes the 1,900 ha are lost in priority areas at a steady rate of 0.1 percent per year (based on the current historic rate of forest loss). We assume this deforestation occurs in priority areas, which are forests that currently retain the most sediment, and used the InVEST Sediment Yield Model to identify these areas (see Appendix B for details).
- The “Conservation” scenario (**C1900**) assumes the 1,900 ha of forest are conserved in Year 0, and no forest is lost over the 30-year period.

Table 6 shows the biophysical results. A well-targeted forest conservation strategy could avoid a slight uptick in sediment export. Under D1900, an additional 172,000 tons of sediment would enter the Cantareira System over 30 years, increasing turbidity by 3.8 percent. Over the same period, additional costs associated with treating this turbidity could result in a reduction of 1.1 percent in ROI for Sabesp.

> Standing forest can also reduce the cost of reforestation by supporting natural regeneration. Forest conservation, therefore, could complement restoration activities, ultimately enhancing natural infrastructure’s sediment control services in the region.

Table 7 | Financial Performance of Conservation Investment Portfolios

FINANCIAL MEASURES OF PERFORMANCE	C1900 ($, MILLIONS)
AVOIDED COSTS	
Water treatment	15.2
Dredging	0.9
Depreciation	0.5
TOTAL	**16.6**
COSTS OF CONSERVATION	
Investments (assuming priority areas are already fenced for protection)	0
Opportunity cost of land (proxied by payment for ecosystem services values paid)	5.0
Operations and maintenance costs (fencing repairs, years 0 and 15)	0.6
Transaction costs	1.5
TOTAL	**7.1**
Benefit-cost analysis index	2.4
Net benefits margin	1.4
IRR (%)	11
NPV ($)	390,000
Payback (years)	26
ROI (%)	14
Net benefits	9.5

Source: WRI authors.

We estimate the total cost of conserving 1,900 ha to be approximately $7 million over 30 years, depending on the conservation strategies used. We considered the same costs of green and gray infrastructure for C1900 as we did for R4000, with only a few differences in natural infrastructure cost estimates. First, we assumed that fences already exist to protect priority areas, and these fences simply need to be maintained. Also, we adopted the opportunity costs of $88/ha/year for forest conservation compared with $171 for restoration. This reflects the value of payments for ecosystem services for conservation in the region (TNC 2013). The opportunity cost of conserving land is lower than restoring productive land since deforested areas can more readily be used as pasture. (See Appendix C for details on cost inputs.)

C1900 presents a reasonable case for investment, with 14 percent ROI and a positive NPV (Table 7). This investment could generate $17 million in sediment retention benefits alone. However, the financial returns are lower than for R4000, for a few reasons. First, we assumed all land is conserved in the first year, and the modest benefits of avoided deforestation accrue slowly—using a discount rate of 9 percent over 30 years, the up-front costs of conservation have a high impact on financial results, while benefits that accrue in later years have less impact. Also, the results imply that the priority areas for sediment control within the region may have already been deforested, and are now in need of forest restoration.

This analysis provides a small glimpse into the value of forest conservation by analyzing just one potential benefit (sediment control), although forests are known to generate many valuable ecosystem services. For example, forests help mitigate flood risk, provide seeds and habitat conditions to facilitate low-cost natural regeneration of forest, and regulate seasonal water flows (see Chapter 3 for more about this benefit). Standing forests also provide habitat for rare species, offer recreational opportunities, and regulate local climates. Evaluating additional benefits of forests may complement this study to inspire investment from sustainability-minded investors.

Further research is needed to refine these results. Robust land use projections are needed to better understand the possible rate and location of deforestation in the Cantareira System. Information on the conservation status of priority areas is also needed to better estimate the cost of conservation.

Interpreting Results

Will a 12 percent IRR for R4000 and an 11 percent IRR for C1900 entice investment from Brazil's water sector? The annual ROI for water utilities in Brazil is between 3 and 22 percent per year (Junqueira et al. 2017). Therefore, the analyzed natural infrastructure investment options generate returns within the typical range for Brazil's water sector.

Sabesp's average annual ROI over the past two decades has been an impressive 45 percent, but that accounts for all business activities, not only water supply and treatment projects (MC 2015). Even so, as discussed in Chapter 1, Sabesp has experienced failures in this system (for example, during the 2015 water crisis) as well as pushback against proposed built infrastructure projects. Given the significant benefits that natural infrastructure could yield for just one water management objective, the company and related agencies should integrate nontraditional infrastructure such as forests into planning to enhance overall system performance and resilience.

The financial case for investing in forest restoration and conservation as natural infrastructure is relevant for other decision-makers as well. Basin committees can allocate funds to natural infrastructure, and may use this study's maps and financial analysis to guide such investments. Furthermore, this study found that restoring forest to meet the legal requirements of the Forest Code and NDC commitments generates significant benefits for the water sector, which could become a more active partner in restoration projects.

While this chapter has answered why, where, and how to invest in natural infrastructure for sediment control benefits in the Cantareira, some questions remain to fully assess the value and feasibility of such a strategy. For one, São Paulo water managers may hesitate to invest in such an opportunity until they know more about the impact of natural infrastructure on water flows. Also, water managers may want to ensure prior to investment that natural infrastructure strategies are designed for success.

These two questions are further explored in the following chapters.

CHAPTER III

NATURAL INFRASTRUCTURE'S EFFECT ON SEASONAL WATER FLOWS

Maintaining a reliable urban water supply, especially in dry seasons, is the top priority for São Paulo and many other cities in Brazil. The conventional wisdom among water managers is that increasing forest cover reduces water availability, representing a potentially significant trade-off. However, some small-scale studies discussed later in this chapter suggest it is possible for healthy native forests to help regulate the timing and flow of water in a way that helps meet water quantity targets.

Overall, the evidence base to determine forests' impact on water availability in this region is incomplete, complex, and still open to interpretation. Further analysis is needed to determine whether forest restoration or conservation decreases or enhances water supply in the Cantareira.

This chapter examines the links between forests and seasonal water yield and demonstrates a possible methodological approach to considering the impacts of forests on dry season water supply. We developed our approach through a literature review and by using a Dynamic Water Balance Model to understand local conditions (see Appendix B for details). We analyzed natural infrastructure's impact on two main hydrological parameters:

- **Baseflow,** which occurs during dry weather when the landscape has the capacity to slowly release soil and groundwater over time. Baseflow is also sometimes called dry season flow, drought flow, or sustained flow. Soil and subsurface infiltration enhances baseflow.
- **Total flow** (also called streamflow), which is the total flow including both quick flow (occurring during or soon after rainfall events) and baseflow. It represents the total discharge in the stream channel.

We found that under the R4000 portfolio, the magnitude of impacts, positive or negative, would probably be small enough to slightly improve dry season water flows but not force a change in water management practices. Recent studies have found that there is a significant proportion of high altitude forests (often called cloud forests) in the Cantareira System: at least 5 percent of the area has a 50 percent probability of occurrence of cloud forest (Pompeu et al. 2018). Cloud forests possess the unique ability to generate soil water and streamflow from fog, as tree branches and leaves capture and collect droplets of water that would otherwise remain in the atmosphere. This "fog capture" slightly increases the positive impact of restoration scenarios on both annual and dry season water flows.

Literature Review of Studies Investigating Forests' Impact on Water Availability

Although links between forests and water quality are well established, the impact of forests on water quantity is a more complex and controversial topic. This section presents the findings of the literature review we performed to determine the state of scientific knowledge regarding forests' impacts on annual and seasonal water availability in the Cantareira System.

Filoso et al. (2017) recently conducted a global systematic literature review on the impact of forest restoration on water yield. Most studies (about 80 percent) found that forest cover expansion negatively affected annual water yields, but examining the subsets of the case studies reveals a more nuanced picture. Increasing forest cover leads to reductions in aquifer recharge rates (67 percent of studies) and impacts in baseflow (73 percent negative, 27 percent positive or no impact), but typically helps reduce peak flows or flooding frequency (82 percent). The study also found that more forest cover leads to higher water infiltration rates and soil moisture levels, which can eventually lead to groundwater recharge and greater baseflow, helping with dry season water availability.

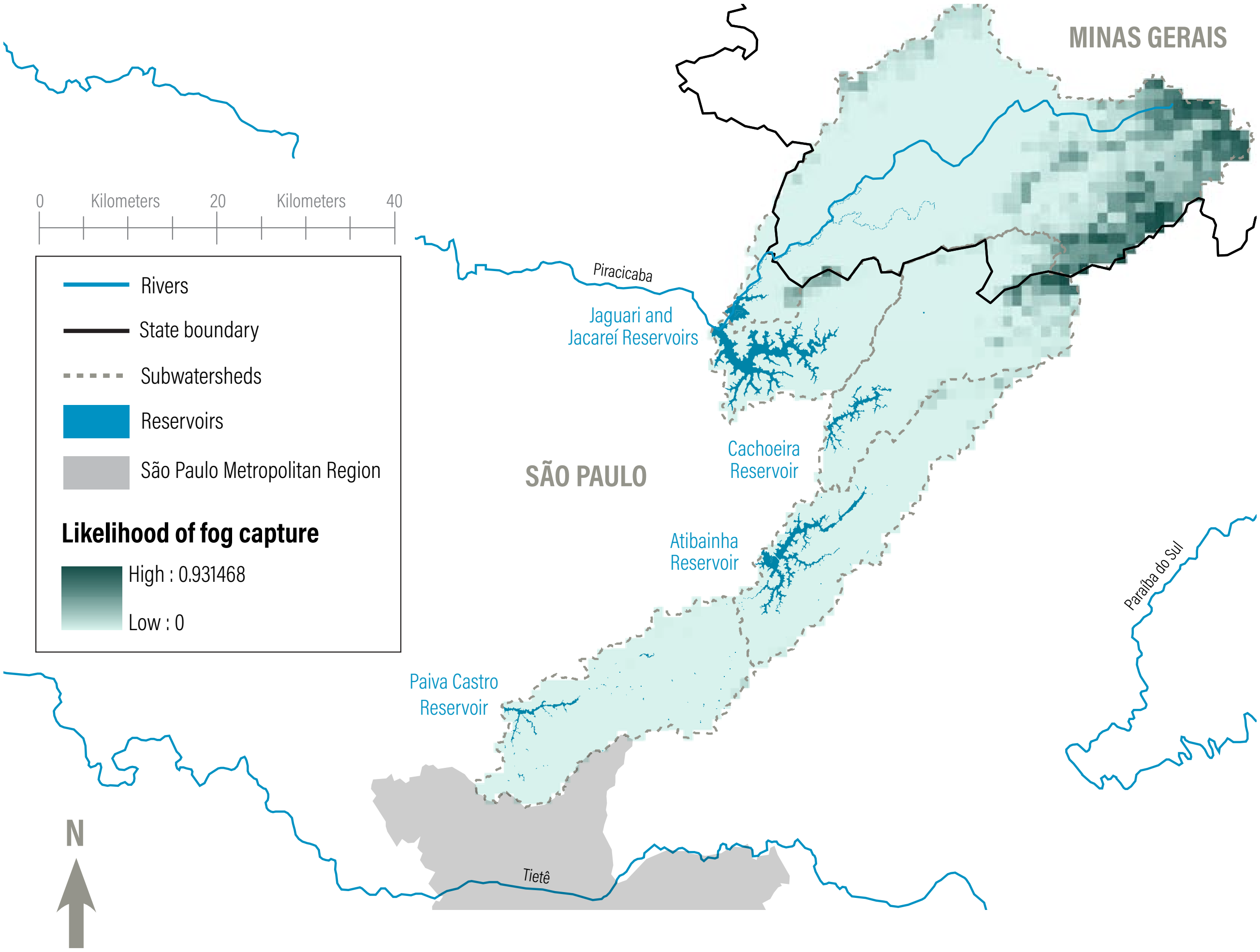
While this analysis of 208 case studies is considered the most comprehensive study of its kind to date, it highlights important gaps in the literature. For example, the great majority of studies were conducted on forests in Oceania, Europe, and Australia, giving temperate forests a disproportionate representation. The tropics and subtropics are understudied, with only 23 of 208 cases (7 percent) addressing Central and South America.

To supplement the findings of Filoso et al. (2017), we reviewed hydrological studies of Brazil's Atlantic Forest region, but these studies also demonstrate mixed results regarding how watershed restoration and reforestation/afforestation impact water yields. Fujieda et al. (1997) found that forested riparian areas in the Serra do Mar, São Paulo, Brazil, can hold water in soil and feed groundwater sources. In contrast, Alvarenga et al. (2016) found that increasing the Atlantic Forest cover from 63 percent to 100 percent of the watershed would decrease the average monthly streamflow by 12 percent during the wet season and by 11 percent in the dry season. Pereira et al. (2014) found that an increase in native forest cover in a watershed in Espírito Santo corresponded to a reduction in surface water availability while increasing soil water storage, helping ensure minimum flows during dry periods.

While these global and local studies seem to paint an inconsistent picture, our analysis found some important factors that suggest existing studies cannot be applied directly to the Cantareira System. First, the majority of studies did not address the purpose of the restoration projects. It is well accepted that protecting or restoring forests in certain areas, such as mountain tops and riparian zones, can generate more baseflow than in others (Ellison et al. 2017). Restoration projects aimed at providing water benefits typically target zones and forest types that are known to provide hydrological benefits. Restoration projects conducted for other reasons may not have designed interventions to optimize hydrological benefits, so studies of non-hydrological forest restoration projects are not necessarily a good gauge of how natural infrastructure restoration in the Cantareira System might affect water availability.

Second, most studies were conducted over a very short timeframe (one to five years) and therefore did not sufficiently account for the impacts of restoration scale and forest age on water yield (Filoso et al. 2017). For example, a forest undergoes rapid growth during its early years and has a high need for water, but Brown et al. (2005) suggest that as forests mature, water requirements may reach a lower equilibrium, potentially returning to pre-deforestation levels and consequently passing on more water to the water system through the soil. Because most studies in the Filoso et al. (2017)

Figure 7 | Probability of Cloud Forest Occurrence in the Cantareira (proxy for fog capture)



Source: Contributed by Patrícia Vieira Pompeu. See Pompeu et al. (2018) for more information.

literature review covered short timeframes, a result that correlates reforestation with a decrease in water yield does not account for an initial drawdown of water. Considering longer time horizons and mature forest areas may better capture forests' positive impacts on water quantity, but few studies of that type exist, and none are specific to the Atlantic Forest in southeast Brazil.

Third, fog capture contributes to annual water availability, but the process was not explored in Filoso et al. (2017) or local studies. Global literature shows that fog capture can account for up to 30 percent of annual water availability in cloud forests, depending on temperature, elevation, proximity to coast, and the condensation potential on leaves (Ellison et al. 2017). Although there were no measurements of fog capture in the Upper Tiete and Cantareira Systems, these geographic areas possess the topographic and ecological characteristics that lead to fog capture. The probability of fog capture occurrence in these regions has been mapped (Pompeu et al. 2018; Figure 7). Pompeu et al. (2018) estimated that cloud forest conditions (probability >0.5) occur in about 5 percent of the entire Cantareira System. Therefore, it seems plausible that forest restoration targeted to these areas could increase dry season water flows through that hydrological function.

Because the studies in Filoso et al. (2017) and in our local literature review did not address fog capture, timeframe, or purpose of restoration projects, the existing literature base is not a trustworthy predictor of natural infrastructure interventions proposed for the Cantareira System. To understand the variety of mechanisms that determine annual water yield, studies that focus on this region and its unique biophysical features are needed. As a first step toward addressing this substantial knowledge gap, we created a preliminary model examining how forest loss or gain will impact water flow to determine whether this issue is significant enough to include in water management decisions.

