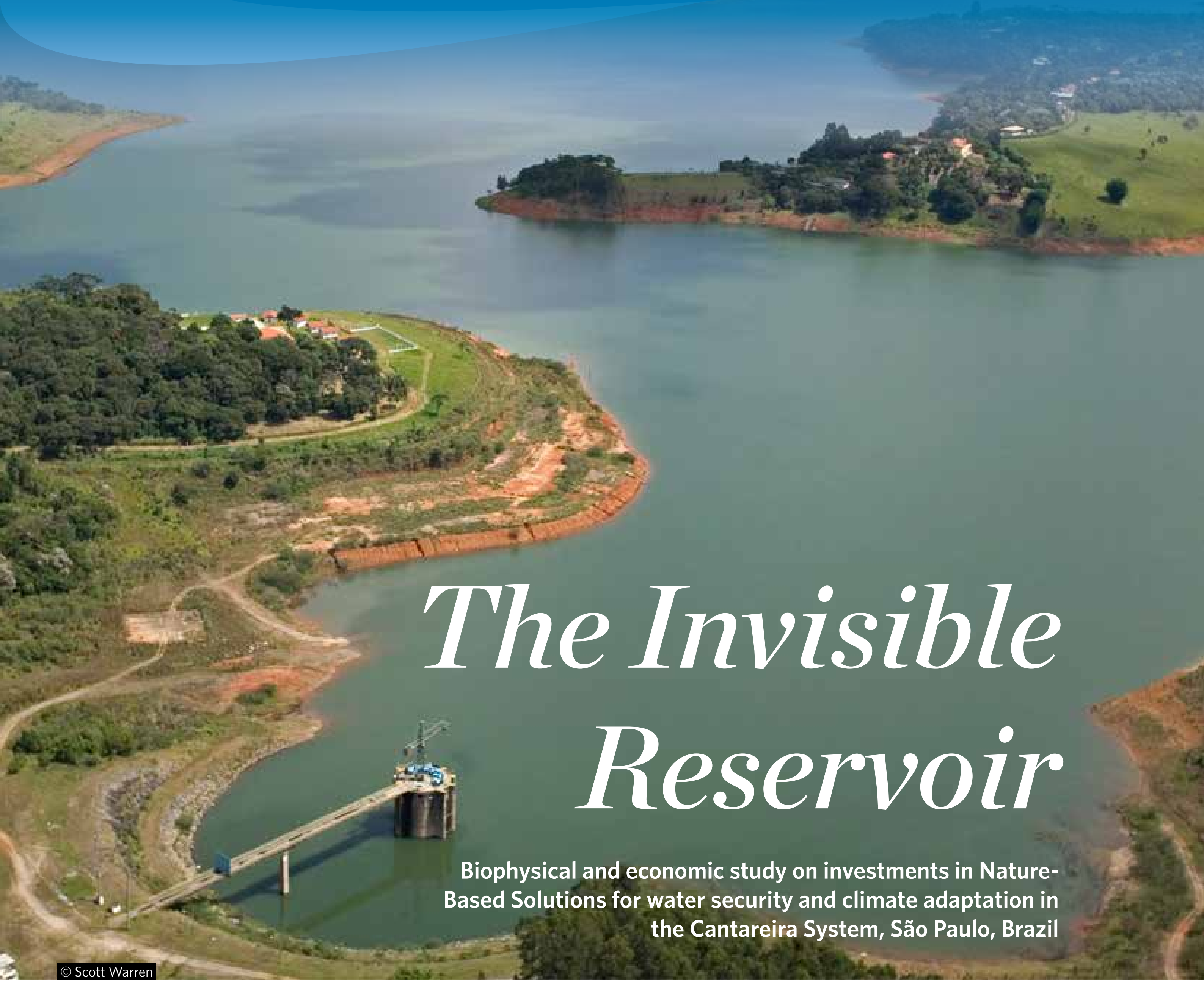
The Nature Conservancy
Brasil


© Scott Warren

The Invisible Reservoir

Biophysical and economic study on investments in Nature-Based Solutions for water security and climate adaptation in the Cantareira System, São Paulo, Brazil

Latin American Water Funds Partnership
The Nature Conservancy
Fundación FEMSA
IDB Inter-American Development Bank
gef
Supported by:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
based on a decision of the German Bundestag
IKI International Climate Initiative

Invisible Reservoir
Foreword

The Cantareira water supply system has a challenging job—to provide clean, reliable water to more than 7.5 million people in the São Paulo Metropolitan Region amidst a period of rapid conversion of natural areas and shifting weather patterns.

When the rivers and reservoirs serving the São Paulo Metropolitan Region ran dry during the most recent drought (which was also the worst the area has ever seen), the economic toll of water scarcity was severe. Now, as climate change continues to bear down on the region, determining how this system should adapt to the impacts of increased drought conditions remains a matter of urgent debate.

The answer, in part, lies in nature.

As the authors of The Invisible Reservoir make clear, investing at scale in nature-based solutions offers a credible path to ecosystem health and in turn, to building climate-resilient, water-secure communities long into the future.

To understand how this works, the authors asks that we look no further than to the soil beneath our feet.

As the title of this study suggests, the volume of water found in streams and reservoirs depends not only on rainfall but on the intimate link between the water we can see (surface water) and the water we can't (that which is stored as soil moisture and groundwater).

Just out of sight, these "invisible reservoirs" help to mitigate extreme flow events, reducing peak flow during storms and increasing baseflows during dry periods.

Importantly, while this natural storage capacity can be reduced—as has been the case in São Paulo's watershed through the decade's long destruction of Atlantic rain forests, poor territorial planning, and urban sprawl—it can also be increased.

The authors demonstrate that a portfolio of nature-based solutions such as native vegetation restoration in specific areas, riparian forests recovery, and use of agriculture best management practices (BMP)—deployed at a significant scale (32,000 ha) but targeted at only a small fraction (~15%) of the drainage area feeding the Cantareira supply network—can deliver 33% more water during drought events. It is during these days, when the reservoir level is dropping, that additional water in hydrological systems matters most.

The cost of a nature-based solution portfolio is significant. The authors estimate it conservatively at $180M USD. But they show the return on investment is significant too, with 1.2 cost-benefit ratio from seasonal water quantity-related benefits alone. Monetize the carbon generated from a restoration program of this scale and the cost benefit ratio goes up to 1.5.

The authors also note that the water quality benefits are also likely to be outsized, however the narrative of nature-based solutions for water security in this study aimed at quantity. As this study so expertly demonstrates, the power of nature to help solve water scarcity exists, even if it has been largely overlooked, as a climate adaptation strategy.

We must move swiftly to put these learnings into action. Brazilian utilities and regulators, like Sabesp and Arsesp, are in unique positions to carry this work forward, to champion an investment in nature that matches the scale of the climate crisis facing São Paulo.

Indeed, adoption of nature-based solutions won't happen without the leadership of water utilities and regulators. With this study, Sabesp and Arsesp have yet another tool to continue the momentum already established. Their example would no doubt inspire other water service providers in Brazil and inspire those around the world seeking solutions to a changing climate.

Daniel Schemie is the Resilient Watersheds Strategy Lead for The Nature Conservancy

Biophysical and economic study on investments in Nature-Based Solutions for water security and climate adaptation in the Cantareira System, São Paulo, Brazil

Currently, more than half of the world's population lives in cities. Basins are being degraded all over the globe due to the conversion of natural environments, poor territorial planning, and urban sprawl.

The warning signs regarding climate and water security are many. The UN's Intergovernmental Panel on Climate Change (IPCC) demonstrated that extreme weather events are becoming more frequent and intense. The World Economic Forum (WEF) has also warned that failure in the decision-making process regarding extreme climate and water events represents the main threat to the global economy regarding probability and impact.

Ensuring an adequate drinking water supply is one of the world's most urgent challenges. Conventional strategies focused on engineering interventions, such as dams, system integration, and transfer between basins, are limited in guaranteeing water security, especially with climate change and the increasing water demand.

Adopting nature-based solutions (NbS) is essential to ensuring quality and adequate water supply in the long run, providing resilience to the public supply systems.

Based on a robust database, this study brings new evidence and analysis on the hydrologic and economic implications of NbS adoption. The study focuses on the Cantareira Water Supply System, and its goals are:

- Highlight the potential hydrological and economic benefits of investing in NbS in the Cantareira System;
- Propose prioritizing interventions that protect the Cantareira System as a source of public water supply;
- Support the coordination and development of landscape planning and territorial management policies in the Cantareira System;
- Validate the allocation/coordination of additional financial resources through water tariffs to achieve the protection objectives in all contributing areas in the Cantareira System.

Nature-based solutions are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, while providing human well-being and biodiversity benefits.
For water security, NbS include restoring the functionality of natural ecosystems and the adoption of good land-use practices in priority hydrological areas to reduce water risks.

Why the Cantareira System?

One of the main water supply systems in the São Paulo Metropolitan Region (RMSP in Portuguese), the Cantareira System still holds good conditions to serve as a source watershed today and in the future. Located between the states of São Paulo and Minas Gerais, it covers a 220,000-hectare area. It comprises four interconnected reservoirs (Jaguari-Jacareí, Cachoeira, Atibainha, and Paiva Castro) that supply water to around 47 percent of the RMSP.

That territory is subject to dynamic land use, state and municipal policies, and various social and economic tendencies. In the natural environment, the Cantareira is subject to the climate regime and its associated effects in the hydrological cycle reflected in the dynamic of water on land, vegetation, soil, land use, rivers, and subsurface hydrological components.

The Cantareira System region is a territory that can catalyze water-security actions in the RMSP as an excellent example for other watersheds in the country and for the sanitation sector.

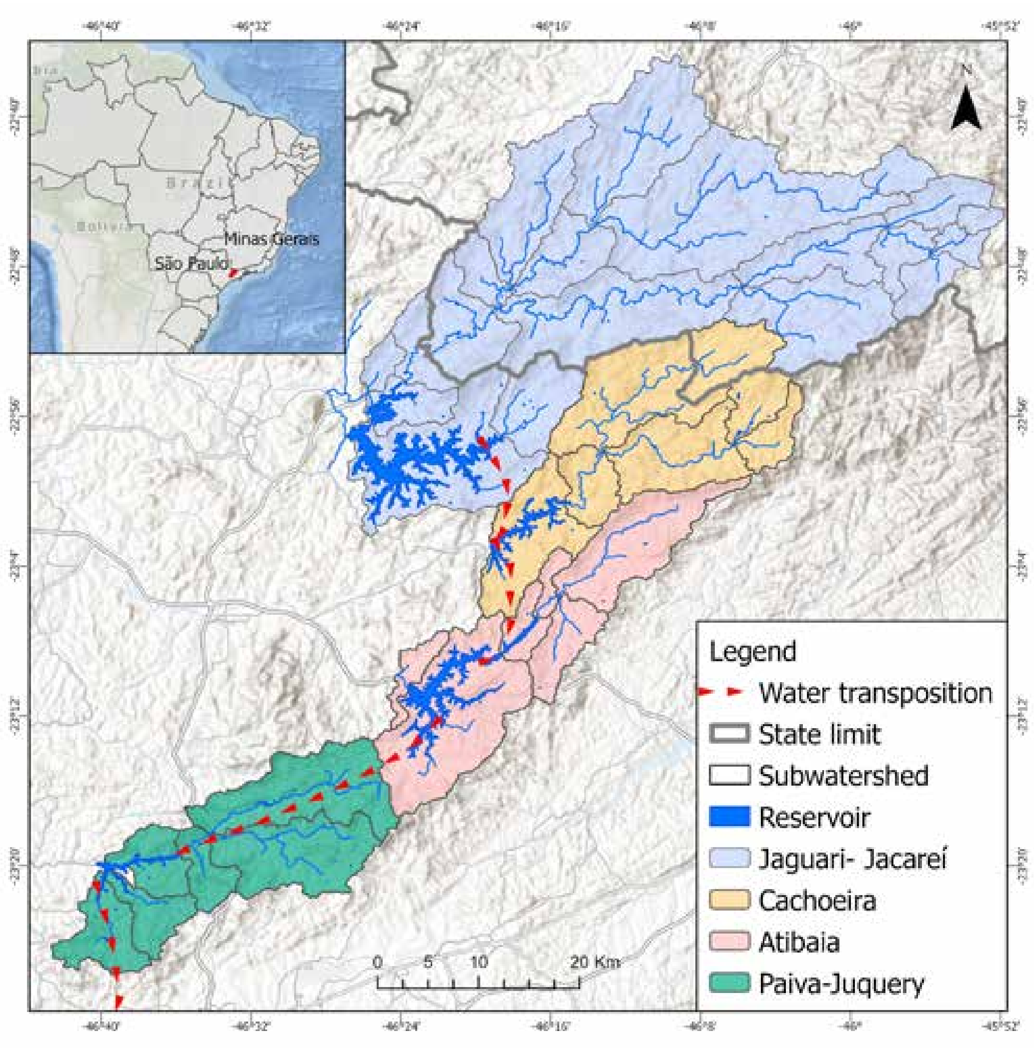


FIGURE 1 CANTAREIRA SYSTEM

Springs are extremely important territorial spots for the well-being of society and economic development.
All cities, large or small, or any human settlement of any size need to have access to safe, reliable and clean water.

Stakeholders and Institutional Cooperation

The complex challenge of territorial planning and management involving multiple stakeholders is inherent to the Cantareira System. So is the opportunity to demonstrate the potential of effective NbS investing and allocation to develop a sustainable water source for today and the future.

Joint efforts by stakeholders and decision-makers are the starting point for connecting scientific knowledge and political decision-making to support territorial planning, justifying public and private investments.

Thanks to a joint effort to conduct this study, it was possible to ensure the availability of qualified data, agree on a structure for the hydrological models, define alternative scenarios for land use and land cover (LULC), and promote the debate about models, their algorithms, assumptions, and results.

The following were part of that effort: The Nature Conservancy (TNC), the São Paulo State Basic Sanitation Utility (Sabesp) through the Metropolitan Water Resources Management Division, the Public Services Regulatory Agency of the State of São Paulo (Arsesp), the National Socio-Environmental Synthesis Center of the University of Maryland (Sesync), in addition to other researchers and public managers.

