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NATURAL INFRASTRUCTURE IN VITORIA'S WATER SYSTEM, ESPÍRITO SANTO STATE

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RAFAEL FELTRAN-BARBIERI, SUZANNE OZMENT, MARCELO MATSUMOTO, ERIN GRAY, THIAGO BELOTE SILVA, AND MARIANA OLIVEIRA

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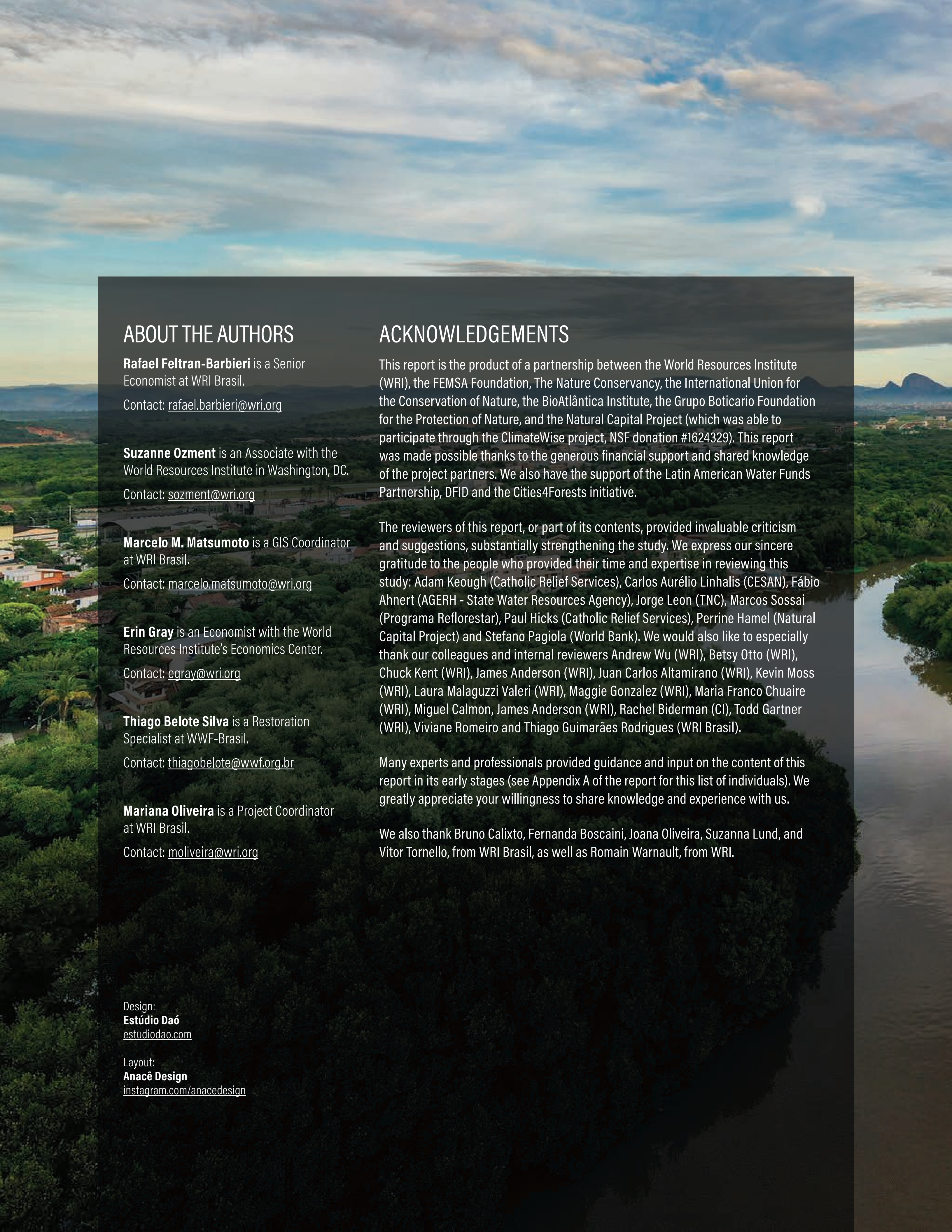

ABOUT THE AUTHORS

Rafael Feltran-Barbieri is a Senior Economist at WRI Brasil.

Contact: rafael.barbieri@wri.org

Suzanne Ozment is an Associate with the World Resources Institute in Washington, DC.

Contact: sozment@wri.org

Marcelo M. Matsumoto is a GIS Coordinator at WRI Brasil.

Contact: marcelo.matsumoto@wri.org

Erin Gray is an Economist with the World Resources Institute's Economics Center.

Contact: egray@wri.org

Thiago Belote Silva is a Restoration Specialist at WWF-Brasil.

Contact: thiagobelote@wwf.org.br

Mariana Oliveira is a Project Coordinator at WRI Brasil.

Contact: moliveira@wri.org

Design:
Estúdio Daó
estudiodao.com

Layout:
Anacê Design
instagram.com/anacedesign

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TABLE OF CONTENTS

FOREWORD

Water crises are provoked by unusual weather conditions. But the causes themselves are structural. Brazil's water sanitation and supply infrastructure are recognized as both underdeveloped and flawed: 16 percent of Brazilians do not receive services and 46 percent do not have sewage. Annually, the country invests less than half of its expected investment and universal water access has been delayed to beyond 2050. The demand for water in the next 25 years is expected to grow between 18 and 25 percent, while electricity consumption is expected to triple by 2050, increasing the challenge of water management.

Ongoing climate changes have made atypical conditions daily ones, leading to a new level of systemic water risk. Investing five times more in infrastructure to simply cover past deficits, for example, is not sufficient. It must be urgently recognized that conventional infrastructures such as reservoirs and water treatment plants can manage the water emanating from a water resource but are not capable of altering production capacity of such resources themselves. However, conservation and restoration of forests and native ecosystems, such as natural infrastructure, does provide essential and complementary services to the structure created through civil engineering.

With nature-based solutions, the natural infrastructure rehabilitates water sources to provide water with greater regularity and better quality. With better-protected springs, better-conserved valleys and floodplains, more riparian forests along the rivers, more hilltops covered by forest-sized vegetation and sustainably used, there will be more water to fill reservoirs, irrigate plantations, and supply industries.

The State of Espírito Santo has an inherently high water-vulnerability level and has suffered from water scarcity since the 2014 crisis. At the time of publication of this report, a new water crisis plaguing the Brazilian Southeast in 2021 is a national and regional focus. It mainly affects energy production, which is particularly expensive for economic recovery in times of the COVID-19 epidemic.

Fortunately, through the Reflorestar Program and other local initiatives, Espírito Santo has emerged as a national leader in recognizing the importance of natural infrastructure, including as part of the water management solution. This is, however, just the start of a long journey to reach water security. This report is intended to help assist in taking these first steps.

Marcos Franklin Sossai
Reflorestar Program
Manager/Seama-ES

Suzanna Lund
Senior Project Manager/
Forests Program WRI Brasil

EXECUTIVE SUMMARY

Natural infrastructure, that is, forests and other forms of native vegetation, can serve as among the most important strategies for nature-based solutions for water resource management. Such infrastructure enhances the performance and resilience of conventional structures, rehabilitating the landscape to provide more regular and better-quality water to springs. This report demonstrates how forest restoration of critically degraded areas in the Jucu and Santa Maria da Vitória watersheds could improve the operational performance of the water reservoir and treatment for the Metropolitan Region of Vitória. It indicates areas with the highest cost-effectiveness for the implementation of natural infrastructure, confirms the economic feasibility of investment in natural infrastructure, and offers recommendations on how to strengthen forest restoration programs and initiatives now underway in the State of Espírito Santo.

HIGHLIGHTS

- In the Jucu and Santa Maria da Vitória Watersheds in Espírito Santo State, a unified green-gray strategy of forest restoration and new water infrastructure can generate twice the net benefits compared to investments focused only on conventional infrastructure.
- Applying WRI's Green-Gray Assessment (GGA), this study found that targeted restoration of 2,500 hectares (ha) of degraded pastureland in the watersheds would require an investment of US$9.7 million[1] and generate benefits of $26.4 million in water treatment cost savings. Over 20 years the Internal Rate of Return (IRR) would be 13.9 percent and payback 11.6 years, on par with sanitation investments.
- Through the Reflorestar Program, the state already invests in forest restoration to protect its water supplies, though more resources are needed. The Espírito Santo State Water Company (CESAN from its initials in Portuguese), could be a key investor in Reflorestar, as it is the direct beneficiary of forest restoration.
- Local stakeholders pointed out the need to complement the present analysis with actions to create an enabling environment for green-gray strategies, including improved watershed monitoring, engagement of landowners, and exploring new and greater sources of financing.

Restoring Espírito Santo for Water Security

Since 2014 the Greater Vitória Metropolitan Region (Região Metropolitana da Grande Vitória; RMGV) has been suffering from chronic drought and occasional heavy rains, which has posed an enormous challenge for water management (INMET 2021). In response to these challenges, the Central Coast Water Resources Management (UGRH-Litotal Central from its initials in Portuguese) which manages the primary water source for the RMGV, has proposed a re-engineering of the water systems (AGERH, SEAMA, 2018). This has created an opportunity to rethink the role nature plays in the water supply.

Water resources for RMGV come from the Jucu, Santa Maria da Vitória (SMV) and Reis Magos watersheds. Jucu and SMV supply 59 percent and 38 percent of the water treated and distributed to the region, respectively. Recent investments to secure water supply have led to the construction of traditional built infrastructure (referred to as gray infrastructure), such as the "Imigrantes Reservoir", the largest water-storage reservoir in the region (AGERH, SEAMA 2018).

Healthy forests can help maintain water supply systems by controlling erosion and sediment pollution. Reservoirs are important for storing water and trapping of sediments, while forests, in turn, reduce the sediments exported to reservoirs and water systems, thus reducing the costs of water treatment, dredging, and depreciation of water treatment equipment (Ozment et al. 2018). These cost savings primarily accrue to CESAN, the water and sanitation company.

Espírito Santo has a rich history of forest restoration through its Reflorestar Program, a statewide forest conservation and restoration initiative that helps rural landowners comply with environmental legislation. Reflorestar recognizes the benefits of native forests for hydrological systems and offers payments for environmental services (SEAMA 2020). The program is the main executor of forest restoration in other strategic programs led by the State of Espírito Santo, such as the Integrated Water and Landscape Management Program and Forests for Life (Espírito Santo Government 2013).

To take advantage of the potential synergies between forest restoration and water benefits, the Reflorestar Program and UGRH-Litoral Central (UGRH-LC) management system must know where to prioritize forest restoration in order to optimize the improvement of water quality. To address this need, this study points out priority areas and analyzes how Reflorestar's restoration strategies could financially benefit CESAN by reducing water treatment costs. It finds that pairing forest restoration with the new water supply reservoir could be significantly more cost-effective compared to the current plan of installing the reservoir alone.

Evaluating the Role of Natural Infrastructure in Urban Water Supply

This study is a financial analysis using WRI's GGA, a six-step method that helps incorporate natural infrastructure through forest restoration into water investment decisions. In this case, the GGA was applied to estimate the costs and benefits that would accrue to sanitation companies with implementation of targeted natural infrastructure restoration strategies in the UGRH-LC, and to compare the results to a scenario only using built infrastructure.

The ideal type and location of natural infrastructure investments depends on which benefits are sought. The study identifies priority areas for restoration to maximize erosion control using the Natural Capital Project's Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) biophysical model. Forest conservation, agroforestry, silvopastoral systems, or management of other natural areas may also contribute to reduce erosion and sedimentation but were excluded from this version of the study for simplicity (though future versions of this study could incorporate such scenarios). Natural areas may also provide other ecosystem services to communities such as food production, carbon sequestration, disaster risk mitigation, recreation, etc. While important, the study narrowly focuses on the sediment management benefits of native restoration.

This study provides an approximate account of potential costs and benefits. Ideally, an analysis of natural infrastructure's return on investment (ROI) would be based on local observed biophysical and financial data. In this study we did not have access to data on costs with chemical products incurred in the operations of the sanitation companies. As a result, the study often approximated key data inputs, based on literature, nearby sites, or local expert opinion. While the results likely represent a realistic order of magnitude, they are approximations that could be improved through additional local data collection for future iterations of this analysis. Values are primary estimated in Brazilian currency (R$) and then converted into dollars without rounding. Not rounding the figures may give the impression that the numbers are more precise than they in fact are.

Natural Infrastructure Enhances and Complements Gray Infrastructure

Forest restoration in strategic areas of the watershed is likely to result in substantial cost savings for the water utilities. The study shows that restoring 2,500 ha of native forest currently occupied by degraded pasturelands (scenario LC2500) encompassing the restoration of 1600 ha in Jucu and 900 ha in **SMV** would require an investment of about $9.7 million. This investment could reduce turbidity by as much as 9 percent, generating cost savings of about $22.4 million over 20 years and achieving a Net Present Value (NPV) of $3.2 million (Table 1, Figure 1).

Considering the restoration in Jucu alone, the investment required would reach $6.2 million over a period of 20 years (see JUCU1600 scenario in Table 1). By reducing

Table 1 | Financials of Restoring 2.500 Hectares Combined with Building a New Reservoir, over 20 Years

NET BENEFITS			
	LC2500	**JUCU1600**	**SMV900**
TOTAL	**16,706**	**12,503**	**4,203**
NATURAL INFRASTRUCTURE BENEFITS (USD THOUSANDS)			
TOTAL	**26,404**	**18,710**	**7,694**
Avoided costs – chemical products[a]	2,590	1,773	817
Avoided costs – filter	156	109	47
Avoided costs – dredging and sludge removal	3,002	2,102	900
Avoided costs – energy	16,936	11,694	5,242
Avoided depreciation[b]	3,720	3,032	688
NATURAL INFRASTRUCTURE COSTS (USD THOUSANDS)			
TOTAL	**9,698**	**6,207**	**3,491**
Investments	5,830	3,731	2,099
Transaction costs	58	37	21
Opportunity costs	3,810	2,438	1,372
FINANCIAL PERFORMANCE (Discount Rate = 8.5% p.y.)			
NPV (USD THOUSANDS)	**3,165**	**2,745**	**420**
IRR (%)	**14**	**15**	**10**
PAYBACK (YEARS)	**12**	**11**	**16**

Note: a) Chemical products, filters, and energy refer to costs incurred for water turbidity treatment only. b) Depreciation of equipment is also applied as wear and depreciation of equipment used in water treatment processes only. See Appendix C for more details. All values in this report were estimated in Brazilian currency (R$) and converted into US at an exchange rate of R$ 1 = $ 0,2841.
Source: Authors.

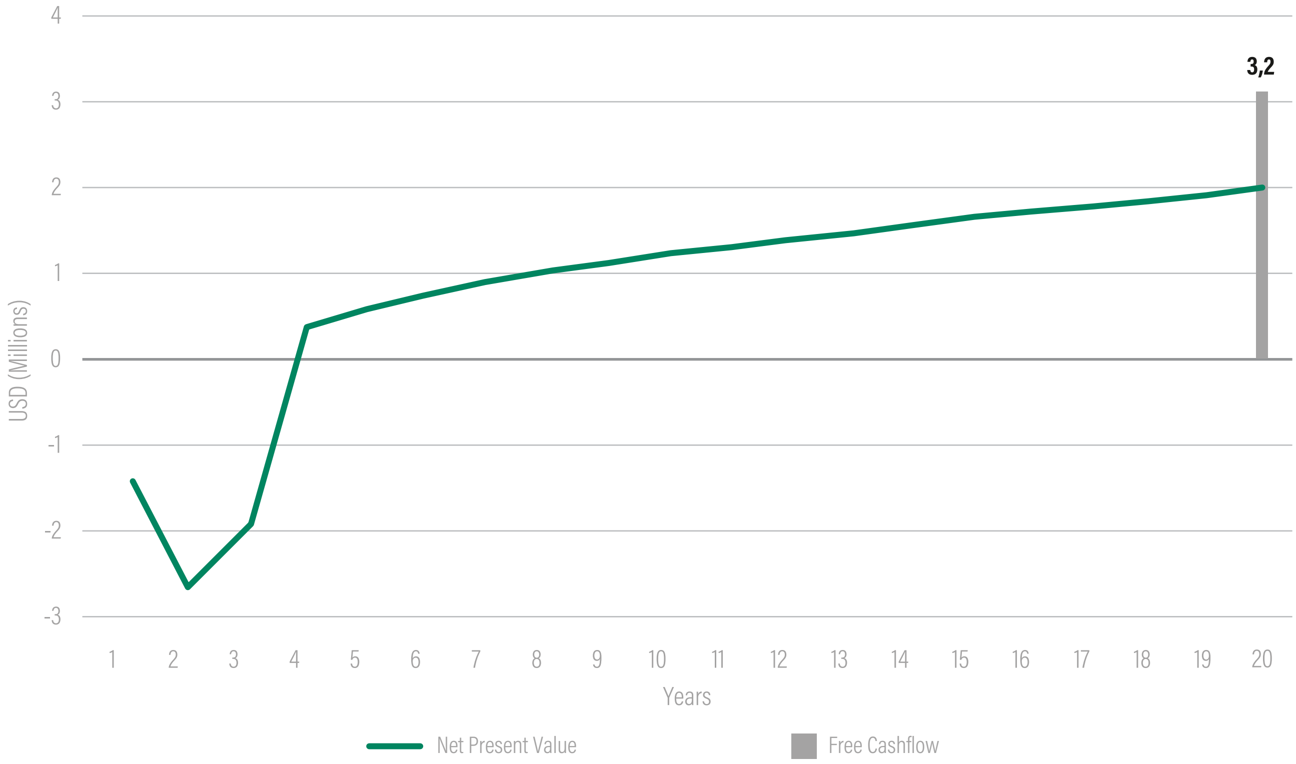
turbidity in the watershed up to 15 percent, this investment could generate benefits of around $18.7 million and a Net Present Value (NPV) of $2.7 million (Table 1, Figure 1). **In SMV, the restoration of 900 ha would require $3.5 million in investments** over the same period (see SMV-900 scenario). By reducing sediment pollution of up to 5 percent, it could generate benefits of $7.7 million and NPV of $420,000.

These restoration efforts align with the Reflorestar Program and similar program goals and budget for forest restoration of degraded areas in Espírito Santo. The Reflorestar Program, the Integrated Water and Landscape Management Program, and the Forests for Life Project, which have focused on Jucu and SMV watersheds, planned to invest approximately $53.7 million in Jucu and $38.1 million in SMV for forest restoration in headwaters, gallery forests, and water recharge areas. The investments required for the restoration of 2,500 ha evaluated in this study will be equivalent to one-third of that planned for the watersheds through these three initiatives.