A Modeling Approach to Understanding Water Balance in the Cantareira System

Studies focusing on larger water catchments such as the Cantareira tend to use biophysical models to explore the relationship between forest cover and hydrological response. In this study, we applied a monthly watershed model, the Dynamic Water Balance Model (Hamel et al. 2017; Zhang et al. 2008), to represent the Jaguari Basin in the Cantareira System. The Jaguari is the largest subwatershed of the Cantareira System, comprising almost half the total area (103,277 ha). We assessed monthly water availability under various land cover scenarios, with and without fog capture functions. This baseflow modeling exercise assessed the impact of forest conservation on seasonal water availability, finding that large forest area plus the potential effect of fog capture increased both total flow and baseflow.

Because there are important gaps in the scientific literature regarding the hydrological modeling of changing land use in the tropics, the results of any hydrologic modeling need to be interpreted with caution. This modeling exercise is purely illustrative, meant to begin a conversation about some of the forest hydrology dynamics often omitted from water management decisions, such as cloud forests' fog capture abilities and native forests' baseflow functions, and to demonstrate an approach for future analysis.

For these reasons, we used a simple monthly model (the Dynamic Water Balance Model) to represent the hydrologic behavior of the São Paulo watersheds and estimate the potential for natural infrastructure to affect reservoir water levels. Details about the model, calibration, assumptions, data inputs, and uncertainty assessment are included in Appendix B.

We ran the following scenarios, which illustrate the general effect of land use and the impact of realistic land use change through investment in natural infrastructure:

- **Scenario 1, Baseline:** Current land cover of the Jaguari, composed primarily of pastureland (59 percent) and forest (33 percent, not distinguishing between native and planted forest due to data constraints), among other land uses. We assumed native and planted forests provide the same erosion control benefits.
- **Scenario 2, 100 Percent Pasture:** The entire landscape, including currently urban areas, is converted to pasture. Pasture was selected because it is the main land cover of the basin and the main land use on deforested land. Pasture does not have the biophysical structure to capture fog, so we assumed no fog is captured in this scenario. This scenario represents the upper bound of the effect of deforestation (no forest exists in the watershed).
- **Scenario 3, 100 Percent Forest:** The entire landscape, including areas currently under urban development, is forested. This scenario represents the upper bound of the effect of afforestation (67 percent of the watershed reforested). It portrays a range accounting for the potential fog capture services provided by cloud forest in the region. It assumes that fog capture services provided by cloud forest amount to the equivalent of a 5 percent increase in precipitation.
- **Scenario 4, R4000:** The forest area is increased by 8 percent. It portrays a range conservatively assuming the forest's fog capture services are not enhanced (i.e., that reforestation occurs in areas where cloud forest conditions are not met), and assuming the forest's fog capture services are enhanced.

Scenarios 2 and 3 represent the range of possible impacts by showing the extremes, and are not intended to reflect feasible management decisions. For Scenarios 3 and 4, which assume increases in forest cover, we force the model to ignore fog inputs, and then represent them as an additional 5 percent in precipitation input, producing a range. The 5 percent assumption was adopted because forest at altitudes that constitute cloud forest are thought to have the ability to generate 5 percent more water capture through fog capture than other forest types (see Appendix B for details).

We included scenarios with and without fog capture for two reasons. First, although local researchers have mapped the extent of cloud forest for this region, no studies have been published that estimate the level of fog captured by these forests or the amount of water input to the system contributed by this mechanism. Here, we used the results from ongoing research on cloud forest in the region (Pompeu et al. 2018) and assessed the impact of potential fog capture on total flow and baseflow.

As the Dynamic Water Balance Model is not a spatial model, it does not account for geographic variance in the extent of cloud forests. The scenarios we analyzed did not assume any prioritization of reforestation activities, for example, in areas that would maximize fog capture or soil infiltration. Rather, we used an average value of fog capture and infiltration. The priority areas we selected for sediment control—to create the R4000 restoration scenario in Chapter 2—may or may not overlap with the areas of cloud forest that maximize seasonal and annual water flow contributions. Presenting results of each scenario as a range to represent impacts with and without fog capture shows the possible outcomes considering these uncertainties.

Table 8 shows the impact of land cover on water flows. Each scenario was assessed for two parameters: baseflow and total flow. Reforestation scenarios show mixed impacts in total flow (depending on assumptions about fog capture) but consistently higher baseflow during the dry season, demonstrating a general trend of smoothing the peaks and valleys of interseasonal water flow. These results suggest that forests in the Cantareira may demonstrate the "sponge effect," in which they hold water in the wet season and slowly release it in the dry season. Pasture, on the other hand, increases total water availability, but significantly reduces baseflow, and therefore does not help moderate the timing and flows of water as much as forest does.

While the forest scenarios may lead to an increase in evapotranspiration and consequently result in lower total flows compared with the baseline, our results indicate that fog capture could counterbalance this trend and would still satisfy reservoir demand. Managing landscapes to restore forests' fog capture functions could therefore yield important benefits for water quantity. For R4000, the results show a low magnitude of impacts, reflecting that only 2 percent of the watershed is altered. Water baseflow in the Cantareira System could be increased by as much as 1.2 percent under R4000, if fog capture occurs.

When considering only the dry season between June and August (Figure 8), water flow increases under both forest scenarios (with or without fog capture), but decreases under the pasture scenario. This illustrates two main benefits of forest cover in the Cantareira. First, forests' production of baseflow helps control the timing and flow of water in a way that could alleviate stress in dry periods. Second, forests' fog capture services increase total water availability. Water managers likely see both benefits as desirable and can plan for them by conserving existing forest cover and restoring forests, especially in areas that experience frequent or heavy fog.
Given that the intensity of wet season rainfall is likely to increase in this region, the sponge effect

Table 8 | Land Cover Effect on Water Flows

SCENARIO	BASELINE (TOTAL ANNUAL, MM[a])	100% PASTURE	100% FOREST		R4000	
			NO FOG CAPTURE	WITH FOG CAPTURE	NO FOG CAPTURE	WITH FOG CAPTURE
Baseflow	435.1	−66.8%	+54.2%	+68.0%	+1.0%	+1.2%
Total flow	720.2	+21.5%	−5.5%	+3.9%	−0.1%	+0.1%

Note: [a] The abbreviation mm stands for millimeters.
Source: WRI authors.

could be increasingly important in combating future water scarcity by more effectively managing water volumes that, by midcentury, may surpass current built water storage capacity. While our results suggest that fog capture and a forest's sponge effect may have significant benefits for water management infrastructure, further research is needed to verify the possible impacts. Due to a lack of data and scientific understanding of this region, the current study has high uncertainty.

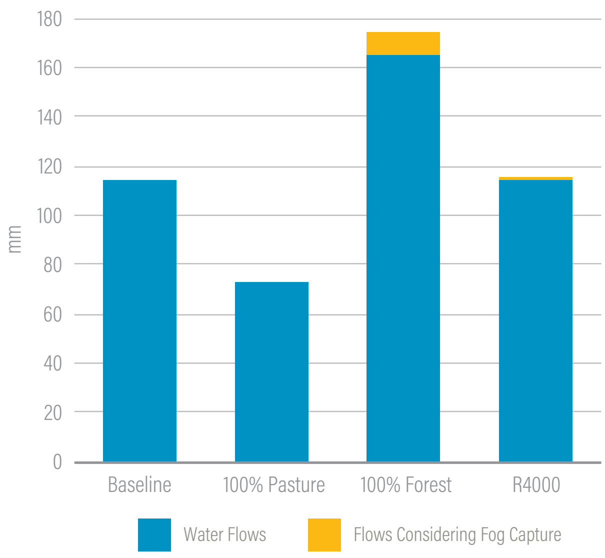
Uncertainty and Limitations

We originally set out to conduct a robust, decision-relevant Green-Gray Assessment focused on natural infrastructure's contribution to seasonal water flows in the Cantareira System. However, further biophysical research is needed to input the full data into our model, including factors like interannual variances, different impacts of native and plantation forests, the contribution of water inputs from cloud forest fog capture, and the impact of climate change. Conducting this analysis again with a model capable of accounting for spatial and topographic variability could refine the results and account for the probable location of cloud forests. More sophisticated modeling of the entire system, including demand, reservoir rules, and land use change, and calibration of the model using local data are needed to increase confidence in our results. The limitations of this analysis are further discussed in Appendix B.

Interpreting Results

Although the research to support natural infrastructure investments comes with some uncertainty, our study shows a modeled range of water quantity effects to be quite narrow (+/–1 percent) and most likely very slightly positive. While that may not seem like a significant change, based on the estimate by Sabesp (2014) of the average water consumption in the Cantareira System, the contribution could be enough to supply water for a population of 103,000–256,000 people for one year. Even so, such a change is unlikely to impact water management decisions. As a point of comparison, in 2015, 182 billion liters—enough water to supply 2.7 million people for one year—were lost through leakage, fraud, or theft in the PCJ Basin, which includes the Cantareira System (Reinfra Consultoria 2017). On average, in the state of São Paulo, 23.5 percent of water is lost before reaching the consumer.

Figure 8 | Land Use Effect on Water Flows (dry season, June-August)



Source: WRI authors.

Given the majority of available climate change projections for the region forecast a 10–20 percent increase in annual water flows by midcentury, it is unlikely that any negative impact on water supply of the predicted magnitude would be relevant (PBMC 2013; Marengo et al. 2013; CCST and USP 2017; Nobre et al. 2010). Therefore, forest restoration's impact on annual water supply is perhaps not a threat to current water management objectives in the São Paulo area and may in fact aid in achieving future water management goals as climate change progresses. However, the lack of local studies and paucity of local data to calibrate this model present important limitations; our results must therefore be interpreted with caution.

Water utilities are accustomed to working with imperfect knowledge of water yields and have a variety of tools for managing hydrological risks (Jacobs and Fleming 2017). With access to utility-level data and more detailed research on the impact of cloud forest restoration on annual water availability, future studies can provide context comparing the costs and benefits of conventional infrastructure and natural infrastructure investments with much greater certainty.

CHAPTER IV

A ROAD MAP TO SCALE INVESTMENT

This report has addressed the business case for investment by showing that under this study's assumptions, restoring 4,000 hectares of forest provides an attractive ROI for water companies and basin committees. We identify more ambitious interventions and suggest a research agenda that could further strengthen the business case for investment. This chapter seeks to inform the activities of a broader network of stakeholders, including basin committees, government agencies, and natural infrastructure programs.

In the Cantareira, many of the essential ingredients for scaling natural infrastructure strategies are already in place, with massive capacity, practical knowledge, and enthusiasm among many stakeholder groups. Following a decade of small-scale successes, natural infrastructure programs are becoming more ambitious. They aim to secure more funding to become fully operational, engage the water sector beneficiaries who stand to benefit from their activities, and implement natural infrastructure strategies with more landowners to produce outcomes at scale. This chapter sets out an agenda to achieve this transformation.

Through workshops, one-on-one consultations, and a survey, we worked with stakeholders to examine the key challenges and opportunities involved in advancing natural infrastructure strategies (see Appendix A for more information). We complemented stakeholders' contributions with an extensive literature review focused on natural infrastructure programs in the study area. Borrowing the watershed investment success factors framework provided in Ozment et al. (2016), we organized our findings into four priority areas for action:

1. Identify investors and financing mechanisms for initial and long-term funding. Currently, the largest funder of natural infrastructure in the Cantareira System is the public sector. Natural infrastructure program representatives in the region are interested in engaging the water sector and private entities to invest more in these strategies so they can achieve scale. Several natural infrastructure programs active in the area have successfully accessed sufficient funding to develop pilot projects, but they are in need of larger-scale and sustained funding to reach their goals.

2. Develop a scientifically informed watershed plan. Stakeholders noted that the business case for investment is also hampered by the lack of a clear scientific understanding of the relationship between proposed natural infrastructure interventions and their outcomes.

3. Evaluate the business case for investment. Stakeholders consistently commented that the lack of a robust and trusted assessment of the natural infrastructure investment opportunity prevented further engagement by the water sector. The São Paulo Water Fund conducted a preliminary study about this in 2013, and this study closes the gap. However, we found the business case for investment could be sharpened by modifying strategies to address uncertainty and appealing to investor interests.

4. Engage landowners to conserve, restore, and sustainably manage natural infrastructure. In São Paulo, program representatives have already built strong relationships with communities and enacted monitoring and compliance protocols. They also have experience providing technical assistance and financial incentives to land managers. Even so, the land ownership composition and dynamics of the Cantareira continue to make this a challenge. The sustained support of the basin committees or water company, as well as municipalities, could potentially increase interest among landowners.

Securing Financing for Natural Infrastructure

Stakeholders consistently identified as a top priority the need to secure sufficient financing to advance natural infrastructure in the Cantareira System. Recent estimates of investments in on-the-ground natural infrastructure programs appear to be much lower than the required budget (Bremer et al. 2016). Many programs in the region use a blend of funding sources but are interested in further diversifying these sources to provide more program flexibility and financial sustainability.

The findings presented in Chapters 2 and 3 suggest that investing in 4,000 ha of targeted forest restoration should prove attractive to a risk-averse water sector investor such as Sabesp or the basin committees. This investment portfolio is estimated to produce a sufficient ROI via sediment retention benefits while providing minimal but potentially positive impacts to annual and seasonal water flows. Accessing sufficient funds to speed restoration may be one way the program can increase the odds of a sufficient ROI. Given these conditions, the São Paulo Water Fund may benefit from a blended finance model, where multiple investors pool funds to reduce risk and enhance benefits beyond the private benefits accruing to the public utility and water sector (Box 2).

BOX 2 | FINANCING OPTIONS TO ENGAGE RISK-AVERSE INVESTORS IN NATURAL INFRASTRUCTURE

Because natural infrastructure investments fall outside the traditional business activities of a water infrastructure operator, many projects have been stymied by water companies' hesitancy to engage. Innovative financing models can overcome this challenge. Some of these finance models are already being pursued in São Paulo.

Leveraging seed funding early on: Watershed investment programs often rely on seed funders to cover startup costs and demonstration projects and engage water utilities or city governments to invest only once a project is proven and is fully operational. It appears that programs in São Paulo are pursuing this strategy based on their reliance on corporate donations and government funding.

Water funds: The Latin American Water Funds Partnership has established 20 programs that pool funds from multiple water-dependent companies and public-sector actors so that each individual company's contribution contributes to a larger cumulative impact. The São Paulo Water Fund program is led by TNC and currently funded through the basin, private funds from the Green Blue Water Coalition, and other sources. The fund is searching for additional funding sources and finance mechanisms to use this successful strategy to sustain larger-scale activities.

Leveraging private capital in a pay-for-success model: Pay for success is an approach to contracting that ties payment for service delivery to the achievement of measurable outcomes. The DC Water Environmental Impact Bond represents one of the first applications of a pay-for-success model to environmental issues. In this case, private investors paid all up-front costs for the installation of green infrastructure to improve stormwater management, on the condition that the local water company would pay back their investment at an interest rate that would vary according to how well the green infrastructure performs (e.g., the more successful the project, the higher the interest rate—and vice versa). A similar model might support natural infrastructure investments in the Cantareira or other basins throughout Brazil.