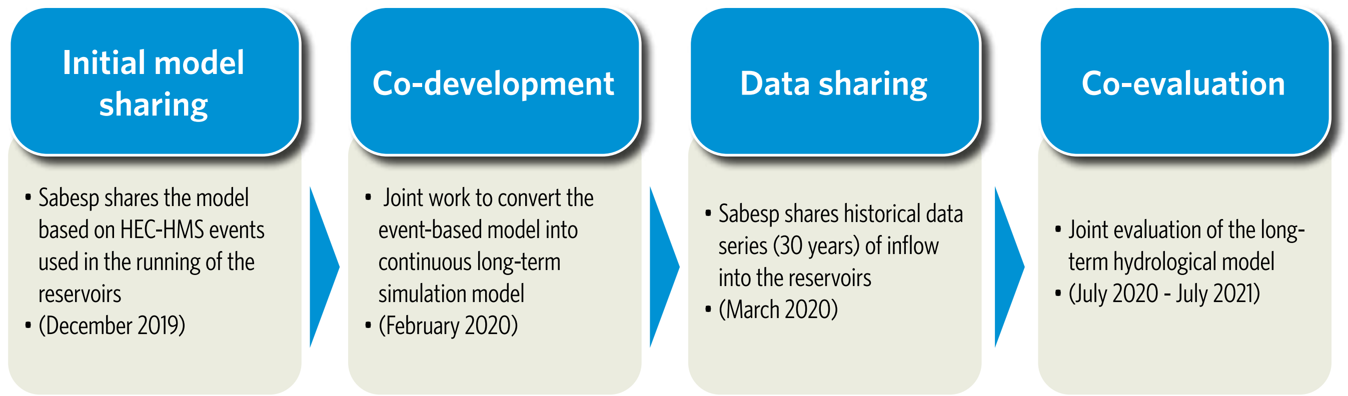


FIGURE 2 CO-DEVELOPING LONG-TERM HYDROLOGICAL SIMULATION MODELS THROUGHOUT THE PROJECT, ADAPTING THE HYDROLOGICAL-MODEL STRUCTURE ALREADY BEING USED BY THE BASIC SANITATION COMPANY OF THE STATE OF SÃO PAULO (SABESP)

The Influence of Landscape Planning and Management on Water Balance

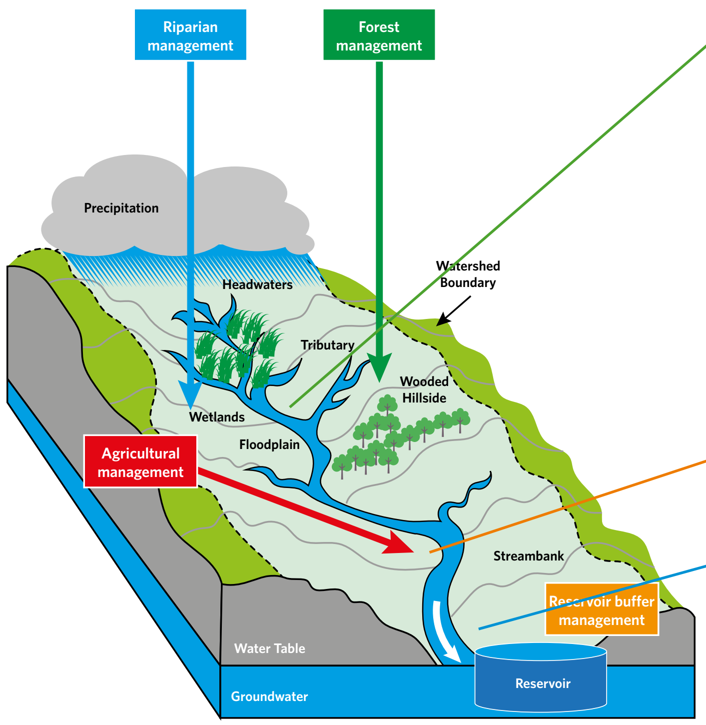
Different types of LULC can affect the hydrological cycle and water balance of a basin, especially in the case of springs.

The use of agricultural techniques and forest and land management in a given landscape result in changes in LULC and, consequently, influence the water retention time in a watershed and its capacity to retain sediments and nutrients.

Changes in LULC have hydrological implications if one of the land uses significantly alters the water balance components.

Precipitation is the main water input into a hydrological system. With a rich and diverse LULC matrix, that entry can increase due to fog capture. Part of the water that enters the system is captured by plants and part returns to the atmosphere via evapotranspiration. The water retention time in the hydrological system increases if the LULC is diversified. In other words, more water is contributed to the groundwater flow through the increased infiltration and soil water content. At the same time, the surface runoff decreases, and the water travel time is attenuated downstream. Water quality is also expected to change with LULC, decreasing or increasing soil erosion, nutrient and pollutant inputs in the watershed.

To compare alternative LULC scenarios in the Cantareira System, we used hydrological models to simulate the potential water quantity and quality effects on the hydrological systems.



Source watershed management

Source watershed landscape management involves different combinations of actions including:

- Floodplain and wetland restoration to increase surface water storage and infiltration
- Conservation and reforestation to increase canopy/soil storage and evapotranspiration
- Agricultural BMPs to conserve water use and reduce soil and pollutant loading
- Reservoir buffers can trap sediment and pollutant

Downstream (at reservoirs) effects

- Reduce erosion and sediment loading
- Reduce pollutant loading

- Increase long-term water yield
- Attenuate episodic flood and risk reduction

FIGURE 3 BASIN MANAGEMENT AND ENVIRONMENTAL RESULTS

The components of hydrological processes most relevant to water availability include:

- precipitation
- evapotranspiration
- surface runoff
- stream flow
- infiltration
- plants uptake
- lateral flow
- base flow
- deep aquifer recharge

Different interests, collective and private, must be combined in a supplying watershed area, focusing on territorial planning and management and a very long-term vision. Economic activities and land use that contribute to the health of a watershed must be encouraged via public policies. On the other hand, activities that degrade the noble deed of supplying water must be discouraged in those areas and promoted elsewhere.

© Scott Warren

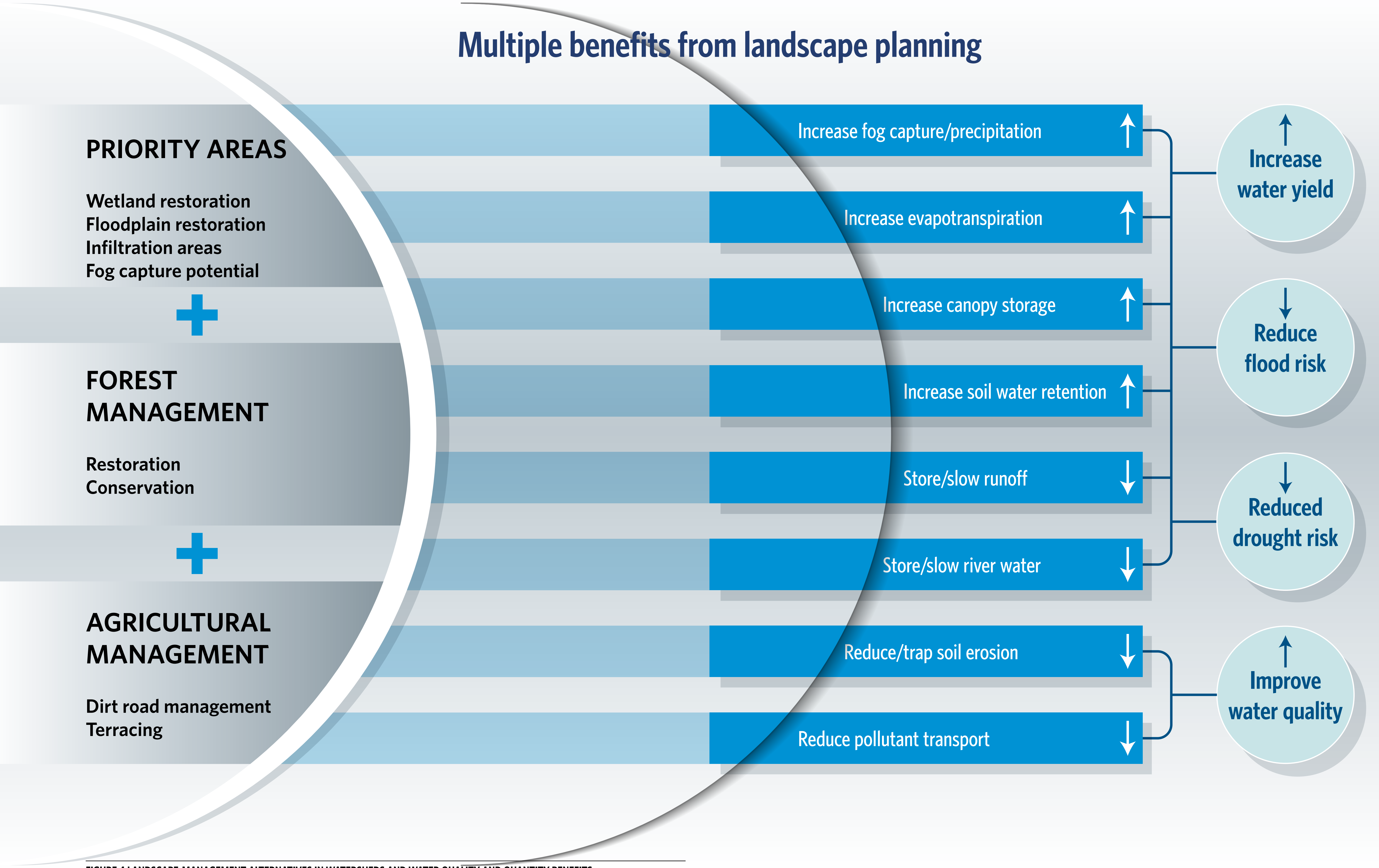


FIGURE 4 LANDSCAPE-MANAGEMENT ALTERNATIVES IN WATERSHEDS AND WATER QUALITY AND QUANTITY BENEFITS.

Biophysical Models

The biophysical and hydrological models used in this study are intended to support defining territorial planning and management policies for water resources management and source watersheds protection. They seek to understand the long-term cascading hydrologic impact from interventions across the watershed.

The potential impacts of landscape restoration on the basin hydrology were simulated via a synthesis of various models to:

- Identify intervention areas with the greatest potential for hydrological impact
- Predict changes in the water balance and water quality
- Simulate the long-term watershed hydrology

Three hydrological simulation models were deployed to estimate the possible results in the Cantareira System's hydrological dynamics arising from alternative LULC.

The three models were applied together to represent the Cantareira System's spatially variable conditions and simulate the different physical processes relevant to decision-making about landscape management.

An additional model called RIOS was used to identify the high impact areas for NbS interventions that would optimize long-term water yield.

In this study, various modeling techniques were combined. One of the landscape intervention scenarios was developed by the RIOS model. The fog capture rates were estimated using the FIESTA model simulation. These model outputs were then subjected to the HEC-HMS and SWAT hydrological simulation to estimate the water quantity and quality impacts of the landscape intervention.

FIESTA MODEL

Forest formations have the capacity/potential to capture the humidity in the air. The FIESTA model simulates the interception and fog capture that represents an additional water input to a hydrological system, added to rainfall.

The occurrence of fog capture depends on microclimate pre-conditions that are locally specific, such as temperature, altitude, the prevalence of winds, land orientation, land-cover patterns, and the seasons.

The FIESTA model was used to quantify the hydrological flow arising from the fog capture in a basin and to estimate the potential total water input from adopting NbS in the watershed.

HEC-HMS MODEL

The HEC-HMS model (Hydrologic Modeling System/Hydrologic Engineering Center), which was already being used by SABESP at the beginning of this study to manage and operate the Cantareira System's reservoirs, was adopted to integrate the accumulated knowledge regarding this study area and its hydrological processes with other relevant information to the long-term water management.

Through the Soil Moisture Accounting (SMA) algorithm, the model was adjusted to simulate long-term watershed hydrology, including drought conditions, rainy seasons and impacts of distributed water retention.

Through hydrometeorological data, the model calculates the basin's surface runoff, evapotranspiration loss (ET), infiltration, groundwater flow, and deep percolation, representing different components of the hydrological system.

SWAT MODEL

The Soil and Water Assessment Tool was developed to estimate the hydrological balance and water routing. It utilizes climate data and geospatial attributes such as type of soil, land use and land cover, topography, and crop management practices to predict watershed responses to NbS application, similar to HEC-HMS in terms of water balance simulation but with a greater complexity to represent a multitude of the watershed processes.

RIOS MODEL

We used the Resource Investment Optimization System (RIOS) to identify priority intervention areas for hydrological gains, such as increasing water infiltration in the soil, surface aquifer recharge and sedimentation and nutrient input reduction in bodies of water.

The RIOS software was originally developed by the Projeto Natural Capital (NatCap) to help prioritize areas, activities, and resource allocation in landscape planning specifically focused on NbS.

The main function is to allow an initial analysis to identify the areas and activities with the biggest impact on ecosystem services. The optimization is based on the combination of groundwater biophysical data, baseflow, type of soil, topography, and soil cover, resulting in the identification of priority intervention areas.

Baseline and alternative scenarios

Countless possibilities for allocating alternative scenarios for a given territory are possible. One of the objectives of modeling is to identify those with the greatest financial and political viability while maximizing the desired hydrological services.

The Cantareira System's 2018 LULC, generated from remote-sensing data, was considered as the baseline for this analysis.

The counterfactual landscape intervention scenarios consist of different spatially-distributed NbS allocations, such as native vegetation restoration, riparian forest recovery on riverbanks and reservoirs, and use of agriculture best management practices (BMP), among others.

The following intervention scenarios were considered in this study:

1. Minimum intervention (MI): It considers the restoration of native vegetation in ecologically sensitive areas, such as riparian areas and spring buffers, according to the minimum standard defined by the Brazilian Forest Code.

2. Enhanced Interventions (EI): It follows the same logic as the minimum intervention scenario; however, it considers larger restoration tracts in riparian and spring buffers.

In these two scenarios, the pasture areas surrounding the reservoirs, owned by SABESP, were considered as a part of the restoration extents, representing 1,238 hectares in the minimum intervention scenario and 3,225 hectares in the enhanced intervention scenario.

Although these two scenarios have the Forest Code as a reference, this study is not related to any existing command-and-control mechanisms or policies.

3. Customized Scenarios (RIOS): It considers the Cantareira System's geophysical characteristics, such as climate, topography, soil type, and underlying geology. By applying the RIOS model, it spatially defines the areas that maximize water infiltration and baseflow. In this scenario, 32,085 hectares have been defined for interventions distributed in the four sub-basins.

In the minimum intervention scenario, we considered the current rules of the Forest Code, which define permanent protected areas ranging from 5 to 30 meters along rivers and streams, 500 meters around reservoirs, and 15 meters around springs.

For the expanded intervention scenario, we considered Forest Code parameters before the changes made by Law 12.651/12, that is, 30-meter riparian strips around rivers and streams, 500 meters around reservoirs, and 50 meters around springs.