Conventional gray infrastructure for water storage may also contribute to sediment control. A new reservoir in the Jucu Basin would most greatly reduce sediment pollution. While the primary purpose of the reservoir is to store 20 million cubic meters (m^3) of water, it will also act as a sedimentation tank, which in turn will reduce downstream water treatment costs. According to this report, the reservoir alone could reduce the sediments entering the treatment plants in Jucu by 28 percent. On the other hand, the siltation of the reservoir will require maintenance costs of $1.4 million over 20 years.

Natural infrastructure can cost-effectively complement and enhance the performance of gray infrastructure. The reservoir may trap sediments, but it cannot change soil erosion

Figure 1 | Financial Performance of the Natural Infrastructure for Water in the LC2500 over 20 Years



Note: In the first three years of the project the costs include the implementation of the restoration. The benefits (avoided costs in water treatment and depreciation of equipment) are gradually accumulated and increased with the development of the forest and, consequently, of services ecosystems. NPV over 20 years (using a discount rate of 8.5% p.a.) is about R$ 11.1 million.
Source: Authors.

from the landscape that makes its way into waterways. Restoring 1,600 ha of degraded pasture to native forest cover in the Jucu Basin would reduce the sediment discharge to the reservoir by approximately 1,800 tons/year, equivalent to load of 40 dump trucks per year. Total economic benefits from water treatment cost savings, avoided depreciation, and dredging costs would be $22.4 million over 20 years, 50 percent higher than the benefits achieved in water treatment costs provided by the reservoir alone.

Established public programs already investing in natural infrastructure could share risk with water sector investors. The Reflorestar Program has established the necessary administrative infrastructure to incentivize and manage state-wide restoration, but requires funding. CESAN could benefit from investing in the Reflorestar Program to implement targeted restoration. To seize this investment opportunity, stakeholders need to communicate the business case for investment to key decision-makers at CESAN, the water agency, and the Reflorestar Program, and develop a coherent long-term financing strategy. The Watershed Committees of Santa Maria da Vitória (CBH SMV from its initials in Portuguese) and Jucu (CBH Jucu from its initials in Portuguese) have already been consolidating an integrated financing plan and deciding priorities for investment in the watersheds. Different objectives may overlap in the same restoration actions to boost raising capital for investment in the forest to maximize the environmental and social benefits.

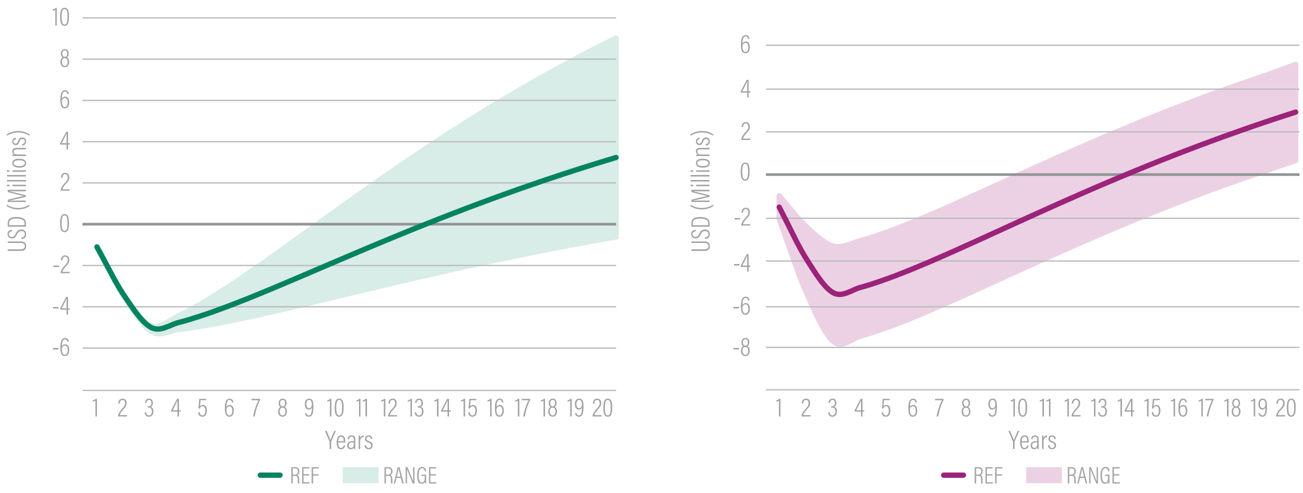
Sensitivity Analysis Results

Location and pace of restoration impact financial performance of natural infrastructure. The LC2500 proposed herein was designed to maximize sediment retention in water-critical areas—the 2,500 priority hectares contribute more than one-third of all sediment from pastureland in the watersheds. The pace of implementation also has a major impact on results—if LC2500 were completed in the first year of the project (rather than following a three-year restoration schedule), the project's NPV would be 20 percent higher. Accelerating the pace of restoration or targeting specific areas may not be feasible if local landowners in those areas are not interested in reforesting their land.

The sensitivity analysis shows that the capacity of the forest to retain sediments is the main risk factor. Natural infrastructure has demonstrated solid financial performance even under variations in discount rates, restoration cost, land opportunity cost and inclusion of labor

costs. However, the performance of the projects is very sensitive to variations in sediment retention capacity estimated during forest growth. If the sediment retention is 31 percent lower than estimated, the project's NPV is negative. This level of performance is unlikely but possible. On the other hand, if 59 percent more sediments are retained (the estimated upper bound of performance), then the NPV increases to $9 million. Restoration cost is the second variable that most affects the financial performance of natural infrastructure, while water treatment costs have no major impact. The magnitude of these differences is determined by turbidity levels, and therefore forest capacity for sediment retention, rather than by different treatment cost values.

Figure 2 | Financing Performance and NVP over 20 Years, LC2500 Scenario



Note: The figure on the right shows NPV over 20 years, main output (REF) and output band based on range of sediment retention (41% lower to 59% higher retention than the REF). On the left, NPV over 20 years, main output (REF) and output band based on restoration costs for active restoration (48% less expensive compared with 50% more expensive than the REF).
Source: Authors.

CHAPTER 1

CONTEXT

The Metropolitan Region of Greater Vitória is formed by seven municipalities and is home to more than half of the four million inhabitants of the State of Espírito Santo. The Jucu and Santa Maria da Vitória watersheds account for 97 percent of the region's urban supply, through the sanitation services provided by CESAN. Approximately 500 million liters of water are treated daily, using nearly 20 tons of chemical products. This study examines investment options in natural infrastructure to support water supply management, evaluating the financial performance of forest restoration to improve water quality as an ancillary strategy for investments in conventional infrastructure such as the Imigrantes Reservoir.

Between 2014 and 2020 the Santa Maria da Vitória Greater Metropolitan Area (RMGV) experienced severe and prolonged droughts. For four consecutive years (2014 to 2017), the annual rainfall average was less than 65 percent of the historical average. In 2015 at the peak of the crisis, rainfall was only 730 millimeters (mm), with an expected rainfall of 1,500mm (INMET 2021). In order to mitigate the risks of water insecurity, in 2017 Espirito Santo State launched the State Program for Reservoir Construction, which aimed to build 40 reservoirs statewide, including the Imigrantes Reservoir in the Jucu Watershed, the state's largest (SEAG 2018).

From2018 to 2020, annual rainfall varied between 5 and 10 percent above average, but was insufficient to counteract the deficits of previous years. In addition, rainfall was poorly distributed; there were 679 days without rain and 48 days of heavy rains (above 30 mm) (INMET 2021). Severe droughts impose serious restrictions on well-being and the economy - requiring rationing, company shutdowns, and risk to agricultural production, while heavy rains cause disasters such as landslides and floods, resulting in homelessness, displacement, serious infectious diseases, or even deaths. Between 2003 and 2018, Espírito Santo State registered 154 natural disasters; 52% related to droughts and 45% to rainfall, mostly landslides and floods. Losses totaled $830 million during the 2016-2017 season (CNM 2018).

Water treatment systems are also impacted by weather events. Droughts lead to increased pumping costs in reservoirs or in water catchment, while heavy rainfall can lead to a sharp increase in the cost of treating turbidity and pollutants, and can even imply in system shutdown (Taffarello et al. 2016; Frame et al. 2020). In this context, conventional infrastructure investments in water catchment, storage, and treatment are fundamental to provide redundancy and improve crisis management capacity. However, this type of infrastructure does not alter the landscape's ability to produce water with greater seasonal stability or better quality. Natural infrastructure does.

Natural infrastructure projects involve strategically planned and managed network of natural lands, such as forests and wetlands, working landscapes, and other open spaces. Theyconserve or enhance ecosystem values and functions and provide associated benefits to human populations. (Benedict, McMahon 2006). In this report, implementation of natural infrastructure for water refers to the restoration of forests that are currently pastures that have been severely degraded by soil loss, erosion and sedimentation. The goal is to recover the ability of the landscape to deliver water with less turbidity to water treatment systems.

This report examines options for investing in natural infrastructure as a water management strategy for RMGV in Espírito Santo, Brazil. It focuses on the UGRH-Litoral Central shaped by the Jucu and SMV, which are responsible respectively for supplying 59% and 38% of the treated water distributed to the RMGV population. The Reis Magos System – the third source of water for RMGV – is an important ally in the supply of the region, with a treatment capacity of 500 liters per second (l/s), but it was not included in this study (AGERH, SEAMA 2018).

The study evaluates how and to what extent natural infrastructure can complement and safeguard existing and planned water supply infrastructure from the impacts of sediment pollution, thereby reducing costs of operations. It also provides recommendations for design of natural infrastructure programs that increase the likelihood of success. Through this analysis, we begin to explore if and how the local water company could benefit from investing in natural infrastructure to realize operational and water security benefits.

BOX 1 | THE BENEFITS OF INTEGRATING NATURAL INFRASTRUCTURE INTO WATER MANAGEMENT

Natural or green infrastructure is the strategic protection, restoration, or management of natural systems such as forests and wetlands that contribute to core infrastructure services such as water supply. Natural infrastructure can generate a range of benefits, from carbon sequestration to rare species conservation, and from flood control to drought resilience. It can be multifunctional to simultaneously accomplish multiple benefits such as reduced flooding, creation of space for recreation, biodiversity protection or it can be focused on achieving just one or two outcomes.

Infrastructure operators such as water supply companies may potentially benefit from investing in natural infrastructure because of the cost savings and security due to stabilized water supply, and reduced water treatment costs, flood risk and consequent reduced risk of damage to infrastructure. These programs can be propelled by engaging infrastructure operators as investors in natural infrastructure programs, by generating a durable source of funds collected from water users who directly benefit from the program, and by integrating natural and built infrastructure components together into optimal infrastructure designs.

While the general benefits of natural infrastructure are broadly understood, the exact role that natural infrastructure can play as a central water management strategy depends on local context and therefore requires site-based assessment. Because natural infrastructure is not routinely considered in water infrastructure planning processes, water managers often overlook promising opportunities to use it to improve water security. Therefore, analysis of costs, benefits, risk and return for natural infrastructure for water investments is needed.

Source: Browder et al. (2019).

Water Management in the UGRH-LC (Jucu and SMV Systems)

The Jucu and SMV watersheds are contiguous and form the URGH-LC, located in the southeast Atlantic Basin in the Atlantic Forest Biome (AGERH, SEAMA 2018). They are currently the main source of water collection, treatment, and distribution for public supply of the RMGV, where more than 1.7 million people live (Pagiola et al. 2019).

The recognition of the need for decentralized management of water resources and the autonomy of decision-making processes in the Jucu and SMV are guaranteed by independent committees created in 2007. Decree 1934-R established the Santa Maria da Vitória River Committee (CBH SMV) and Decree 1935-R created the Jucu River Committee (CBH Jucu), dissolving the Intermunicipal Consortium of the Santa Maria da Vitória and Jucu River (Oliveira 2011).

The planning of actions that require alignment of strategies that benefit the RMGV population have been conducted by the two committees in conjunction with state agencies including the State Environment Institute (IEMA from its initials in Portuguese), State Secretariat of Environment and Water Resources (SEAMA from its initials in Portuguese), and the State Water Resources Agency (AGERH from its initials in Portuguese). Among the main joint actions are the water resources framework plans for the two basins (CBH SMV, CBH JUCU, IEMA 2016), the State Water Resources Plan-PERH (AGERH, SEAMA 2018), and the Integrated Water and Landscape Management Program (Espírito Santo Government 2013).

The company responsible for the water and sanitation services for the RMGV is CESAN, which operates five Water Treatment Plants (WTP) in the Jucu-SMV Basins. Three capture water directly from the Jucu River, and two directly capture from the Santa Maria da Vitória River. Although the WTPs have different installed capacity and different treatment systems, all fit into the same level of technological intensity (Gonzales-Perez et al.2018). CESAN's most recent ESG report points out that in 2017, approximately 7,600 tons of chemical products and more than 97 gigawatt hours (GWh) in electricity were spent in the treatment of nearly 180 million m^3 of water to supply RMGV (CESAN 2019a, 2019b, 2020).

Table 2 | Water Treatment Capacity and Methods in the WTP, Jucu and SMV

CATCHMENT WATERSHED	WTP NAME	WATER TREATMENT CAPACITY (M^3/S)	WATER TREATMENT METHODS
Jucu	Cobi	1.0	Conventional
	Caçaroca	0.4	Flotation with recirculation
	Vale Esperança	1.5	Conventional
		1.8	Direct descending with flotation
	TOTAL	**4.7**	
Santa Maria da Vitória	Santa Maria	0.3	Flotation
	Carapina	1.4	Direct filtration
		0.9	Flotation
	TOTAL	**2.6**	
UGRH Litoral Central	**TOTAL GERAL**	**7.3**	

Source: Authors. Based on Cesarino and Lima (2012), Pagiola et al. (2019), CESAN (2019a, 2019b, 2020), Linhalis (2019), Ahnert (2020).

Gray Infrastructure Projected in the UGRH-LC

Currently 91 percent of the population of RMGV has water services and 60 percent sewage services (Instituto Trata Brasil 2020). The greatest challenge is the expansion of the sewage treatment system, with the largest volume of the $323 million provided for the Integrated Water and Landscape Management Program, under execution by the Government of the State of Espírito Santo, CESAN and financed by the World Bank (Espírito Santo Government 2013).

Expansion of sewage treatment systems is already necessary but given the climate crisis and recurring droughts, the need for investments in water supply is especially urgent. Espirito Santo has recently experienced some of the worst water crises in its history. In the last five years, CESAN has often adopted water rationing measures (Elesbon 2020). To mitigate the risks of water insecurity, the State Program for Reservoir Construction has invested $200 million in building 40 reservoirs statewide (SEAG 2018).

Among the major planned investments in reservoirs and extension of the water distribution network is the first reservoir in Jucu River, the Imigrantes Reservoir. This reservoir will likely affect the greatest change in water management due to its size. The new reservoir will cost $28 million, and will begin operations in late 2022, storing up to 20 million cubic meters (m^3) of water, with additional water storage capacity equivalent to 30 percent of RMGV's annual demand (CESAN, 2019a).

The WTP in the Jucu and SMV watersheds, water catchments occur directly from the rivers. Intense rains carry large amounts of sediment to water courses that flow directly to the treatment plants. This requires that Cesan considerably increase the amount of chemicals used in water treatment and, in extreme cases, temporarily suspend its operations (CESAN 2010; Espírito Santo Government 2017).

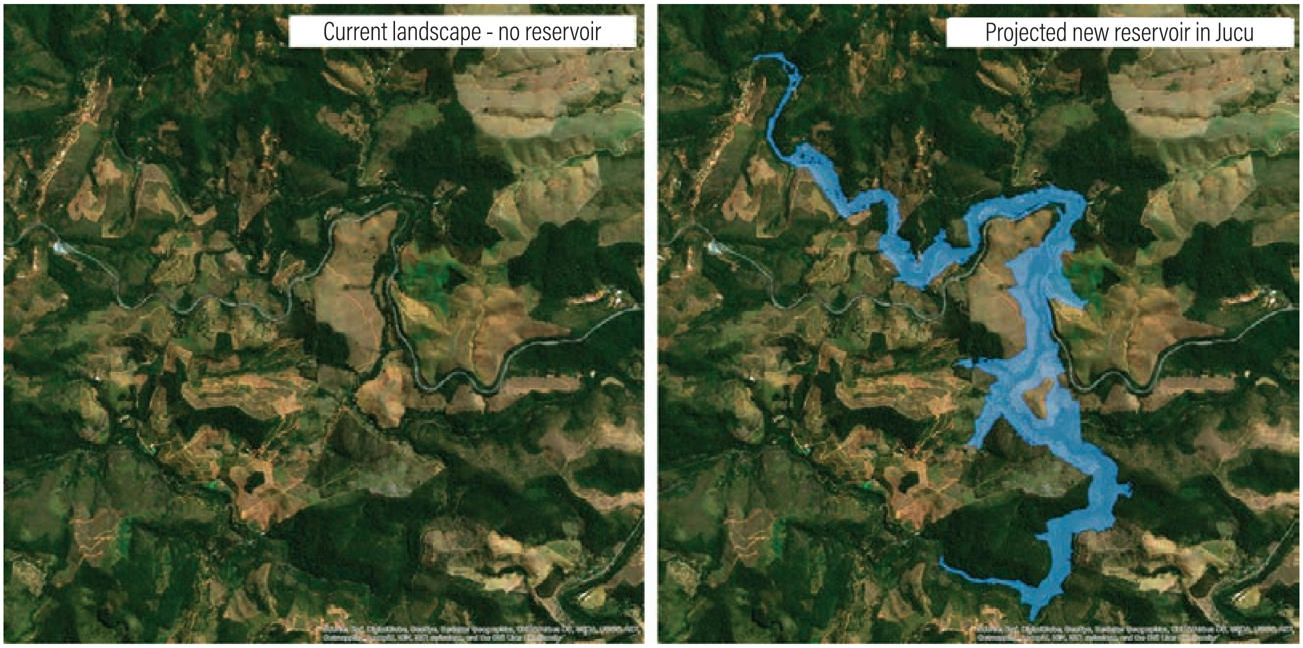
This sedimentary pollution – which materializes in turbidity – is a key factor in water treatment costs and causes wear and tear on equipment, shortening useful life and increasing depreciation.

With the new reservoir on the Jucu River, the dynamic changes and it will be able to storage around 20 million cubic meters of water, which equals about four months of consumption at RMGV, forming a water mirror of approximately 150 hectares (Scalzer 2016). The Imigrantes Reservoir will also capture sediment, thereby reducing the volume of pollution that reaches the water treatment plant. Studies have revealed that reservoirs may trap from 10 percent to 95 percent of the sediments produced in the watersheds (Pagioro, Thomaz 2002; Kummu and Varis 2007; Ran et al. 2013). Experiments in southeast Brazil in similar reservoirs suggest sediment trapping capacity is around 32 percent (Condé et al. 2019). Considering the Imigrantes Reservoir, the Jucu catchment presents two main regions in terms of turbidity dynamics:

- **Upper Region:** the upstream of the reservoir (75 percent of the basin land area);
- **Lower Region:** the downstream of the reservoir, or the portion of the watershed between the dam and the treatment plants (the water catchment occurs 20 km downstream of the reservoir spillway).