Partnerships with finance institutions that have sustainable development missions: Development banks have made significant investments in water resources systems in São Paulo State, and in river basins that border the Cantareira System. For example, the World Bank's Global Environment Facility contributed a $31 million grant to the states of São Paulo, Minas Gerais, and Rio de Janeiro for strategic restoration of water supply areas to increase carbon stocks and to promote ecosystem-based adaptation in the Paraíba do Sul Basin (GEF 2016). The Inter-American Development Bank (IDB) has also contributed funding to support TNC's water funds throughout Latin America, including the São Paulo Water Fund (IDB 2017).

While these grant funds have been essential to advancing forest restoration and natural infrastructure activities, there may be opportunities to engage development banks in larger, longer-term financing of these projects. IDB and the World Bank have both expressed interest in funding natural infrastructure alongside conventional water infrastructure projects as one way to advance their sustainable development agendas. However, these financing opportunities would likely require a funding level of $30 million or more, and be contingent on commitments from Sabesp or the government. They would likely require system-wide reporting of outcomes to evaluate whether benefits are being realized. Therefore, development bank investments in natural infrastructure (outside of grant funding) are likely not suitable for most of the natural infrastructure programs active in the Cantareira, at least not in their current form. Rather, tapping these opportunities would likely require programs to pool their efforts and operate at a system level and also engage Sabesp.

We found that the programs rely primarily on public funds but face challenges to secure sufficient funds from these sources. At the same time, some programs are pursuing corporate and international funding sources. The following sections discuss current and potential future funding from public and private sources.

Public Funds

Public funds are the primary support for water resources management in Brazil, but typically only a small portion is allocated to natural infrastructure programs (Table 9). The primary public funding sources include the following:

- **State Water Resources Fund:** As a public fund managed by the government of São Paulo, the State Water Resources Fund (FEHIDRO in its Portuguese abbreviation) collects money from water use fees, financial compensation (e.g., licensing fees and royalties), government transfers, fines for environmental infractions, and so on (Estado de São Paulo 2015). FEHIDRO funds an array of water management activities, including PCJ basin committee plans and implementation of the State Water Plan, both of which could potentially pass on funds to natural infrastructure programs.
- **State water use charges:** In 2007, the PCJ basin committees approved a water use charge on every water bill. This charge generates about $20 million annually for the committees, (SMA 2013; Padovezi et al. 2012). FEHIDRO manages these funds.
- **Federal transfers:** Because the PCJ Basin crosses São Paulo and Minas Gerais States, it is considered an interstate river basin, and the committees overseeing the basin are eligible to receive federal funding from the national water agency. The committees receive about 40 percent of their annual funds from federal transfers (PCJ Agency 2015). In addition, the national water agency directly allocates funding in the federal budget to activities in the Joanópolis, Nazaré Paulista, and Extrema municipalities through its Water Producer Program.

There are several opportunities to expand the portion of these funds dedicated to natural infrastructure, and stakeholders noted that increased involvement from the PCJ basin committees would be especially welcome. The committees have supported natural infrastructure in the Cantareira since they created their first plan for forest restoration in 2005 (Padovezi et al. 2012), and that support was formalized by including natural infrastructure in their watershed plan for 2012–25. So far, only around 2 percent of their annual investments have been operationalized for natural infrastructure (Padovezi et al. 2012). Most of their investments have historically been used to fix leaks and improve sanitation services, but their recent cap on investment in sanitation projects at 50 percent of the budget creates an opportunity to expand allocations for other efforts as they review their policy on protecting and restoring watersheds. Educating basin committee members about the costs, benefits, risks, and opportunities of the proposed natural infrastructure approach is a natural starting place to increase the committees' involvement in these projects.

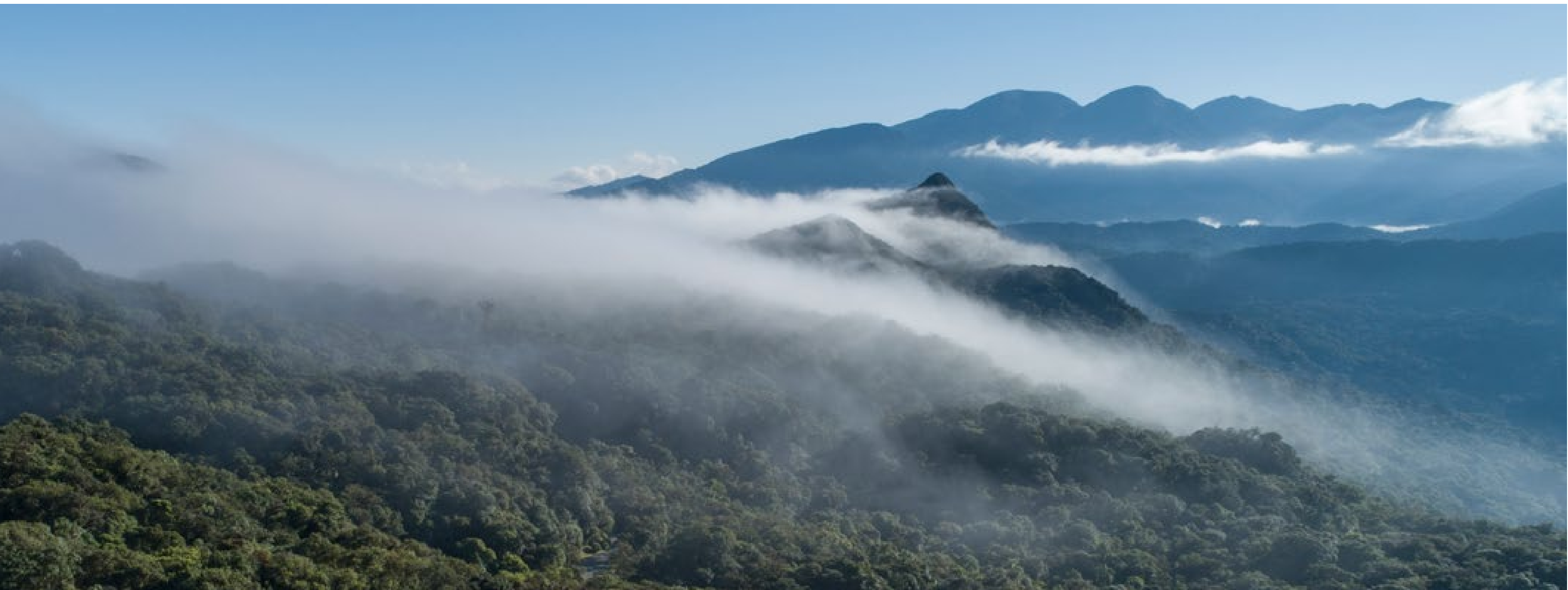


Table 9 | Main Public Funding Sources for Natural Infrastructure in the Cantareira System

FUNDING SOURCE	ESTIMATED AVERAGE AMOUNT PER YEAR ($, MILLIONS)	RECIPIENT	AMOUNT MADE AVAILABLE FOR NATURAL INFRASTRUCTURE	NATURAL INFRASTRUCTURE PROGRAMS SUPPORTED
State water use fee	20–30[a]	PCJ basin committees	2%[d]	PCJ WPP; Extrema; WPP[e]-ANA[f]
National water agency	9	PCJ basin committees	2%[d]	WPP-ANA, WPP-PCJ, WPP-EXTREMA
Municipal ICMS-e tax	7[b]	Municipalities	Unknown	Extrema
SNUC environmental compensation	10[c]	State government	Unknown	N/A

Notes: a. Oliveira et al. 2015; b. SMA 2015b; c. Oliveira 2015; d. Padovezi et al. 2012; e. WPP stands for Water Producer Program; f. ANA is the Portuguese acronym for Brazil's national water agency.
Source: WRI authors.

The Alto Tietê Committee, which governs a river basin adjacent to and interlinked with the Cantareira, could also potentially play a role. It has the capability to set up a water use fee to generate funds to pay for ecosystem services. However, it manages only 15 percent of the Cantareira System and thus may play a relatively small role in executing this report's direct recommendations. Further research may show how these natural infrastructure opportunities could also benefit the Alto Tietê Basin and engage its committee.

The Ecological Tax on Circulation of Goods and Services

There are opportunities to tap additional public funding sources, such as the ICMS-e (Ecological Tax on Circulation of Goods and Services). This fiscal instrument is designed to reward local governments that promote biodiversity conservation and other environmental initiatives. By one estimate, ICMS-e taxes in the Cantareira System generate $7.2 million annually, but these funds are rarely used for natural infrastructure (TNC 2010; SMA 2015b). Municipal involvement is legally necessary and strategically essential to implement natural infrastructure in the Cantareira. Of the 12 municipalities in the region, at least 3 of them are already actively partnering on natural infrastructure programs (Extrema, Joanópolis, and Nazaré Paulista), but so far only Extrema has invested part of the ICMS-e in natural infrastructure (SMA 2013, 2015b). Stakeholders indicated that for other cities to follow suit, they would need political will, new regulations and procedures, and transparency and anti-corruption mechanisms—conditions that go beyond the scope of a typical natural infrastructure program. For example, in the state of São Paulo, the law currently restricts ICMS-e tax revenue to creating new protected areas, rather than facilitating broader concepts of environmental stewardship. While the ICMS-e provides a potential source of funding for natural infrastructure, legal changes are necessary before those commitments can be realized.

Environmental Compensation Funds

Several laws in Brazil require companies to pay fines for damaging habitat or the environment. For example, the National System of Protected Areas (SNUC in its Portuguese abbreviation) established that development or infrastructure projects that damage the environment within an environmental protection area (APA in its Portuguese abbreviation) must offset these impacts with a compensatory payment referred to as "environmental compensation." Because nearly 99 percent of the Cantareira System is designated as an APA, SNUC funds may be another high-potential source of expanded public funding for natural infrastructure in the Cantareira System (Oliveira et al. 2015). By one estimate, these compensatory payments amounted to about $100 million between 2001 and 2013, but it is largely unknown how much of these funds has been invested, and where (Oliveira et al. 2015).

As with many federal and state financial resources for environmental restoration (e.g., from environmental compensation and royalties), the environmental compensation funds must be regulated by technical, administrative, and operational procedures. These procedures are still being developed and are often delayed by the lack of government staff capacity to analyze and track these processes (Oliveira et al. 2015). Programa Nascentes is the only program we studied that has leveraged environmental compensation funds for natural infrastructure. This state-run program has created an online registry where companies paying regulated or voluntary compensation can be matched with restoration project proposals. This program could forge a path for natural infrastructure programs to access environmental compensation funds.

We identified many other state and federal funds that could be leveraged to cover the costs of natural infrastructure interventions, such as the State Fund for Pollution Prevention and Control, natural heritage reserves, and the Low-Carbon Agriculture Plan (SAA 2016). Collectively, all public funding sources for environmental restoration likely amount to several million dollars each year. However, because use of these funds is restricted, learning how to access them would require considerable time and effort. Perhaps more importantly, there are governance, transparency, and capacity factors that must be addressed at an institutional level before these funds can be unlocked for large-scale natural infrastructure strategies (Oliveira et al. 2015).

Corporate Funds

Corporate donations comprise a small but important portion of funding available for natural infrastructure in the Cantareira System. These funds are typically either donations or voluntary offsets; for example, Banco do Brasil contributes to the WPP PCJ program. The São Paulo Water Fund is the only active program that has explicitly targeted private sector contributions to fund its program, creating a network of businesses interested in investing in natural infrastructure to reduce water risks and offset their water footprints (TNC 2013).

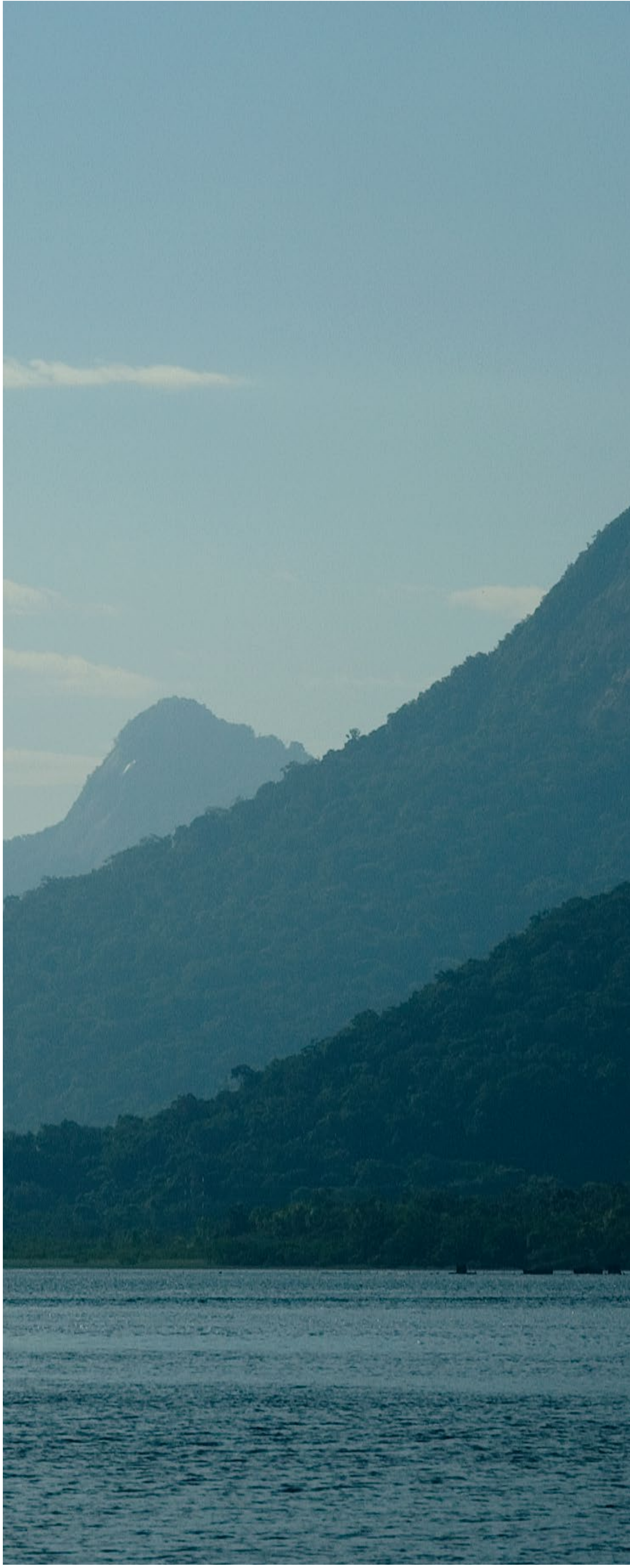
Looking ahead, the stakeholders we consulted believe natural infrastructure strategies offer a lucrative investment opportunity for companies that need water, and therefore aim to grow corporate support for natural infrastructure. Stakeholders strongly urge the participation of Sabesp in such efforts. To date, Sabesp has planted almost 1,200 hectares of forest adjacent to its reservoirs in the Cantareira, but the company's participation in natural infrastructure programs that extend beyond its fence lines has been negligible. It is important to know why Sabesp has not engaged in partnerships, but unfortunately Sabesp did not contribute data or perspectives to this analysis. Possible reasons for Sabesp's lack of engagement include the following:

- **Mismatch in priorities.** Sabesp's current investment strategy is focused on increasing water supply to curtail impacts of future drought, not on reducing sediment yield. Perhaps engaging Sabesp at a moment when the utility is considering investing in new water treatment plants would be more effective.
- **Mismatch in scale.** Sabesp manages the Cantareira System as a single unit and might be more interested in system-wide solutions and outcomes as opposed to the hyper-local efforts of current programs. In that case, improved coordination and annual reporting of impact on a basin-wide scale could promote a useful dialogue.