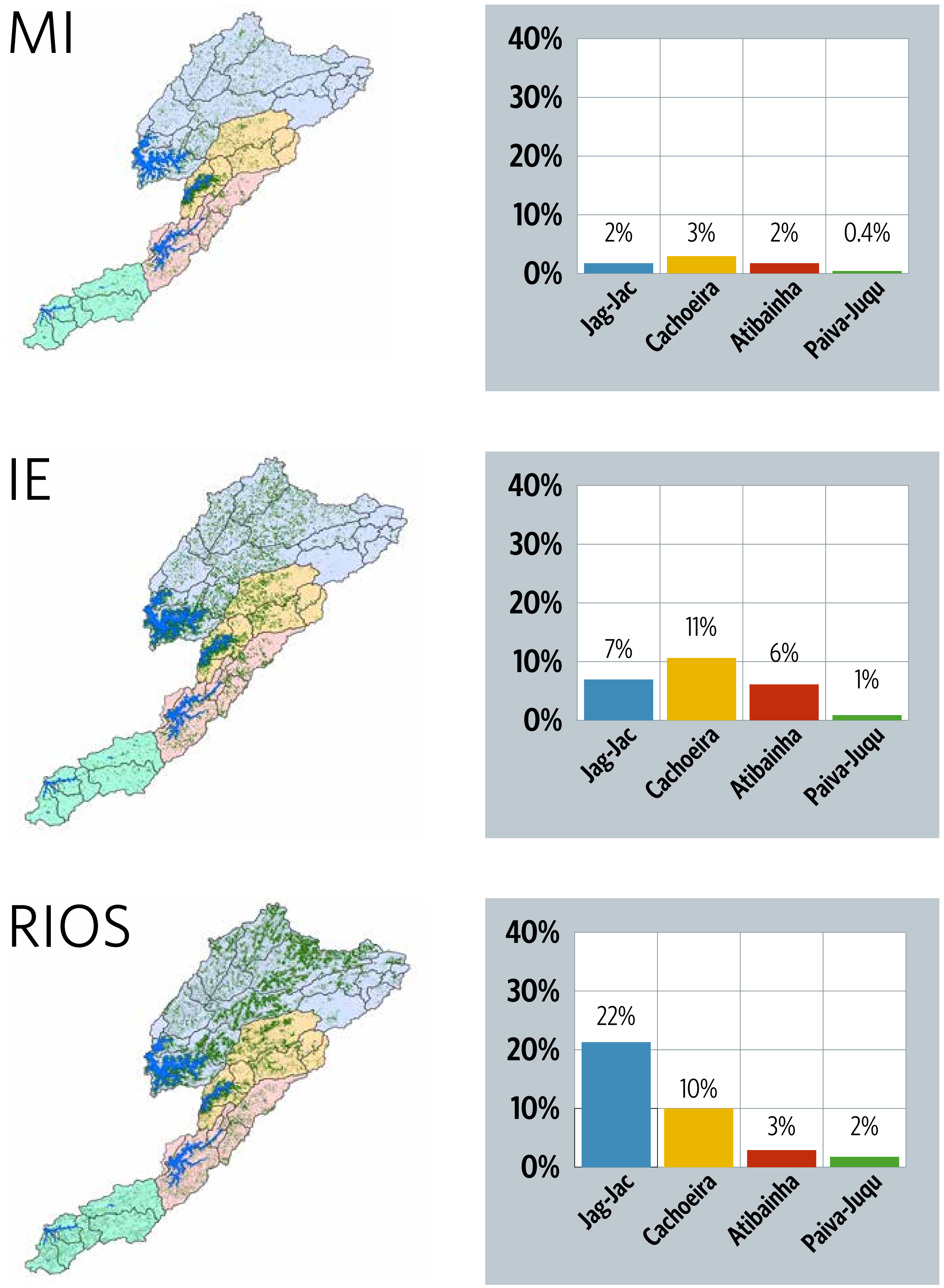


FIGURE 5: SPATIAL DISTRIBUTION OF INTERVENTION SCENARIOS IN THE CANTAREIRA SYSTEM AND QUANTIFICATION OF INTERVENTIONS WITHIN EACH SUB-BASIN

Hydrological Models Results

Two hydrological models – HEC-HMS and SWAT – were used to simulate the long-term hydrology of the Cantareira System, and to estimate the water quantity and quality effects of the intervention scenarios (Figure 6). The model results provide decision-relevant information on land use and territorial planning in the Cantareira System.

These models represent different levels of watershed complexity and hydrologic functionality. HEC-HMS model simulates water balance functions within a simple algorithmic structure to represent storage and movement of water broadly and requires a relatively small number of parameters. In contrast, the SWAT is a semi-distributed continuous hydrologic simulation model that includes multiple hydrologic and water chemistry processes to simulate the watershed hydrology more precisely at a greater spatial resolution. Model outputs include surface runoff, groundwater flow, soil water retention, and water quality metrics. However, SWAT requires more detailed model inputs at a greater spatial resolution including, geospatial attributes such as soils, land use/ land cover, topography, and crop management parameters.

The modeling was conducted in the individual watersheds draining to the Cantareira System reservoirs as follows:

- Jaguari-Jacareí watersheds
- Cachoeira watershed
- Atibainha watershed
- Paiva Castro watershed

Nature-based landscape management actions, such as restoring and protecting the Atlantic rain forest can amplify the local effects of fog capture, precipitation interception and storage in canopy, and increase infiltration and soil water storage. Changes in these hydrologic components can affect the overall water balance and timing of water yield. For instance, more water is partitioned to groundwater flow through increased infiltration and soil water storage while decreasing surface runoff and attenuating flood downstream (figure 8).

While the water quality impacts were a part of the modeling study, this document focuses on the water quantity impacts of the intervention scenarios, as outlined in the following.

In general, the RIOS scenario demonstrated the greatest hydrological benefits in all watersheds with the largest increase in water storage and yield.

Compared to observed data, the calibrated HEC-HMS model provided a better response when considering the average flow. In contrast, the SWAT model resulted in a better correlation with the hydrograph's extremes, that is, the flow peaks and drought flows (Figure 7).

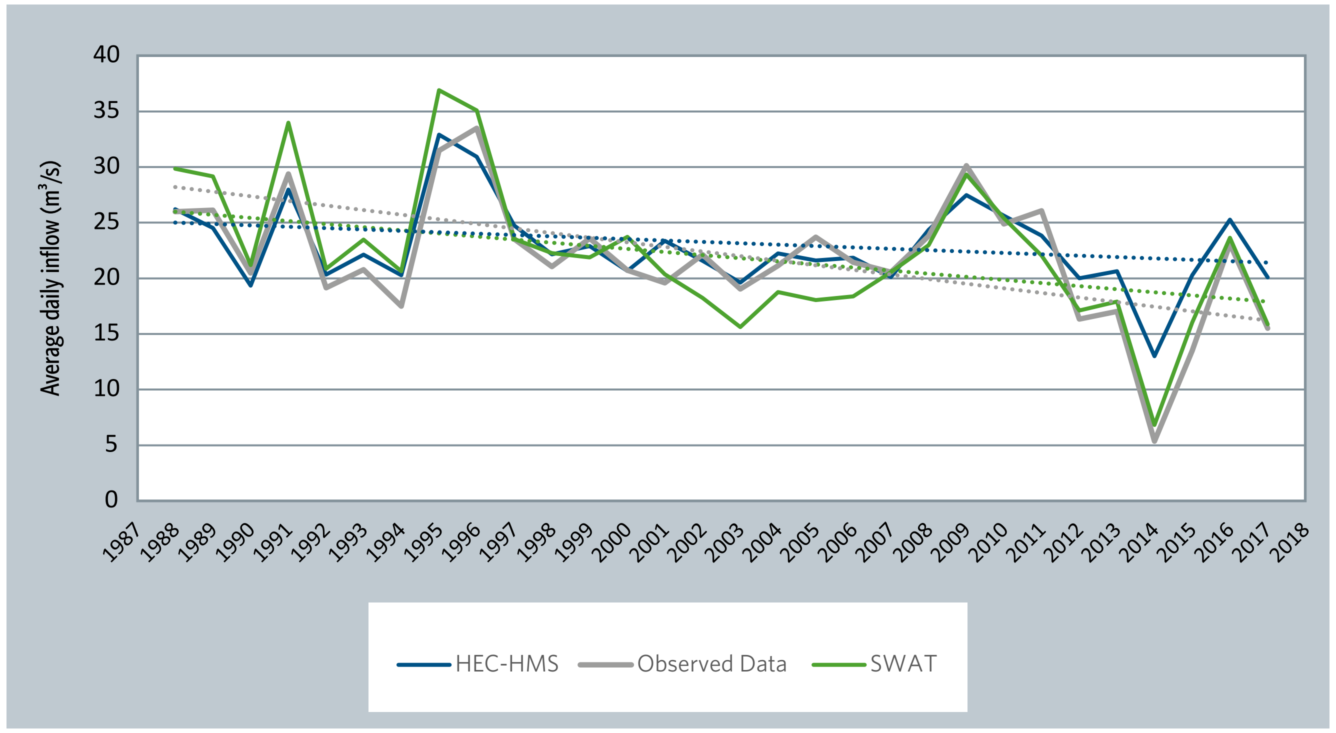


FIGURE 6: COMPARISON BETWEEN CALIBRATED MODEL BASELINE OUTPUTS AND OBSERVED DATA.

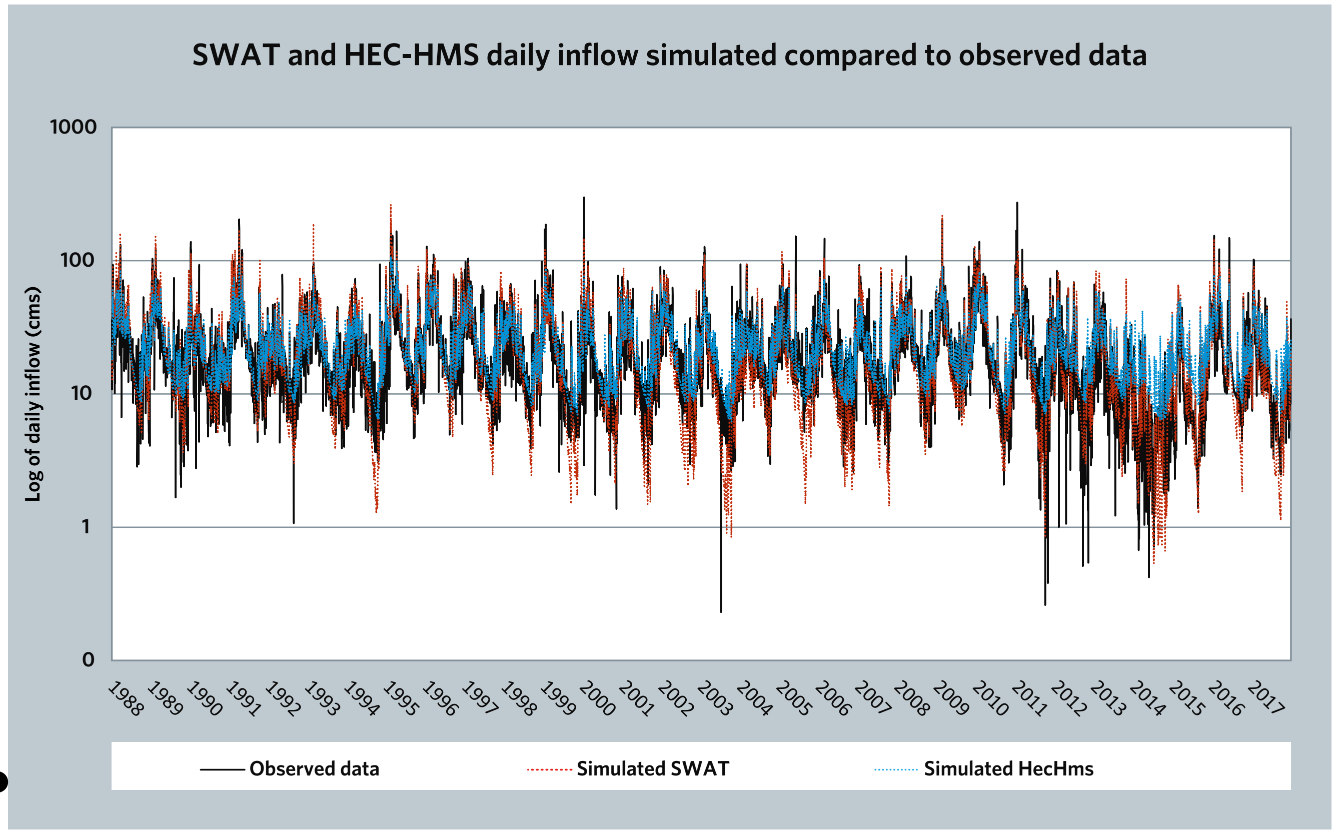


FIGURE 7: RESPONSE ACCURACY OF SWAT AND HEC-HMS MODELS COMPARED TO OBSERVED DATA.