Assuming the Imigrantes Reservoir would trap 32 percent of the sediments produced in the upper region, the turbidity of the water in the WTPs will be given by the weighted average between the turbidity of the water at the outlet of the reservoir and the turbidity of the water produced in the landscape of the lower region.

Figure 3 | Comparison Between Current Landscape and the New Reservoir Projected in Jucu



Source: Authors. Simulation based on *Digital Elevation Model*. Details in Appendix B.

Considering Natural Infrastructure Strategies for the UGRH-LC

The new reservoir will improve water security, trap sediment, and reduce turbidity at the treatment plant, but will not change the sediment produced in the landscape. As highlighted by Dargahi (2012), sediment trapping in reservoirs it is only a relocation of the silting problem, as it moves from the WTP to the reservoir. On the other hand, natural infrastructure can play a role in controlling erosion at its source (Neary et al. 2009).

For example, natural areas that protect the soil during rainfall and have sturdy roots to hold soil in place can reduce sediment export from the landscape. They also may absorb water during rainfall events and reduce runoff into streams, which in its turn reduces channel erosion and avoid sediment accumulation in reservoirs. Erosion control benefits (due to forest restoration) may therefore translate into sediment management cost savings. Additional benefits are microclimate maintenance, pollinator protection, biodiversity conservation, and carbon sequestration (Assad et al. 2019).

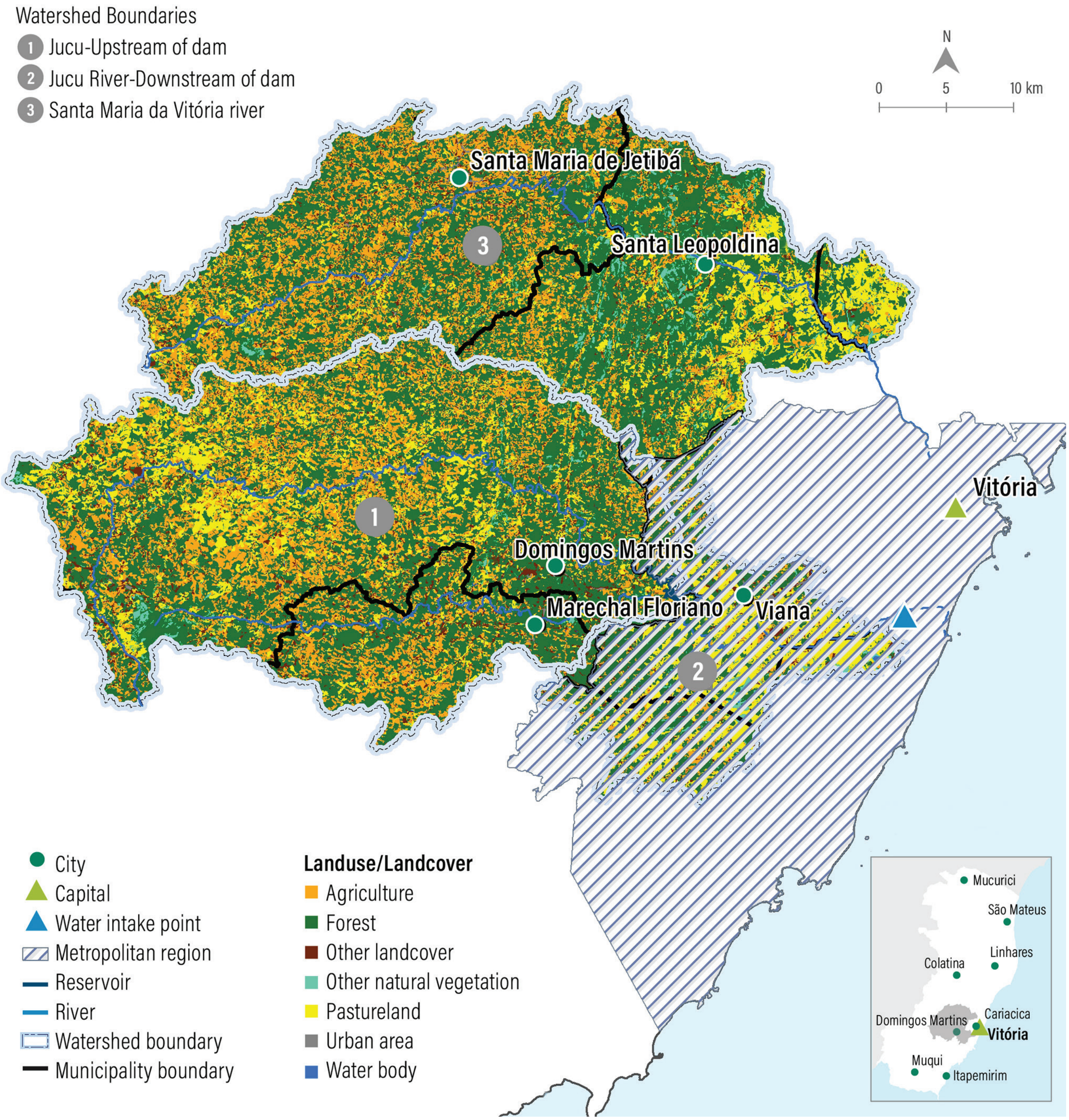
Globally, natural infrastructure has gained much attention as a way of better addressing challenges faced in water management, combining forest restoration and new water infrastructure into a unified green-gray strategy (Browder et al. 2019). There is reason to believe that natural infrastructure could be potentially effective in the UGRH-LC as well: the Atlantic Forest, as the region's native vegetation cover, has an innate ability to regulate the timing and flows of water, to control erosion by holding soil in place, and to filter pollutants from water, thereby safeguarding water infrastructure and improving water quality (Ozment et al. 2018).

The Atlantic Forest historically covered almost 100 percent of the UGRH-LC, but today it covers only about 36 percent in Jucu and 39 percent in SMV, as shown by Figure 1.1 (Geobases-ES 2018). Nearly 20 percent of the forest has been replaced by cattle pasture. As of 2018, however, 8 percent of the watershed land area was regenerating into native forest cover (see Appendix B). There is a sizable opportunity for even more restoration, in places and ways that could safeguard and enhance the performance of infrastructure (LAPIG 2020).

Ongoing Natural Infrastructure Efforts in the UGRH-LC

Key stakeholders of the Jucu River Basin have already shown significant support for restoring forests as natural infrastructure (Kissinger 2014). In 2008, Espírito Santo was the first state in Brazil to establish a law for Payments for Ecosystem Services (PES from its initials in Portuguese) (Sossai et al. 2013). In 2009, the State Water Resources Fund, FUNDÁGUA, was created to commit funds from oil and gas royalties, plus other sources, for water and forest conservation. This law allocates 2.5 percent of oil royalties to PES and land stewardship throughout the state. By one estimate, these royalties were set to provide $4.6 million annually for forests.

Figure 4 | Land Use and Cover in UGRH-LC (JUCU and SMV)



Source: Authors. Based on Geobases-ES (2018).

Currently, several programs and key stakeholders are developing and/or implementing natural infrastructure plans and setting investment goals. For example:

The Reflorestar Program

State-run program to increase forest cover, with a goal of restoring 80,000 ha of forest across Espírito Santo by 2020 (SEAMA 2020). It is funded by oil and gas royalties through FUNDÁGUA, in addition to support from the World Bank and Global Environmental Facility (Sossai et al. 2013). The Reflorestar Program supports several types of sustainable landscape management practices including conservation, restoration through planting, natural regeneration of vegetation, agroforestry and silvopastoral systems, and managed forests. The program offers payment for ecosystem services to enable landowners to participate. Predicted payments for ecosystem services are on the order of $80/ha/year for sites restored through active restoration (e.g. plantings and active maintenance), and $76/ha/year for naturally regenerated sites (where land is set aside and allowed to return to its natural state). The program also pays farmers $3,030/ha for active restoration implementation and $ 977/ha for natural regeneration (fencing and area isolation) (Sossai 2020).

By December 2020, the program had supported the restoration of 10,000 ha and invested R$15 million in total. Of this, $5 million was invested between 2019 and 2020 (SEAMA 2020). Reflorestar has reserved another $6 million for the restoration and conservation of forests, with approximately $1.4 million exclusively for Jucu and SMV (Sossai 2020).

With financial resources from the GEF, through the Forests for Life Project ("Florestas para Vida Project"), the Espírito Santo Biodiversity and Watershed Conservation and Restoration Project), the Reflorestar Program has raised funds for exclusive application on rural properties located in Jucu and SMV (SEAMA 2020).

The Jucu and Santa Maria Basin Committees

Responsible for the management of 97 percent of the RMGV water sources. They were established in 2007 and developed their Watershed Plans and Framework in 2016 (CBH Jucu Santa Maria 2017). This project is a partnership between the two committees, Espírito Santo State Government and Global Environmental Facility (GEF) to leverage an estimated investment of $340 million to be invested over 10 years for the management of water resources, with$196 million for Jucu and $144 million for SMV.

The Forests for Life project prioritizes forest restoration and conservation of native vegetation for natural infrastructure in two components: (1) Water Supply Management Component focuses on the restoration of headwaters, gallery forests, and aquifer recharge areas totaling required investment of $54 million in Jucu and $38 million in SMV; (2) For the Environmental Management and Regional Development Component, a provision of $1.25 million is estimated for the creation of Integral Protection Conservation Units, and resources that would be divided equally between the two watersheds. The amounts for natural infrastructure represent 26 percent of the total investment budget in SMV and 27.5% in Jucu (CBH SMV, CBH JUCU, IEMA 2016).

Notably, these investments depend crucially on the establishment of water charge, fundamental for the shared management of water resources and land planning. Even so, the resources that could be raised by water charge programs would at best cover 18 percent of programs. This implies that, while the efforts of this program may not have a solid foundation, a combination of funding is needed to meet the challenges of these watersheds.

The Integrated Water and Landscape Management Program

Led by Government of Espírito Santo State, CESAN, and the World Bank. It focuses on the 31 municipalities of the Jucu, SMV, and Caparaó micro-region and planned investments of $323 million. One of its five components aims to expand forest coverage by 8,500 ha. To meet this goal, the program will invest $35 million in the Reflorestar Program activities across the microregion, as well as the Restoration–Mangaraí Demonstration Unit in SMV, with technical and financial support from CESAN (Espírito Santo Government 2013).

By 2019, about 50 hectares had been restored or had their areas isolated and prepared for restoration, with investments from the order of $200 thousand (CESAN 2019a). Due to Covid-19 pandemic, there was no significant progress in the project during the year 2020.

Need for Scaling Up Natural Infrastructure to Achieve Water Benefits

Many actors in the state are considering approaches to accelerate natural infrastructure progress on the ground. We conducted a survey of local stakeholders from the water, environmental, and agricultural sectors across government and NGO organizations to identify the high-priority activities that could impact the success of utilizing natural infrastructure for water in the UGRH-LC (Appendix A). Among the responses we received, the most mentioned needs were:

1. **Evaluating the business case for investment:** Estimate the financial costs and benefits of the program to determine whether water dependent companies, public water managers or others could benefit from the program.
2. **Monitoring implementation and evaluation of project impacts**: Monitoring and evaluating progress by measuring hydrological, environmental, and social benefits of natural infrastructure efforts. Stakeholders noted that the baseline conditions of natural infrastructure (i.e., the current levels of water benefits generated from the current landscape) need to be established in the UGRH-LC, and this work should start immediately.
3. **Engaging landowners and land managers to conserve, restore, and manage natural infrastructure**: Recruit and sustain the participation of public and private owners and managers of land. Get the incentives right so that true cooperation among upstream and downstream communities can develop.
4. **Securing more funding for natural infrastructure**: Restoration programs have been ambitious but accessing sufficient funding to operationalize natural infrastructure projects is an ongoing challenge. This funding insecurity raises questions of the feasibility of implementing natural infrastructure plans, as well as long-term sustainability. On the other hand, if there is a strong financial case for

CESAN or other water-sector entities to invest in natural infrastructure, it may result in more funding for the restoration program. This could serve as an example for other river basins in the state, as there are currently 40 more dams planned statewide (SEAG 2018).

In assessing these needs for accelerating forest restoration investment, we focused on evaluating the business case for restoration for water security (Priority 1), while also exploring other co-benefits. To address this priority, site-based assessment is needed to determine whether the water-related benefits of forest restoration as natural infrastructure would outweigh the costs, and to gauge the feasibility of various potential program designs. Site-based assessments of the financial performance of natural infrastructure have been conducted in other Brazilian watersheds, including Espírito Santo's SMV (Pagiola et al. 2019), as well as Camboriú (Kroeger et al. 2017), São Paulo (Ozment et al. 2018), and Rio de Janeiro (Feltran-Barbieri et al. 2018) watersheds.

Using local data, literature review, stakeholder consultation, and biophysical and financial models, we evaluated the business case for water managers to invest in natural infrastructure, and, where applicable, strategies to enable investment. We followed the WRI's GGA method, which evaluates the overall financial performance of different green-gray investment options, examines each of the common priorities identified by local stakeholders, and produces recommendations on program design to optimize results (Gray et al. 2019). See Box 2 for more information on the Green-Gray Assessment.

The following chapter discusses results of the Green-Gray Assessment showing the strategic potential of combining natural and built infrastructure. Chapter 3 then presents results of the sensitivity analysis, providing recommendations and insights on priorities two through four from the list above.

BOX 2 | GREEN-GRAY ASSESSMENT OVERVIEW

To evaluate the financial performance of alternative infrastructure investment options, including green infrastructure options, we applied GGA developed by WRI. This is a conceptual method designed to analyze how natural (green) infrastructure can complement and support built (gray) infrastructure in producing goods and services for communities (Gray et al. 2019)

Each step of the GGA is summarized below and further discussed throughout Chapter 2:

1. **Define the investment objective:** This analysis defined the objective as maximizing the return on investment (ROI) in sediment control strategies for CESAN over a 20-year time frame, which reflects typical water management decision-making.

2. **Specify investment portfolios:** Working with local stakeholders, we constructed native forest restoration targets for the basin and identified an implementation schedule based on input from the local Reflorestar Program. We used InVEST's Sediment Yield Model to identify suitable areas for these interventions (Sharp et al. 2016).

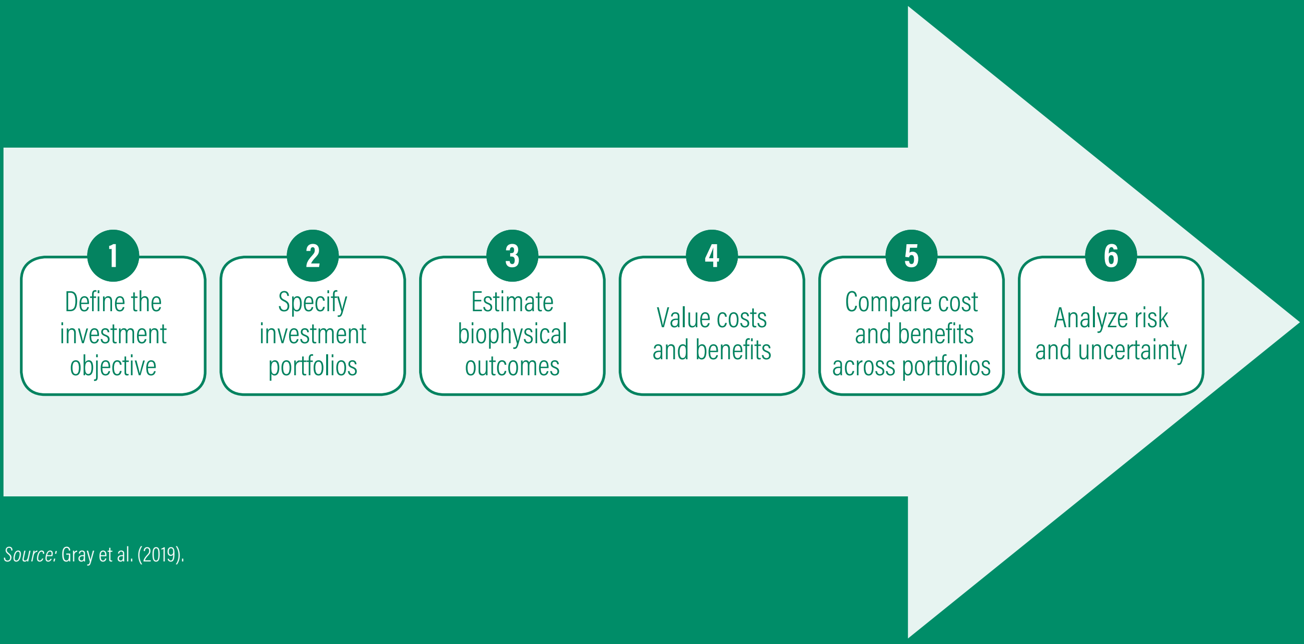
3. **Estimate biophysical outcomes:** We used InVEST's Sediment Yield Model to estimate landscape sediment yield rates under each portfolio. We then converted these sediment yield rates to measures of water quality and volumes of sediment caught in reservoirs.

4. **Value costs and benefits:** We calculated the full project costs of each investment portfolio, considering up-front costs, operational 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 water treatment, and equipment wear and tear (proxied by depreciation). These cost components are described in more detail later in Chapter 2.

5. **Compare costs and benefits across portfolios:** Applying an 8.5 percent discount rate that reflects the weighted average cost of capital (WACC) for most water utilities in Brazil, we examined and compared each investment portfolio's performance in terms of NPV, ROI, payback period, and IRR.

6. **Analyze risk and uncertainty:** Because this project may appeal to a range of public and private investors from the water sector with different risk thresholds, 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, namely the native forests' ability to control erosion, the opportunity cost of land, and forest restoration costs.

The Six Steps of WRI's Green-Gray Assessment



Source: Gray et al. (2019).

CHAPTER 2

GREEN-GRAY ASSESSMENT OF SEDIMENT CONTROL

This chapter provides a summary of investment scenarios and estimated biophysical results and financial performance from avoided costs of water treatment following implementation of natural infrastructure. It also features insights to support natural infrastructure programs and investment decisions. Finally, it assesses the impacts of restoration on the Jucu and SMV watersheds separately and aggregates the results to reflect costs and benefits for the entire RMGV.

This section presents detailed results on GGA steps one to five, summarizing the alternative investment portfolios, the estimated biophysical outcomes of each portfolio, and the financial performance in terms of program costs, avoided water treatment costs, and avoided wear and tear on infrastructure assets. It also highlights several insights from the analysis that could inform natural infrastructure program design and support investment decisions. This study evaluated the impacts of restoration in these basins separately, given their biophysical and structural particularities, then aggregated results to reflect the costs and benefits for the UGRH-LC and the entire metropolitan region.