- **Risk aversion.** Although globally many water utilities have invested in natural infrastructure with successful results, Sabesp could be risk averse and unwilling to invest in an effort that could fail. The water managers we interviewed voiced concerns that the program would be too costly and difficult to implement, and that forest restoration could negatively affect water supply. In that case, a pay-for-success model (Box 2) and further research on baseflow impact (Chapter 3) might entice the water company to participate.

In sum, natural infrastructure stakeholders fully agree that securing financing is a key priority to advance natural infrastructure in the Cantareira, but there is a need to clarify a shared version on how to accomplish that. Stakeholders must weigh the costs and benefits of targeting different funding sources for their future work and must address some important precursors to larger-scale investment. The array of financing options suggests that the basin committees active in the region could benefit from housing a working group dedicated to developing a 10-year financing strategy for natural infrastructure that would leverage multiple funding sources and design a plan that meets potential investors' interests.

Stakeholders must weigh the costs and benefits of targeting different funding sources for their future work and must address some important precursors to larger-scale investment.



Implementing a Natural Infrastructure Plan for the Cantareira System

Current natural infrastructure programs logically emerged at the municipal level or as pilot projects where hyper-local benefits accrue but limited resources were available. As a result, investments in natural infrastructure across the Cantareira System are diffuse and do not treat the Cantareira as a single management unit. Although many of the programs we identified involve the same group of organizations and agencies, each one operates at a different scale and in a slightly different geography. This may present challenges in aligning perspectives, much less work plans.

The São Paulo Water Fund and PCJ Basin Agency are working to integrate natural infrastructure efforts in the region. The State Secretariat of Environment (SMA in its Portuguese abbreviation) has also specified goals of coordinating across natural infrastructure programs and has developed partnerships with every municipality in the Cantareira System to advance natural infrastructure strategies. These efforts could centralize program information regarding targets, activities, performance, and monitoring, and more efficiently connect programs operating in different parts of the watershed.

Substantial capacity for watershed planning already exists in the region. For example, TNC and other partners provide technical assistance and practical know-how to engage landowners, design forest restoration projects for water, implement changes, and manage and evaluate contractual obligations (SMA 2013). The PCJ Basin conducts state-of-the-art forest hydrology research run from the University of São Paulo's School of Agriculture; the team of researchers there specialize in monitoring hydrological impacts of forest gain, loss, and changes. They are also researching techniques to more quickly restore hydrological functions via forest restoration (Lozano Baez et al. 2017). Establishing a system-wide natural infrastructure performance monitoring system would be essential for developing a large-scale natural infrastructure program, but some fundamental information gaps must be overcome before this will be possible.

Further research to understand how natural infrastructure could be designed to optimize benefits across these objectives could increase the social value of the program, potentially reduce costs or increase benefits, or perhaps engage additional investors interested in different outcomes. Stakeholders should define a research agenda on these pieces so that the many qualified researchers in the region can tailor their research to fit these purposes. Some research questions already raised by stakeholders are discussed in Box 3. A natural next step for answering these questions may be to expand the Green-Gray Assessment provided herein to evaluate more investment objectives (such as flood control

BOX 3 | TOPICS FOR FURTHER RESEARCH TO IMPROVE NATURAL INFRASTRUCTURE PLANNING

Which natural infrastructure interventions are most cost-effective?
While this study examines native forests as natural infrastructure, other forms of sustainable landscape management such as agroforestry, pastureland restoration, and rural road management can also achieve sediment reductions. Possibly more than half of the pasturelands in the Cantareira System are degraded, which reduces their productivity and increases their risk of sediment export. The São Paulo low-carbon agriculture plan already aims to restore 15 million ha of degraded pastureland (SAA 2016), so incorporating pasture restoration into natural infrastructure programs could unlock more funds as part of a larger natural infrastructure strategy.

However, further local research is needed to determine which interventions would be most cost-effective or attractive to program investors. These natural infrastructure interventions have been studied in other regions (Filoso et al. 2017), but the dearth of relevant local research data presents a barrier to evaluating their costs and benefits.

How can natural infrastructure interventions address other water management objectives and provide social value?
As discussed in Chapter 3, we found that there is a need for further scientific research regarding the impacts of natural areas on water availability. This is perhaps the most critical research area to address water managers' concerns about natural infrastructure strategies.

Nature-based solutions exist to address flood risk, rural sanitation challenges, and climate resilience, but further research can help determine which interventions will be most effective for the Cantareira. Managing water availability between extreme rainfall and extended dry periods is especially relevant in regions like São Paulo, where, some studies suggest, the primary water management challenge will be dealing with floods and siltation due to heavy rains (Nobre et al. 2010).

Assessing impacts on different income classes and genders could help in designing interventions to support rural poverty alleviation needs. Better understanding the impacts of natural infrastructure on land productivity and the rural economy could be particularly useful in engaging landowners in these programs.

How can we ensure that natural infrastructure plans are feasible?
Stakeholders emphasized that research is needed to confirm the practical feasibility of the interventions. Due to harsh terrain or a lack of willingness to participate on the part of key parties, it may not be feasible to bring some model-identified priority areas into the programs. Stakeholders should carry out additional spatial analysis and field studies to incorporate these parameters to prioritize which natural areas to target for restoration or conservation.

What additional areas should be targeted for natural infrastructure interventions?
While this study focused on natural infrastructure in the Cantareira System, that system is increasingly interlinked to neighboring watersheds. For example, São José dos Campos is located in the watershed where Sabesp will link the Jaguari Reservoir in Paraíba do Sul to the Cantareira. Also, stakeholders noted that the Cantareira experiences the lowest sediment pollution rate in all of São Paulo's source watersheds. Expanding this analysis to consider additional water systems could reveal more value and inform current investment decisions.

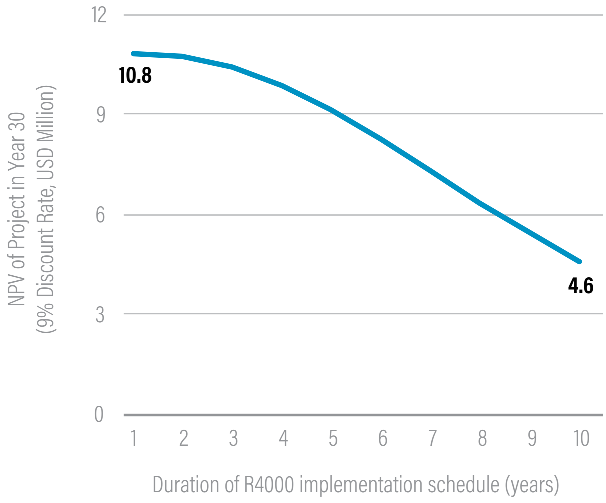
or co-benefits of natural infrastructure) or more investment portfolios (including cloud forest management, adoption of agroforestry or silvopastoral systems, or rural road maintenance, for example).

Sharpening the Business Case for Natural Infrastructure

To increase investor confidence in predicted program outcomes, natural infrastructure programs must address key sources of uncertainty, either by closing information gaps or by designing robust programs prepared to perform well even in the face of uncertainty.

Scientific research and data collection efforts discussed in the previous section can certainly improve project planning. There is also room to improve cost data inputs and assumptions about water management decisions and a need to improve practical understanding through improved research and data collection. Accessing water treatment costs is a challenge faced by researchers, consumers, and even governmental agencies around the world (Wilbert et al. 1999; Reddy et al. 2015; Sousa Júnior 2011). For this study, direct data were not available. We consulted quarterly financial reports published by Sabesp from 2000 to 2016, and supplemented this source with an additional literature review and expert consultation. The public financial reports do not provide the necessary cost data to directly inform this study. Notably, similar studies in Camboriu and Quito (Kroeger et al. 2017) have been able to access water utility data through partnerships with the local water company. Partnerships with Sabesp or regulatory bodies could improve access to data or estimates.

Figure 9 | Impact of R4000's Implementation Schedule on NPV (sediment retention)



Source: WRI authors.

In addition, improving some elements of program design could increase the financial viability of R4000 despite persistent sources of uncertainty. For example, the schedule of restoration activities significantly impacts NPV (Figure 9). If the project were conducted over 5 years, the NPV would be $7.1 million with a 20-year payback period. Such a project would likely be financially viable under our assumptions, even if sediment retention performs at the lowest expected rate or if restoration costs are higher than we assumed. However, as we discuss in the following section, accelerating the pace of implementation has its own challenges and may not be feasible.

Engaging Landowners

Because landowners are the decision-makers responsible for implementing natural infrastructure actions, their involvement and endorsement is key to any natural infrastructure program. We assumed transaction costs are 20 percent of investment and operations costs because landowner engagement is such a critical and expensive factor. Uncertainty and doubts about landowners' willingness to participate in the program are also driving our assumption that it could take 10 years to restore 4,000 hectares of forest in the Cantareira. Developing an effective landowner engagement strategy is therefore critical to delivering results effectively and on budget.

A key challenge to overcome is reaching landowners in the first place. Most land in the Cantareira System is privately owned, oftentimes by landowners who live elsewhere and contract someone else to produce or take care of their land, which can increase the difficulty of communicating with landowners in the first place. Contracting landowners to participate in natural infrastructure efforts requires proving clear land tenure, which can be complex in the region if landowners do not have their property papers up to date. The São Paulo Water Fund has years of experience engaging rural landowners and capacity to map individual properties and projects to make progress on overcoming this challenge.

Ensuring the program is designed to benefit landowners is also critical. As previously discussed, many farmers aim to maximize their production, and do not see forest conservation or set-asides as compatible with their individual income plans. Offering a sufficient incentive to overcome the landowner's opportunity cost is one way to incentivize participation. While many local programs do offer incentives in the form of a Payment for Ecosystem Services, it is important to ensure that the payment level is sufficient to motivate landowner participation, and fair to compensate for the value of benefits generated. There are standard methods that can be used to determine contract value, accounting for opportunity costs. The Boticario Group Foundation has a method to define how much to pay landowners for restoration activities, considering the opportunity cost of land as well as the value of ecosystem services (Young et al. 2012; Young et al. 2014). Programa Nascentes has also developed a method to measure and standardize environmental assets and liabilities using the "tree equivalent" unit (Estado de São Paulo 2014).

Another way to address this could be to promote natural infrastructure interventions that enhance landowners' income down the line—for example, programs could focus on implementing silvopastoral or agroforestry systems, which meet the dual goals of enhancing ecosystem services and generating on-farm income. These strategies have been challenging to implement to date due to a lack of data connecting these land management strategies to hydrological impacts. Further research and planning are needed to incorporate these strategies into natural infrastructure programs. Yet, addressing these questions could drastically increase landowner interest in participating in these programs, and therefore may deserve prioritization.

Interpreting Results

The financial case for natural infrastructure presented in the preceding chapters may be useful for increasing water sector decision-makers' interest in natural infrastructure, but this chapter shows that important enabling conditions must also be put in place to facilitate meaningful investment. Natural infrastructure programs should prepare for larger investments and attract risk-averse investors by developing a shared vision of success, coordinating a watershed management plan, and agreeing on a long-term financing strategy that allows them to achieve more together than each can alone.

CHAPTER V

CONCLUSION

This report has presented a robust financial analysis for investing in nature to complement and safeguard São Paulo's largest water supply system. It adds to the growing evidence base that natural infrastructure can be a powerful tool for water management. In assessing only two potential benefits of forests, the value proposition of natural infrastructure for water is already enticing. Efficient and wise program design can further enhance the business case for investment. Managing sediment and water treatment costs, and helping to regulate the timing and flow of water in a changing climate, are likely to become even more salient water management objectives in the future.

São Paulo has an opportunity to meet its water needs by combining natural and built infrastructure strategies. A key step toward this objective is to incorporate natural infrastructure considerations into water management planning processes, and to expand water management strategies to begin working with nontraditional partners like rural landowners to achieve shared objectives. At the same time, natural infrastructure programs and government agencies should support water managers by providing well-planned natural infrastructure strategies and by working to put enabling conditions in place. Addressing some of the elements highlighted in this report can help achieve these objectives.

These results can be used locally to

- inform water management, helping to determine the role that natural infrastructure can play in achieving goals around sediment pollution and water availability;
- guide the refinement of natural infrastructure strategies to efficiently deliver results at scale;
- highlight local data collection and research needs going forward; and
- provide a new frame of reference to foster dialogue and partnerships that lead to win-win investment opportunities for the water sector and natural infrastructure programs.

In addition to informing local water management decisions, this study provides the best available data and approaches to facilitate Green-Gray Assessments in Brazil and globally. Despite important data and research gaps acknowledged through the report, it serves as a foundation for deeper analysis of the financial performance of using natural infrastructure for water. The data and approaches provided herein could be applied iteratively in the Cantareira as new data become available, or used to evaluate natural infrastructure's role in meeting other water management objectives. The Green Gray Assessment is also ready to be applied in nearby basins, drawing on experiences and data documented in this report.

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APPENDIX A. METHOD OF STAKEHOLDER CONSULTATION AND ROAD MAP DEVELOPMENT

This appendix explains the method and data sources used to conduct the contextual analysis presented in Chapter 1 and to formulate the analysis presented in Chapter 4.

Our partners and key stakeholders in the area expressed interest in developing an action plan to advance natural infrastructure strategies in the Cantareira and São Paulo based on the findings of the Green-Gray Assessment. To meet this interest, we conducted a line of inquiry for identifying key success factors and approaches to establishing successful watershed investment programs using a framework from Ozment et al. (2016). Because the framework was based on U.S. research, we worked with stakeholders to review the framework's list of 10 factors and verified that they were relevant to the local context in Brazil prior to application.

To apply the framework, we mapped local stakeholders by asking project partners to identify people expected to have a role in natural infrastructure management, including the following:

- *Current or potential investors*: Watershed committees, water companies, philanthropic organizations, and government environmental programs working or with interest in working on natural infrastructure programs in the Cantareira
- *Natural infrastructure program coordinators:* Government and nongovernmental organizations that oversee program funding, broker deals, bridge communication, act as intermediaries between investors and landowners, and administer natural infrastructure projects
- *Landowners and manager representatives:* Associations or nongovernmental organizations that represent the interests and perspectives of rural land owners who could enroll in natural infrastructure projects
- *Approving bodies*: Municipal, state, and federal government agencies that approve relevant regulatory measures
- *Technical experts*: Academic and research organizations with natural resource expertise and active research projects in the vicinity

We consulted stakeholders in three ways:

A workshop in São Paulo in November 2016 to collect high-level input. Forty people participated. Discussions to inform this research included the following: status of green and gray infrastructure in the Cantareira System; data sources to evaluate natural infrastructure; and identification of relevant natural infrastructure initiatives and opportunities to collaborate.

One-on-one semi-structured interviews conducted over Skype between September and October 2016, and again in June 2017, to collect data and perspectives on financing natural infrastructure in Brazil. Twelve interviews were conducted.

A survey conducted by email between June and July 2016 to collect data and perspectives on which success factors deserve the most immediate attention in the Cantareira System. The survey was sent to 14 stakeholders who were either senior water managers and/or directly involved in executing natural infrastructure programs in the region. Ten people responded to this survey.

To complement these efforts, we also solicited documents to analyze and formulate the action plan. The document review primarily focused on studies and program documents that described natural infrastructure programs currently active in the Cantareira System. We synthesized this literature to gain a better understanding of the most important sources of funding, main leaders and stakeholders involved, current investments, key risks and concerns, and other key features.