Hydrological model variables for natural infrastructure simulation model

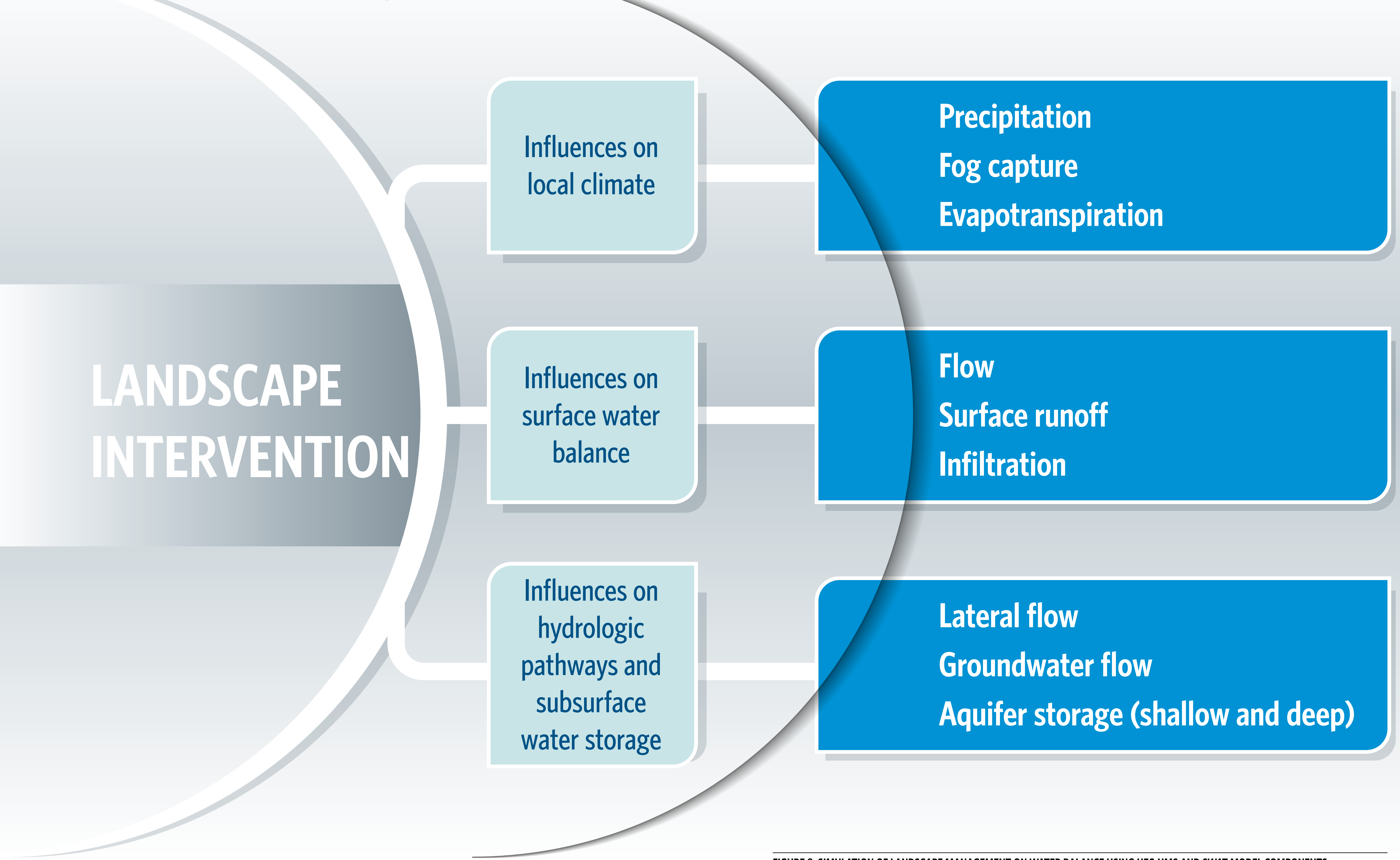


FIGURE 8: SIMULATION OF LANDSCAPE MANAGEMENT ON WATER BALANCE USING HEC-HMS AND SWAT MODEL COMPONENTS

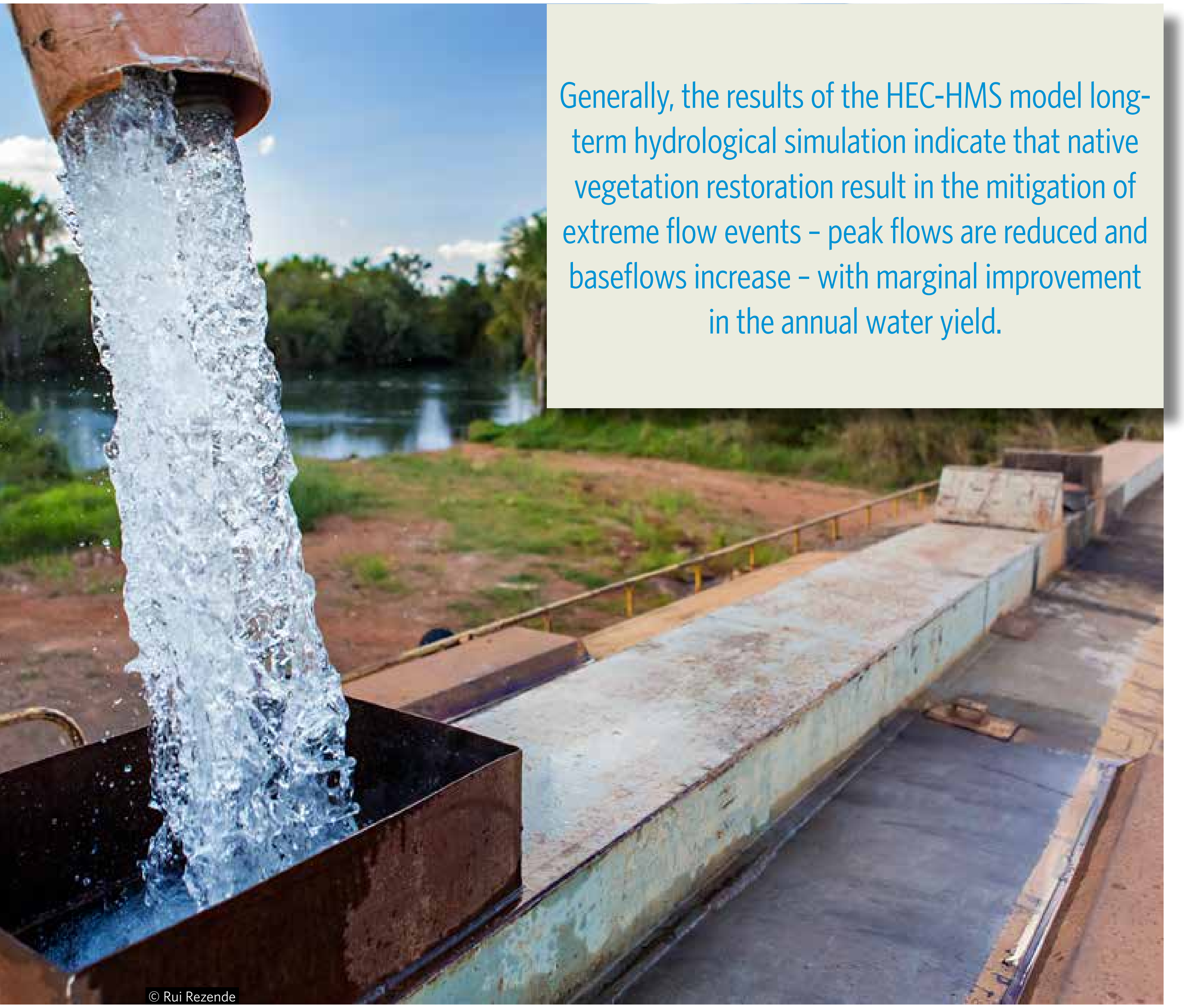
HEC-HMS Model Results

HEC-HMS model provides a general understating of how the intervention scenarios impact water balance and yield in the reservoirs.

Monthly average flows were calculated for the entire simulation period (1988-2018), and for the drought years of 2013-2015. In general, the results show an increase in river flows with the intervention scenarios throughout the years with largest increases during the dry months. The largest increases were observed in the Jaguari-Jacareí sub-basin.

Flow increase with intervention scenarios are greater during the 2013-2015 drought period, compared to the entire simulation period, indicating that the intervention scenarios have the potential to mitigate water scarcity conditions.

Generally, the results of the HEC-HMS model long-term hydrological simulation indicate that native vegetation restoration result in the mitigation of extreme flow events – peak flows are reduced and baseflows increase – with marginal improvement in the annual water yield.



© Rui Rezende

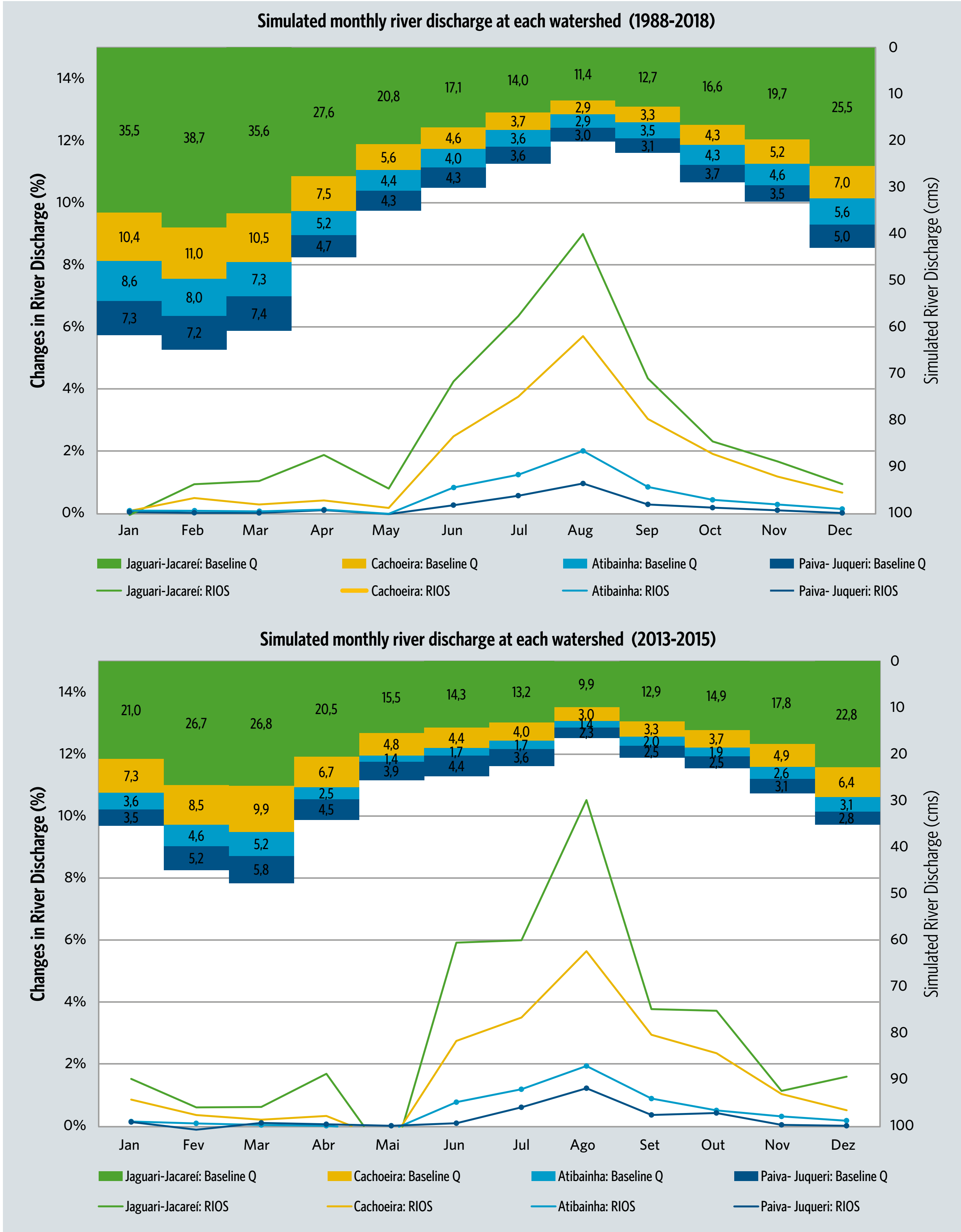


FIGURE 9 AVERAGE MONTHLY RIVER FLOW AND THE CHANGES IN EACH INTERVENTION SCENARIO FOR (A) THE ENTIRE SIMULATION PERIOD AND (B) DROUGHT YEARS.

SWAT Model Results

Water Balance

The SWAT model was calibrated to estimate the spatially distributed daily water balance, including surface runoff and water infiltration in the soil layers for each hydrological response unit (HRU).

Figure 10 demonstrates the main water balance components generated by the SWAT model for the baseline scenario in the Jaguari watershed, including precipitation, surface runoff, lateral flow, input from groundwater to baseflow, soil water, and percolation.

Soil-water storage represents accumulated water over the years of analysis. It is important to highlight that soil water is the greatest volume of water storage among all the hydrological components. Changes in soil-water storage can influence the water table and the lateral flow to the Cantareira System reservoirs.

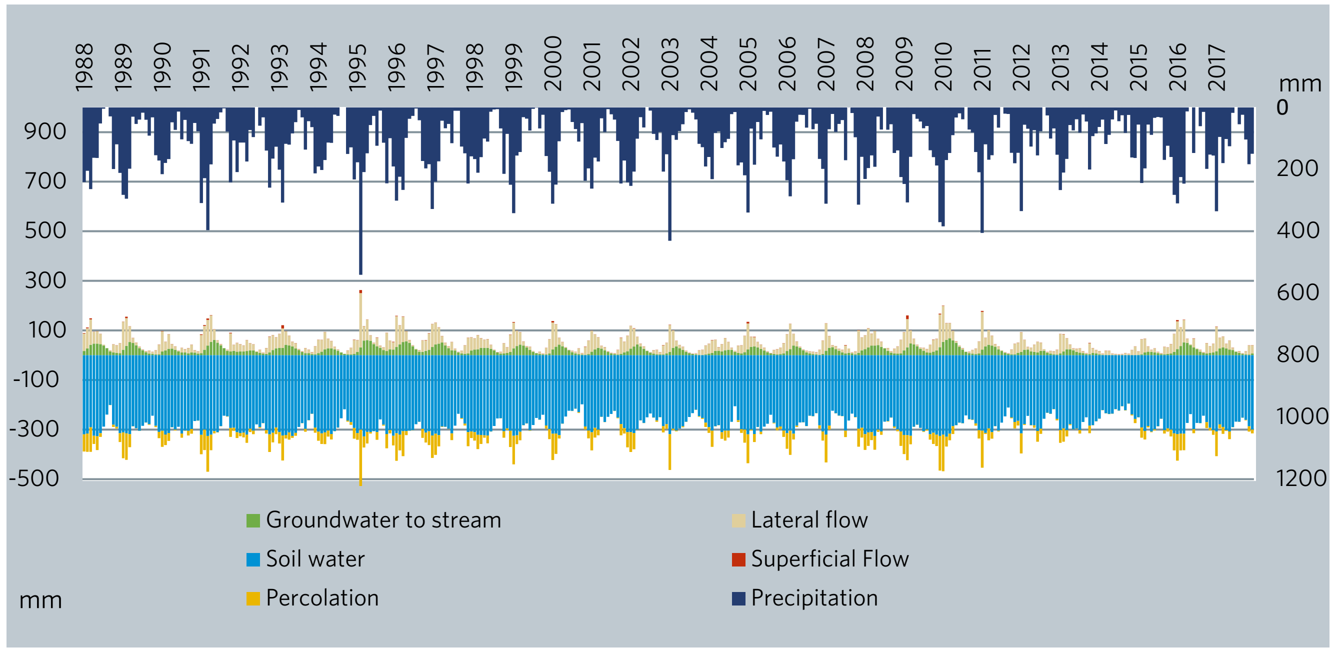


FIGURE 10 COMPONENTS OF THE WATER BALANCE IN THE SWAT MODEL RESULTS FOR THE BASELINE IN THE JAGUARI WATERSHED.