The forest restoration costs are based on the Reflorestar Program for two types of restoration: implementation of active restoration and natural regeneration costs. The opportunity cost of the land is related to Payments for Environmental Services (PES). We also added 1 percent on the total value of the investments by way of transaction cost. We estimate that transaction costs will be low because existing projects already plan to cover farmer engagement and rural extension. For example, $100 million from the Integrated Water and Landscape Management Program and the Forests for Life Program has been set aside for farmer engagement in this specific region (Sossai 2020). Labor costs associated with restoration were not counted because Reflorestar Program requires participating producers to cover these costs. However, in Chapter 3 of this study, dedicated to sensitivity analysis, labor costs were included.

Defining the Investment Objective (GGA Step 1)

The investment objective is to reduce sediment management costs (especially costs incurred due to turbidity) over a 20-year time horizon, aligning with a typical time horizon used for water infrastructure investments.

Specifying investments Portfolios (GGA Step 2)

PWe designed three investment portfolios to compare how they performed on the investment objective, being one for the Jucu watershed, one for the SMV, and finally for the entire UGRH-LC which is the Jucu and SMV analyzed together (Table 4).

Table 3 | Restoration Costs of Active Restoration and Natural Regeneration

INTERVENTIONS AND INVESTMENTS	COSTS (USD $/HA)
Active Restoration - Full Planting (TOTAL)	**5.552**
Fencing	994
Soil preparation	164
Ant control	56
Chemical inputs	219
Seedlings transportation	24
Seedlings	644
Planting	929
Transaction Costs	925
Opportunity Costs of Land (PES)	1.597
Natural Regeneration (TOTAL)	**2.993**
Fencing	977
Transaction Costs	499
Opportunity Costs of Land (PES)	1.517

Source: Authors, Sossai (2020).

Table 4 | Investment Portfolios in Jucu

INVESTMENT PORTFOLIOS	DESCRIPTION AND ASSUMPTIONS
Baseline (reference) REF JUCU	Gray Infrastructure maintained
	No investment in natural infrastructure
Gray-Infrastructure (RES-JUCU)	The planned reservoir goes into operation. All additional water demand is met by current infrastructure
	No investment in natural infrastructure
Green-Gray Infrastructure (JUCU1600)	The planned reservoir goes into operation. All additional water demand is met by current infrastructure
	1,600 ha of forest restoration on degraded pastureland with highest sediment yield
	Restoration is completed in three years, with360 ha (first year), 720 ha (second year) and 520 ha (final year)
	67% of the priority areas are recovered through assisted restoration (planted forest) and 33% is restored through natural regeneration

Source: Authors.

Table 5 | Investment Portfolios in SMV

INVESTMENT PORTFOLIOS	DESCRIPTION AND ASSUMPTIONS
Baseline (reference) REF SMV	Gray Infrastructure maintained
	No investment in natural infrastructure
Green Infrastructure SMV 900	Gray Infrastructure maintained
	900 ha of forest restoration on degraded pastureland highest sediment yield
	Restoration is completed in three years, with 200 ha (first year), 400 ha (second year) and 300 ha
	67% of the priority areas is recovered through assisted restoration (planted forest) and 33% is restored through natural regeneration

Source: Authors.

Table 6 | Investment Portfolios in UGRH LC (JUCU + SMV)

INVESTMENT PORTFOLIOS	DESCRIPTION AND ASSUMPTIONS
Baseline (REF-LC)	REF-JUCU + REF-SMV
Gray Infrastructure (RES-LC)	RES-JUCU + REF-SMV
Green-Gray Infrastructure (LC2500)	JUCU1600 + SMV900

Source: Authors.

Table 7 | Water Treatment Costs

OPERATIONAL COSTS (USD CENTS/M³)			
Operation	REF-JUCU	RES-JUCU	REF-SMV
Chemical products	2.70	2.45	2.81
Sand replacement	0.02	0.01	0.02
Anthracite replacement	0.03	0.02	0.02
Sludge management	0.79	0.71	0.77
Energy	4.38	3.95	4.47
TOTAL	**7.91**	**7.15**	**8.08**
Depreciation	0.49	0.54	0.50

Source: Authors.

Across all portfolios we assumed water supply and climate factors were constant, and that water demand increases as a function of population growth and water demand elasticity (see Appendix C). We assumed land use and cover are held constant — exception for the 2,500 ha of degraded pasturelands recovered by forest restoration.

Although the RMGV's future demand for water can be met by other watersheds using technologies very different from those currently available, we consider that demand should be met by UGRH-LC with technologies and costs compatible with the current ones in order to measure the potential impact of natural infrastructure avoiding exogenous variables and speculative extrapolations.

Although the 5 WTPs in UGRH-LC have different operational and capacity systems, all have the same level of technological intensity. To simplify the analysis, we consider water treatment cost differs only among the WTPs for different watersheds.

Baseline and projected costs under gray infrastructure are presented in Table 7.

Estimating Biophysical Outputs (GGA Step 3)

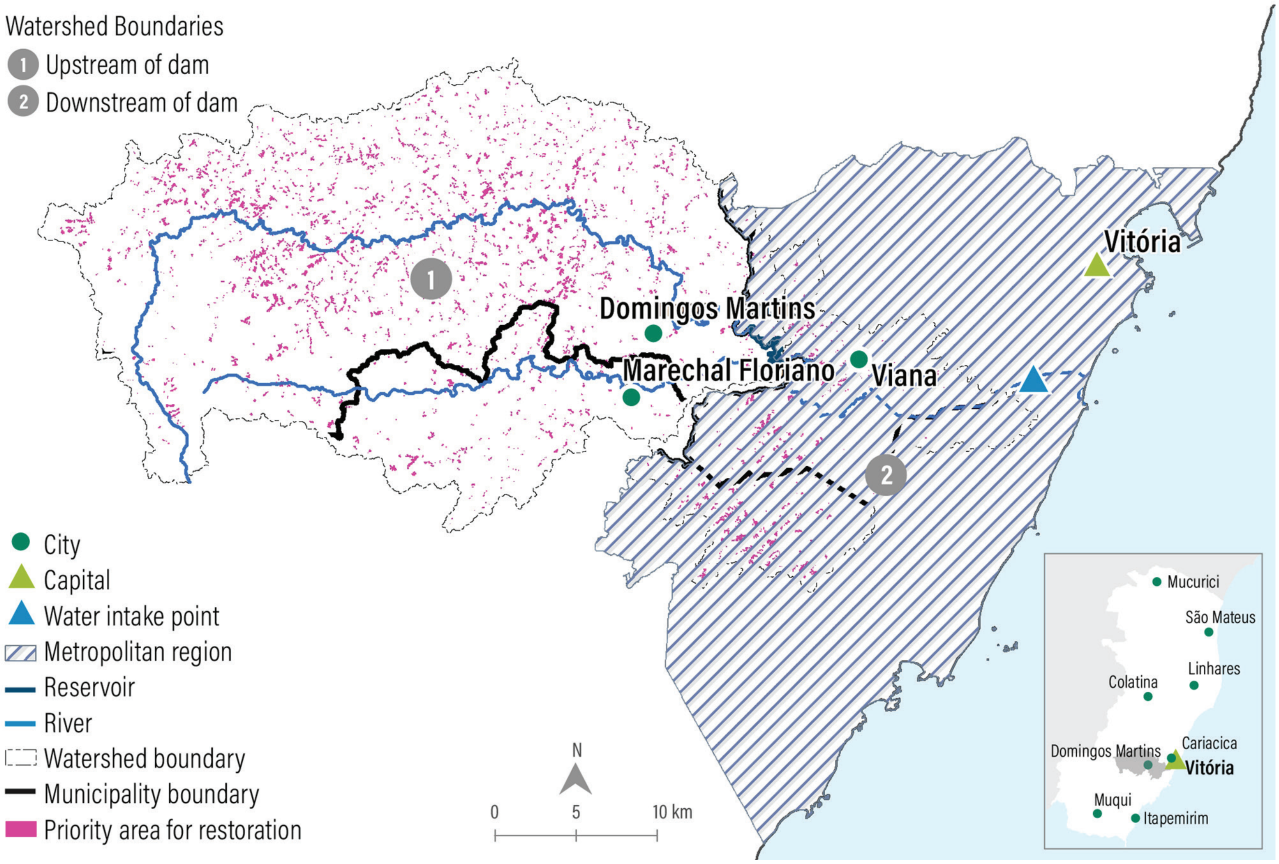
Jucu would significantly benefit from combining green and gray infrastructure.

In the JUCU-1600 scenario, we identified priority areas for natural infrastructure interventions, based on estimated sediment reduction potential of each hectare. Although restoration generally leads to less soil erosion, the impact of these initiatives may differ because of the heterogeneity among landscapes regarding of land use, type of soil, slope, and proximity to relevant water bodies.

Using the InVEST model, we identified 1,600 ha of pastureland in the watershed with highest sediment export potential. Of this, 1,200 ha are upstream of the reservoir (upper region), 400 ha in between the reservoir and the WTP water intake locations (lower region). The InVEST model predicts that these 1,600 ha are responsible for over 6 percent of the sediment flowing into the Jucu watershed, and for approximately 26 percent of sediment yield due to current pasturelands in the watershed.

Currently in the (REF-JUCU) scenario, total sediment exported in the Jucu River Basin is approximately 30,000 tons per year, which results in an average of total suspended solids of around 45 milligrams per liter (mg/l) and a turbidity level of 34 nephelometric turbidity units (NTU) at the water treatment plant. In contrast, under the RES-JUCU scenario, a total of 26,300 tons per year of sediment would flow into the reservoir, 68 percent of which would pass through and flow down to the WTPs. The Jucu watershed downstream of the reservoir would also continue to yield 3,300 tons per year of sediment into the WTPs. This new dynamic would result in a flow of water intake

Figure 5 | Priority Areas for the 1,600 ha of Forest Restoration in Jucu



Source: Authors. See Appendix B for details.

of WTPs with suspended solids of 32 mg/l and turbidity of 23 NTU. Although the new reservoir is primarily planned to store water, it has the added benefit of decreasing turbidity in the water treatment plant by an estimated 34 percent.

However, as the sediments accumulate in the new reservoir, its lifespan decreases. Silting is inherent in the life cycle of reservoirs, and should alter water storage capacity, implying new depreciation accounts and maintenance costs. The depreciation of the fixed capital in the reservoir and all its equipment and constructions, and the provision of resources for silting or dredging containment, would increase the depreciation accounts by up to 7.7 percent over 20 years.

The natural infrastructure would reduce turbidity in 27% beyond what would be possible with the new reservoir

The restoration of 1,600 ha in priority areas (highly degraded pasturelands) would potentially decline the total sediment exported from the landscape to Jucu system waterways by six percent in 20 years, which in turn would further reduce turbidity nine percent beyond the reductions achieved through installing a reservoir alone. Table 8 shows the potential sediment avoidance over 20 years.

Notably, those potential sediment export reductions would continue to grow after the time horizon of this study to as much as 10 percent until year 40. That is because it takes around 40 years for a restored forest in the Atlantic Forest to fully recover its structure, including the Atlantic Forest in southeastern Brazil (Poorter et al. 2016). We assume that erosion control services will develop similarly, beginning in the first year and gradually increasing, but not reaching not entirely reaching full potential until year 40. It is worth noting that many experts believe these maximum erosion control services could be achieved on a faster timeline, and that our assumption here is perhaps too conservative.

SMV would decrease sediments by 1,975 tons per year, and turbidity by 5 percent

We predict that the 900 priority ha for forest restoration with an emphasis on eroded soils are currently responsible for about 31 percent of the sediment production from pastures in the SMV watershed (Figure 6). In the reference scenario REF-SMV, the total sediment exported in the SMV was estimated at approximately 36,000 tons per year, with an average concentration of suspended solids of around 70 mg/l and turbidity of 39 NTU.

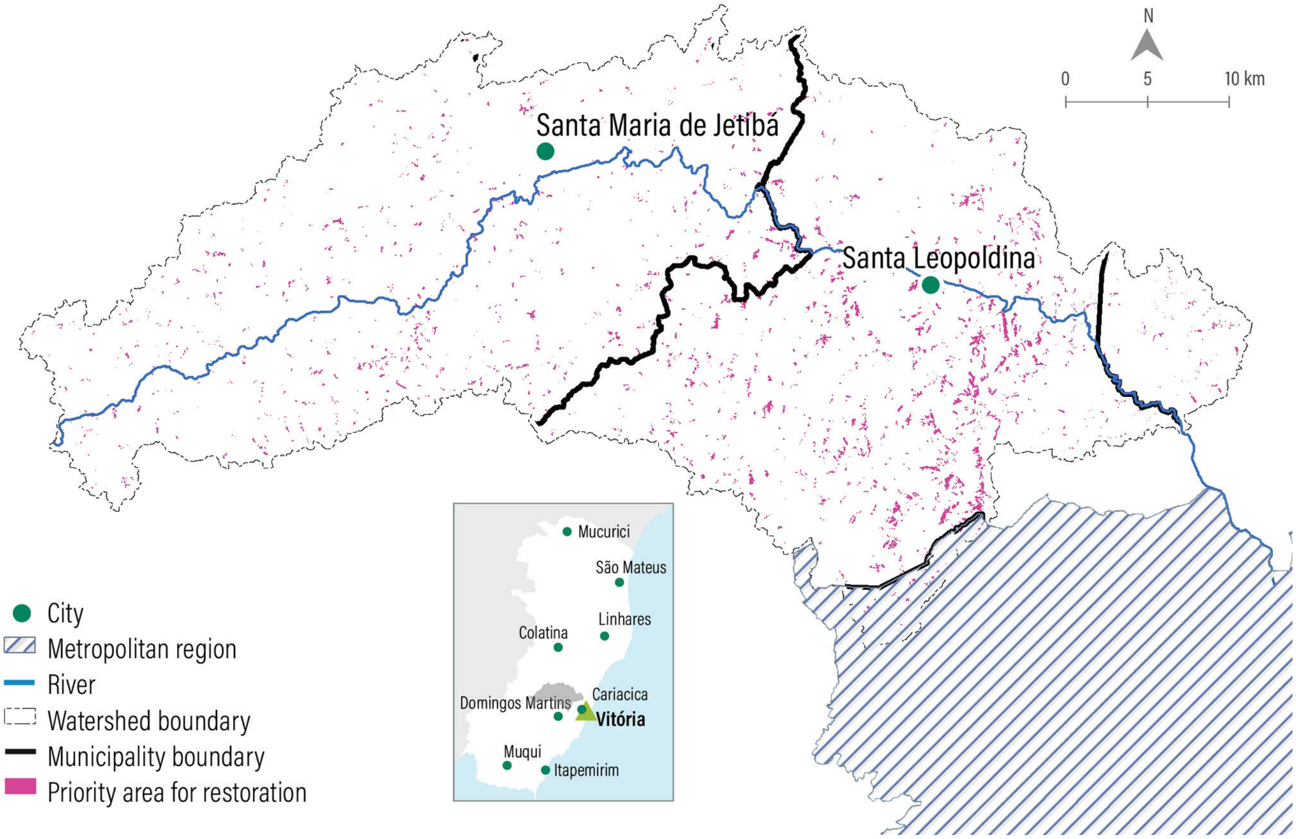
Table 8 | Exported Sediments, Suspended Solids and Turbidity REF JUCU, RES JUCU and JUCU 1600 Portfolios

BIOPHYSICAL OUTPUTS	REF-JUCU	RES-JUCU	JUCU1600	CHANGES (REF JUCU TO JUCU 1600)
Total Exported Sedments in watershed (tons/year)^{a,b}	29,659	29,659	27,871	-6%
Total Sediments in WTPs catchments (tons/year)	29,659	21,232	19,445	-34%
Suspended Solids in WTPs catchments (mg/l)	45	32	29	-36%
Turbidity in WTPs catchments (NTU)	34	23	20	-41%

Source: Authors.
Note: a) Sediment export refers to the amount of sediment the landscape yields and is not impacted by creation of a reservoir. Therefore, the REF-JUCU and RES-JUCU scenarios experience the same rates of sediment export throughout the basin. b) Average sediment exported estimated over 20 years, considering the time lag associated with implementation schedules and the time it takes for the forest to grow and achieve maturity (Details in Appendix C).

With the forest restoration of 900 ha of highly degraded pastures, the export of sediments would decrease to an average of 34,000 tons/year, lowering the concentration of suspended solids to 66 mg/l and turbidity to 37 NTU. The discharge of approximately 40,000 tons of sediment over 20 years could be avoided in the water catchments sites (Table 9).

Figure 6 | Priority Areas for 900 ha of Forest Restoration in SMV



Source: Authors.

Table 9 | Exported Sediments, Suspended Solids and Turbidity in REF SMV and SMV 900 Portfolios

BIOPHYSICAL OUTPUTS	REF SMV	SMV 900	CHANGES (REF SMV TO SMV 900)
Total Exported Sediments in watershed (tons/year) [a,b]	36,000	34,025	-5%
Total Sediments in WTPs catchments (tons/year)	36,000	34,025	-5%
Suspended Solids in WTPs catchments (mg/l)	70	66	-6%
Turbidity in WTPs catchments (NTU)	39	37	-5%

Source: Authors.

Valuation of Costs and Benefits (GGA Step 4)

Green Infrastructure would cost $6.2 million in Jucu and $3.5 in SMV over 20 Years

According to green infrastructure pricing assumptions and consulting Reflorestar Program (Sossai 2020), the full cost of restoring 1,600 ha was estimated to be $6.2 million, with costs mainly incurred during the first three years when restoration investments are made. Similarly, investments in restoration to restore 900 ha in SMV would require $3.5 million.

As previously mentioned, the Reflorestar Program offers one-time transfers to participating farmers, in order to help cover the costs of transitioning their land from pasture to forest. The program transfers $3,030 per ha to farmers for active restoration and $977 for natural regeneration. Additionally, payments for ecosystem services are $80/ha/year for sites restored through active restoration, and $76/ha/year for naturally regenerated sites.

Based on a mapping exercise described in Appendix B, it was determined that two-thirds of JUCU1600 and SMV900 priority areas may need to be restored through assisted restoration (also known as planting) due to their remoteness from standing forest seed stocks. The remaining third, however, was close enough to standing forests to allow for natural regeneration.

The program also issues PES to participating farmers annually in order to help compensate them for opportunity costs of transitioning their land from productive pasture to natural forest. Transaction costs, such as cost of recruiting and enrolling landowners, monitoring of results, and general program administration must also be considered. They are estimated to be about just one percent of total green infrastructure costs in similar sites in Brazil (Ozment et al. 2018; Feltran-Barbieri 2018).