Written survey and interview questions were as follows (translated from Portuguese):

1. We are structuring this research based on 10 success factors identified in the WRI study Protecting Drinking Water at the Source*. Which factors are most important to advance the natural infrastructure agenda in the Cantareira System? (Choose 5 or fewer.)*

- Identify risks and opportunities to support the project. *Develop support to address water risks caused by the degradation of natural infrastructure; seize political moments that focus on these issues to make progress.*
- Strengthen partnerships to fill essential roles and responsibilities. *Formulate collaborative partnerships that benefit from the skills, resources, and connections of multiple organizations.*
- Develop a shared vision of success. *Create a shared vision among key players in a successful project and develop goals that are measurable and achievable.*
- Cultivate leaders and advocates to build support. *Design and train leaders in government agencies that support the project, and engage actors that help build alliances, leverage interest groups, and build public support for natural infrastructure.*
- Develop a scientifically robust plan for the watershed. *Create a work plan to prioritize important river basin interventions based on accepted scientific knowledge regarding the hydrological benefits of forest protection or restoration.*
- Assess the strategic focus for investment. *Estimate the financial and economic costs and benefits of the program to determine whether water-dependent companies, public water managers, or others can benefit from the program.*
- Identify long-term investors and new financial resources. *Obtain sufficient funding for program activities and involve a diverse group of investors.*
- Engage landowners and land managers to conserve, restore, and manage natural infrastructure. *Recruit and sustain the participation of public and private land owners and managers.*

- Define roles and plans for managing programs. *Assign administrative staff to provide financial management, communication, decision-making, and administrative support for the program.*
- Monitor implementation and evaluate project impacts. *Monitor progress and evaluate program implementation by measuring the hydrological benefits and environmental and social benefits of efforts in natural infrastructure.*

2. For each selected factor in Question 1, do you think the factor is working well or not in São Paulo? Why?

3. Is any important factor missing from our list?

4. What is your vision for natural infrastructure in the Cantareira within the next 20–30 years?

5. Is the collaboration of partners on this agenda weak or strong? Why do you think that? Are there differences in approach?

6. On a scale of 1–10, what is the importance of securing more funding for natural infrastructure in this basin?

7. Which sources of funding represent the best opportunity to increase resources for natural infrastructure programs? For example, donations, water fees, or compensation?

8. What are the main problems you see related to the financing of natural infrastructure?

9. What do you believe the next steps are for advancing natural infrastructure restoration in the Cantareira System? Who needs to participate in these actions?

It is critical to note that these recommendations must be further socialized and tested among key stakeholders, especially by water sector decision-makers. Of the stakeholders consulted through surveys or interviews, 58 percent represented NGOs or foundations, 17 percent were state government officials, 17 percent were researchers or technical specialists, and 8 percent were federal government officials. The list of stakeholders who participated in surveys, interviews, or workshops to contribute to this research are listed in Box A1.

This list of local stakeholders who contributed to the project is based on written record of workshop attendance and survey responses. Several other local stakeholders helped shape this project through informal interactions.

The collective responses and synthesized literature review are presented in Chapter 3 of this report. To ensure the utility and relevance of the recommendations, drafts were shared with the project partners on two occasions and revised based on feedback.

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BOX A1 | LOCAL STAKEHOLDERS WHO CONTRIBUTED TO THIS RESEARCH (NAME, ORGANIZATION)

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APPENDIX B. METHODS AND ASSUMPTIONS FOR BIOPHYSICAL MODELS AND MAPPING COMPONENTS

This appendix provides an overview of biophysical modeling methods, assumptions, and data sources for the study. We used models under the Natural Capital Project's Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) toolset to do the following:

- Create spatial scenarios of baseline and future land use scenarios used to inform investment portfolios in Step 2 of the Green-Gray Assessment
- Model sediment yield and retention
- Estimate seasonal water flows for baseline and future land use scenarios

The models used here—the InVEST Sediment Delivery Ratio Model and the Dynamic Water Balance Model—were peer-reviewed (Hamel et al. 2017a, 2017b). They were chosen for their ability to represent spatially explicit information on hydrological services, and to leverage synergies with a concurrent project (ClimateWise 2018).

Spatial Scenarios of Land Cover Used to Define Investment Portfolios

We assessed five land use scenarios, each associated with a distinct land use map and with an investment portfolio. For the targeted restoration and conservation scenarios, target areas were first established by local stakeholders and the InVEST Sediment Delivery Ratio Model was used to spatially map where these hectares would be placed: the target pixels were the highest values of sediment export on the landscape. For the conservation scenarios, we assumed that these areas would be degraded in the absence of green infrastructure investments. Table B1 provides an overview of each scenario.

To estimate the opportunity cost of land restoration or protection, we assumed that all lands required to be forested in the Forest Code had an opportunity cost of zero in our core analysis, reflecting what would happen in the case of perfect law enforcement. We also varied the opportunity cost in our sensitivity analysis to reflect cases where law enforcement is not perfect.

To quantify opportunity costs, we estimated which and how many areas are regulated as areas of permanent protection according to the Brazilian Forest Code (LEI Nº 12.651). We identified where and how many of these lands were present in the Cantareira System following the technical methods for creating scenarios for Brazil's Forest Code in the Cantareira (NCP 2016). The general rules we adopted are summarized below:

Table B1 | Land Use Scenarios Used in This Study

LAND USE SCENARIO	DESCRIPTION
Baseline	Current land use/land cover (20 meter [m] resolution). Year 2010. Provided by The Nature Conservancy.
Full forest	The entire landscape, including currently developed areas, is forested. This scenario represents the upper bound of the effect of afforestation.
Full pasture	The entire landscape, including currently developed areas, is converted to pasture. This scenario represents the upper bound of the effect of deforestation.
Targeted restoration	Reforestation of the landscape with a target conservation area of 4,000 hectares. Priority areas for reforestation were identified based on the highest impact on sediment export.
Deforestation	Deforestation of the landscape, over an area of 1,900 ha, based on a projection of the historical deforestation rate in the area (see Appendix C for details). This scenario was used to select priority areas for conservation based on forested pixels with the highest sediment retention index.

Source: Authors.

Deforested areas were classified as pre-2008 or post-2008 (based on Hansen et al. 2013 data).

For post-2008 deforested areas, APPs included the following:

- Slopes >45 degrees
- Altitude >1,800 m
- Natural lakes and artificial reservoirs
  - In rural areas:
    - >20 ha in area, buffer of 100 m
    - ≤20 ha in area, buffer of 50 m
  - In urban areas, buffer of 30 m
- Wetlands and springs, buffer of 50 m
- Hilltops
- Stream buffers:
  - Small streams (up to 10 m width), buffer of 30 m
  - Medium streams (10–50 m width), buffer of 50 m

For all other deforested areas, APPs included the following:

- Slopes >45 degrees
- Altitude >1,800 m
- Hilltops
- Stream buffers: 15 m (small landholders) or 30 m (large landholders)
- Wetlands, buffer of 30 m (small landholders) or 50 m (large landholders)
- Springs, buffer of 15 m
- Lakes/ponds, buffer of 15 m (small landholders) or 30 m (large landholders)

Further details on calculating opportunity costs are provided in Appendix C.

Table B2 | Summary of Inputs Used for the Sediment Model

INPUT	DESCRIPTION	SOURCE
Rainfall erosivity index (R-factor)	A geographic information system (GIS) raster dataset, with an erosivity index value for each cell. This variable depends on the intensity and duration of rainfall in the study area.	Xavier et al. 2016 Oliveira et al. 2013
Soil erodibility (K-factor)	A GIS raster dataset with a soil erodibility value for each cell. This is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff.	TNC*
Digital Elevation Model (DEM)	A GIS raster dataset with an elevation value for each cell (30 m resolution). The DEM was filled with a routine in GIS to facilitate routing.	Raster data obtained from TNC*
Land use/land cover (LULC)	A GIS raster dataset with an integer LULC code for each cell.	São Paulo: TNC* See Table B3
Biophysical table	A .csv table containing model information corresponding to each of the land use classes. Includes a cover-management factor (C) and a support practice factor (P), two factors in the Universal Soil Loss Equation used in the InVEST sediment model.	From InVEST parameter database for Brazil See Table B3

Note: *These inputs were obtained from The Nature Conservancy Brasil.
Source: Authors.

Table B3 | Cover Management Factors (C-factors) Used in This Study, Based on a Review of the Studies Contained in the InVEST Parameter Database

LULC TYPE	C-FACTORS
Water body	0.0001
Barren	0.01
Forest closed	0.009
Forest plantation	0.009
Agriculture	0.16
Pasture	0.04
Natural grassland	0.02
Natural shrub	0.01
Urban	0.01
Wetlands	0.001

Source: Authors.

Sediment Modeling

Context

The objective of the sediment modeling exercise was to determine the change in sediment retention in the study area—in other words, the sediment prevented from entering the Cantareira—due to the investment portfolios (compared against baseline conditions). This allowed us to estimate avoided sediment management costs to the water infrastructure operators.

We used the InVEST Sediment Delivery Ratio Model v3.1 (Sharp et al. 2016) to estimate the reduction in sediment export (tons per square kilometer per year, or tons/km^2/year) to reservoirs in the study area for each land use scenario. This model maps annual overland sediment generation and delivery to streams or a reservoir intake point, so is a valuable tool for estimating sediment retention by a watershed. It is a spatially explicit model that works at the resolution of the input Digital Elevation Model (DEM) raster. For each pixel, the model computes soil loss and the Sediment Delivery Ratio factor; i.e., the proportion of eroded soil that reaches the stream based on the position of the pixel on the landscape and surrounding land use/land cover (LULC).

Data inputs

Data sources for the sediment model are described in Tables B2 and B3. Practice factors (P-factors) that account for the effects of contouring, plowing, etc., are set to 1 for all LULC types.

Table B4 | Current Land Cover in the Cantareira System

	SUB-BASIN	AREA (HA)	NATURAL FOREST (%)	PASTURELAND (%)	PLANTATION FOREST (%)	AGRICULTURE (%)	URBAN (%)	BARE SOIL (%)
PCJ BASIN	Jaguari Dam	103,277	19	59	16	1	2	0
	Jacareí Dam	20,235	14	53	8	2	3	1
	Rio Cachoeira Reservoir	39,248	20	44	34	0	1	0
	Atibainha Reservoir	31,741	28	34	30	0	2	0
ALTO TIETÊ BASIN	Paiva Castro Reservoir	31,400	42	27	18	0	10	0
	Águas Claras Reservoir	2,321	59	15	13	0	13	0
	TOTAL	**228,222**	**24**	**47**	**21**	**1**	**3**	**0**

Source: TNC 2010.

Uncertainty Assessment

Given the scarcity of information on the long-term sediment yields in the region, it is difficult to verify model performance at large scales. We present in Table B5 a list of key sources of uncertainty that may affect our main results and the relative difference between scenarios.

Model input errors. We assessed the effect of model input errors by conducting simple sensitivity analyses on the C-factor and erosivity data. Preliminary tests identified the C-factor for pasture as a sensitive parameter, and we tested model sensitivity to a large change in this parameter (–50 percent and +200 percent). This resulted in a change in sediment export by an average of –24 percent and +75 percent. In addition, we estimated that erosivity data, obtained from the empirical relationship for Brazil developed by Oliveira et al. (2013), have an uncertainty bound of +/–40 percent, which directly translates into the uncertainty in sediment export. Erodibility values also typically have large uncertainties (see value in Hamel et al. 2015). We note that bias in erosivity and erodibility do not affect the relative results since all scenarios are similarly affected by these errors.

Model structure and verification data. The InVEST model used in this study has known limitations related to its focus on sheetflow erosion (ignoring other sediment sources) as well as its simple calibration process, which affects the contrast between land parcels close to the stream and those further away (i.e., the overland retention capacity). In reality, such calibration requires information on the sediment budget; i.e., the proportion of sediment that comes from hillslope erosion versus other sediment sources (channel erosion and potential legacy sediment from the riverbed). In the absence of such data, we used the InVEST conceptual model, which has been validated in other regions for its ability to represent land use change (Hamel et al. 2017a). To verify that outputs are realistic, we used local sediment yield as described in the next paragraph.

Table B5 | Main Sources of Uncertainty for the InVEST Sediment Model Output

TYPE	SOURCE OF UNCERTAINTY	IMPORTANCE
Inputs	Erosivity and erodibility	Medium: Errors in erosivity and erodibility can be compensated by the model calibration without affecting the relative results (relative difference between scenarios). The effect of this uncertainty on model outputs is estimated through quality assurance (see below).
Inputs	C-factor value	High for dominant land uses (e.g., forest). This uncertainty is assessed through sensitivity analyses (see below).
Model structure	No inclusion of in-stream deposition and other sources of erosion	High: The model focuses on the effect of land use on sediment export and ignores other sources of sediment such as bank erosion or landslides.
Model structure	Robustness to land use change	Medium: The model has been validated in other regions for its ability to represent land use change.[a]

Note: [a] Hamel et al. 2017a.
Source: Authors.

Sediment model calibration/verification

Erosion and sediment yield data are scarce in the region. For model verification and calibration, we used two sources of data. First, we obtained data from Saad (2016), who calculated mean sediment export from 2010 to 2015 for the Posses watershed (located in Extrema, Minas Gerais, in the upper reaches of the Cantareira System). Saad used turbidity measurements and streamflow time series from Brazil's national water agency and estimated sediment export to be around 135.6 tons/km^2/year. This estimate has large uncertainty bounds, in part due to the sampling frequency and duration. To quantify this uncertainty, we used a different relationship between turbidity and total suspended solids from Teixeira et al. (2016) and found that the error on sediment export may be as high as 40 percent. Second, we used a different source of turbidity data for the Upper Jaguari watershed (JAGR00005) obtained from the University of São Paulo: annual sediment export was estimated around 11 tons/km^2/year, based on the TSS-turbidity relationship from Teixeira et al. (2016).

We calibrated the InVEST model based on the sediment estimate for the Posses subwatershed from Saad (2016). The calibration parameter (kb) was set to 1, which yielded a calibrated model value of 112 tons/km^2/year for the entire Jaguari watershed. This value is in the upper range of regional estimates (11–136 tons/km^2/year), which seems possible given that in-stream sediment deposition is more likely in the larger Jaguari watershed. (Because this process is not represented by the InVEST model, the model likely overestimates sediment export when it is calibrated based on a small watershed like the Posses watershed.)

Results

Results from the sediment export modeling exercise are presented in Table B6 and in Chapter 2. Table B6 presents sediment export values for each land use scenario and for each subwatershed in the study area. The estimated change for the 4,000 ha scenario is generally large, indicating that a relatively small area contributes a high proportion of sediment. The values differ per watershed since the restoration areas are defined over the entire area, rather than a similar percentage per watershed.

Baseflow Modeling

The objective of the baseflow modeling was to assess the impact of forest conservation on seasonal water availability in the Jaguari Reservoir. To put these analyses in context, we highlight two points. First, the Cantareira System that supplies the water to São Paulo comprises many reservoirs, which affects the benefit of increased baseflow (since timing of water availability is influenced by available storage). Second, the scientific literature recognizes important limitations in hydrological modeling of land use change in the tropics (Filoso et al. 2017). These limitations are due to the state of the science (with tropical areas having received less attention than temperate areas) and limited site-specific information (e.g., tree characteristics, long-term hydrologic data to study watershed behavior). This implies that this hydrologic modeling exercise will need to be interpreted carefully with associated uncertainty.

Related to the hydrologic modeling, the question of interest is whether the water level in the reservoir crosses any management thresholds under the studied land management scenarios; i.e., where a physical trend will create an obstacle that either requires capital expenditure or high costs to deal with it. For example, a threshold in this context may be the reservoir level at which the dead volume is reached and temporary pipes must be installed to continue production.