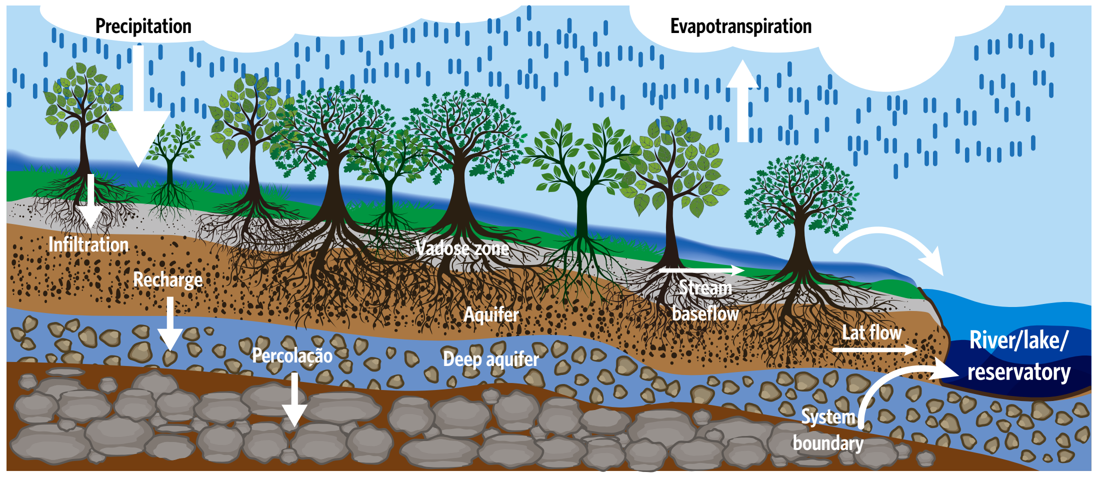


FIGURE 11 PROCESSES RELATED TO SWAT MODEL GROUNDWATER.

The SWAT model can simulate detailed water balance components, including surface, sub-surface, and underground flow.

Groundwater

The groundwater component is represented in the SWAT model as three types of reservoirs:

- **The layers of soil in which water is stored and redistributed:** This type of water is available for plant uptake, evapotranspiration, or water table recharge/free aquifer
- **Water table or free aquifer:** It's located below the top soil layer and separated by the 'vadose zone,' which receives percolated water from the soil's deepest layers. Water table or free aquifer can flow to the nearest body of water as groundwater input to the baseflow or can percolate to the deep aquifer
- **Deep aquifer:** The water that flows to the deep aquifer is outside of the study boundary layer

Modeling indicates that in the Cantareira System, a great portion of water is stored in the aquifer layers. Thus, the modeling results of intervention scenarios are found mostly in the soil storage component as opposed to the surface flow.

To evaluate that particular aspect adequately, we estimated the monthly average for each hydrological component in the drought period (2013-2015). Figure 12 demonstrates significant addition to the water balance in all the months of the year, especially in the soil water component.

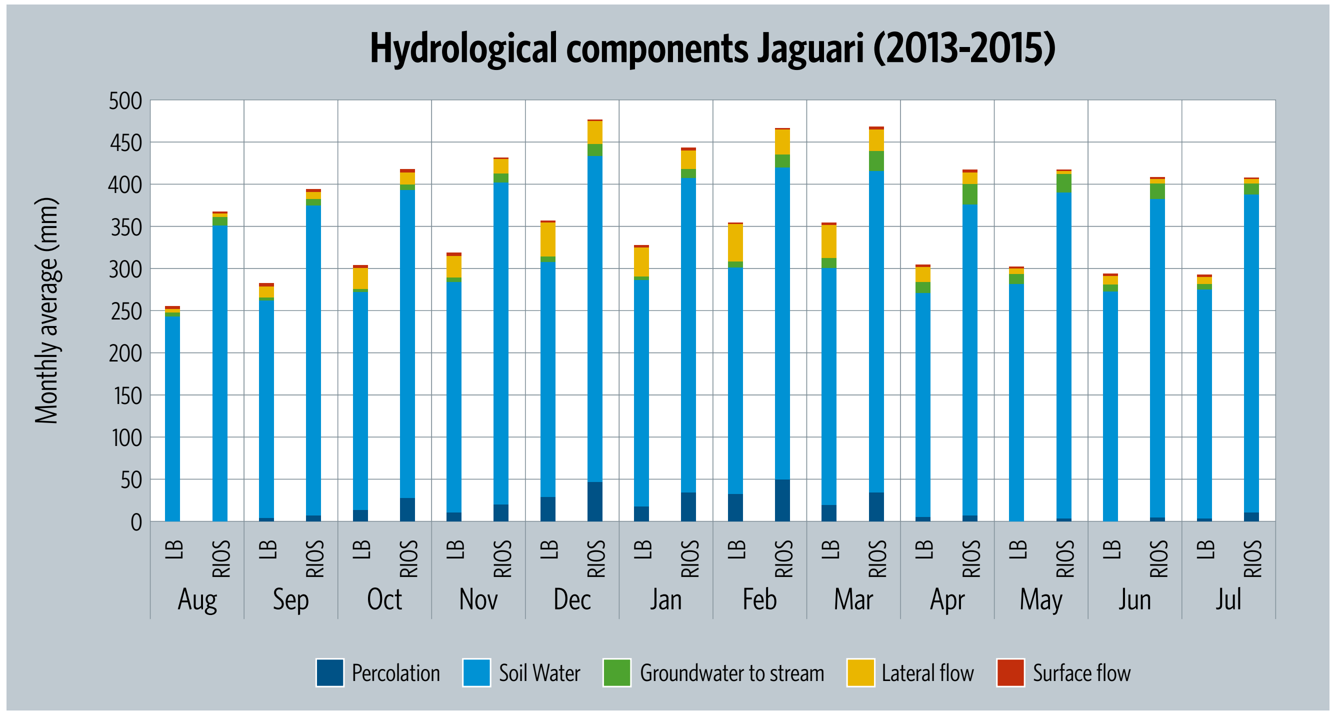


FIGURE 12 MONTHLY AVERAGES OF THE WATER BALANCE SIMULATED WITH THE SWAT MODEL FOR THE 2013-2015 DROUGHT PERIOD (BASELINE VS. RIOS SCENARIO).

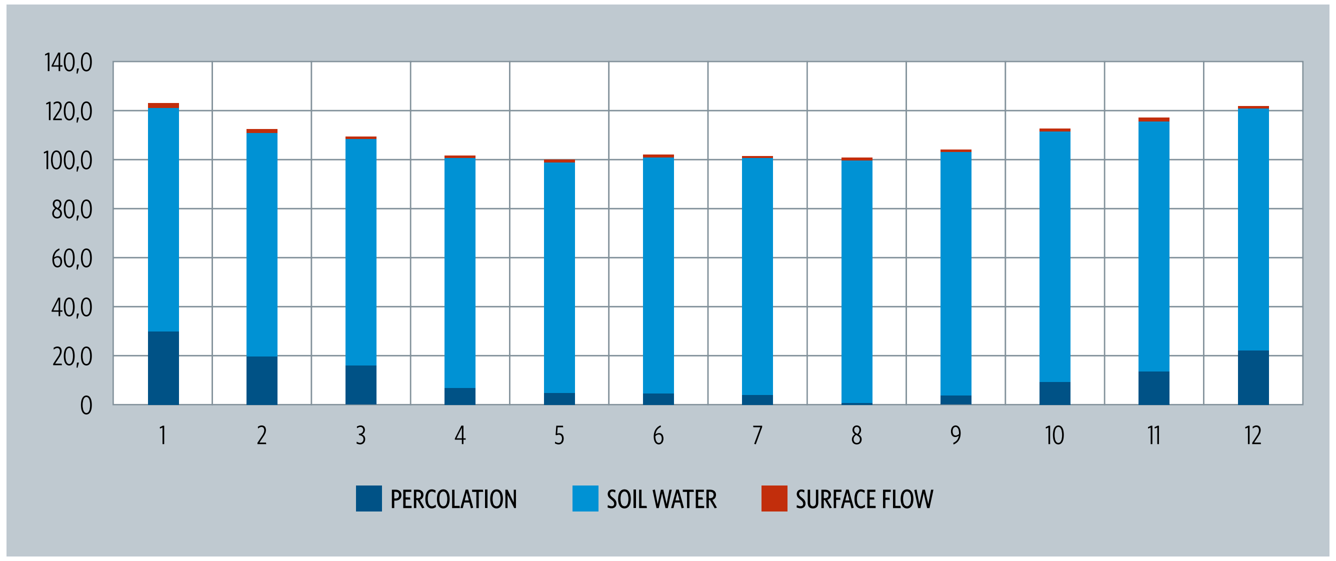


FIGURE 13 DIFFERENCE IN THE MONTHLY AVERAGE FOR PERCOLATION, SOIL WATER, AND SURFACE RUNOFF BETWEEN INTERVENTION SCENARIOS IN MILIMETERS (2013-2015).

Figure 13 demonstrates the difference between the baseline and the customized RIOS scenario in the monthly water balance for the drought season, shown in millimeters. On average, the RIOS intervention scenarios represent a monthly water storage increase of 100 mm.

Those results support the hypothesis that NbS s can bring significant ambient water storage to the general water balance in the Cantareira System, increasing soil moisture and aquifer recharge.

Due to the modeling's limitation, it is impossible to predict the exact proportion between the quantity of water that becomes part of the baseflow versus the quantity that recharges the aquifer.

It's worth noting that soil water storage represents accumulated water balance throughout the years of analysis, demonstrating that the NbS contribute to water security, not only in the sub-basins where the Cantareira System's reservoirs are located but also in the neighboring sub-basins, which benefits the supply of other municipalities in addition to the water use by economic activities, such as agriculture.

> *If the alternative scenario represented the predominant LULC the 30 years of the study, the hydrological answer would be similar to the one found in the modeling results.*

> *The results of this study clearly indicate that the hydrological components of soil and groundwater represent the Cantareira System's "Invisible Reservoir."*

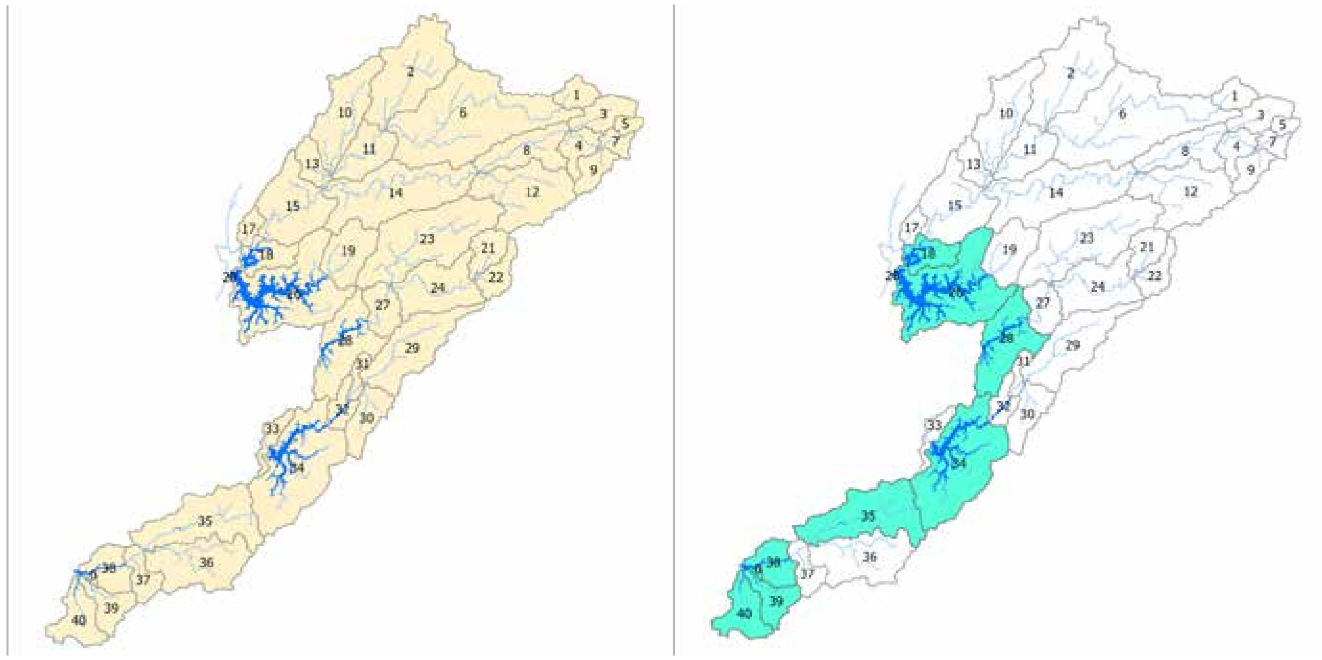
Recharge and Drainage Areas

The SWAT model outputs are evaluated in the sub-basins that recharge (Figure 14a) and drain to the reservoirs (Figure 14b).

Since the RIOS scenario maximizes the aquifer recharge by prioritizing specific areas for NbS implementation, most significant impacts are observed in the drainage sub-basins near the reservoirs.

By conducting a similar exercise over the time of the study, the NbS contribution to the general water balance is estimated.

The SWAT model estimates: 1) the average water storage in all the sub-basins across the Cantareira System and 2) the average water storage in the sub-basins that drain to the reservoirs (Figure 15).



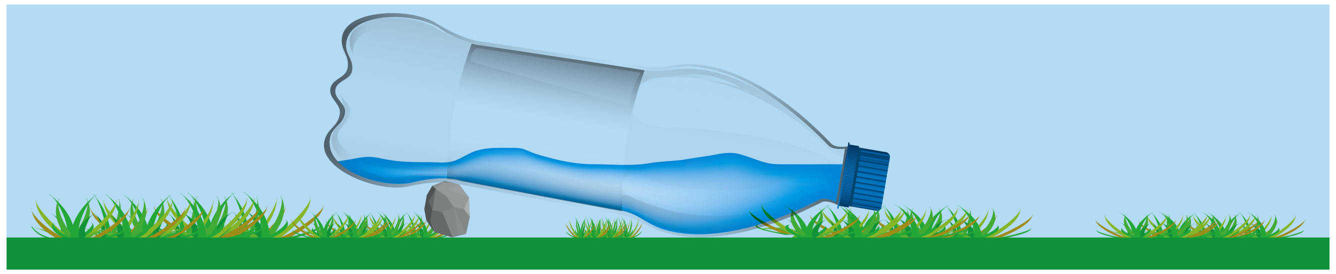


FIGURE 14 ALL THE SUB-BASINS THAT CONTRIBUTE TO THE CANTAREIRA SYSTEM (A) AND THE DRAINAGE-ONLY SUB-BASINS (B).

If all recharge areas are considered, an average increase of 33% (206 hm3/year) of water in the hydrological system is indicated.

If only the discharge sub-basins are considered, an average increase of 58% (or 341hm3/year) of water in the hydrological system is indicated.