Considering the needed up-front investments, operations and maintenance, opportunity costs and transactions costs, assisted restoration would cost approximately $5,552/ha while natural regeneration $2,993/ha. These are average values due to forest restoration being implemented over three years, those implemented in the first year, the costs of opportunity and transaction focused for 20 years while in the areas implemented in the third year, such values would apply for 18 years.

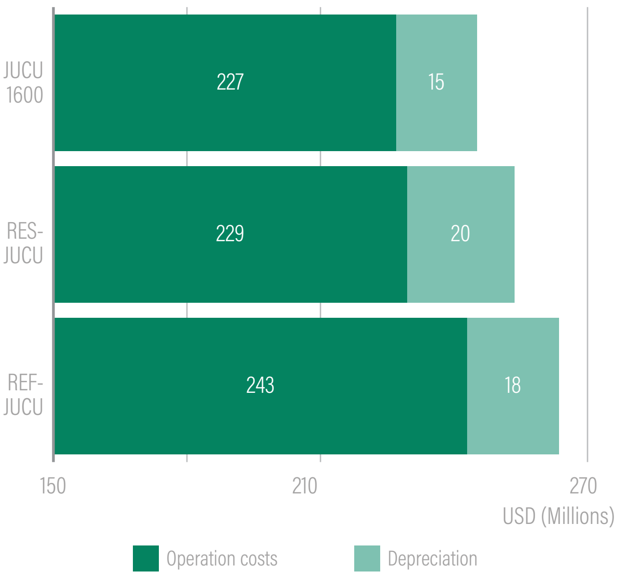
Comparing Costs and Benefits Across Portfolios (GGA Step 5)

Restoration could significantly reduce water treatment costs in the Jucu and SMV

Estimated costs of water turbidity treatment for the three scenarios show that the new reservoir itself (RES-JUCU) would save $13.8 million in water treatment costs. This is because the reservoir works as a sediment-holding tank and thereby reduces total suspended solids flowing to the water treatment plant. On the other hand, reservoir siltation, losses of storage capacity would add $1.4 million over 20 years. Pairing this new reservoir with targeted restoration as natural infrastructure (JUCU1600), the cost savings on water turbidity treatment would rise significantly to $15.7 million and the avoided depreciation of capital (wear of equipment, storage capacity and reservoir siltation)could reach as high as $3 million. Therefore, the total savings would total $18.7 million compared with the baseline (REF-JUCU) or additional $6.3 million on RES-JUCU.

Along the 20-year timeframe, we estimate that the average demand for treated water will be 3.4 billion m^3 of water per second (4.6 m^3/s at the beginning of the project and 6.0 m^3/s in the last year), with a total consumption of 111,000 tons of chemical products in order to treat turbidity (Polyaluminium Chloride, Aluminum Sulphate, lime, and slaked lime). It means an average consumption of 32.6g/ m^3 of chemical products against the current 33.3g/ m^3, corresponding to an economy a savings of 2,400 tons. For the pumping and filtering systems, in which efficiency depends on the density of the treated water (Pagiola 2020), the energy consumption would drop from the current 139 MWh/thousands m^3 to an average of 135 MWh/thousands m^3, generating a saving of 13.5 GWh in 20 years (details in Appendix C).

Figure 7 | Water treatment Costs and Savings (USD Millions) in 20 Years



Source: Authors.

These findings clearly show that natural infrastructure could work as an ancillary structure that boosts gray infrastructure’s efficiency in controlling sediment and enhancing water quality in the Jucu Watershed. The strategy of building a reservoir to increase water security and restoring forests to control sediment, not only simultaneously addresses the two main issues in water management but is also a better design in terms of finance.

There are likely other means of cost savings. Reduced siltation in the reservoir, for example, will lead to improved water storage capacity and/or lower reservoir dredging costs over time. Wear on equipment and depreciation rates are also slightly reduced, due to water that is less abrasive and with fewer suspended solids than in the reference scenario.

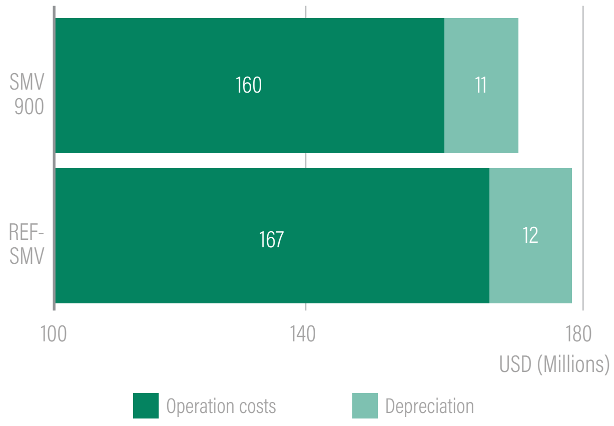
The JUCU1600 portfolio has a total cost of $6.2 million, but net benefits of $18.7 million at current values. Considering a 20-year time horizon with a discount rate of 8.5 percent per year, JUCU1600 generates an NPV of $2.8 million and an IRR of 15.2 percent. Our results show that it would be costlier in the long run to install a new water supply reservoir without reforesting the watershed. On the other hand, combining green and gray infrastructure produces optimal financial results.

Restoration can significantly reduce the consumption of chemicals and energy in the SMV

Current consumption estimated at 38.2 g/m^3 of chemicals would drop to 34.5g m^3 of treated water while energy consumption would go from the current 157 MWh/thousand m^3 to 154 MWh, resulting in savings of 1,000 tons of chemicals and 6 GWh, since the volume of treated water in the 20-year period was estimated at 2.1 billion m^3 (treatment of 2.8 m^3/s at the beginning of the project and 3.7 m^3/s at the end of the 20 years).

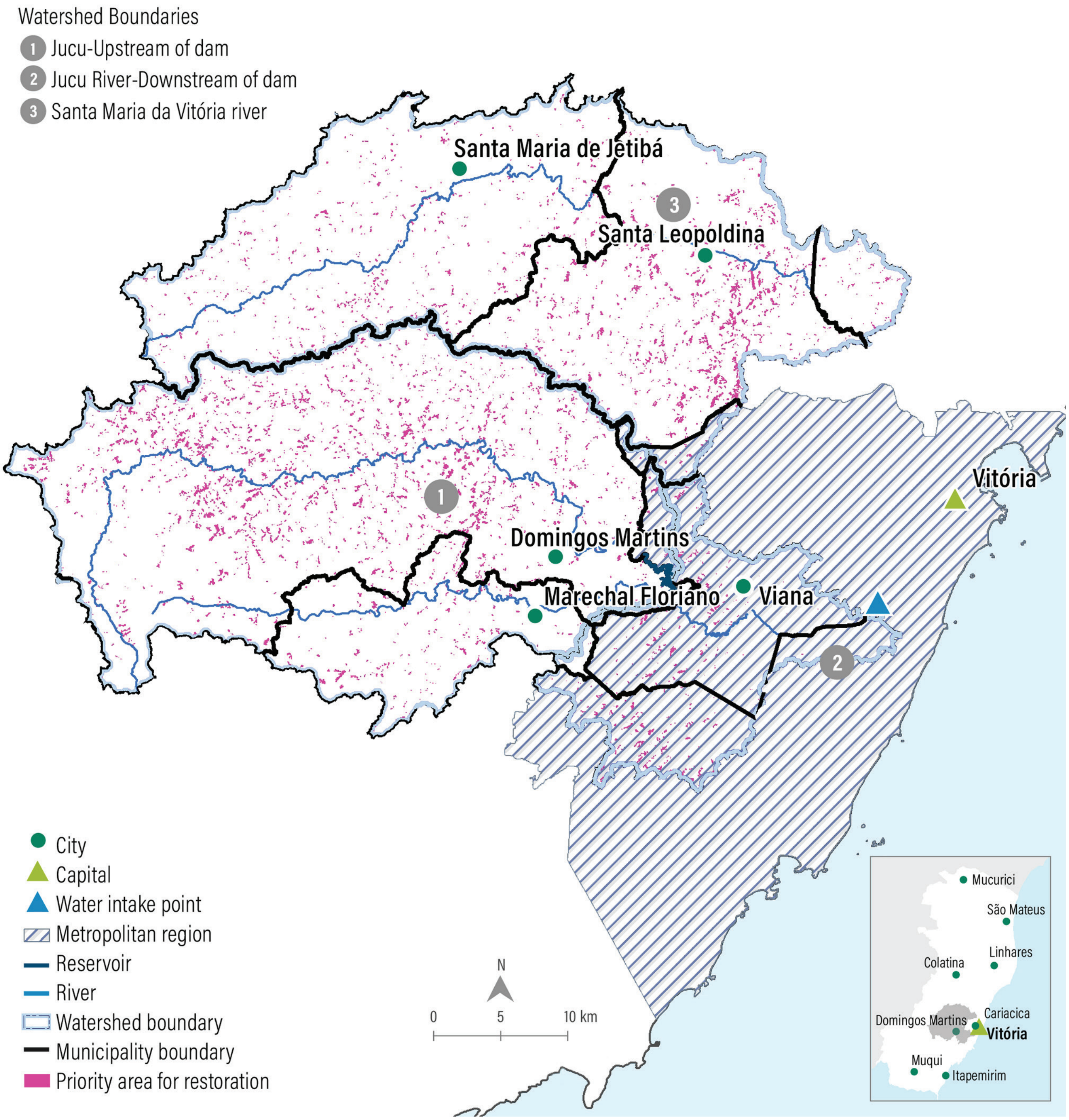
Although at first glance a modest change, there is significant reduced use of chemicals and energy. During this period, forest restoration would account for $7.7 million in savings in terms of avoided costs for treatment of turbidity. Such costs would include use of chemical products, replacement of filter elements, and electricity. There would also be less wear and tear on equipment due to the proportional drop in water abrasiveness. Forest restoration would require investments and project maintenance costs in the order of $3.5 million, generating net benefits of $4.2 million in 20 years.

Figure 8 | Water Treatment Costs and Savings (USD Millions) in 20 Years



Source: Authors.

Figure 9 | Priority areas for restoration at UGRH-LC (LC2500 scenario)



Source: Authors.

The Benefits for the Entire UGRH-LC

Efforts to promote restoration across the Jucu and SMV are underway, such as in the Integrated Water and Landscape Management Program, the Reflorestar Program, the State Water Resources Plan, and the Forests for Life Project. Coordinated restoration across these watersheds are important so that the greatest number of residents of the RMGV can benefit. Initiatives that focus on joint actions can optimize the pace of restoration imposed by various respective committees and budgetary constraints of each watershed committee.

It is known that forest restoration carried out in two or more watersheds simultaneously may result in economy of scale and multiple additional benefits due to cascading effects (Rugani et al. 2019). However, here we considered the benefits of the entire UGRH-LC would correspond as simple as the sum of ones that could be achieved in Jucu and SMV. The overview of the UGRH-LC results is important for the RMGV community and managers of plans, programs, and projects can better understand the concomitant impacts of the interventions.

It is noted that the distribution of the 2,500 priority ha for restoration (1600 ha in Jucu and 900 ha in SMV) is relatively homogeneous over the landscape, signaling that the actions within the UGRH-LC could be coordinated specially along the limits of its administrative divisions. It also draws attention to the concentration of priority areas in the eastern portions of the two watersheds, figuring a priority belt around the urban area of the RMGV, which could form a restoration arch. This arch would have as points of reference the Juara riverbank in the extreme north, following west to Mangaraí, São Paulo de Cima, Biricas de Baixo, Glória and, closing to the south, the Rio Calçado region.

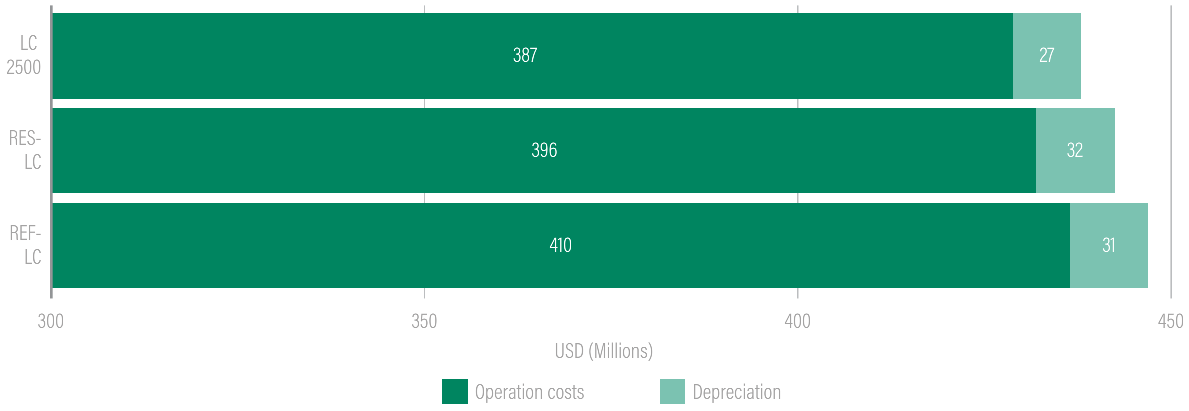
Considering the restoration costs according to the reference values of the Reflorestar Program, adding PES to be disbursed annually to compensate for land opportunity and transaction costs, the total cost of the natural infrastructure project (LC2500) would total $9.7 million, which corresponds to a little more than 10 percent of the budget provided by the Forests for Life Project to the component destined for the recovery of headwaters, riparian forests and water recharge areas. $5.9 million would be disbursed in the first three years to implement the restoration, while approximately $44 million would be destined to sustain PES over the other next 17 years.

The natural infrastructure attained in the restoration of the 2,500 ha would avoid the use of 35,000 tons of chemical products (PAC, Aluminum Sulphate, lime and slaked lime), besides saving 19.5 GWh of electric energy. The avoided costs with turbidity treatment (chemical products, filtering, and sludge disposal) would add up to $5.7 million, the depreciation avoided by fixed capital (including the Jucu Reservoir) and reduced equipment wear were estimated at $4 million. Energy savings corresponds to another $16.9 million, totaling benefits of $26.4 million over 20 years.

There is a great imbalance throughout the project not only because the initial three years to absorb more than 60 percent of the entire cost, due to the implementation of the restoration, but also because the restored forest takes 40 to 50 years to acquire structure capable of providing all its sediment retention potential (see Appendix C). The expected mismatch between cash inflows and outflows means that benefits are more heavily penalized by cash flow discount rates. Still, the natural infrastructure at LC2500 would generate a NPV of $3.2 million at a discount rate of 8.5 percent and IRR of 13.9 percent, comparable with investments in conventional structures (CESAN 2020). The natural infrastructure project is viable and should be considered in the plans and programs for water safety and quality improvement for all the population of the RMGV.

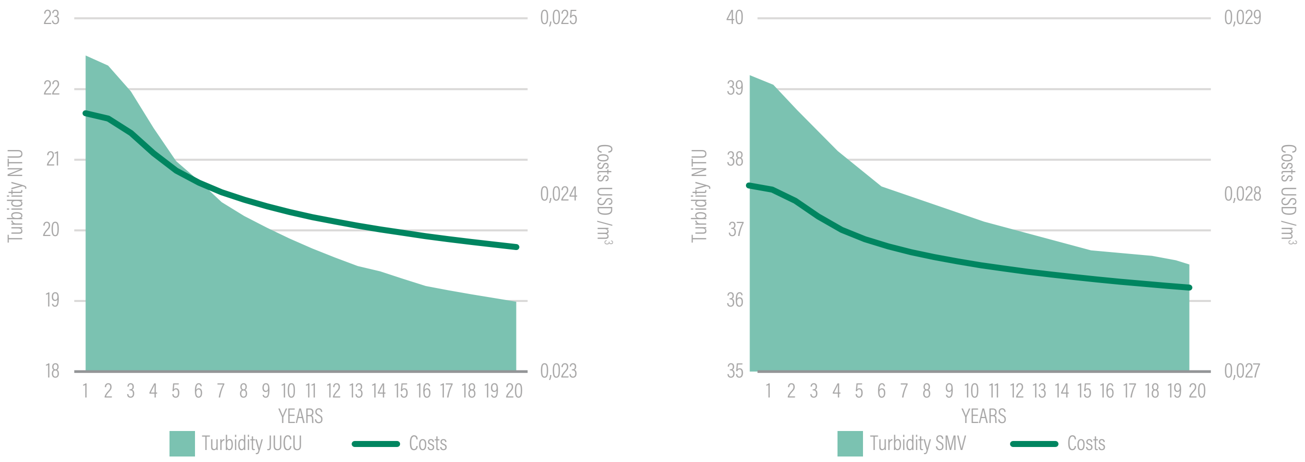
Figure 10 | Performance Panel of LC2500 Scenario

Graph A | Water Treatment Costs by Cost Group and Scenario

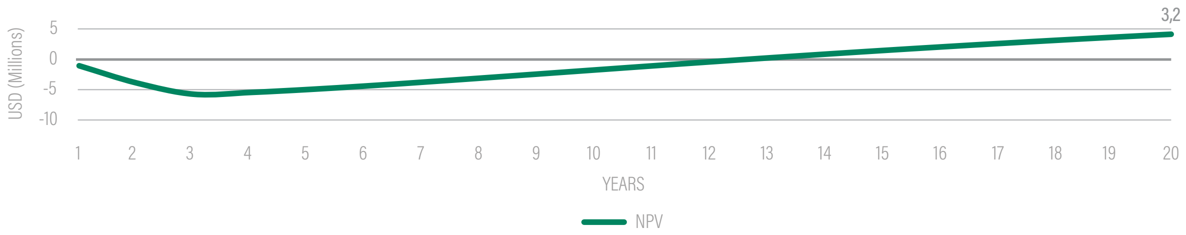


Graph B | Turbidity (UTN) and Costs (USD/m³) in the Jucu Watershed

Graph C | Turbidity (UTN) and Costs (USD/m³) in the SMV Watershed



Graph D | Net Present Value (USD Millions) for the LC2500 scenario over 20 years



Source: Authors.

CHAPTER 3

SENSITIVITY ANALYSIS

This natural infrastructure is viable in both Jucu and SMV, and therefore for UGRH-LC. However, it is essential to carry out a sensitivity analysis, seeking to evaluate the financial effectiveness of the restoration portfolios and identify the main variables to be managed according to risks of oversizing benefits. This section outlines step six of the GGA and highlights important finding on variables that may affect financial performance of natural infrastructure.

Sensitivity analysis is discussed only for the LC2500 portfolio because it reflects the results that could benefit the entire RMGV. Further, because this portfolio itself results from the combination ofcosts and benefits of concomitant interventions in the two watersheds. Sensitivity tests were performed simultaneously in Jucu and SMV, obtaining partial results for incorporation into the final results of LC2500. Each of the following sections addresses a risk factor, considered relevant by stakeholders during project consultations (described in Chapter 1).