For the present study, because of the limited resources and data available, we used a simple monthly model to represent the hydrologic behavior of the São Paulo watersheds and estimate the potential for nature-based solutions to affect reservoir water levels. Of note, a study using the Soil and Water Assessment Tool is in progress (Domingues 2017) to represent the hydrologic behavior of the Upper Jaguari watershed and investigate land use and climate change effects on reservoir water levels.

Table B6 | Sediment Yields from the Five Watersheds in the Cantareira System by Land Use Scenario

SUB-WATERSHEDS OF THE CANTAREIRA	AREA (KM^2)	OBSERVED SY[a] (TONS/KM^2/YEAR)	MODELED SY (TONS/KM^2/YEAR)	CHANGE IN SY (%)	
			BASELINE	R4000	C1900
Jaguari	1,032	11–136	112	–81%	4%
Cachoeira	391	N/A	54	–50%	10%
Jacareí	203	N/A	91	–83%	4%
Atibainha	315	N/A	26	–41%	8%
Paiva Castro	338	N/A	50	–69%	10%

Note: [a] SY stands for sediment yield.
Source: Authors.

Hydrologic Modeling

To represent the change in water availability in the Upper Jaguari Reservoir due to land use change, we coupled a monthly watershed model (Dynamic Water Balance Model) with a reservoir model (Hamel et al. 2017a; Zhang et al. 2008).

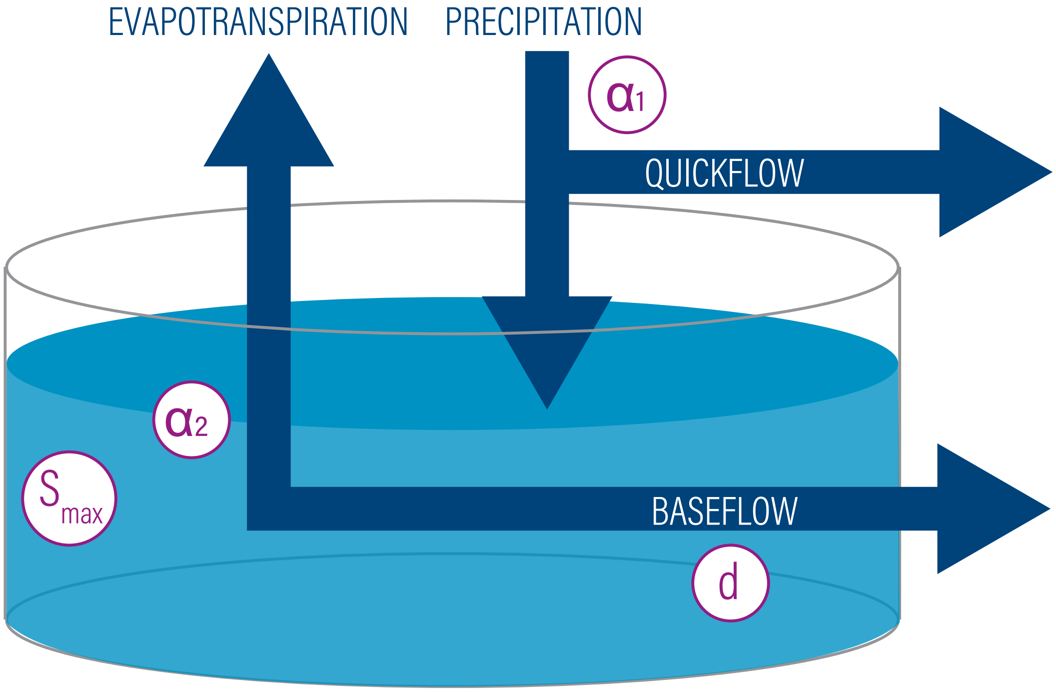
Dynamic Water Balance Model Description: A monthly rainfall-runoff model that has been used in reservoir management studies (Kirby et al. 2014). It represents a watershed as a simple bucket, partitioning precipitation into surface runoff, subsurface flow, and evapotranspiration. Four parameters govern these relationships: $\alpha 1$ and $\alpha 2$ govern the partitioning between surface runoff and infiltration, and between groundwater recharge and evapotranspiration, respectively; S_{max} represents maximum soil storage, and governs the timing of groundwater release (see Figure B1 and Wang et al. 2008); and, *d* is the groundwater store time constant, characterizing the groundwater drainage rate; i.e., the release of groundwater storage to baseflow.

Dynamic Water Balance Model Calibration: We calibrated the model for the Sabesp gauge at the outlet of the Jaguari watershed (Domingues 2017). We used monthly average observed data, and calibrated the four model parameters by minimizing the Nash-Sutcliffe efficiency using the R-package *sceua*. The monthly runoff model was able to represent the average hydrologic behavior of the Jaguari basin (Figure B2, r2 = 0.96 between monthly predicted and observed flow values).

Fog capture: Fog capture represents a significant input to the water balance in our study watersheds. To account for fog contribution, we tested the Dynamic Water Balance Model with a 5 percent increase in precipitation across the year. The assumption for the relative precipitation inputs was based on results obtained with the WaterWorld model (Mulligan 2013), which suggest that on average fog capture is 5.2 percent (minimum 2.9 percent, maximum 10.2 percent) of precipitation for cloud forest in the Cantareira (Pompeu 2018). The model also suggests that conditions for cloud forest are met in about 5 percent of the Cantareira (including 10 percent of the Upper Jaguari watershed), which means that restoration activities (4,000 ha, about 4 percent of the Cantareira) could be entirely implemented in areas where fog capture can occur.

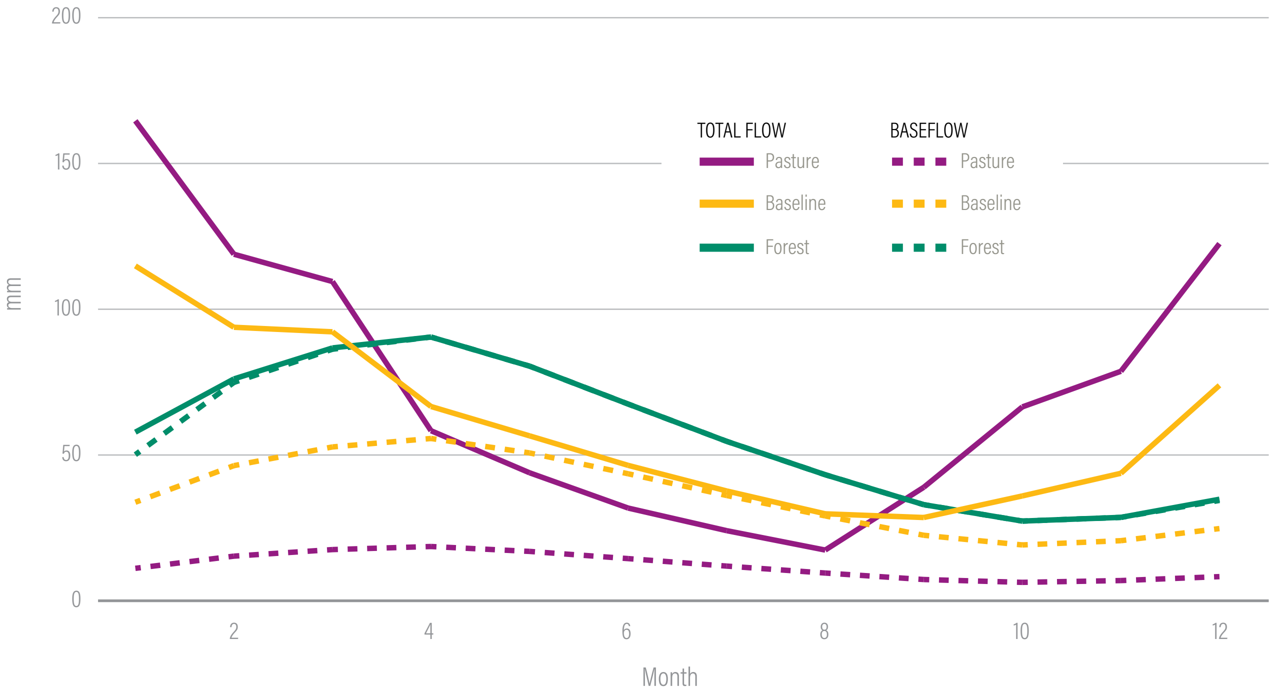
Scenario assessment: We used the Dynamic Water Balance Model's modeled runoff (both surface and subsurface flow) as an input to the reservoir model under three scenarios: current (baseline), 100 percent forest cover, and 100 percent pasture cover. The first scenario is represented by calibrated model parameters. The second scenario is represented by setting the land use parameter to a high value (0.9), corresponding to high infiltration (Hamel et al. 2017b). Conversely, for the third scenario we used a low value (0.3) for the land use parameter, corresponding to higher runoff and lower evapotranspiration, typical of degraded pasture (Figure A2). The realistic scenario (restoration of 4,000 ha, R4000) is obtained by computing the area-weighted average of the streamflow or baseflow for the baseline and 100 percent cover scenarios. Four thousand hectares represents 1.75 percent of the total Cantareira Basin's area (228,000 ha), so the hydrologic effect of restoration is small.

Figure B1 | Schematic of the Dynamic Water Balance Model



Notes: S_{max} is the maximum catchment storage capacity; α_1 is the catchment retention, affecting the partitioning of precipitation into direct runoff and water available in the soil-moisture store (S) for evapotranspiration and groundwater recharge; α_2 is the evapotranspiration efficiency, affecting the partitioning of soil water into storage, recharge, and actual evapotranspiration; d is the groundwater store time constant.
Source: Hamel et al. 2017a.

Figure B2 | Comparison between Monthly Streamflow and Baseflow for Baseline, Pasture, and Forest



Source: Authors.

Reservoir Model

We also used a reservoir model to illustrate the role of gray infrastructure (specifically the Jaguari Reservoir) in storing excess surface water from the wet season to make it available for use and consumption during the dry season. This model focused only on the Jaguari subwatershed of the Cantareira System, but its results are relevant to the entire system, which has similar biophysical and topographic characteristics. The model takes as input the watershed inflow to the reservoir, then subtracts for each month water diverted to the municipality and lost by evaporation or infiltration. Outputs are the total water supplied and water level in the reservoir. See Appendix C for additional information on the reservoir characteristics for the Cantareira reservoirs:

- Watershed drainage area: 1,031 km^2 (Domingues 2017)
- Reservoir storage: 0.808 km^3
- Water diversion (demand): 25.2 cubic meters per second (m^3/s)

With the simplifying assumption of a constant demand, the model illustrates the reservoir's role in storing water during the wet season for use in the dry season. We modeled the long-term average reservoir operation by using average monthly precipitation and evapotranspiration data (Xavier et al. 2016). To discard the effect of initial conditions, we used a warm-up period of seven years starting with a half-full reservoir, bringing the system to a steady state.

RESERVOIR STORAGE IS UPDATED EACH MONTH BY CLOSING THE WATER BALANCE:

Equation 1

$$SR(m+1) = MIN(SR_{max}, SR(m) + Q(m) - E(m) - L(m) - D(m))$$

WHERE:

SR is the monthly storage volume;

SR_{max} is the reservoir storage volume;

Q is the inflow from the watershed;

E is evaporation from the reservoir;

L is water loss by infiltration; and

D is the diversion volume.

All values are in m^3 annual averages.

The diversion volume, D (m^3/month), corresponds to water supplied monthly to the municipality. It is set constant over the year, based on the average flow rate obtained from Sabesp. When D was higher than the reservoir storage, we used a simple operation rule, dividing the water demand by two, until the demand could be satisfied.

E AND L, IN M³, ARE FUNCTIONS OF THE MONTHLY STORAGE:

Equation 2

$$E = 0.7 * ET0/1000 * A$$

Equation 3

$$L = \frac{k_h}{10} * 24 * \frac{30}{1000} * A$$

WHERE:

$\boldsymbol{A}$ is the reservoir area, in m^2; and

$\mathbf{k_h}$ is the hydraulic conductivity of underlying soil in centimeters per hour (cm/h), estimated around $3.6 * 10^{-6}$ cm/h (silt).

TO ESTIMATE THE RESERVOIR AREA FROM THE STORED VOLUME, WE USED THE RELATIONSHIP DEVELOPED BY RODRIGUES AND LIEBE (2013) (USED HERE WITH MEAN COEFFICIENT VALUES):

Equation 4

$$V = 0.003 * A^{1.67}$$

THE MONTHLY SPILLAGE (THE AMOUNT OF WATER THAT SPILLS OVER THE RESERVOIR, M³/MONTH) CAN BE COMPUTED AS:

Equation 5

$$Spill(m) = MAX(0, SR(m) + Q(m) - E(m) - L(m) - D(m) - SRmax)$$

For the pasture scenario, the benefits of decreased infiltration (lowering baseflow) were compensated by the decrease in evapotranspiration, which results in higher total runoff in the watershed. Therefore, both forest and pasture scenarios can satisfy the demand in our simplified system model. However, the increase in baseflow predicted by the model for forest scenarios is higher during dry months (i.e., June–August) and could be useful in cases of water shortage in the dry period.

Uncertainty Assessment

The coupled watershed-reservoir model has several key limitations, due to the limited availability of data and time for the analyses: in particular, the model used monthly average data, rather than long-term time series data that would account for interannual variability, and the reservoir operations were simplified (with a constant water demand and the assumption that monthly demand is halved when reservoir storage is insufficient.)

The model is used here for illustrative purposes, capturing the simple dynamic effect of reforestation or the deforestation effect on the water balance, with the well-known trade-off between infiltration and evapotranspiration, as well as the overall reduction in total runoff from the watershed. In this context, quantitative uncertainty assessment focuses on two sources of uncertainty: the climate input data and the model structure (representation of hydrologic processes).

Climate change: Climate projections for the region of São Paulo suggest that average temperatures will increase, but are inconclusive regarding precipitation, with some models predicting an increase and others a decrease by the 2050s (Schneider 2017).

To assess the effect of temperature increases in the model outputs, we ran the model for one additional scenario, corresponding to a 10 percent increase in temperature. The model predicted that this change would decrease total streamflow and baseflow by 7 percent.

Alternative models: To assess model structural uncertainties, we ran another model based on the InVEST annual water yield (AWY) and seasonal water yield (SWY) models to evaluate differences in annual baseflow between the three scenarios (current, forest, and degraded). These models computed the watershed annual water balance. Specifically, we used the AWY model to predict total streamflow (Q) and the SWY model for quickflow (QF);

WE THEN COMPUTED THE BASEFLOW FOR EACH SCENARIO AS THE FOLLOWING:

Equation 6

$$B = Q - QF$$

The alternative model also predicts a very small effect of the target scenario on baseflow: –1 percent change for the Jaguari watershed, with a –9 percent to +7 percent range possible given model uncertainty.

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APPENDIX C. FINANCIAL ANALYSIS METHOD AND ASSUMPTIONS

This appendix provides detailed information on the methods employed to estimate costs and benefits for the return on investment analysis for São Paulo, as well as underlying assumptions and data sources. Information is provided in seven sections following the Green-Gray Assessment steps: general model assumptions, sediment modeling, cost valuation, benefit valuation, financial model and cost-benefit analysis, sensitivity analysis, and climate change. For all values, the exchange rate is 1 R$ = 0.3125 US$, which is the daily average from 2015–17. Throughout this appendix, the symbol $ is used to denote U.S. currency. The Brazilian *real* is denoted by R$.