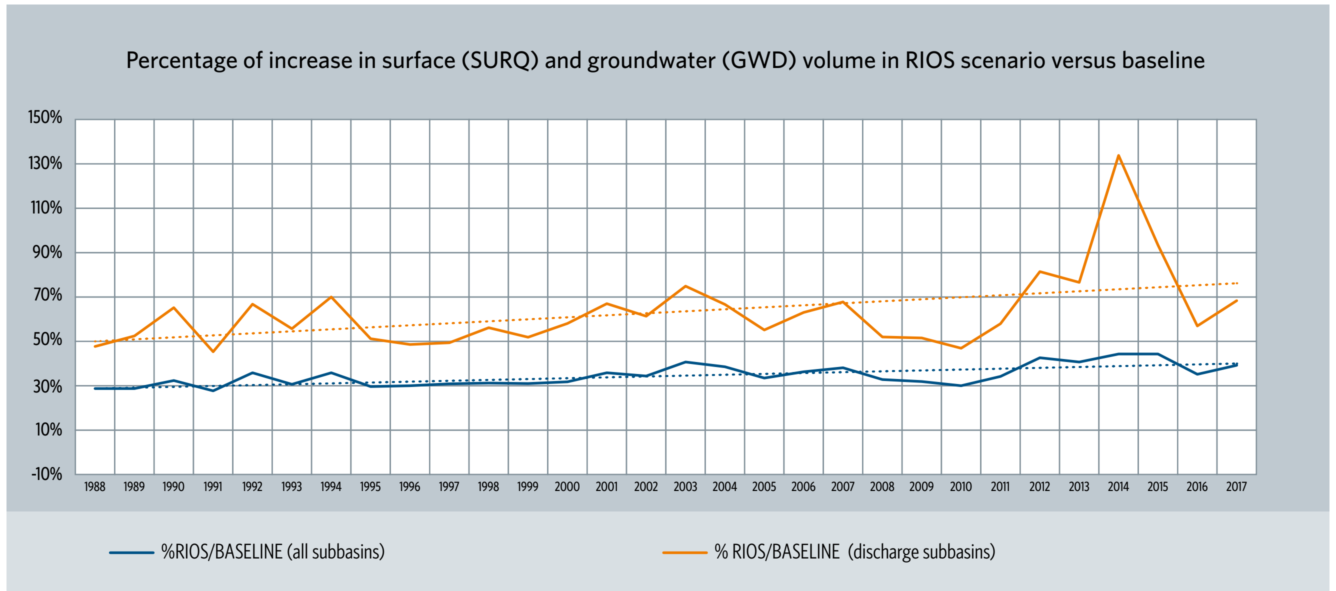


FIGURE 15: PERCENTAGE OF INCREASE IN THE VOLUME OF SURFACE AND GROUNDWATER IN RIOS SCENARIO IN RELATION TO THE BASELINE - AVERAGE WITH ALL BASINS AND AVERAGE WITH THE DISCHARGE BASINS

The difference between the baseline and the RIOS scenario is greater each time water availability decreases. A significant peak of this difference is observed in the period of the greatest drought recorded in the history of the state of São Paulo, between 2014 and 2015. At these times, the modeling shows how nature-based solutions, particularly during extreme weather conditions, can attenuate the peaks in floods and droughts, reducing water risks.

Hydrological Component of Water Flow

The result combining the hydrological components that contribute to the overall water yield – namely, surface flow and the input from groundwater to surface flow – shows a significant increase with the RIOS scenario compared to the baseline.

If all the sub-basins across the Cantareira System are considered, the modeling results indicate an average increase of 33% (or 206 hm3/year).

If the results are considered in the sub-basins that drain to the reservoirs, the modeling results indicate an average increase of 58% (or 341 hm3/year).

It's worth highlighting the specific benefit during the periods of low water availability, as was the case in the 2013-2015 drought event when those two hydrological components were considered together. The difference between the baseline and the RIOS model scenario increases with decreasing water availability. A significant peak in the difference was observed in the 2014-2015 drought period (figure 16).

Both HEC-HMS and SWAT demonstrate the hydrological benefits associated with NbS implementation to increase water security. The results align with the central message of the United Nations World Water Development Report, published by UNESCO, titled "Groundwater: Making the Invisible Visible," highlighting the critical importance of promoting subsurface water storage, which represents approximately 99% of all liquid fresh water on Earth, as a part of a water resources management.

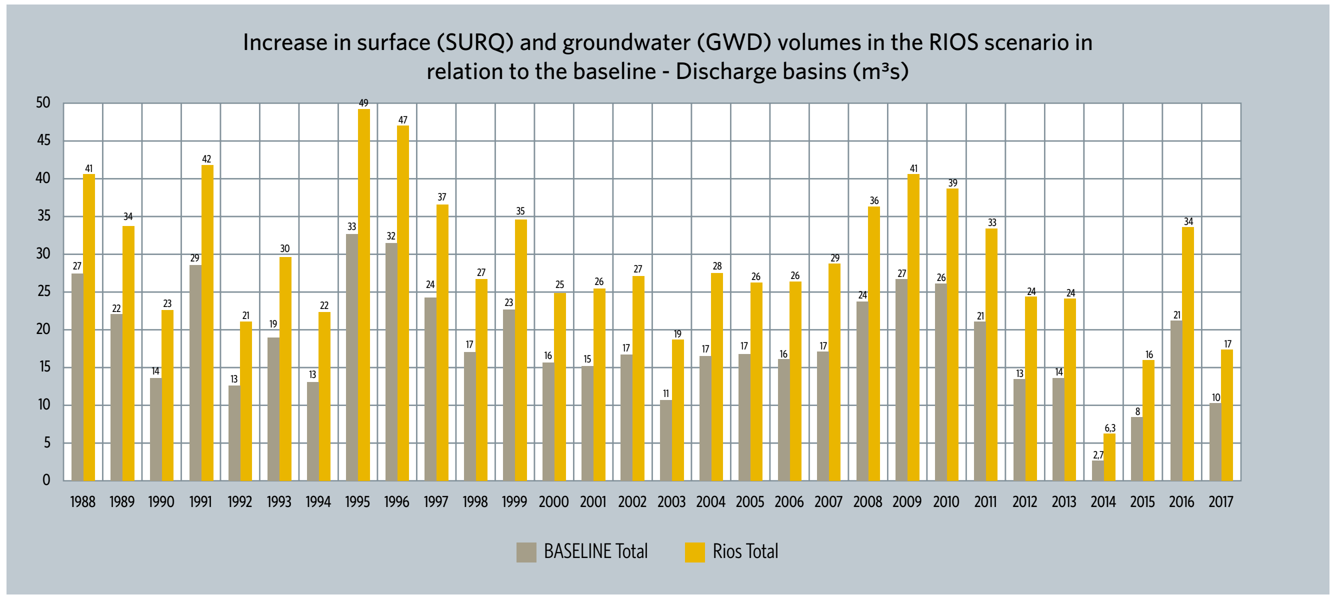


FIGURE 16: INCREASE IN THE VOLUME OF SURFACE GROUNDWATER IN THE RIOS SCENARIO IN RELATION TO THE BASELINE CONSIDERING THE DISCHARGE BASINS ONLY

Economic Analysis

Based on the hydrological results, the study conducted an analysis to assess the possible economic consequences associated with greater hydrological resilience during low water availability events. The analysis focused on the RIOS customized scenario as it obtained the best hydrological results based on large-scale NbS spatial prioritization.

RIOS investment scenario overview

The investments involved in implementing the RIOS scenarios were estimated based on a full-cost account that was grouped in the following categories:

- **Implementation Costs:** Labor and resources in the first year of implementation
- **Maintenance Costs:** Monitoring labor and resources needed to maintain a long-term intervention
- **Opportunity Costs:** Compensation for owners whose lands are designated for restoration through Payment for Environmental Services (PES)
- **Transaction Costs:** Planning and organizing costs required mobilize and engage landowners, develop associated contracting, and execute monitoring
- **Management Costs:** Management of a watershed protection program

The RIOS scenario contemplates an intervention portfolio of 32,085 hectares spread

over the four sub-basins. The estimated cost of the interventions was calculated considering two restoration techniques that apply to the Cantareira System, namely:

Natural Regeneration / Passive Restoration Management: This technique involves isolating the area from degradation factors to expedite restoration process. This may include measures including fencing out livestock, control of exotic invasive species, and sporadic enriching via seedling planting. The technique assumed to compose 75% of the intervention portfolio in the RIOS scenarios.

Active Restoration: This technique is applied in degraded areas with a low potential for natural regeneration. It implies the intensive planting of selected seedlings to accelerate the regeneration process in addition to the techniques mentioned above. This technique was considered for 25% of the intervention portfolio in the RIOS scenarios.

The average cost per hectare for the program's 35-year life cycle is estimated at $6,343 per hectare for the managed regeneration activities and $9,774 per hectare for active restoration. When multiplied by the intervention portfolio of 32,085 hectares, total costs for the Cantareira System implementation program are estimated at $236 million on nominal basis (or $180 million on a Net Present Value basis, referencing a social discount of 4.36%).

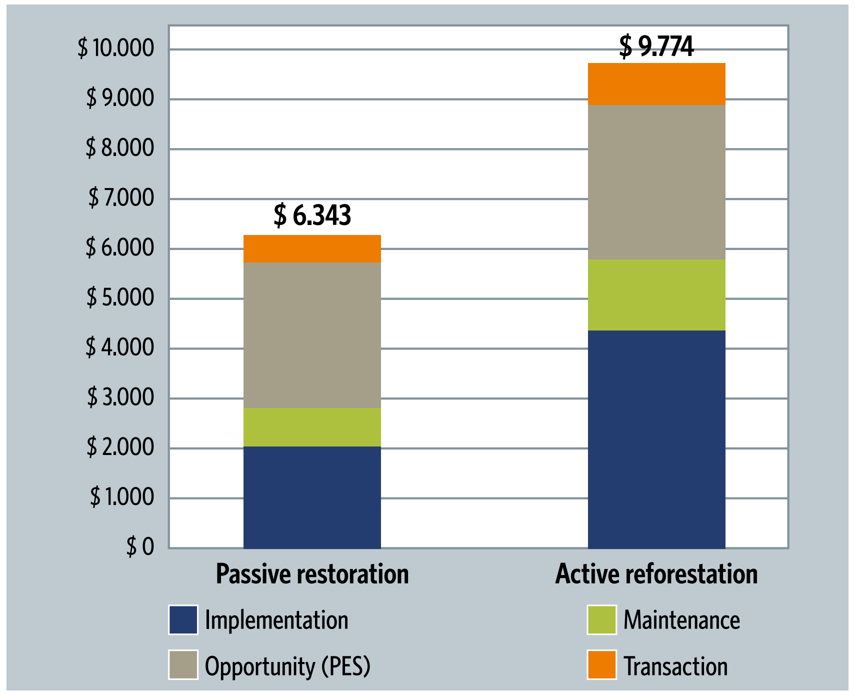


FIGURE 17: RESTORATION COSTS PER HECTARE

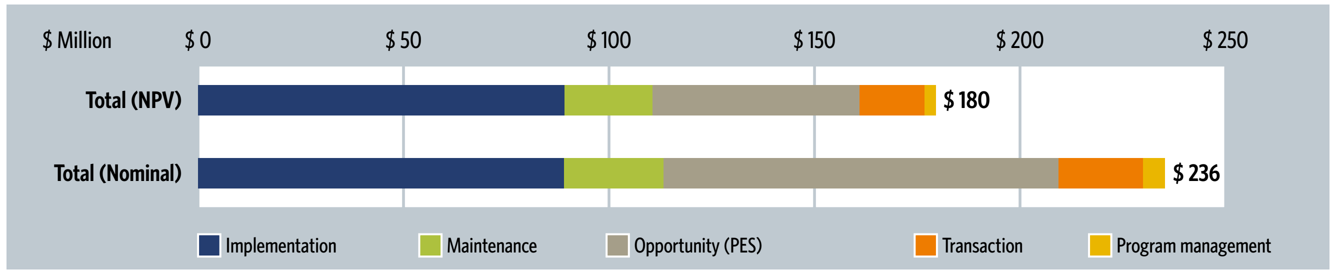


FIGURE 18 TOTAL PROJECT LIFECYCLE COSTS IN NOMINAL VALUE AND NPV (IN $ MILLION)

Economic valuation of the cost of extreme drought and value of ambient-water storage

The total financial loss associated with the water crisis was estimated at $450 million

To assess the economic benefits of water storage in the environment with the implementation of the RIOS scenario, the cost of the water crisis occurred in the Cantareira System from 2014-2015 was estimated. To this end, two components representing the income surplus of the municipalities served by the Cantareira System were considered in the economic modeling:

- The loss of industry Gross Value Added (GVA)
- The loss of water supply and sewage treatment Net Value Added (NVA)

To estimate the financial loss during a water crisis, a counterfactual scenario is created considering the industry GVA between 2002 and 2013 and the water supply and sewage treatment NVA curve between 2008 and 2013. Both parameters are projected for 2014 and 2015 without water restriction using a regression equation. The difference between the projected and observed data represents the financial loss resulting from the water crisis, i.e., the drought cost (DC).

Using this methodology, industry GVA losses due to the drought were estimated at $302.7 million while the losses attributable to water and sanitation services were estimated at $147.2 million.

Nature-based Solutions and the Potential for Mitigating Financial Loss

The results of this study are interpreted as if the RIOS scenario represented the prevalent LULC in the Cantareira System during the 30 years preceding the 2018 baseline.

With the RIOS scenario, we estimate that the benefits associated with NbS investments would have been $82.4 million and $41.6 million in avoided financial losses attributable respectively to industry GVA and water supply and sanitation sector NVA. In summary, NbS could have avoided financial losses of $124mm, or 28% of the total financial cost of the drought.

The study indicates that NbS investments can provide meaningful resilience to water scarcity events in the Cantareira System. Therefore, such investments should be considered as part of water sector investment allocations for protecting source watersheds, as well as being part of the territorial planning set in public policies.

The avoided financial loss with NbS would be $124 million, representing a 28% reduction in the financial cost of the drought.