Analyzing Risks (GGA Step 6)

Evaluating the Strategic Focus and Business Case for Investment

There are uncertainties regarding restoration costs. For example, the total cost of restoring forests in southeast Brazil may be less than $2,800 or as high as $8,500 (Benini and Adeodato 2017). The costs used in this study are based on the Reflorestar Program's historic costs, which coincidentally hit the average of these aforementioned figures. How would the project be impacted if the active restoration costs were altered? The sensitivity analysis shows that this variability in green infrastructure costs does not present serious financial risk to the project. Even with these higher costs, the project would still have a positive NPV (and therefore be financially viable). On the other hand, if restoration costs are on the lower end of what is reported in existing literature, the project's NPV would increase from $3.2 million to $5.4 million, with an anticipated payback in 2.5 years.

Natural Infrastructure Performance

Performance of natural infrastructure for sediment control greatly depends on biophysical characteristics and landscape management. In addition, there exist inherent uncertainties in the models used in measuring for sediment control. Using the InVEST model, the most frequent final output is an estimated 5 percent of sediments retained in the LC2500. Extreme outputs varied from 3 to 8 percent. The 5 percent figure is normal-distribution with positive skew as determined by the InVEST equations). These variations vary from the main analysis in the previous sections. The figures demonstrate financial performance of restored forests by different growth or sediment retention capacity. In Table 11, we estimated the economic implications of those extreme results.

This analysis shows that the project is highly sensitive to the forest sediment retention capacity. Under minimum normal sediment retention capacity, the project would have a negative NPV of $900,000 and an ROI in 46 years. These results could reflect, for example, unexpectedly dry conditions, greater frequency of fire, or use of lowquality seedlings. This would result in a higher mortality rate, slowing forest growth. Uncontrollable conditions – such as greater erosivity and natural soil erodibility, for example – could also explain lower performance, and should be considered in the decision-making process prior to restoration implementation.

Table 10 | LC 2500 Financial Performance under Restoration Cost Variations

IMPLEMENTATION FACTORS (REGULAR DISCOUNT RATE = 8.5%)		IRR (%)	PAYBACK (YEARS)	NPV (USD, MILLIONS)
LC2500 - Benchmark	Restoration Cost of $3,030 per ha	14	12	3.2
Cost of restoration is 50% higher	Active restoration costs at the maximum found in literature on the Atlantic Forest (Benini and Adeodato 2017)	11	14	0.9
Cost of restoration is 48% lower	Active restoration costs at the minimum found in literature on the Atlantic Forest (Benini and Adeodato 2017)	18	10	5.4

Source: Authors.

Table 11 | LC 2500 Financial Performance under Sediment Retention Variations

BIOPHYSICAL FACTORS (REGULAR DISCOUNT RATE = 8.5%)		IRR (%)	PAYBACK (YEARS)	NPV (USD, MILLIONS)
LC2500 – Benchmark	8% of sediments are retained	14	12	3.2
Sediment retention is 50% lower than the benchmark	3% of sediments are retained	2	46	-0.9
Sediment retention is 33% higher than the benchmark	8% of sediments are retained	26	7	9.0

Source: Authors.

On the other hand, if the retention capacity is higher than that considered in the main analyses, the NPV would jump to $9 million, with an ROI reached in seven years. Such a scenario could be achieved by a favorable climate and better and more resistant seedlings, as well as greater participation of the owners in isolation of the area, greater influence of pollinators and seed dispersers. Another factor would be a more effective response to the impact of root systems on erosion retention.

An important need is early investment in comprehensive monitoring. Such monitoring can ensure that the financial risk posed by scientific uncertainty can be adaptively managed throughout the project duration. Seasonal variation in hydrology and erosion requires well-designed monitoring systems. Monitoring and evaluating of natural infrastructure not only provide opportunities to adaptively manage the project, but also contribute to the growing body of evidence that can help set realistic expectations for other project sites.

Creation of a project monitoring plan could increase confidence in natural infrastructure performance. However, a long-term view must be taken, because as Chapter 2 discussed, results may take several years to emerge. Stakeholders expressed much interest in developing a monitoring system collaboratively and mobilizing partners to coordinate execution across organizations.

Engaging Landowners

Many stakeholders question if the incentives are strong enough to encourage landowners to participate in the Reflorestar Program or similar efforts, and whether the program could incorporate design elements that better meet landowner needs and interests.

Currently, the Reflorestar Program pays $76–80/ha annually to participate. These figures are used as a proxy for the opportunity cost. Based on limited local interviews, however, we estimate that the revenue generated from cattle on the same land would be closer to $120 per year—about 35 percent higher than the payment offered by Reflorestar. Based on our limited evidence and the perspective of stakeholders consulted, it appears a higher incentive, or a package of monetary and non-monetary incentives, may pique the interest of more landowners.

Similarly, the Reflorestar Program does not pay for labor, as farmer participation is meant to be a co-investment of time and effort. For this reason, this cost was not covered by the main analysis. However, workforce costs could be included as an opportunity cost of labor that impact a farmer's decisions and willingness to be engaged in the program. We consider that the implantation of 1 ha would cost on average $1,023, with the hiring of 3 workers in 12 days at $ 28.40. By including labor costs in the analysis, the NPV falls short by $570,000 compared to the figure obtained by the variation in the opportunity cost of land, and the payback period is extended by four years. Even so, implementing the natural infrastructure would be a good deal. NPV drops and the payback period is extended by two years, but it is still positive.

The Reflorestar Program expects restoration of 2500 ha to take three years. That timeline, however, could be accelerated. Table 12 shows that if the project were implemented in one year instead of three, NPV would reach $3.7 million. However, less aggressive actions, such as execution of the restoration project in 10 years, at 250 ha/year, would result in NPV of $ 1.7 million. The implementation schedule has a high impact on the project's financial performance; the faster the project is implemented, the greater the benefits over a 20-year horizon.

Financing and Funding Sources

Diversifying funding sources and combining resources from multiple groups may also be beneficial for landowner engagement in the Jucu and SMV, as well as for enhancing the overall financial performance of the project.

Stakeholders expressed a concern that funds provided by the government may be affected by elections. Similarly, the basin committees do not yet have access to the necessary funds to carry out these plans. By law, the committees should receive funds through a water use charge placed on all water users; however, the watershed committees have yet to enact such a charge. The involvement of CESAN in the program may quell these concerns and help overcome these challenges.

The benchmark scenario models the project's performance with the water company as sole investor (using an 8.5 percent discount rate, which is the water company's weighted average cost of capital). However, the water company is not currently investing in green infrastructure. All project costs are expected to be incurred by the government-run Reflorestar Program, fully paid through FUNDÁGUA.

We varied the discount rate to address different perspectives of costs of capital. While our benchmark discount rate was 8.5 percent, we considered a "low-risk scenario" of 5 percent, and a "high-risk scenario" at 12 percent which includes Brazilian Risk Premium. Further information on definition and selection of these discount rates and more information on the sensitivity analysis is provided in Appendix C.

LC2500 scenario shows a moderate sensitivity to the intrinsic risk represented in discount rates. Under a scenario with higher risks and/or more investor capital present, represented by a discount rate of 12 percent, the project's financial performance is weaker but still viable with a 14-year payback.

The IDB and World Bank have recommended a 12 percent discount rate for Brazilian water sector investments.

Table 12 | LC 2500 Financial Performance under Other Cost Variations

IMPLEMENTATION FACTORS (REGULAR DISCOUNT RATE = 8.5%)		IRR (%)	PAYBACK (YEARS)	NPV (USD, MILLIONS)
LC2500 – Benchmark	No labor costs included	14	12	3.2
PES covers pasture rental price $120/ha/year	Assumes the Reflorestar Program's PES cost equivalent to the pasture rental prices incurred by participating farmers	10	13	2.2
Labor costs included	Opportunity cost of labor is $1,023/ha during the implementation of project. It includes the labor of 3 workers from 12 days to implement the active (complete) restoration	9	17	1.6

Source: Authors.

Under a hypothetical scenario with lower risks and/or more philanthropic capital present, or under a scenario with greater investor appreciation and recognition of non-economic benefits, such as a higher share of impact investment capital or investments capitalized by green bonds, represented by a 5 percent discount rate, the return is achieved almost a year and a half earlier compared to the baseline scenario.

One can also imagine scenarios where the state government and water company enter into a partnership to fund the project. Table 3.4 presents one such scenario, wherein the Reflorestar Program covers 20 percent of project costs and assumes a 5 percent discount rate, while CESAN covers 80 percent of the project costs assuming its standard 8.5 percent. The financial performance of this scenario is slightly better than the benchmark scenario, suggesting that this type of partnership could indeed be advantageous to both parties.

Table 13 | LC 2500 Financial Performance under Other Cost Variations

INVESTOR RISK-REWARD AND FINANCING OPTIONS		IRR (%)	PAYBACK (YEARS)	NPV (USD, MILLIONS)
LC2500 - Benchmark	Discount Rate of 8.5%	14	12	3.2
Social discount rate 5%	Lower discount rate accepted by impact investments, social discount rate for less risk-averse investors, or investors with longer time horizon	14	10	6.8
Discount rate 12%	This discount rate would be applied by many water-sector investors such as IDB, World Bank, and others	14	14	0.9
Cost-share/co-investment scenario	WACC is 7.8%, assuming that Reflorestar Program covers 20% of capital under Social Discount rate (5%) and 80% under CESAN's Discount Rate of 8.5%	14	12	2.6

Source: Authors.

Additional Financing and Funding Sources

Stakeholders pointed out that the mechanisms that enable financial flows at scale must still be activated. While FUNDÁGUA (mentioned in Chapter 1) has been a critical foundation to enable landscape restoration, stakeholders are seeking to diversify their funding sources to ensure consistent and long-term financial sustainability. Stakeholders pointed out the following potential funding sources:

- **Water charge:** A charge for water use is legally required by federal law but it has not been enacted in Espírito Santo's basin committees, despite 10 years of discussion. Passing this water charge is fundamental for the basin committees' contributions to natural infrastructure programs and creation of sustained funding sources for program sustainability.
- **Environmental compensation**: Companies that destroy natural habitat are legally required by law to restore native habitat on double the land area. As discussed in Appendix B, we estimated that the creation of a new water supply reservoir would inundate 60.5 ha of native forests, thereby requiring restoration of 121 ha of native forest, which could be routed towards the priority areas identified in Chapter 2. Growing tourism in the Jucu (resulting from the creation of the new lake) could also be a source of environmental compensation funds. Despite these opportunities, environmental groups throughout Brazil have criticized Brazil's environmental compensation law for being opaque regarding the use of funds raised through compensation.
- **Water sector investment:** This study raised another possibility for financing natural infrastructure, demonstrating that CESAN could potentially achieve a decent ROI in targeted forest restoration when combined with built infrastructure investments. However, the lack of local information on natural infrastructure performance could impede water sector investments.
- **Impact investments**: There is a growing concern from investors in quality infrastructure that is more resilient to climate change and, therefore, less vulnerable to idleness or climate. Poor estimation of future availability of water resources implies serious risk of idleness of operations or an increase in operating costs, as well as extreme events affect the emergency costs of control and remediation, such as those caused by prolonged droughts or torrential rains. Impact investors are interested in infrastructure designed to deal with these contingencies and, at the same time, provide positive externalities such as "carbon neutral", biodiversity protection, etc. Such investors see beyond conventional rates of return. Natural infrastructure for water is the right investment for this impact investor profile and resources capped by green bonds.
- **Sharing risks over time:** a combination of different types of investors throughout the project is an arrangement more common. Impact investors associated with public investors may take greater risk imputed by the steps of project implementation, compensating them for higher returns throughout the consolidation of the provision of ecosystem services, since natural infrastructure is appreciated as the project matures while conventional infrastructure depreciates. Thus, the risk is offset in rates of appreciation.

CONCLUSION

The natural infrastructure – forest restoration – improves the water quality in the Jucu and Santa Maria da Vitória watersheds, and enhances the performance of grey infrastructure, in an economically viable way. It is necessary to strengthen the governance and seek convergence of restoration objectives forestry and water resources management aiming to increase fundraising and implement the natural infrastructure.

This report has shown that combining green and gray infrastructure could be cost-effective for managing sediment pollution. The local water utility, CESAN, could financially benefit from investing in natural infrastructure strategies, and the Jucu-Santa Maria Watershed Committees could also more cost-effectively achieve their objectives. The Reflorestar Program could be a key agent of natural infrastructure development. As Reflorestar helps farmers to restore degraded pasturelands and reforest the region, it has the potential to converge its main objectives with the mitigation of the water crisis in Espírito Santo, helping the public and private investors to improve water quality and safeguard infrastructure assets.

This report also serves as a foundation for deeper analysis of the effectiveness of natural infrastructure strategies in achieving water management objectives. It provides the best available data needed to estimate natural infrastructure costs and benefits in a water management context for southeast Brazil, while also providing an assessment of data collection needs going forward.

However, this report also illustrates that while the business case for investing in natural infrastructure is strong in theory, these investment opportunities have not been realized for several reasons. Some examples are uncertainty regarding landowners' willingness to participate and lack of a coordinated and robust financing plan. All of these gaps can be addressed through closer collaboration of local stakeholders, strengthening of partnerships, and design of natural infrastructure interventions to address these challenges.

Uses for this Analysis in Local Decision-Making

Water resource stakeholders in the Jucu and SMV, and the entire UGRH-LC can utilize and build on these findings as they develop their water management strategies. As natural infrastructure programs mature and seek financial sustainability to secure their efforts into the future, they face a choice of how they want to proceed: At what scale will they operate? Which investors will they target? Will successes be achieved independently or collectively? Which interventions will they prioritize? This study provides the biophysical and financial analysis to improve decision-making on these questions.

Our study shows that natural infrastructure investments should be able to meet the investment requirements of CESAN and other water sector investors, if a watershed-scale approach is adopted by stakeholders. But first, this business case must be communicated to water sector actors and other potential program investors, and possibly supplemented with additional analysis to meet their needs and interests. The proposed natural infrastructure strategies and elements of the roadmap presented in this report must still be considered, reworked, and adopted by stakeholders. As a first step, we invite stakeholders to review this report together in detail, critique it, and discuss how to apply it to immediate decisions.

The population of Espírito Santo has the opportunity to meet their water management needs through partnerships with farmers and rural land managers. At the same time, rural development and environmental practitioners such as those involved in the Reflorestar Program should refine their strategies to efficiently deliver natural infrastructure objectives at scale, addressing some of the program design elements highlighted in this report.

Regulatory agencies need to recognize the relevance of natural infrastructure as a complementary strategy to the structures of conventional engineering, allowing the sanitation companies and watershed committees to include their spending on environmental restoration as investments - as they should be - and not costs, as they currently are.

Expanding and Replicating the Analysis

Stakeholders noted that program design has a major impact on the strength of natural infrastructure's business case for investors. The hypothetical program activities, costs, and intended benefits presented in this report are rather narrow, focusing strictly on restoration of native forest, water quality benefits, and avoided costs to the local water utility. Future follow-up studies to this report could examine additional green-gray infrastructure scenarios and benefits, to further strengthen the business case. For example:

1. **Expanded green infrastructure practices.** Green infrastructure can take many forms, such as silvopastoral systems, vegetation strips, streambank stabilization, Low Carbon Agriculture and Better Practices in Agriculture (improved pasture, etc.). These expanded practices would need to be selected based on their abilities to produce natural infrastructure benefits as well as their feasibility and compliance with the guidelines for land use and occupation in the project territory provided for in the Strategic Plan for the Development of Agriculture in Espírito Santo (Espírito Santo Government 2016). The assessment to identify restoration opportunities (ROAM) in the Espírito Santo State is also an important support tool to the expansion of these infrastructure models (SEAMA 2017).
2. **Natural infrastructure to boost dry season water availability.** Although scientific reports are not yet sufficient to determine whether restoration in the Atlantic Forest can increase water availability already in the short term, new studies are collecting data on the capacity of high-altitude coastal forests to capture mist as an additional source of water entry into the landscape. Also, AGERH, , in partnership with the Federal University, is currently mapping water recharge areas in the state in order to promote greater water security. These new studies could provide new research

inputs for a green-gray Assessment focused on evaluating natural infrastructure's role in providing water supply seasonally and over longer time periods.

3. **Natural infrastructure to reduce flood risk.** Global studies have consistently found that upland forest restoration can help reduce the impacts of small and medium floods. Flooding has been a challenge in this region. A follow-up study identifying priority natural infrastructure areas and interventions to reduce flood risk in the UGRH-LC could provide an additional rationale for green infrastructure efforts in this region, in addition to the investments already foreseen in PERH-ES, Water and Landscape Integrated Management Program and other plans already mentioned in this document.

4. **On-farm productivity boosts and income generation.** Income generation opportunities and profitability of forest restoration could be further researched and incorporated into program design and evaluation. Natural infrastructure investments can be designed to enhance pastureland productivity and farmer net income through Crop-Livestock-Forest Integration, as well as agroforestry or silvopastoral systems.

5. **Fostering public policies that integrate natural infrastructure agendas and water resources policy instruments.** Natural infrastructure is an efficient instrument that addresses via conservation and planting several issues in land planning and management, including Forest Code compliance, Economic-Ecological Zoning and Watershed Planning, mainly through specific laws such as the "Water Resources Compensation" instruments provided for in Law 10,179/14.

6. **Expand the understanding of impacts of natural infrastructure.** It is known that the treatment of water turbidity is among the lowest costs incurred in the water sanitation, and that the financial impact is larger considering algae control and disinfection. On the other hand, these same problems are associated with carrying of sediments, often rich in nutrients, hormones, pesticides and fecal coliforms. The report shows that the natural infrastructure would pay for itself considering only the treatment of turbidity. Much greater benefits can be expected in improving the quality of widely measured water, although there is a need to improve the methods for this type of assessment.

APPENDIX

This document details the methods used in a series of three case studies on Natural Infrastructure for Water in the Brazil, namely:

- ☐ **Case 1:** Natural Infrastructure in São Paulo's Water System
- ☐ **Case 2:** Natural Infrastructure in Rio de Janeiro's Water System
- ■ **Case 3**: Natural Infrastructure in Vitoria's Water system, Espírito Santo State

As it is a series of cases that share much of the documentation and methods, this appendix presents information specifically used in the Case 3. General information about project scope, data collection and methods used in biophysical and financial analyzes common to three cases can be found in the Case 1 Appendix.

1: Natural Infrastructure in São Paulo's Water System, which gave origin of the series, available at https://www.wri.org/publication/naturalinfrastructuresaopaulo.