General Model Assumptions

General assumptions define the main conditions of the return on investment model and correspond with data needs under Step 2 of the Green-Gray Assessment method, including the time horizon for the analysis (i.e., planning horizon), the discount rate, the sequencing of infrastructure interventions, and assumptions on counterfactual trends relevant for the ROI analysis.

Assisted (Full) vs. Natural Restoration

Restoration can be achieved using several methods (e.g., full restoration or natural regeneration), which implies different investments and operational and maintenance costs depending on the method used (Instituto Escolhas 2016). Selecting the most adequate method depends on the biophysical attributes of the study area, such as soil type, slope, aspect, creek, ecological vectors like seed banks, landscape design, and economic and demographic constraints (Antoniazzi et al. 2016). It is clear that some regions have a high potential for natural regeneration (Rezende et al. 2015; Chazdon and Uriarte 2016; Strassburg et al. 2016). In these cases, a simple intervention, such as fencing the area, may be enough to ensure the restoration process. On the other hand, full restoration may be necessary for areas with low potential; a variety of interventions such as fencing, actively preparing the soil, using fertilizers and pesticides, planting the seedlings, and, in extreme cases, irrigation are used for full restoration projects.

To define the share of full restoration versus natural regeneration for São Paulo, we developed maps of areas with "high regeneration potential" and overlaid them with the priority area map for sediment retention, detailed in Appendix B. We assumed that priority areas that overlap with high regeneration potential areas can use natural regeneration, while full restoration would be required for areas that do not overlap. To develop the regeneration potential maps, we first identified areas of historic forest restoration as recorded by Hansen et al. (2013) between 2000 and 2012. Then we considered a buffer of 150 m from the Euclidian distance from each restored pixel as zones with high restoration potential. We assumed that for all pixels that had been reforested between 2000 and 2012, the eight surrounding pixels had a high potential of restoration. This assumption was based on several studies conducted in the Atlantic Forest that found the main drivers of restoration are topographic position, slope, solar radiation, soil type, and distance to the existing forest (Rezende et al. 2015; Chazdon and Uriarte 2016; Strassburg et al. 2016).

Implementation Schedule

We assumed restoration would be implemented over a 10-year period, following a schedule provided by TNC and the São Paulo Water Fund. We also assumed that natural infrastructure operation and maintenance (O&M) expenses occur during the first three years following implementation, based on guidance from the São Paulo State Secretariat of Environment (SMA 2014). The sequencing of restoration during the 10-year period is presented in Table C1.

For our investment portfolio C1900, where 1,900 hectares are protected from deforestation, we assumed all protection would occur in the first year, so as to ensure that all hectares are protected over the entire 30-year timeframe.

Table C1 | Restoration Schedule

YEAR	1	2	3	4	5	6	7	8	9	10
R4000 (ha)	16	33	164	328	492	607	656	656	656	393

Source: Authors.

Counterfactual Trends

Water demand

According to the São Paulo State Department of Water and Hydropower Energy (DAEE 2013), current water availability and demand in the Cantareira System is 33 m³/s, and might grow to 37 m³/s by 2035 (see Table C2). However, the Cantareira is one of eight integrated water systems that together supply 68.2 m³/s of treated water to the São Paulo metropolitan region. Because these systems are highly interdependent, it is difficult to estimate how much the Cantareira System alone will contribute to meeting the region's future water demand (ANA 2010).

Table C2 | Projected Water Demand in the Cantareira System

YEAR	URBAN DEMAND(M³/S)
2008	31.35
2018	34.52
2025	35.90
2035	37.04

Source: DAEE 2013.

As our analysis timeframe is 30 years into the future, we used demand projections from DAEE (2013) and extrapolated to 2047 based on their equation.

THE DAEE DEMAND EQUATION 7 IS:

Equation 7

$$WD_y = -0.0059705882x^2 + 24.3489725541\,x - 24{,}787.5814445039$$

WHERE:

WD is the urban water demand;

and **x** is the year.

Using the equation provided by DAEE, we estimated an expected water demand of 33.67 m³/s in 2015 and 36.91 m³/s in 2045, showing an increase of 9.66 percent over the 30-year timeframe, or 0.31 percent growth per year (compared with the population growth increase of 0.35 percent per year estimated by IPEA 2017).

Conservation (degraded forest area)

To determine the area relevant for forest conservation, we created an alternative baseline scenario in which deforestation continues at a rate commensurate with the average deforestation rate from 2001 to 2013 based on Hansen et al. (2013). Projecting recent historic deforestation trends has its limitations: it fails to capture any future possible land use policies, population growth, or changes or commodity demand that could impact the rate of deforestation. However, there is no better data source on which to base our assumption because no robust future land use projection has been conducted for the region. The annual deforestation rate was calculated based on forest loss data (Hansen et al. 2013) for all municipalities included in the study area watershed.

THE RESULTING DEFORESTATION RATE WAS COMPUTED USING EQUATION 8:

Equation 8

$$def\,\% = \left(1 - \frac{\sum_{2015}^{2001} def}{veg\ 2000}\right)^{0.067} * 100$$

WHERE:

***def* %** is the historical deforestation rate to be used on projections (% per year);

def is deforestation, with t0 = 2001, tf = 2015 (ha); and

***veg* 2000** is native forest cover in 2000 (ha).

This results in a rate of 0.2 percent per year, which means a total of 1,901 ha in 30 years.

Table C3 | Timeframe for Analyzing Water Infrastructure

INFRASTRUCTURE AND EQUIPMENT	LIFESPAN (YEARS)	AMORTIZATION (YEARS)	TIMEFRAME USED TO ASSESS ROI (YEARS)
Dams, pipelines, reservoirs	80–100	50–60	50
Pump stations and other concrete buildings	40–60	30	20–40
Pumps and other equipment	25–35	20–25	20–25
Water treatment tanks and machinery rooms	40–60	30	20–40
Chemical tanks and chemical reservoirs	20–30	15	20–25

Source: U.S. EPA 2003; Sabesp 2014a.

Timeframe

Natural infrastructure projects, as a substitute or complementary strategy to conventional infrastructure projects, should consider an analysis timeframe that is relevant for decision-making processes. While green infrastructure may generate benefits that last over decades, decision-making on water infrastructure investments may be more limited to the lifespan of built infrastructure.

Whereas infrastructure "lifespan" refers to how long infrastructure can properly function, "timeframe" is the lifetime of a given project and can be used to define the planning horizon for decision-making. Table C3 presents recommended lifespans and timeframes used to assess major water infrastructure components.

As our analysis considers a water system with multiple infrastructure components, we chose to use an average value of 30 years. Sabesp also uses this timeframe in its own analysis (Sabesp 2011a).

Discount rate

The discount rate is the interest rate used to determine the present value of future cash flows. It reflects the time value of money and the risk of future cash flows (Assaf Neto 2010). For our benchmark scenario, we used a discount rate of 9 percent based on Sabesp's Weighted Average Cost of Capital (WACC) of 9.11 percent, which is also the discount rate Sabesp has applied to its own projects (Sabesp 2011b). The WACC reflects how much interest a company owes for each dollar it finances, and is also officially used by the Brazilian government to review water tariffs (ANA 2010).

Financial experts also recommend using a range of discount rates to increase robustness of the analysis (Assaf Neto 2010). The Inter-American Development Bank recommends using a discount rate of 12 percent for public water infrastructure projects in Latin America (Fontanele and Vasconcelos 2012). Financial experts in Brazil recommend accounting for the Brazilian risk premium. The Brazilian Institute for Applied Economic Research's database shows that in the last 10 years the Brazilian risk premium presented an average of 256 ± 90.4 points, which translates to 2.56 ± 0.904 percent per year (IPEA 2017).

For our sensitivity analysis, we varied the discount rate from 5 to 12 percent, accounting for the risk premium and its standard deviation to represent higher and lower risk scenarios (see Table C4 and Section VI).

Table C4 | Discount Rates for This Analysis

FINANCIAL SCENARIO	DISCOUNT RATE APPLIED
Optimistic	5% (minimum required – BRPA[a] – SD[b])
Regular	9% (minimum required)
Pessimistic	12% (minimum required + BRPA + SD)

Note: [a.] BRPA is the Brazilian risk premium average; [b.] SD is the standard deviation.
Source: Authors.

Sediment Modeling

This section explains how we translated results from the InVEST Sediment Retention Model into annual avoided sediment values. As described in Appendix B, this InVEST model estimates the capacity of a land parcel to retain sediment and can estimate avoided sediment for baseline and portfolio conditions. We used the model to estimate Year 0 and Year 30 sediment values for each portfolio and baseline conditions to allow us to estimate the total avoided sediment value. Recognizing that there is a time lag between forest restoration and conservation and the accrual of sediment retention benefits, we developed an approach to estimate annual avoided sediment based on the number of hectares of restoration and conservation and tree structure.

Several studies have evaluated the relative rates of soil erosion between forest and other land covers in the Atlantic Forest biome (Avanzi et al. 2013; Machado et al. 2003; Martins et al. 2010; Ribeiro et al. 2014). These studies have consistently concluded that in the Atlantic Forest, tree cover provides better sediment retention than pastureland, and native forest cover provides better sediment retention than eucalyptus plantations, possibly because native forests have more variation in canopy and root structure.

The sediment retention benefits of forests, especially native forests, in the Atlantic Forest biome are clear, but when these sediment retention benefits establish is less understood. Local stakeholders highlighted anecdotal evidence that sediment retention services establish quickly after a forest is planted. However, to our knowledge no studies have estimated the flux of erosion control in a restored natural forest in the Atlantic Forest biome over a 30-year time horizon. The closest study was focused on eucalyptus plantations, where eucalyptus stands showed a high soil loss rate during the first 4 years of growth, with substantially lower soil loss rates 8–12 years after planting (Martins et al. 2010).

Due to this lack of data, we used forest structure as a proxy for the sediment retention services, assuming that the level of erosion control services in restored forests directly correlates with the rate of forest recovery (Chazdon 2017). Sediment retention services directly correlate with forest structure characteristics, such as canopy leaf area, vegetation root depth, soil depth, and forest floor leaf litter depth. Ecological characteristics like species diversity and composition can also impact the provision of this service. These structural and ecological characteristics mediate hydrological fluxes across the globe (Ellison et al. 2017).

We used the average recovery rate for forests in the neotropics derived from Poorter et al. (2016), who quantified rates of aboveground biomass stocks in secondary forests to estimate recovery rates in a 45-site study in the neotropics, across an area that includes our study site. Some factors that might significantly affect this rate are local climate, soils, and management intensity (Poorter et al. 2016). We assumed that 10 percent of erosion control services are provided after 1 year of restoration, and 100 percent of erosion control services are provided by the 44th year, when the restored forest has a similar structure to a mature forest.

Since the restoration will not be done all at once, but rather will follow a specific schedule, the total yearly maximum erosion control is a function of restored area, age of the restoration, and percent of maximum erosion control.

TO ESTIMATE THE YEARLY AMOUNT OF SEDIMENTS EXPORTED, WE BUILT A MATRIX FUNCTION AS PRESENTED IN EQUATION 9:

Equation 9

$$ec_{year\ y} = \begin{bmatrix} a_{1,1} & \cdots & a_{1,30} \\ \cdots & \cdots & \cdots \\ a_{30,1} & \cdots & a_{30,30} \end{bmatrix}_{30,30} * \begin{bmatrix} p_{1,1} \\ \cdots \\ p_{30,1} \end{bmatrix}_{30,1} * ta = \mathrm{EC}$$

WHERE:

$ec_{year\ y}$ is the contribution of erosion due to restoration in year y (tons of sediments);

$a_{i,j}$ is the area restored in the year i (ha) with age j;

$p_{i,j}$ is the percent of maximum erosion control for a restored forest with age j (%);

ta is the total area restored at the end of 10 years (ha); and

EC is the average erosion contribution estimated by the InVest model (tons/ha).

Figure C1 portrays the trend in erosion control over 30 years, considering a staggered implementation schedule and allowing time for forest growth.

Cost Valuation

Investment costs are different for natural regeneration and assisted restoration. Natural regeneration simply entails fencing and allowing nature to take its course, while assisted restoration requires additional interventions such as soil preparation, planting, fertilizer, and sometimes irrigation (as described in Table C5).

Operation and maintenance costs

Operation and maintenance costs for reforestation include expenses necessary to maintain healthy forests and avoid tree mortality. We assumed O&M costs are incurred over the three years directly following restoration, based on recommendations from the São Paulo State Secretariat of Environment (SMA 2014). We also assumed fencing repairs occur every 14 years after installation (so occur only twice in the 30-year timeframe of this study).

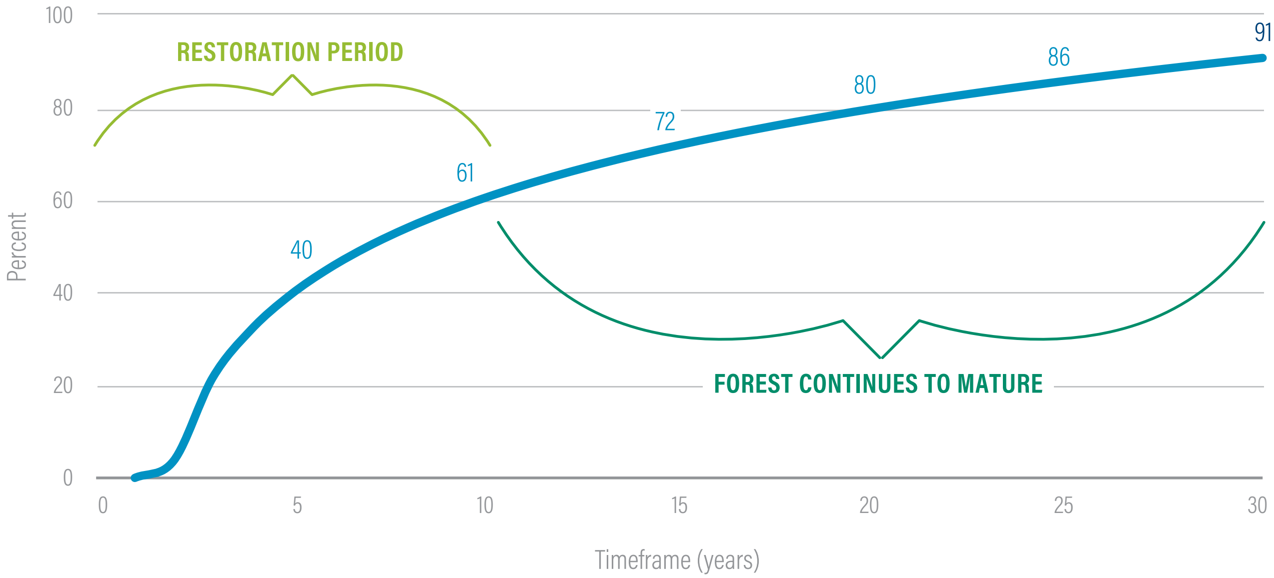
Transaction costs

Transaction costs are expenses required for negotiating, drafting, and ensuring compliance with a given contract (Assaf Neto 2010). In restoration programs, transaction costs could represent labor costs and those to engage partners, investors, and landowners. Although transaction costs are considered crucial to an economic and financial analysis, there is a lack of knowledge about the magnitude of transaction costs for a given restoration project. Even in studies about large-scale restoration in Brazil, transaction costs are highlighted but their values are omitted (Antoniazzi et al. 2016; Instituto Escolhas 2016; Benini and Adeodato 2017).