Avoided costs in the industry with a RIOS scenario ($1,000) - 2014-2015			
Industry GVA loss in the Cantareira System municipalities (I)	Industry GVA loss in the Cantareira System municipalities under the RIOS scenario (II)	Avoided industry GVA financial losses with the RIOS scenario (III = I - II)	Percentage of avoided industry GVA financial losses (%) (IV = III/I)
302.691	220.266	82.425	27%
Avoided costs in the water supply and sanitation services with the RIOS scenario ($1,000) - 2014-2015			
Loss of water and sanitation services NVA in the municipalities served by the Cantareira System (V)	Loss of water and sanitation services NVA in the municipalities served by the Cantareira System under the RIOS scenario (VI)	Avoided financial loss of water and sanitation services NVA with RIOS (VII = V - VI)	Percentage of avoided financial loss of water and sanitation services NVA with RIOS scenario (%) (VIII = VII/V)
147.198	105.590	41.608	28%
Total avoided financial loss (IX = III + VII) 124.032			
Percentage of total avoided financial loss (%) [X = IX/(I+V)] 28%			

TABLE 1: SUMMARY OF THE MITIGATED FINANCIAL LOSSES IN THE INDUSTRY GVA AND THE REVENUES IN THE SUPPLY SECTOR UNDER THE RIOS SCENARIO

Benefits Monetization

The complete estimative of benefits requires the projection of results for the complete program life cycle, stipulated in 35 years.

We followed three steps to arrive at this estimate:

- **Inflation adjustment :** Avoided financial losses of $124 million in 2015 with the RIOS scenario were adjusted according to the inflation data from Brazil's Central Bank (IPCA) accumulated through December 2021 to $170.4 million.
- **Drought recurrence period:** We adopted an incidence factor of 1/10 years to reflect the probability that similar losses from 2014-to 2015 will occur once every ten years.
- **Benefits realization curve:** Restoring ecosystems with forest restoration techniques considered in this study demand time for achieving the full hydrological functionality and water security benefits. The study assumed that ecosystem restoration benefits reach ecosystem and hydrological maturity by the eighth year of active restoration and by the twelfth year with natural regeneration.

Together and considering the 35-year horizon, those three steps generate ***a total estimated value of $500.9 million (nominal value) or $220.4 million (NVA) for the financial benefits associated with the additional availability of water during the drought periods*** potentially provided by the RIOS scenario.

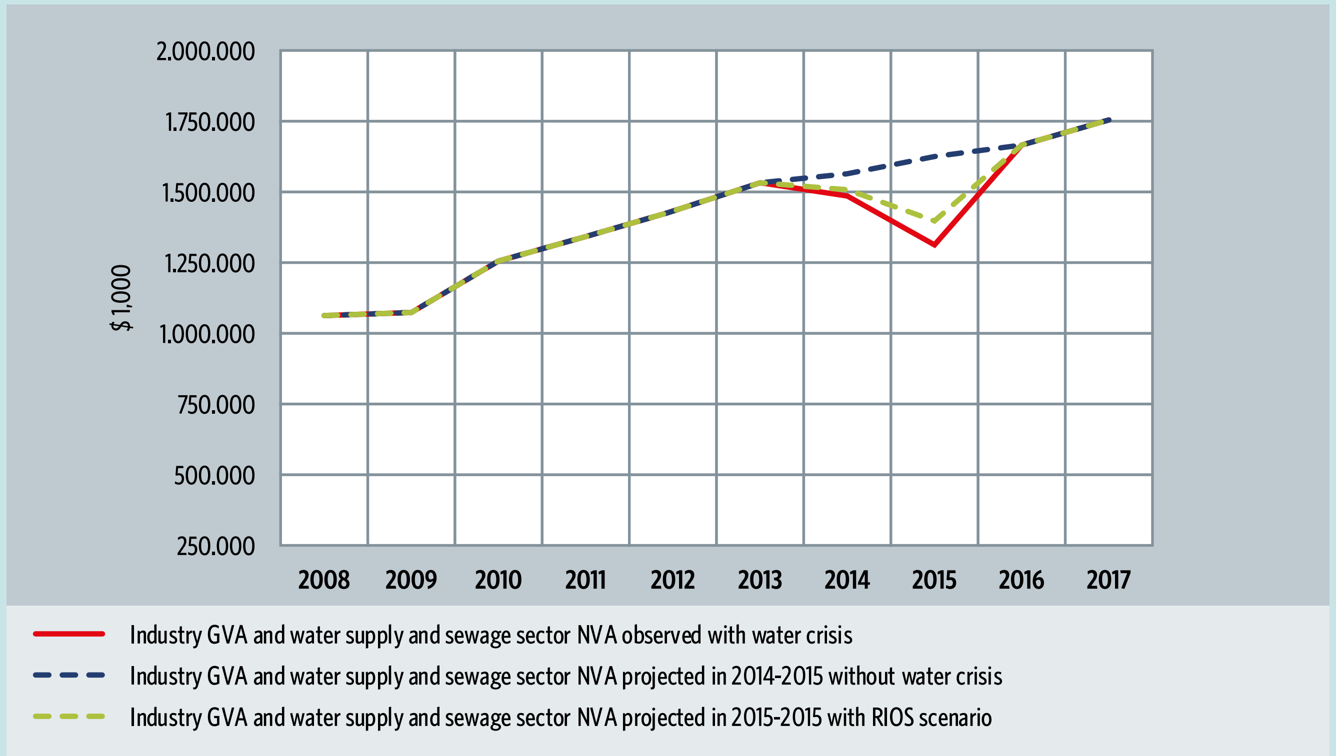


FIGURE 19 INDUSTRIAL GVA FINANCIAL PERFORMANCE (OBSERVED VS. PROJECTED) AND THE WATER SUPPLY REVENUES.

Cost-Benefit Analysis

Cost-benefit analysis (CBA) seeks to include environmental benefits in the financial analysis' scope. NbS investments generate benefits associated with environmental services not internalized by the market, such as hydrological regime regulation and sediment retention, among others.

An exception is that the carbon offsets market provides an opportunity to drive project cashflows from forest restoration activities. This is particularly true because the voluntary market has shown viability in recent years and therefore has the potential to contribute towards project cashflow.

Three financial benefit scenarios have been considered:

- **Water storage benefits only scenario:** Water storage benefits are estimated from the cost of the water crisis and the premise of a drought event recurring once every ten years. It should guide decision-making from the perspective of public and private gains due to the increased watershed resilience in cases of water scarcity.
- **Water storage benefits + voluntary carbon credit sales scenario:** Water storage benefits from the potential revenue from certified carbon credit and sale in the voluntary market. This benefit scenario should also guide decision-making from the perspective of public and private gains due to the increased watershed resilience in cases of water scarcity.
- **Water storage benefits + carbon social welfare scenario**: Water storage benefits from carbon's social cost as a proxy of the social benefits related to carbon sequestration. It should guide decision-making from the general social welfare perspective.

Regarding the water storage benefits scenario, **the RIOS scenario showed an estimated Net Present Value (NPV) of $40 million** (benefits of $ 220 million vs. costs of $ 180 million), representing a **1.2x cost-benefit relationship**.

In the **water storage benefits and voluntary carbon credit sales scenario**, considering the premise of an average carbon price of $7.69 and credit issuance every five years for 35 years, the NbS scenario indicates **an estimated NPV of $84 million** (benefits of approximately $264 million vs. costs of $180 million), representing **a cost-benefit relationship of 1.4x**. Meanwhile, if evaluated using the social cost of carbon of $24.00, the NbS scenario showed an estimated NPV of $177 million ($357 million benefit vs. costs of $180 million), representing a cost-benefit relationship of 2.0x.

© Erik Lopes

The financial results demonstrate that in all the scenarios in which we included benefits associated with increased hydrological resilience and climate-change mitigation, the restoration of the Cantareira System shows positive financial viability.

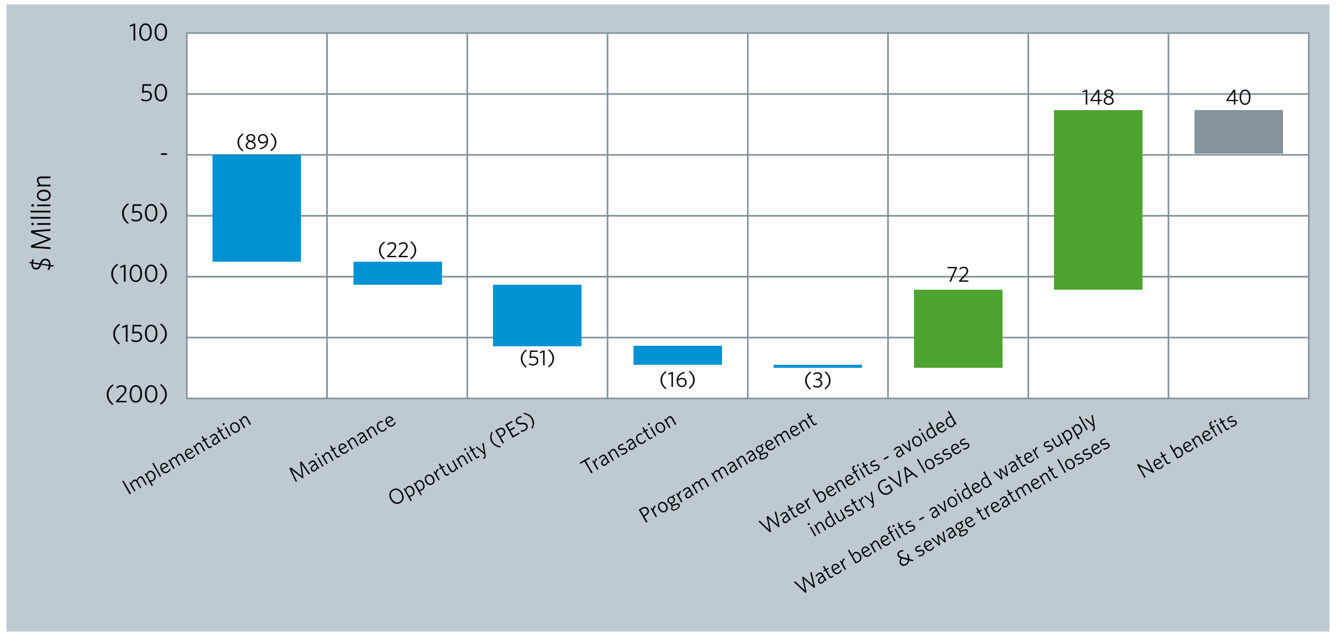


FIGURE 20 THE NPV FOR THE NBS SCENARIO FOR THE FULL 30-YEAR LIFE CYCLE CONSIDERING THE WATER STORAGE BENEFIT.

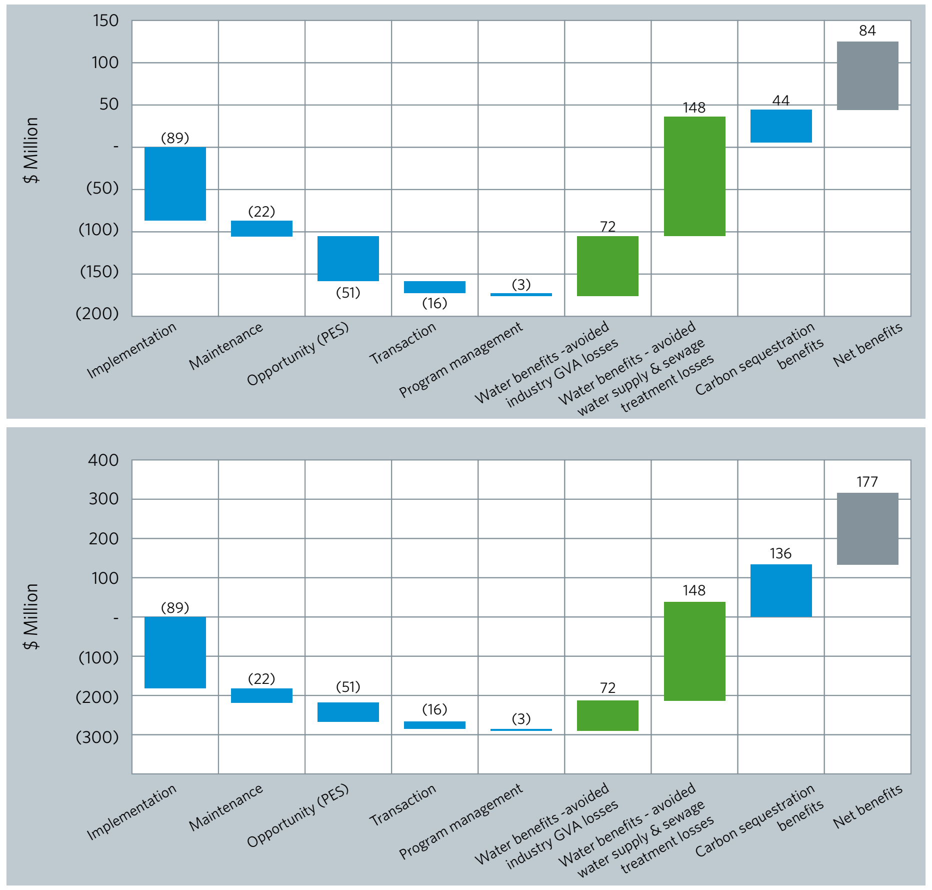


FIGURE 21 NPV FOR THE NBS SCENARIO FOR (THE FULL 30-YEAR LIFE CYCLE CONSIDERING THE AVERAGE PRICE OF CARBON (LEFT) AND CONSIDERING THE SOCIAL COST OF CARBON (RIGHT).

Premises, Co-benefits, and Uncertainties

Since a study like this one is subject to various implicit uncertainties due to complexity of the analytical tasks, conservative premises have been carefully selected to avoid overestimating results.

Drought Recurrence Period

The drought recurrence period determines the frequency with which drought-related financial losses are avoided due to the implementation of the RIOS scenario. We adopted an incidence rate of one event every ten years as a starting point in the analysis.

According to Brazil's Fourth National Communication to the United Nations Framework Convention on Climate Change, the evidence points to an increase in extreme climate events, including an increase in the intensity of both precipitation and drought events (Brazil, 2021).

Considering the ever-growing demand for public supply due to population growth, urbanization, and an increase in use by industry, the degree of economic impact on future drought events tends to be proportionally higher, opening up the margin of NbS return on investment in the Cantareira System.

Social Discount Rate (SDR)

Cost-benefit analyses of projects related to climate and/or ecosystem factors depend largely on which approach is used with the long-term discount rate. For long-term public investment, as is the case with watershed protection programs, usually the discount rate represents how society sees the value of present and future well-being (Arrow et al., 2014). Moore et al. (2020) evaluated SDR for 17 Latin American countries and estimated a Brazil-adjusted SDR of 4.3%. We used that rate to adjust costs and benefits to the NPV.

Since other authors suggest different values and considering the nature of NbS -promoted water security, which in principle benefits all spheres of society and tends to be permanent over time, we created a sensitivity analysis. **Table 2** demonstrates the general CBA for the NPV as a function of different combinations that result in an NPV > 1.0 are highlighted in green.