APPENDIX A. METHOD OF STAKEHOLDER CONSULTATION AND ROADMAP DEVELOPMENT

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

Our partners and key stakeholders in the area expressed interest in developing an action plan to advance natural infrastructure strategies in the Jucu and throughout the state of Espírito Santo. To this end, we conducted a line of inquiry that adapted the framework presented in Ozment et al. (2016) to identify key success factors and approaches to establish and grow successful watershed investment programs. Because the framework presented in Ozment et al. (2016) was based on U.S. research, we worked with stakeholders to review the list of 10 factors and confirmed the relevance of these factors in the Brazilian local context prior to application.

To apply the framework, we consulted stakeholders in three ways:

Workshop in Vitória. A workshop was held on November 18, 2016 to collect high-level input. Forty people participated. Discussions to inform this research included status of green-gray infrastructure in the Jucu Basin, data sources to evaluate natural infrastructure, and identification of relevant natural infrastructure initiatives and opportunities to collaborate.

Written and Oral Survey. The survey was conducted by email between October and December 2017, to collect data and perspectives on which success factors deserve the most immediate attention in the Jucu Basin. Written survey and interview questions were directly based on the questionnaire used in Ozment et al. (2018). The survey was sent to 21 stakeholders who were either water managers or directly involved in executing natural infrastructure programs in the region. Nine people responded to this survey: three through in-person interviews, and six in writing. Between August and December 2020, video calls were made with representatives of the Jucu and SMV basin committees, staff from AGERH, SEAMA, IEMA, and the World Bank to update relevant data and information.

Review of Program Documents. The document review primarily focused on studies and program documents that described natural infrastructure efforts in the Jucu Basin. We synthesized this literature to gain a better understanding of the most important sources of funding, the main leaders and stakeholders involved, current investments, key risks and concerns, and other key features.

Study Review. Participating institutions representing stakeholders were invited to review the content of this report. Six of them agreed to be formal reviewers (identified on the back cover of this report) and six others preferred to review the report in a more informal capacity. All contributions were considered and, to the extent relevant, incorporated into the final content.

The results of this inquiry must be further socialized and tested among key stakeholders, especially by water sector decision makers. Of the stakeholders consulted through surveys or interviews 44 percent represented NGOs or foundations, 44 percent were state government officials, and 12 percent were from the water sector. While members of the water, environmental, and agriculture sectors participated in the survey, the sample size was quite small. The stakeholders who participated in surveys, interviews, or workshops to contribute to this research are listed in Table A1. To ensure the utility and relevance of the proposed action plan, draft recommendations were shared with the project partners and heavily revised on two occasions. The first was held in December 2018 and the second in December 2020.

Table A1 | Local Stakeholders Who Contributed to this Research Area

NAME	ORGANIZATION
Aladim Cerqueira	SEAMA
Robson Monteiro	SEAMA
Marcos Sossai	SEAMA/Programa Reflorestar
José de Aquino	SEAMA/UFES
Fabio Ahnert	AGERH
Paulo Paim	AGERH
Anselmo Tozi	AGERH
Antônio de Oliveira Junior	AGERH
Aline Serau	AGERH
Fabricio Zanzarini	IDAF
Ahnaiá Silva	IDAF
Aline Nunes Garcia	FUNDÁGUA
Maria Aparecida dos Santos Chiesa	CERH
Edmilson Teixeira	UFES
Bruno Peterle Vaneli	UFES
Karla Libardi	UFES
Fernando Aquinoga de Mello	Instituto Aplysia
Robson Melo	Instituto Aplysia
Tatiana Heid Furley	Instituto Aplysia
Emerson Espíndula	Vale
George Hilton Venturim	Prefeitura Municipal de Domingos Martins
Alisson Lopes	IBIO
Eduardo Figueiredo	IBIO
Edimar Binotti Jr	Instituto Lorentzen
Murilo Pedroni	FAES
Vanessa Girão	TNC
Carlos Aurélio Linhalis	CESAN
Elza Abreu	CESAN
André Sefione	CESAN
Andreia Neves	CESAN
Stefano Pagiola	World Bank

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 Jucu Basin Green-Gray Assessment (GGA).

Spatial Analysis of New Reservoir Location and Impact

We simulated the dam location and reservoir size to calculate investment portfolios for GGA Step 2. To map the location and flood area of the planned water supply reservoir on the Jucu River, we simulated the flood area using the reservoir location and available satellite imagery in association with the Digital Elevation Model (DEM) data in ArcGIS. The simulation resulted in a reservoir with a storage capacity of 20 million m^3 and a flooded area of 151 hectares, of which 65 ha is currently covered by native vegetation. This volume is largely consistent with the publicly reported proposed project specifications (Scalzer 2016).

General flowchart to run biophysical models

The GGA, used to estimate the potential water quality impact, is conducted based on several steps. The general flowchart in Figure B0 shows the required steps to run the analysis.

Step 1. Data collection

Data collection of input data required to run the biophysical model. The required data are: Land use/land cover, rainfall, soil map, and elevation (interpolation from the contour lines and quoted point).

Step 2. Data preparation

Preparation of input data: the data need to be cropped to the same image size and projected into the same coordinate system. The vector layer field and parameters of the biophysical table need to be standardized.

Step 3. Preparation and execution of the biophysical model

Run the Sediment Delivery Ratio (SDR) using the data prepared and organized in the previous step using the standardized parameters.

Step 4. Model calibration

Model calibration is a step designed to adjust the output generated by the biophysical model to actual observed data. CESAN provided data on suspended solids from the Jucu and SMV watersheds. The data included 24 observations, 12 for each basin, representing monthly average of suspended solids for the year 2016.

Step 5. Set restoration scenarios

The restoration goal setting is based on the graph of accumulative sediment exported versus available restoration area.

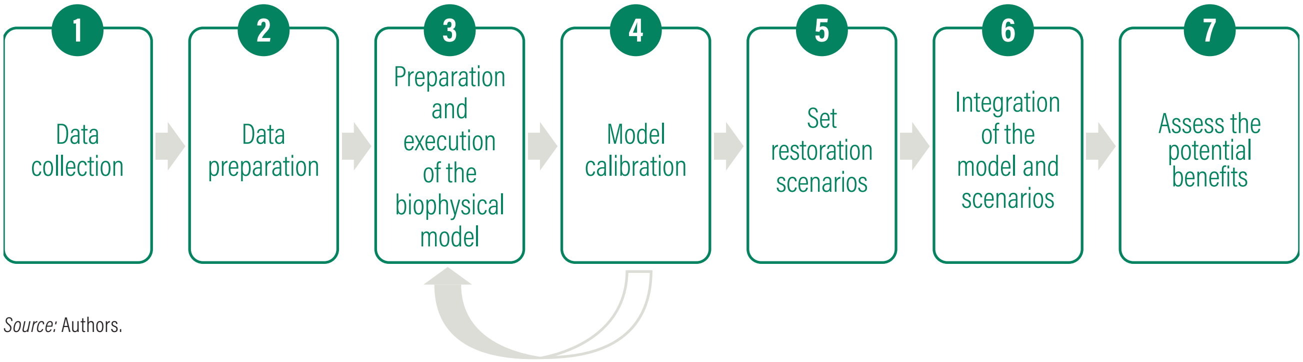
Step 6. Integration of the model and scenarios

The current LULC (Land Use/Land Cover) layer is replaced by the LULC restoration scenario to estimate the potential sediment reduction if the region is restored.

Step 7. Assess the potential benefits

The restoration scenario is compared to the current LULC to estimate the potential sediment exportation reduction.

Figure B1 | General Flowchart to Run the Analysis to Evaluate Biophysical Models and Restoration Scenarios



Source: Authors.

Sediment Modeling

In identifying the highest potential hectares that should be restored, and in estimating the overall sediment reduction impacts provided by natural infrastructure, we used the InVEST Sediment Delivery Ratio (SDR) Model v 3.7.0 toolset (Sharp et al. 2016). InVEST's Sediment Yield Model (Transfer Rates) generates an output that shows areas with a high level of sediment exportation in the region. We used this to create multiple spatial scenarios of the baseline and future land cover, and to model sediment yield, exported and retention impacts of those scenarios. The scenarios considers the restoration of 1,600 hectares of degraded area in the Jucu watershed and 900 hectares in the SMV watershed, *ceteris paribus*.

The SDR function estimates the amount of overland sediment generation which is delivered to the stream (Figure B2). There are several potential sources of sediment generation; however, the SDR tool estimates only the overland source.

The SDR is based on the USLE (Universal Soil Loss Equation) initially proposed by Wischemeier and Mannering (1969). The model consists of an estimation of soil loss according to biophysical attributes of the assessed region which include rainfall pattern, soil type, topography, crop system, and land management practices. The equation is given by the following formula (Stone and Hilborn 2012):

$$A = R * K * LS * C * P$$

Where:

A is the total estimation of soil loss per year/hectare

R is the rainfall erosivity index based on monthly rainfall which estimates the runoff factor. The potential for erosion increases accordingly with the intensity and duration of the rainstorm

K represents the soil erodibility index, which is the potential of soil particles to be detached and transported by rainfall and runoff. This factor is associated directly with soil texture and structure. Soil matter and permeability can influence this factor

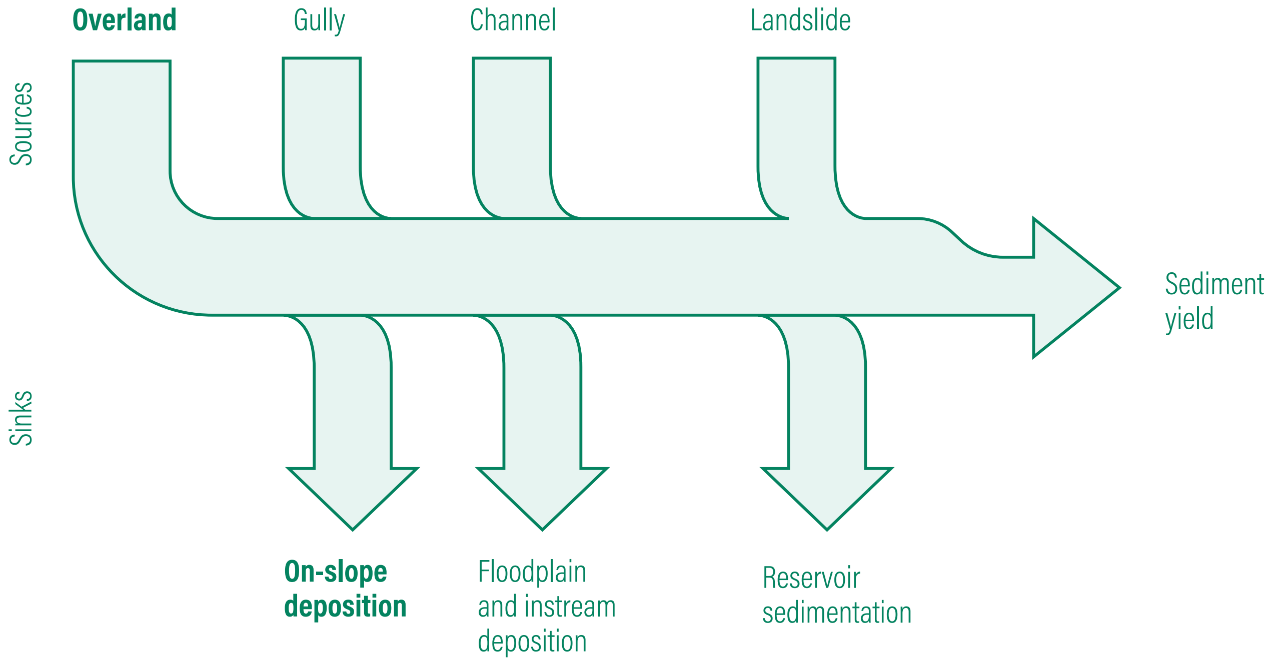
LS is the slope length-gradient factor. Steep and long terrain tends to increase the erosion risk

C determines the factor of crop/vegetation cover, which indicates the relative effectiveness of soil and crop management systems to prevent erosion

P represents the supportive practice factor in land management, if there is any type of land management practice employed to reduce the amount and rate of water runoff and consequently the amount of erosion

Most biophysical factors cannot be controlled, such as rainfall pattern, soil type and relief. Land use and land cover classes are the ones that can be changed, either by replacing the type of land cover (Factor C) or by changing the land management practice (Factor P). Thus, the land-cover change scenario of pastureland into forest is evaluated in terms of soil-loss estimation based on the difference between the current LULC and the potential restoration scenario. Table B1 presents details on the land cover of the Jucu and SMV Watersheds.

Figure B2 | The SDR Function Estimating Only the Overland Source



Source: Sharp *et al*. (2016).
Note: Other sediment sources are not part of sediment yield estimation.

Table B1 | Land Cover Pattern According to Each Region within the Jucu and SMV Watersheds

	JUCU						SMV	
Land Use and Cover Classes	Total (Jucu)		Upstream Reservoir		Downstream Reservoir		Total (SMV)	
	Ha	%	Ha	%	Ha	%	Ha	%
Forest (mangrove and restinga included)	70,496	36%	57,861	38%	12,635	30%	55,197	39%
Forest under natural regeneration	15,091	8%	11,444	7%	3,647	10%	11,189	9%
Wetland	1,027	1%	364	0%	662	2%	420	0%
Exposed Soil	2,062	1%	1,906	1%	156	0%	2,064	1%
Shrublands	13,201	7%	11,964	8%	1,236	3%	9,988	7%
Grasslands	59	0%	59	0%	0	0%	32	0%
Mining	64	0%	49	0%	15	0%	22	0%
Rocky outcrop	1,856	1%	1,288	1%	568	1%	2,993	2%
Forestry – Eucalyptus	17,449	10%	16,725	11%	724	2%	11,837	9%
Forestry – Rubber tree	499	0%	7	0%	492	1%	34	0%
Forestry – Pine	293	0%	293	0%	0	0%	0	0%
Agriculture – Coffee	12,631	6%	12,040	8%	591	1%	8,283	6%
Agriculture – Sugarcane	129	0%	0	0%	129	0%	6	0%
Agriculture – Coconut	127	0%	35	0%	93	0%	83	0%
Agriculture – Banana	2,833	1%	1,903	1%	930	2%	947	1%
Agriculture – Others	2,534	1%	2,204	1%	330	1%	1,335	1%
Crops – One-season crops	7,846	4%	7,286	5%	560	1%	11,199	8%
Pasture	35,833	19%	19,420	13%	16,414	40%	17,825	14%
Water bodies	726	0%	526	0%	199	0%	669	0%
Urban area	754	0%	353	0%	401	1%	352	0%
Others	9,330	5%	7,415	5%	1,915	5%	5,269	4%
TOTAL	**194,840**	**100%**	**153,142**	**100%**	**41,697**	**100%**	**139,744**	**100%**

Source: Geobases-ES 2018.

Model inputs (Assumptions and Data)

Data sources for the sediment model are described in Table B2, while Table B3 presents the crop/vegetation and management factor of USLE for each of the land use/land cover classes mapped in the region. The C values were assigned according to Wischmeier and Mannering (1969), thus the assignment process for different land use/land cover classes were a combination of the following criteria:

1. Predominant type of vegetation (herbs, shrubs, or trees)
2. Estimation of percentage of soil cover (25 percent, 50 percent, and 75 percent)
3. Understory dominant plant type (grass-like or weed-like)
4. Amount of soil exposed (no understory covered) (20 percent – 40 percent – 60 percent – 80 percent – 90 percent+)

Model Calibration

As the USLE is a general equation which is applied globally, there are some local factors that can be adjusted according to actual observations, thus bringing the final output closer to the real observed data. In several cases, the monitored parameter is the water turbidity which is given in NTU (Nephelometric Turbidity Units). NTU are basically the optical properties of light absorption and reflection, where a higher value for turbidity represents higher light scattering due to the presence of sediment or other elements. As the resulting output of the biophysical model is expressed in tons of sediment per year, the conversion of NTU into suspended sediment values is required. For more detail on this conversion see section Conversion of Suspended Sediments into Turbidity.

Table B2 | Summary of Data Inputs

INPUT	DESCRIPTION	SOURCE
Rainfall Erosivity Index (R)	ArcGIS raster dataset, with an erosivity index value for each cell (1 km of spatial resolution). This variable depends on the intensity and duration of rainfall in the study area.	Mello et al. 2012
Soil Erodibility (K)	ArcGIS raster dataset with a soil erodibility value for each cell. This is a measure of the susceptibility of soil particles for detachment and transport by rainfall and runoff. The original data are in vector format and were converted into raster format adjusted to 30 m of spatial resolution.	Medeiros et al. 2016
Digital Elevation Model (DEM)	ArcGIS raster dataset with an elevation value for each cell (30 m spatial resolution). The final raster layer was generated using the interpolation process of contour line mapped for the State.	GEOBASES-ES 2018
Land Use/Land Cover (LULC)	ArcGIS raster dataset with an integer LULC code for each cell. The LULC raster was mapped at 1:10.000 scale (suitable for approximately 5 m of spatial resolution). The original data are in vector format. These data were converted and resampled to 30 m of spatial resolution.	Based on aerial photo from 2012 (GEOBASES-ES 2018).
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).	Adapted from Wischmeier and Mannering (1969). *See Table 3.*

Note: Parameters were assessed for each LULC class considering their characteristics, and a C factor was assigned based on a combination of these parameters.

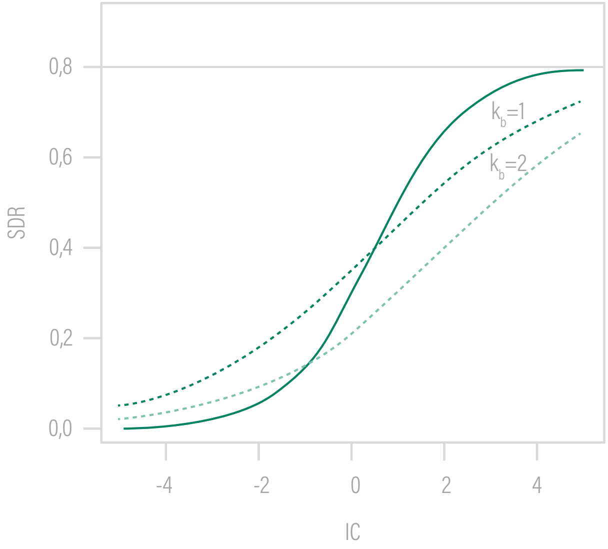
The SDR function allows user to calibrate four variables (Figure B3) (Sharp et al. 2016).

Thus, the following variables are available for calibration in the SDR model (Sharp et al. 2016):

1. Maximum SDR – The maximum proportion of SDR that a pixel can reach, according to the fraction of topsoil particles finer than coarse sand.
2. IC_0 and k_b parameters define the relationship between the index of connectivity and the sediment delivery ratio (SDR) (Figure B3).
3. Threshold Flow Accumulation (TFA). This parameter creates the potential stream network in the study region. The setting value varies according to the region. The output needs to be compared to real-world stream network. Larger values tend to map a stream network with fewer tributaries, while small TFA values will create a stream network with more tributaries.