Kroeger et al. (2017) are an exception. They estimated that over 30 years in a payment for ecosystem services (PES) project, transaction costs could be about five times higher than the payments made to landowners. In this case, however, they considered the whole program design and management, economic and biophysical analysis, as well as high-quality hydrologic monitoring—many of these costs could be covered in-kind by leveraging partners' relative capacities.

In this study's context, forest restoration in the Cantareira System can build on and leverage the efforts of ongoing projects, including the São Paulo Water Fund and Programa Nascentes, which have already covered some transaction costs associated with economic and biophysical analysis, program design, and management. We assumed transaction costs to be a fraction of average administrative costs of PES values in the São Paulo region. The São Paulo State Secretariat of Environment estimates transaction costs in restoration programs to be $500 per hectare (Carrascosa 2017). We adopted this estimate and assumed that around 21.5 percent of the restoration costs would occur in Years 1–4, corresponding with the investment and maintenance period.

Figure C1 | Erosion Control Trends for R4000 over 30 Years (% of total possible erosion control)



Source: Authors.

Opportunity costs

The opportunity costs of land were applied annually over the 30-year timeframe. Opportunity costs are the value (net benefit) of the alternative land use forgone by conservation interventions. Because there are several land use possibilities for any land parcel, the opportunity cost of land is usually determined by either the most common use or the most profitable and/or productive land use category that would have occurred absent the conservation intervention.

We assumed that opportunity costs do not apply for areas protected under Brazilian law—more specifically under the Brazilian Forest Code—as there is no legal alternative land use option for those areas. This assumption has been adopted broadly in Brazil (Soares-Filho et al. 2014) for the cases where restoration will take place in areas of permanent protection. According to the Forest Code (Law 12.651/12), these areas must be preserved with natural vegetation or mandatorily restored, and alternative uses are not allowed. While the future of the Brazilian Forest Code is not clear (Soares-Filho et al. 2014), we assumed that the law will be in place and enforced over the analyzed timeframe.

Outside APP zones, we assumed the opportunity cost to be $171/ha, based on interviews with stakeholders. This is similar to the average pasture rental price reported by the Regional Bureau of the Agriculture Economics Institute of São Paulo State, which indicates that pasture rental prices range from $93 to $243/ha/year across regions of São Paulo, Campinas, Limeira, Bragança Paulista, and Piracicaba (IEA 2017).

Benefit Valuation

While reforestation can potentially produce a variety of benefits, this analysis focuses solely on avoided sediment management costs incurred by water infrastructure operators. As described in the main report, we evaluated three water management costs: water treatment costs, reservoir dredging costs, and wear and tear on equipment (asset depreciation).

The InVEST Sediment Retention Model allowed us to estimate the total amount of annual sediment arriving at the intakes of the reservoir system for the baseline conditions and investment portfolios. Based on expert opinion, we assumed that 87 percent of all sediment arriving at each reservoir stays in the reservoir while 13 percent flows to the water treatment plant (Sousa Júnior 2011). However, because the Cantareira System comprises six reservoirs, and each reservoir's drainage area has a different erosion rate, we estimated that 97.21 percent of all sediment exported in the watershed is retained in the reservoir system while only 2.79 percent enters the water treatment plant, assuming the baseline as cited in Sousa Júnior (2011).

Avoided dredging costs

Due to data limitations regarding current water storage capacity and sedimentation levels of the six reservoirs, and a lack of information from Sabesp on what triggers sediment management actions, we assumed that dredging is the preferred sediment management action for each reservoir, and that all new sediment must be dredged. We assumed dredging will occur annually. This approach was recommended during interviews with stakeholders.

DREDGING COSTS WERE CALCULATED USING EQUATION 10:

Equation 10

$$D_i = C \quad S_i * d_i$$

WHERE:

D_i is the total dredging cost in year **i** (in R$);

C is the percent of total sediments that is retained in the reservoir (97.21%);

S_i is the total sediment that arrives in the water system (tons/ha/year), estimated by the InVEST model; and

d_i is the price of dredging one ton of dried sludge or sediment-equivalent in year **i**. In São Paulo's case, this is 11.18 ($/ton), considering the density (specific weight) of sediments is 1.9925 grams per milliliter.

TO ESTIMATE THE AVOIDED DREDGING COSTS BETWEEN BASELINE AND INVESTMENT PORTFOLIO CONDITIONS, WE CALCULATED THE ANNUAL CHANGE IN AVOIDED DREDGING COSTS USING THE FOLLOWING EQUATION:

Equation 11

$$\Delta D_i = D_i * D'_i$$

WHERE:

ΔD_i is the total avoided dredging cost in year i ($);

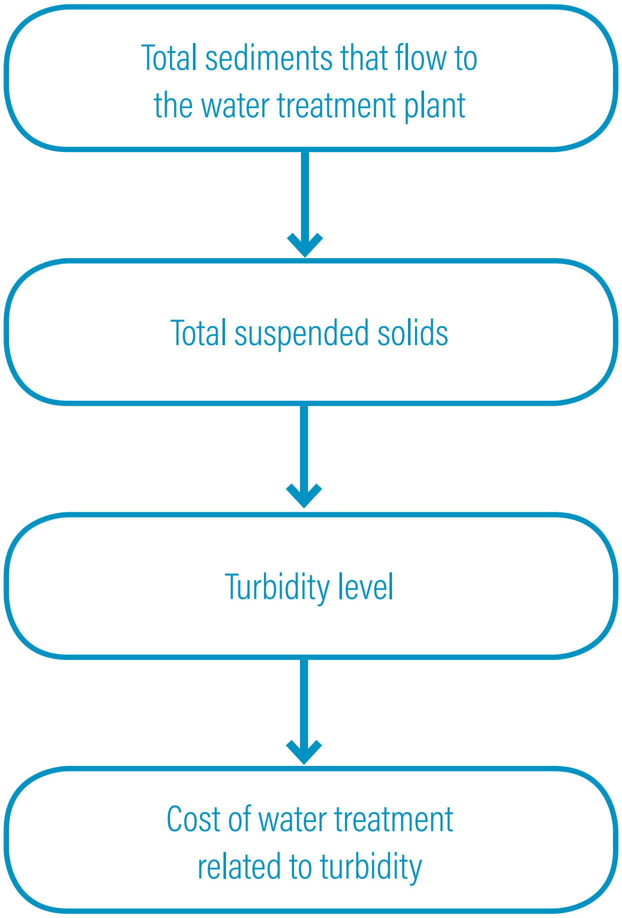
D_i is the total dredging cost in year i in the counterfactual portfolio ($); and

D'_i is the total dredging cost in year i in an alternative portfolio ($).

Avoided water treatment costs

Avoided costs in water treatment were estimated through the development of cost curves as a function of turbidity levels. A unit conversion method was used, following four steps to account for avoided costs of water treatment due to turbidity (Figure A4) (Tomazoni et al. 2005; Sousa Júnior 2011; Arroio Júnior 2013; Bezerra et al. 2015; Medeiros et al. 2015; Mello 2017).

Figure C2 | The Four Steps to Account for Avoided Costs in Water Treatment Due to Turbidity



Source: Authors.

USING INVEST RESULTS AND ASSUMING 2.79 PERCENT OF SEDIMENTS ARE EXPORTED TO THE WATER TREATMENT PLANT, WE APPLIED EQUATION 12 TO CONVERT DAILY SEDIMENTS INTO SOLIDS IN SUSPENSION, ADAPTED FROM CARVALHO (1994), AS FOLLOWS:

Equation 12

$$SS = S_{ed} / 19.11 * 0.0864$$

WHERE:

SS is the concentration of total suspended solids (milligrams per liter or mg/l);

S_{ed} is the total sediment exported in the system, provided by InVest models (tons/day);

19.11 is the constant of water flow volume in the Cantareira System, estimated by InVest in this project (m^3/s); and

0.0864 is the conversion factor between daily sediments and solids in suspension.

TO OBTAIN THE TURBIDITY LEVEL DUE TO TOTAL SUSPENDED SOLIDS, WE USED THE EQUATION ESTIMATED BY SAAD AND COLLEAGUES (2018):

Equation 13

$$T = \left(\frac{SS}{1.114}\right) - 1.4731$$

WHERE:

T is the turbidity level (NTU); and

SS is the solid in suspension (mg/l).

Finally, we estimated costs due to turbidity level using data collected in Cantareira System's Guaraú water treatment plant (Saron and Silva 1997), with deflated values to 2017 using the General Prices Inflator Index (IGP-DI).

WE USED AN EQUATION WITH DATA FOR TURBIDITY UP TO 40 NTU:

Equation 14

$$C = 0.0035912161 * ln(T) - 0.0004325082$$

WHERE:

C represents the cost of chemical inputs to treat turbidity (R$/$m^3$); and

T is the turbidity level (NTU).

Other costs directly affected by the turbidity level were also considered, such as energy and labor expenses incurred in the treatment of water and equipment maintenance, as well as replacement of materials such as sand and anthracite and materials for equipment cleaning and sludge removal. For these costs, we assumed a linear relationship with the amount of sediment that arrives at the water treatment plant. This linear relationship procedure is therefore different from the relationship between turbidity level and chemical costs. This assumption was advised by experts, including the financial director of water utilities, former engineers of the water utility, academic researchers, and staff from the Secretariat of Sanitation and Water Resources.

THE COSTS WERE ESTIMATED USING THE FOLLOWING EQUATION:

Equation 15

$$C'_{i,y} = C_i * \frac{T'_y}{T}$$

WHERE:

$C'_{i,y}$ represents the cost of activity i in year y in the greener portfolio (R$/$m^3$);

C_i represents the baseline cost of activity i in year y in the counterfactual portfolio (R$/$m^3$);

T'_y is turbidity in year y in the restoration greener portfolio (NTU); and

T is total sediment in baseline.

We assumed that the cost of dredging is proportional to the yearly amount of sediment.

Depreciation

As mentioned before, controlling erosion can impact the capital depreciation of water infrastructure systems. Based on Sabesp's financial reports, the regular depreciation rate is 2.33 percent per year on average. We assumed that reduced sediment results in a cost savings equivalent to avoided depreciation of equipment at the water treatment plant.

WE CALCULATED THIS ACCORDING TO THE SEDIMENT AVOIDED (HESPANHOL 2017):

Equation 16

$$AD_{year\,y} = D_{year\,y} * \begin{bmatrix} a_{1,1} & \cdots & a_{1,30} \\ \cdots & \cdots & \cdots \\ a_{30,1} & \cdots & a_{30,30} \end{bmatrix}_{30,30} * \begin{bmatrix} p_{1,1} \\ \cdots \\ p_{30,1} \end{bmatrix}_{30,1} * S^{-1}$$

WHERE:

AD is the depreciation due to restoration already placed in year y (R$);

$D_{year\,y}$ is regular depreciation (counterfactual portfolio) in year y (R$);

$a_{i,j}$ is the area restored in year i with age j (ha);

$p_{i,j}$ is the percent of maximum erosion control for restored forest with age j (%); and

S is the total amount of sediment avoided in 100 percent of restoration estimated by InVEST (tons).

Table C5 presents the estimated per-unit costs of water treatment, dredging, and depreciation incurred by water infrastructure operators in the Cantareira System.

Financial Model and Cost-Benefit Analysis

Our financial analysis follows methods providing results on four financial performance measures, including internal rate of return, return on investment, net present value, and payback (Ittelson 2009; World Bank 2009; Assaf Neto 2010). Access Gray et al. (forthcoming) for definitions, formulas, and complete information on these financial performance measures.

Table C5 | Estimated Unit Costs of Water Treatment, Reservoir Dredging, and Depreciation Related to Turbidity and Siltation (Baseline)

OPERATIONS AND MAINTENANCE COSTS FOR TURBIDITY TREATMENT (US CENTS/m³ OF WATER TREATED)	
Workforce	0.93
Chemical products	0.22
Sand replacement (10%/year)	0.001
Anthracite replacement (10%/year)	0.02
Sludge removal	0.10
Energy	0.46
TOTAL	**1.73**
DREDGING (TOTAL COSTS, $/m³)	
Workforce	0.12
Machinery	9.13
Disposal	0.87
TOTAL	**10.13**
DEPRECIATION ($/m³)	**0.12**

Notes: Operations and maintenance costs are exclusively related to treating turbidity. Workforce includes wages, taxes, and other financial and monetary benefits and rights. Replacement of sand and anthracite refers to filters and equipment, while sludge removal refers to cleaning equipment.
Source: Authors.

Sensitivity Analysis

To address risk and uncertainty, we conducted a sensitivity analysis, which consisted of varying relevant variables in the financial model to measure each variable's impact on overall financial performance. The results are presented in Table ES 2 (page 6), Figure ES-2 (page 7), and Table 5 (page 30). Additional details on the method for sensitivity analysis are presented here. Variables were selected based on criteria outlined in Gray et al. (forthcoming). To understand if and how natural infrastructure project design could impact the risk of poor financial performance, we also varied other factors such as implementation schedules, proportion of government cost-share provided, and transaction costs. We varied the discount rate from 9 percent to 5 and 12 percent.

We used the following alternative assumptions and ranges for the sensitivity analysis:

Amount of sediment (tons/year): We conducted a Monte Carlo simulation (with 1,000 rounds) assuming a normal distribution on the outputs of the InVEST model. In each round we picked a sediment value at random. We assumed that the sediment (tons of sediment per cubic meter) follows a normal distribution with a mean of 226,585 (the InVEST output) and a variance of 714,179,225. For R4000, we assumed a normal distribution with a mean of 58,019 and a variance of 50,541,237.

Opportunity costs ($/ha/year): In theory, APPs have no opportunity costs because there is no legal alternative use for the land according to the Forest Code. However, around 8.1 million ha of APPs are currently being used in Brazil for purposes other than forest conservation. Most of them are degraded pasturelands, but are nonetheless generating some income for farmers (Guidotti et al. 2017). In the Cantareira, 76 percent of APPs—approximately 58,000 hectares—are currently occupied by non-forest land use.

The fact that landowners often do not comply with APP requirements implies there is an opportunity cost for all land, regardless of its APP status. As a result, some payment for ecosystem service programs have built in compensation to cover opportunity costs, even for APPs (Young and de Bakker 2014). Assuming farmers would need compensation for lost income from APPs, the project costs increase such that the project becomes unprofitable.

Restoration costs ($/ha): We used alternative assumptions about the costs of restoration in the region based on estimates by Antoniazzi et al. (2016), Benini and Adeodato (2017), and Instituto Escolhas (2016). In these sources, the investment and O&M costs of assisted restoration ranged from $2,019/ha to $5,038/ha with an average of $4,179/ha, similar to our assumption of $4,449 (based on local interviews). Total restoration costs (including investment, O&M, transaction, and opportunity costs) ranged from $4,931 to $13,057, respectively.

Climate Change: Relevant studies based on climate time series have revealed that in the southeastern region of Brazil, expected temperatures may be elevated by 0.5 to 1.5°C in the next three decades. For the same period, rainfall is expected to increase from 10 to 30 percent, though the number of rainy days per year will probably remain unchanged (PBMC 2013; Marengo et al. 2013; INPE 2017). We adopted a simple theoretical climate change scenario based on Feltran-Barbieri (2018) and found that an increase of 10 percent in heavy rains could imply an increase of 6.4 percent in the average annual turbidity level. Climate change could impact restoration performance as well, leading to tree mortality—even so, the restoration project would be profitable. The IRR could be 0.9 percent per year lower than the benchmark, and the NPV 38 percent lower.

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World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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