Co-benefits

The financial analysis covered water availability during drought specifically and considered the potential carbon removal only as a potential financial contribution. However, the NbS portfolio contemplated has the potential to generate other additional relevant benefits for water security.

Adaptation and Mitigation of Climate Effects

Both hydrological models indicate that the scenarios with NbS attenuate extreme hydrological events – peak flows and drought flows. Peak flow events are also important causes of financial losses related to damage to infrastructure and property, negative impacts on public health, loss of soil-related erosion, and silting of bodies of water/reservoirs, among others. The financial evaluation of such impact is relevant and should contribute positively to increasing the NPV in the CBA, but we did not formally evaluate these benefits as part of this study, which are instead areas for future research.

Water Quality

Another water security benefit expected from NbS investment is that of water quality. The SWAT model structured for this study is also adequate for estimating potential water quality results, including inputs of sediments and nutrients. A previous study has already explored potential water quality improvement and its financial impacts on sedimentation reduction and nutrient load in the Cantareira System (WRI, 2018); therefore, we chose to focus only on the water quantity/availability aspects as part of this study.

However, the water quality results generated by this study relied on an updated and broader database, which would allow a review of the abovementioned study. These new SWAT results can be used to review and update the prior water quality evaluation conducted by WRI in 2018.

Other Co-benefits

In addition to the water security results, the NbS portfolios analyzed in this study also generate other benefits that can be considered in a CBA.

Good management practices and additional alternatives to land use and cover: The study also explored the estimated potential benefits resulting from the adoption of agriculture best management practices (BMP) as one of the alternative scenarios with NbS. We chose not to include it in the financial analysis to avoid additional complexity. However, the BMP scenario also indicates benefits for water quality and soil water availability. We can assume that a combination of NbS interventions, including native vegetation protection and restoration, agroforestry systems implementation, and adopting soil conservation practices such as terracing and rotational grazing, would increase water security in the Cantareira System. In addition, a varied NbS matrix makes implementation more technically and politically viable.

Benefit Ratio/ Cost: Net Present Value (NPV)						
		Drought Recurrence Period				
		5	10	15	20	25
Social Discount Rate	2,0%	3,3	1,7	1,1	0,8	0,7
	2,5%	3,1	1,6	1,0	0,8	0,6
	3,0%	2,9	1,5	1,0	0,7	0,6
	4,5%	2,4	1,2	0,8	0,6	0,5
	5,0%	2,3	1,1	0,8	0,6	0,5
	5,5%	2,1	1,1	0,7	0,5	0,4
	6,0%	2,0	1,0	0,7	0,5	0,4

TABLE 2: CBA SENSITIVITY ANALYSIS FOR THE DROUGHT RECURRENCE PERIOD AND TAX RATES.

Other Socio-economic Benefits: The SWAT model results demonstrate the importance of soil water and groundwater that feed the water bodies due to the adoption of NbS. From the increase in soil water, we expect positive impacts on the profitability of cattle ranching and agriculture if those activities are done using techniques that take advantage of ecosystem services, such as rotational grazing instead of conventional, low-technology grazing and adoption of agroforestry systems. Socio-economic benefits are expected since landowners would have better conditions for production, increased income, and quality of life. If encouraged and managed, such practices take advantage of better hydrological conditions and feed water infiltration into the basin, bringing greater water security.

Uncertainties

The calibration process of a hydrological model implies adjusting biophysical parameters to the local environmental characteristics and demands long-term, good-quality input data. In this study, the best available data at that time (observed, long-term data accumulated over 30 years) was used, and the parameterization was exhaustedly tested to ensure that each model could yield the most precise results possible. Results should be interpreted based on comparisons between modeled baselines and counterfactual scenarios. Therefore, any conclusion must be understood as a simulation of the real world and not as a definitive and unambiguous indication of the hydrological behavior expected of alternative scenarios.

Current climate projections indicate that substantial changes should be expected shortly. According to the Brazilian National Communication to the United Nations Framework Convention on Climate Change, an increase in extreme precipitation events, alongside an overall decrease in annual precipitation and an increase in consecutive dry days, is projected for the southeastern region of Brazil (Brazil, 2021). This adds a layer of uncertainty that must be considered when analyzing the modeling results.

Implications for Public Policy

Nature-based Solutions and Climate Change Adaptation

The results of this study contribute to developing water security policies aimed at public water sources. The results presented here aim to support a decision support framework to enable policymakers in the CWSS to consider appropriate alternatives to generate water security in the face of long-term climate change.

The planning and management of water supply systems are based on historical hydrological patterns to define variation gradients. However, using historical series also needs to consider uncertainties about how hydrological systems will change under varying climate conditions. NbS represent one of the ways to adapt to such changes and mitigate their effects.

The approach exclusively focused on the uncertainties inherent in the spectrum of possible outcomes arising from NbS (Cassin and Matthews, 2021). The results presented in this study contribute to the understanding of the uncertainties implicit in applying NbS to water security in the Cantareira System, and the different potentials of possible benefits.

In addition to the peculiarities that differentiate the NbS from the solutions provided by conventional infrastructure, some challenges to their full adoption lie in the existing policies, the institutional arrangements already established, and the balance of political forces and general interests.

The approach exclusively focused on

Policy decisions on water management must be made urgently, even under uncertainties.

Compared to conventional infrastructure, the timeframe to achieve NbS benefits follows a distinct, less predictable pattern to achieve a stage of ecosystem functionality. The time-lapse between investments and the perception of benefits can be a barrier to persuading managers and decision-makers who generally aim for quick results (Browder et al., 2019).

Insecurity emerges when stakeholders and decision-makers do not fully agree or resist conventional infrastructure is deeply rooted in certain professional contexts, such as engineering in the sanitation sector, and ends up shaping institutional practices, making innovation difficult. Such biases are exacerbated by cognitive barriers, such as a minimized perception of climate risks and insecurity regarding decision-making under uncertainty, making them additional obstacles to implementing climate change adaptation actions (OECD, 2020).

Technical and Political Coordination

Investing in watershed protection with a focus on water security entails considerable policy complexity and coordination requirements. The coordination challenge involves the interconnection between public policies, the sanitation sector and regulation, local businesses, municipal, state, and sometimes federal administrations, among other instances, and stakeholders with specific interests, explicit or veiled.

The notion of shared roles and the need for a broad base of political, technical, and financial support are essential for the long-term success of this initiative. They need to be reflected in public policies. In addition to a solid scientific basis, as offered by this study and others, land-use planning and effective management require refined coordination between the various stakeholders. And that role is exercised essentially by public policy.

We need a rebalancing between policies that encourage economic activities in line with water security and those that discourage unwanted watershed activities.

© Clara Angeleas

Investment Coordination and Territorial Planning in Source Watersheds

This study provides an economic assessment that assumes a hypothetical situation in which a single funding source bears the necessary investments. However, conducting a permanent source watershed protection program involves multiple and synergistic funding sources.

In this case, sanitation regulation stands out due to the fundamental role it plays for the sanitation sector to take the lead in investing in protecting the water sources from which it captures water. That investment, once recognized as a natural component of sanitation operating costs and duly considered in the water tariff composition, provides a solid basis for sustainable financing in the long term. That is the case with ARSESP vis-à-vis SABESP and other concessionaires operating in the state of São Paulo and elsewhere.

Landscape planning is a role inherent to public policy and can impact the profitability of certain economic activities.
Activities that bring development opportunities to municipalities and landowners whose property house springs, in line with the demand for water security, should be encouraged.

On the other hand, the state and municipal administrations are responsible for coordinating territorial management policies. As a result, integrating investments in scale in the territorial management of watersheds demands the development and coordination of new and specifically designed policies.

For example, the analysis of land use and change in cover found in this study shows a slight increase in silviculture's expansion trend in the Cantareira System in recent years. As a water-intensive activity, the expansion of silviculture must be monitored to ensure that the sector's growth does not threaten the overall water balance in the Cantareira System.

Another change in LULC underway in the Cantareira System municipalities is the expansion of urban development and land subdivision, which also requires active supervision and control through adequate planning. In the case of São Paulo, acting preventively to avoid the loss of quality in the Cantareira System, as in the case of the Guarapiranga/Billings System, is imperative.

Lastly, one objective to be achieved is promoting specific economic activities that benefit the economy of municipalities and fit into local and regional economic vocations without prejudice to the noble role of a watershed territory.

Conclusions and Recommendations

Given the growing evidence that extreme weather events pose an adaptation challenge for cities worldwide, ensuring water security for people's well-being and economic development becomes increasingly urgent.

Recognizing that such a challenge represents a complex problem of territorial, economic, social, and political management, this study explored how NbS can contribute to water security in the Cantareira System as a complementary measure to conventional infrastructure investments already made.

By providing technical perspectives on hydrological processes, economic impacts, and policy implications, the results presented here demonstrate that investing in watershed protection positively impacts water security.

The study concludes that a careful spatial prioritization based on specific hydrological criteria offers the best results for enhancing water security. The hydrological models used showed the attenuation of peak and improvement in drought flows, alongside important benefits in water quality metrics.

Importantly, the results show a reversal of the downward trend in water availability observed over the last 30 years, indicating the potential increase in water availability from adopting NbS.

The NbS make an incremental contribution to promoting water security, increasing the water retention time in the sub-basins that make up the Cantareira System, increasing the volume of water in the soil and the water table throughout the year, and improving the water recharge to bodies of water in the dry season.

The "sponge effect" is clearly shown when comparing the hydrological behavior of NbS scenarios against the baseline between the rainy and dry seasons. Its characteristic is storing water in the soil and the water table during the rainy season and its gradual return to bodies of water as surface flow in the dry season.

The study contributes to the notion that the long-term protection of watersheds is viable when different, multiple, and synergistic sources of financing are combined, including public policies created specifically for that purpose.

Considering the specificity of a public supply watershed as opposed to any other river basin, a specific policy approach for those territories is necessary, in addition to involving other stakeholders.

The sanitation sector – under the authority of the municipalities – and its regulation deserve to be highlighted. As this sector is responsible for supplying water to the population and part of the economic activities, its economic viability is threatened if the supply systems are not resilient in the face of climate change.

The sanitation sector has, therefore, a leading natural role in involving other stakeholders and political forces, such as municipal and state governments and even the private sector. Furthermore, the involvement of municipalities is right behind that since most of the NbS are implemented in their territory. In addition, municipalities have the capillarity to mobilize and involve landowners who, in the final analysis, are responsible for deciding on land-use changes.

By encouraging land use that promotes water security, municipalities and state administration share a role in driving existing policies and creating new specific policies to promote better management of water supplies. The complexity of such policy coordination is not negligible. Still, as extreme events such as droughts and floods and their economic impact repeatedly plague cities and the economy, an ever-increasing number of decision-makers will be willing to consider and experiment with unconventional solutions, as is the case of NbS.

The hydrological components of surface water and groundwater can appropriately be defined as the Cantareira System's "invisible reservoir."

© Adriano Gambarini

AKNOWLEDEGEMENTS

The authors are grateful for the contributions of several people and institutions that contributed to this study. In particular, Mara Ramos, Suely Matsuguma, Emerson Martins Moreira, and Giovana Bevilacqua Frota from the Basic Sanitation Company of the State of São Paulo (Sabesp), for providing data authorized by the company. Rodolfo Gustavo Ferreras and Alessandro Silva de Oliveira, from the Public Services Regulatory Agency of the State of São Paulo (ARSESP), for their constant monitoring throughout the development of this work and their contributions during the technical discussions. To Dr. Margaret Palmer, Director of the National Socio-Environmental Synthesis Center (SESYNC), for hosting the postdoctoral program that enabled the institutional collaboration that resulted in this product. To our colleagues at the World Resources Institute (WRI), Rafael Feltran-Barbieri, for the technical contributions to the economic analysis and Suzanne Ozment for the articulation that made possible the collaboration between TNC, SESYNC, and WRI. Carlos Andres Rogéliz Prada and Jorge León for their technical collaborations in the development of hydrologic simulation models and Fernando Cesário, Carbons Specialist at TNC. We also thank the funders, Tinker Foundation, for the financial support that allowed this study to be carried out; the Partnerships for Forests program, funded by the UK Foreign Commonwealth and Development Office (FCDO), which supported part of this work; and the Latin American Water Funds Alliance – This publication is co-financed by the International Climate Protection Initiative (IKI) of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) through the Inter-American Development Bank which acts as administrator within the Latin American Water Funds Partnership. The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of IKI, BMU or IDB, their Board of Directors or the countries they represent.

About the authors

Se Jong Cho – Postdoctoral fellow - The National Socio-Environmental Synthesis Center/University of Maryland - email: se.j.cho@gmail.com

Eileen Andrea Porras Acosta – Freshwater Specialist – TNC Brazil – email: eacosta@tnc.org

Claudio Klemz – Water Policy Specialist – TNC Brazil – email: cklemz@tnc.org

Justus Raepple - Conservation Finance Lead – TNC Global – email: justus.raepple@tnc.org

Bruna Stein Ciasca – Lead Economist – TNC Brazil – email: bruna.ciasca@TNC.ORG

Samuel Roiphe Barreto – Water Program Manager – TNC Brazil – email: sbarreto@tnc.org

Henrique Bracale – São Paulo Water Fund Coordinator – TNC Brazil – email: hbracale@tnc.org

About TNC

Sobre a TNC Brasil A The Nature Conservancy(TNC) é uma organização global de conservação ambiental dedicada à proteção das terras e águas das quais toda a vida depende. Guiada pela ciência, a TNC cria soluções locais inovadoras para os principais desafios do mundo, de forma que a natureza e as pessoas possam prosperar juntas. Trabalhando em 76 países, a organização utiliza uma abordagem colaborativa, que envolve comunidades locais, governos, setor privado e a sociedade civil. No Brasil, onde atua há mais de 30 anos, o trabalho da TNC concentra-se em solucionar os complexos desafios de conservação da Amazônia, Cerrado e Mata Atlântica a partir de uma abordagem sistêmica, com foco na implementação e geração de impacto, para mitigar as mudanças climáticas e a perda da biodiversidade. Saiba mais em www.tnc.org.br.

About SESYNC

The National Socio-Environmental Synthesis Center (SESYNC) brings together the science of the natural world with the science of social systems and decision making to solve problems at the human-environment interface. Funded by and award from the National Science Foundation to the University of Maryland, SESYNC opened its doors in 2011. From the outset, we have sought to accelerate interdisciplinary collaboration that can lead to innovative scientific discovery. For 10 years, SESYNC has accelerated research and learning that seeks to understand the structure, functioning, and sustainability of coupled social and environmental systems.

For additional details, please reference the complete technical report from which the information for this executive version was extracted from. It can be accessed at: www.tnc.org.br

Supported by:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

based on a decision of the German Bundestag