Several studies have been conducted in the region to assess the amount of sediment carried to the streams based on spatial modeling, including Mendonça et al. (2014), Nunes (2013), and Sperandio et al. (2012). There is, however, often a scarcity of field data. The calibration parameters of InVEST were set to adjust the outputs using a turbidity of 32 NTU in the Jucu as estimated by Fioresi a Torres (2019) and 38 to SMW as Pagiola et al. (2019).

Figure B3 | Adjustable Variables in the SDR Model



Source: Sharp *et al.* (2016).
Note: SDR is the Sediment Delivery Ratio, while IC is the Connectivity Index. The curves represent the relationship between SDR and IC when different values are applied.

Table B3 | Biophysical Input Table for C and P Factors of LULC Classes Required by the USLE Equation. C-factor corresponds to type of LULC class and the P factor is the type of land management employed to avoid sediment generation.

LAND USE AND COVER CLASSES	CODE	C-FACTOR	P-FACTOR
Forest (mangrove and restinga included)	1	0.009	1
Forest under natural regeneration	2	0.019	1
Wetland	5	0.003	1
Exposed Soil	6	0.5	1
Shrublands	7	0.019	1
Grasslands	8	0.0001	1
Mining	9	0.0001	1
Rocky outcrop	10	0.0001	1
Forestry – Eucalyptus	11	0.17	1
Forestry – Rubber tree	12	0.17	1
Forestry – Pinus	13	0.17	1
Agriculture – Coffee	14	0.19	1
Agriculture – Sugarcane	15	0.1	1
Agriculture – Coconut	18	0.19	1
Agriculture – Banana	19	0.19	1
Permanent agriculture	20	0.2	1
Crops – One-season crops	21	0.2588	1
Pasture	22	0.1514	1
Water bodies	23	0.0001	1
Urban area	24	0.0001	1
Others	25	0.1384	1

Source: Authors. Adapted from Wischmeier and Mannering (1969).

The calibration process is based on comparison of the NTU value converted into sediment exported and the output data generated by the biophysical model, which consists of the following outputs (Sharp et al. 2016):

1. USLE: Total potential soil loss in the region (tons/pixel)
2. Sediment Export – Total sediment exported from each pixel that reaches the stream (tons/pixel)
3. Sediment Retention Index – A reference for comparing whether all LULC types are converted to bare ground. The amount of sediment should be interpreted as a relative value (tons/pixel).

Based on the NTU reference values, the following parameters were adjusted for both Jucu and SMV: TFA: TFA: 1,000; $IC_0 = 0.65$; $k_b = 0.38$.

Spatial Modeling to Inform GGA

The LegalGeo (Oakleaf et al. 2017) was used to select the pixels to be restored based on the target area to be restored. The tool selects the eligible areas (pixels) with the highest sediment export value until the area that contemplates the restoration goal is reached. We translated results of InVEST into annual avoided sediment values using the method and assumptions detailed in Ozment et al. (2018). Since the restoration schedule takes place over six years, providing costs and benefits along a time frame of 20 years, the total yearly maximum erosion control is a function of restored area, age of the restoration and percentage of maximum erosion control in each year.

APPENDIX C. FINANCIAL ANALYSIS METHOD AND ASSUMPTIONS

This appendix provides details of the estimate costs and benefits as well as sensitivity analysis, Steps 4, 5 and 6 of the GGA/WRI.

Natural Regeneration and Active Restoration

In order to estimate the share of restoration that can occur with natural regeneration for Vitória, we created a local natural regeneration map following the same method presented in Ozment et al. (2018). This map assumes that deforested regions immediately surrounding standing forest will be more able to regenerate than deforested regions further away, due to seed transport, hydrologic conditions, and other ecological factors provided by standing forest. For natural regeneration, the scenarios considered 33% of the areas to be restored. The others would require active restoration, by full planting.

Sequencing of Restoration (Restoration Implementation Schedule)

We assumed restoration and conservation interventions to occur over a three-year period based on a hypothetical schedule provided by consultation with stakeholders following the schedule presented in Table C1.

Water Supply and Demand

According to the State Water Agency and the Jucu and Santa Maria da Vitória Water Committees (AGERH, CBH-SMV and CBH-J 2011), the demand is expected to grow about 35 percent by 2034. We consider that the demand for water is given by the population growth of the seven municipalities of the RMGV projected for the next 20 years, multiplied by the elasticity consumption of water of the population. The population growth was the same used by PERH-ES (AGERH, SEAMA, 2018). We calculated the water elasticity-consumption of the population at 1.41 percent. The elasticity was calculated using the Ordinary Minimum Square model for population and water consumption data in Vitoria, according to SNIS data (SNIS, 2020). Jucu and SMV watersheds themselves would provide the supply for the respective demands.

Timeframe

The 20-year time frame for financial projects in the water sector reflects the weighted average lifespan of most important structures and equipment related to water treatment and has been used by Brazilian water companies in infrastructure analysis (Ozment et al. 2018).

Discount Rate

We assumed a benchmark discount rate of 8.5 percent, based on BTG Pactual's estimated WACC of 8.6 percent for water and sewage sector in Brazil (Junqueira et al. 2017). In the sensitivity analysis (described later) we varied the discount rate from 5 to 12 percent. These values were determined based on Brazilian Risk Premium in financial projects (Assaf Neto 2010); whereas the Inter-American Development Bank (IDB) recommends a discount rate of 12 percent for public water infrastructure projects in Latin America (Fontanele and Vasconcelos, 2012).

Table C1 | Restoration Schedule

YEAR	FOREST RESTORATION AREA (HA) - JUCU	FOREST RESTORATION AREA (HA) - SMV	FOREST RESTORATION AREA (HA) – LC2500 (JUCU1600+SMV900)
1	360	200	560
2	720	400	1,120
3	520	300	820
TOTAL	**1,600**	**900**	**2,500**

Source: Authors. Based on Sossai 2020.

Table C2 | Treated Water Supply/Demand

YEAR	JUCU (M^3/S)	SMV (M^3/S)	UGRH-LC (JUCU+SMV) (M^3/S)
0	4.60	2.80	7.40
4	4.87	2.96	7.83
9	5.22	3.18	8.40
14	5.60	3.41	9.01
19	6.00	3.65	9.65

Source: Authors.

Table C3 | Discount Rate Adopted

FINANCIAL SCENARIO	DISCOUNT RATE ESTIMATED (%)	DISCOUNT RATE APPLIED (ROUNDED RATE) (%)
Low Risk – Social Discount Rate	5.16 (Regular – BRPA - SD)	5
Benchmark	8.6 (Regular)	8.5
High Risk	12.04 (Regular + BRPA + SD)	12

* Regular Value is the Discount Rate applied by CESAN (CESAN, 2020). BRPA is the average of Brazilian Risk Premiums for the last five years (recorded daily). SD is the Standard Deviation of the average of Brazilian Risk Premiums for the last five years (recorded daily).
Sources: Lopez (2008), Assaf Neto (2010), Fontanele and Vasconcelos (2012).

Cost Valuation

Investment costs: Costs which include all investments needed to implement restoration. Investment costs are different for natural and full restoration. Natural regeneration simply entails fencing to keep cattle out, while assisted restoration requires additional up-front investments including seedlings, chemical inputs, and fencing. Based on the recommended practices of the Reflorestar Program (Sossai 2020), the labor costs of implementing assisted restoration are omitted from the benchmark scenario in this analysis. However, we included these labor costs in a sensitivity analysis scenario.

Transaction costs: Costs that are expenses incurred to engage landowners in the restoration projects, design and monitor the program, and administer contracts and payments. We assume these costs amount to one percent on investments since they are already indirectly computed in other existing initiatives, such as the Reflorestar itself (Sossai 2020).

Opportunity costs: In this study, we assumed the opportunity cost was equivalent to Reflorestar's Payment for Ecosystem Services project, which is set at \$80/ha/year for sites with assisted restoration and \$76/ha/year for natural regeneration (SEAMA 2019). This assumption is applied to Areas of Permanent Protection (APP) and commercially viable lands alike, since Reflorestar pays landowners regardless of the protection status of their restoration sites. We assume these payments occur annually over 20 years. These incentives are paid for each year of participation, separate from a one-time payment spread over three years for restoration inputs, which covers the costs of restoration.

Opportunity costs can also be assumed to be equivalent to the most common alternative land use in the region, which in this case would be the pasture rental value (Feltran-Barbieri et al. 2018; Ozment et al. 2018). Published data on pasture rental were not available for the region. However, through interviews with local stakeholders, we estimated the pasture rental value to be about \$120 per hectare per year. The sensitivity analysis presents a scenario with this alternative input.
To entice landowners to implement a natural infrastructure strategy, the investor must meet or surpass the landowner's opportunity cost associated with a likely alternative land use. An effective payment for ecosystem services should account for this opportunity cost.

Benefit Valuation - Parameters conversions

Costs avoided in water treatment: through conversations with CESAN's operational staff and a reading the company's sustainability and financial reports, we estimate that CESAN currently spends approximately \$14.78 cents/m^3 on treated water and R\$ 6.25 cents/m^3 on chemical products, of which 33 percent is to treat turbidity, with the remaining two-thirds for disinfection and fluoridation. We consider that the current cost of energy only related to turbidity is also 33 percent and that electrical energy savings would be directly proportional to reduction of suspended solids concentration throughout the project.

A four-step sequence with unit conversions was used to estimate the avoided cost in water treatment according to the different annual average turbidity levels, following Sousa Júnior's recommendations (Sousa Junior, 2011). Figure C1 illustrates the step-by-step process.

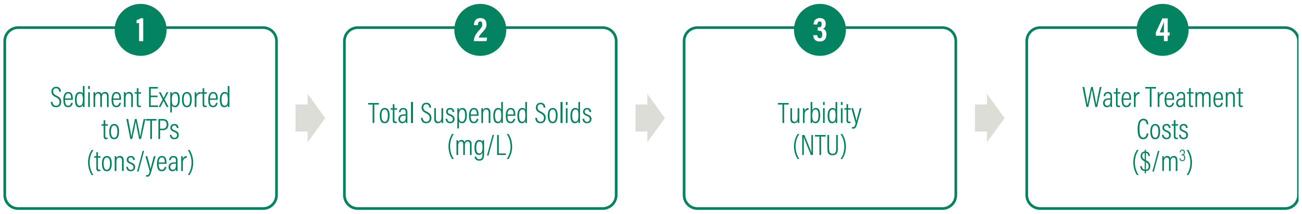
Step 1 – Estimating Total Sediments in Intake Water at WTPs

The annual amount of sediment that arrives at the Jucu treatment plants is equivalent to the sum of the sediment exports in the upstream and downstream region of the reservoir. The former is a function of the sediments produced, sediment retention capacity in the reservoir, restored area, and age of restoration year by year. For the downstream region, it is a function of the sediments produced, the restored area and age of the restoration year by year. Formally:

$$S_{jucu,a} = \left\{ \begin{bmatrix} m_{1,1} & \cdots & m_{1,a} \\ \cdots & \cdots & \cdots \\ m_{a,1} & \cdots & m_{a,a} \end{bmatrix}_{a,a} * \begin{bmatrix} p_{1,a} \\ \cdots \\ p_{a,1} \end{bmatrix}_{a,1} * I_m * (1-k) \right\}$$

$$+ \left\{ \begin{bmatrix} j_{1,1} & \cdots & j_{1,a} \\ \cdots & \cdots & \cdots \\ j_{a,1} & \cdots & j_{a,a} \end{bmatrix}_{a,a} * \begin{bmatrix} p_{1,a} \\ \cdots \\ p_{a,1} \end{bmatrix}_{a,1} * I_j \right\}$$

Figure C1 | 4 Conversion Steps



Source: Authors.

$S_{jucu,a}$ sediments in intake water at WTP (tons/year), in the year *a*

$m_{a,i}$ restored area upstream of the reservoir in the year *a* (hectares), age of restoration *i* (years after planting)

$p_{1,a}$ percentage of retention provided by restored forest with age I, in relation to mature forest. $p=0.2594 * ln(i)+0.0373$ (estimated from Poorter et al., 2016)

I_m amount of sediments retained upstream of the reservoir if all the restored forest had 100% of its retention potential - InVEST output (tons/year)

k reservoir sediment trapping capacity (%), applied $k=32$ (Condé et al. 2019)

$j_{a,i}$ restored area downstream of the reservoir in the year *a* (hectares), with age *i* (years after planting)

I_j amount of sediments retained downstream of the reservoir if all the restored forest had 100% of its retention potential - InVEST output (tons/year)

For Santa Maria da Vitoria, function used was:

$$S_{SMV,a} = \left\{ \begin{bmatrix} v_{1,1} & \cdots & v \\ \cdots & \cdots & \cdots \\ v_{a,1} & \cdots & v_{a,a} \end{bmatrix}_{a,a} * \begin{bmatrix} p_{1,a} \\ \cdots \\ p_{a,1} \end{bmatrix}_{a,1} * I_v \right\}$$

$S_{SMV,a}$ sediments in intake water at WTP (tons/year), in the year *a*

I_v amount of sediments retained downstream of the reservoir if all the restored forest had 100% of its retention potential - InVEST output (tons/year)

Step 2 - Converting total sediments into total suspended solids

Avoided water treatment costs were estimated by developing turbidity-cost curves. For both watersheds we applied equation estimated by Saad et al. (2018) as

$$ss_{B,a} = 0.0317 * S_{B,a} * Q_B^{-1}$$

Where:

$ss_{B,a}$ is the concentration of total suspended solids at WTP in watershed B, year *a* (mg/l)

$S_{B,a}$ sediments in intake water at WTP in watershed B (tons/year), in the year *a*

Q_B average stream water flow (m^3/s). Considering 20.91 for Jucu and 16.22 for SMV (AGERH, SEAMA, 2018)

0.0317 = conversion constant

Step 3 – Converting Suspended Solids into Turbidity

For both watersheds the equation estimated by Piccolo et al. (1999):

Where:

$$T_{B,a} = 0.29 * ss_{B,a}^{1,254}$$

$T_{B,a}$ turbidity at WTP in watershed B, year *a* (NTU)

$ss_{B,a}$ suspended solids at WTP in watershed B, year *a*

Step 4 – Water treatment Costs Due to Turbidity Level

Because the three WTPs in Jucu and two in SMV have quite different production capacities, we estimated an economy of scale using a panel regression. It was applied to three watersheds as a proxy for scale (Jucu, Santa Maria da Vitória and Reis Magos) with data available from 2002 to 2017 using the database from the National Sanitation Information System (SNIS, from its initials in Portuguese) (SNIS 2020). The panel regression is defined as

$$Y_{it} = \beta X_{it} + \alpha + u_{it} + \xi_{it} \qquad (Equation\ A6)$$

Where:

Y = represents *lchemical* which is the natural log of chemical costs in water treatment (R$) (SNIS, 2020), where i is the watershed id and t is the year

X = *lwate*r, natural log of treated water (thousands of m^3) (SNIS 2020)

$indgdpcapita$ – natural log of industrial GDP per capita – lag of 4 years (IBGE 2020)

α – is intercept

u – is the error between watersheds

ξ – is the error within watersheds

Contrary to expectations, we found a diseconomy of scale as shown in the coefficient *lwater* (1.072). This means for every percentage increase in water treated, the total cost increases by 1.072 percent. We assumed the general equation would hold for the Cobi Water Treatment Plant whose capacity is 0.9 m^3/s. For Vale Esperança, we assumed total treatment costs to be 3.92 times higher than Cobi (while the total water treatment capacity is 3.67 larger) and for Caçaroca we assumed total costs to be 0.44 times higher than Cobi (while the total water treatment capacity is 0.53 smaller).

Table C4 | Panel Regression Outputs

VARIABLES	**(1)** *lchemical*
lwater	1.072***
Indgdpcapita	27.91**
Constant	1.604
Observations	46
Number of ottobacialevel	3

Source: Authors.
Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Taking into account the study by Pagiola et al. (2019) on treatment costs at Carapina (SMV), and updating the monetary values to November 2020, the average water treatment costs at Vale Esperança would be approximately $ 0.088/m^3 for turbidity 10 NTU and $ 0.17/m^3 for turbidity 100 NTU, which seems inconsistent (too expensive). Thus, it was decided to use as calculation base for all three stations the values obtained by Pagiola et al, (2019) updated by IGP-DI multiplied by the scale correction factor of 2,27 (inverse of the 0.44 coefficient estimated according to previous paragraph).

The study by Pagiola et al. (2019) does not provide the estimated equation but presents the graph with the sampled points and trend line. Using the software CorelDraw and we projected the graph in 5x zoom and estimating the linear distances between the percent of each sample point and x-axis (turbidity) and y-axis (costs in $/m^3). Maintaining the proportionality of the distances and scale originally published, we estimate the reference values of each point in terms of turbidity and cost. With these estimated values we corrected by the IGP-DI index and multiplied by the scale factor. To simplify the financial analysis, we use the same cost function for all stations and therefore all the volume produced. The cost function derived from the original function by Pagiola et al. (2019) was:

$$C_{B,a} = (0.000756 * T_{B,a}) + 0,069091$$

Where:

$C_{B,a}$ costs of chemical inputs to treat turbidity at WTP in watershed B, in year *a* ($/m^3)

$T_{B,a}$ turbidity at WTP in watershed B, year *a* (NTU)

Other costs directly related to turbidity levels, such as sand replacement, anthracite and sludge cleaning of equipment, we assume a relationship given by:

$$O_{B,a} = O_B * \frac{T_{B,a}}{T_{B,a-1}}$$

Where:

$O_{B,a}$ other costs at WTP in watershed B, in year *a* (US$/m^3)

O_B references costs (see Table 3 at the main text).

For energy costs directly related to turbidity levels the same was applied but using suspended solids levels instead turbidity (replacing T by ss in the formulas).

Asset Depreciation

Based on interviews with technical staff from CESAN, the regular depreciation rate is 1.91 percent per year on average. We assumed that reduced sedimentation results in a cost savings equivalent to avoided depreciation of equipment at the water treatment plant, assuming a reduced amount of suspended solids and sludge and wear and tear on turbidity-treating machines and equipment.

The value was calculated using the same four steps indicated above, replacing, in the last equation, the values of other costs by the reference value of depreciation, obtained in the financial reports of CESAN, whose reference is in the Table 3 of the main text.

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WRI BRASIL

SÃO PAULO
RUA CLÁUDIO SOARES, 72 CJ. 1510
PINHEIROS, SÃO PAULO - SP
05422-030, BRASIL
+ 55 11 3032 1120

PORTO ALEGRE
AV. INDEPENDÊNCIA, 1299 CJ. 401
PORTO ALEGRE - RS
90035-077, BRASIL
+ 55 51 3312 6324

WRIBRASIL.ORG.BR

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