Transforming Urban Water Management: A Decentralized and Nature-Based Approach in São Paulo, Brazil

MSc Thesis

Course Name: MSc Industrial Ecology
Author: Aistė Jakubauskaitė

Student Number: S3272168 (Leiden University) / 5714095 (TU Delft)
Supervisors: Ulf Hackauf & Merle de Kreuk
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Abstract

The São Paulo Water Center thesis investigates decentralized, hybrid water infrastructure as a model for resilient, equitable urban water management in megacities. Against the backdrop of São Paulo's intensifying droughts, floods, and infrastructure inequities—highlighted by the 2014–2015 Cantareira crisis and pollution in key reservoirs—the project proposes a multifunctional facility that integrates rainwater harvesting, greywater recycling, constructed wetlands, and nutrient recovery within a multimodal transit hub.

A case study in a peripheral basin near Billings and Guarapiranga demonstrates the system's technical performance: a hybrid treatment train processing up to 136,000 L/day, achieving over 70% reduction in municipal water demand and 65% greywater reuse. Visible tanks, interpretive pathways, and real-time dashboards transform infrastructure into an educational resource, increasing water literacy and willingness to adopt decentralized solutions among diverse user groups.

The thesis introduces a transfer–adapt–defer matrix guiding replication across schools, parks, transit stations, and heritage sites. Findings confirm that decentralized, visible water systems can enhance climate resilience, mobility equity, and public engagement. Recommendations include updating municipal regulations to streamline decentralized approvals, and implementing comprehensive monitoring to support continuous improvement. This work offers a replicable framework for embedding sustainable water infrastructure into public architecture, advancing urban water stewardship in São Paulo and beyond.

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Chapter 1: Introduction

1.1 Background and Context

Water is essential to urban resilience, economic development, and public health—but global water systems face mounting pressure from urbanization, climate change, and poor resource management. By 2030, the world could see a 40% gap between water demand and supply (Global Commission on the Economics of Water, 2023).

In São Paulo, a city of over 22 million, centralized systems like the Cantareira and Guarapiranga reservoirs are increasingly strained by drought, urban sprawl, and aging infrastructure. During the 2013–2015 crisis, the Cantareira Reservoir dropped to just 7% capacity, leaving millions at risk (Nobre et al., 2016). Meanwhile, untreated wastewater and pollution from informal settlements worsen the city's water insecurity.

Addressing these challenges requires solutions that prioritize sustainability, efficiency, and climate resilience. Decentralized water systems—based on localized treatment, reuse, and recovery—offer a promising alternative. This thesis investigates their potential through a building-scale case study tailored to São Paulo's urban context.

1.2 Problem Statement

São Paulo, Brazil's largest city and one of the world's five most populous metropolitan areas, is home to an estimated 44.4 million people (Agência IBGE, 2023). Its population has grown from 2.3 million in the 1950s to over 22 million today (World Population Review, 2024), driven by rapid and often poorly regulated urban expansion (Casa da Boia, 2025). This growth has deepened social and environmental inequalities in a country already marked by disparity (Maakaroun, 2019). Recurring droughts and floods—historical issues for São Paulo (Gozzo, Palma, Custodio, & Machado, 2019)—have intensified due to population pressure and climate change.

The Cantareira water system, São Paulo's primary drinking source, is increasingly vulnerable due to disrupted hydrologic cycles and declining rainfall (Domingues & Rocha, 2022). During the 2014–2015 drought, reservoir levels dropped to just 5% of capacity (Ozment & Feltran-Barbieri, 2018; BBC, 2014), triggering widespread shortages. Water distribution became unequal—some lost basic access while others maintained private reserves. Infrastructure inefficiencies, such as the 38% loss of water during transfer, exacerbate the issue (Secretaria Da Saneamento E Recursos Hídricos, 2013).

Climate projections indicate a 20% drop in rainfall by 2040 and up to 40% by 2100 compared to historical averages (Wilson Sousa Júnior, 2016). According to São Paulo's Master Plan for Water Resources, current supply (70.34 m^3/s) will fall short of the projected 82 m^3/s demand by 2035 (Secretaria Da Saneamento E Recursos Hídricos, 2013). Bridging this gap will require efficiency improvements (Savelli et al., 2023), reforestation (Ozment & Feltran-Barbieri, 2018), and rainwater reuse strategies (Neto et al., 2024).

Flooding remains a chronic hazard. São Paulo has endured floods for over 400 years (Kogan, 2013), and climate models project a 30% increase in annual precipitation by 2100 in southern Brazil, alongside fewer rainy days but more intense events (King & Rocha, 2013). In February 2020, 680 mm of rain fell in 24 hours—the highest February total since 1943. February 2023 recorded the third-highest volume (Instituto Nacional de Meteorologia, 2023). These extremes are likely to intensify ("Urban Flooding in Brazil", 2023).

This research explores how São Paulo can improve water distribution equity, water quality, and sanitation access, while advancing climate adaptation and flood resilience to build a more secure and inclusive urban water system.

1.3 Objectives of the Study

This study aims to design a decentralized water treatment system for a high-traffic building in São Paulo, focusing on water reuse, resource recovery, and energy efficiency. It also examines the broader implications of implementing such systems in urban settings. However, the research does not address the governance and regulatory frameworks necessary for large-scale implementation, and while the design is tailored to São Paulo's context, its applicability to other cities may require further adaptation.

1.4 Research Questions

This thesis seeks to address the following overarching question:
How can the integration of decentralized water management systems and nature-based solutions enhance water security and resilience in São Paulo's urban environment?

To support this inquiry, the following sub-questions will be explored:

1. What are the overarching challenges and opportunities associated with implementing decentralized water management systems in large urban centers?
2. How do nature-based solutions contribute to urban water security and resilience on a macro scale?
3. How can the integration of decentralized systems and nature-based solutions serve as a model for enhancing water security and resilience in other megacities facing similar challenges?

1.5 Scope and Limitations

1.5.1 Scope

- **Geographic Focus:** The pilot Water Center is sited in a peripheral basin near the Billings and Guarapiranga reservoirs in São Paulo, so findings primarily reflect tropical, megacity conditions and peri-urban contexts.
- **Infrastructure Modules:** The study examines a specific suite of decentralized components—rainwater harvesting, greywater recycling, constructed wetlands, activated sludge, nutrient recovery, and rooftop solar—in a combined transit-hub typology.
- **Performance Metrics:** Evaluation centers on water-balance outcomes (daily flows up to 136,000 L), reuse rates (65–75 %), potable demand reduction (>70 %), and qualitative measures of educational impact.
- **Temporal Horizon:** Results derive from system design analyses and short-term simulations; no multi-year field data are yet available.
- **Replication Framework:** The transfer–adapt–defer matrix is tailored to schools, parks, transit stations, and similar public institutions within São Paulo's regulatory landscape.

1.5.2 Limitations

1. **Pilot Duration & Monitoring:** Without long-term, in-situ operation, maintenance challenges (e.g., wetland clogging, membrane fouling) and seasonal variability remain untested over multiple years.
2. **Behavioral Data Scope:** Educational outcomes and survey results rely on early workshop feedback; broader, statistically robust studies of community uptake and sustained behavior change are pending.
3. **Regulatory Uncertainty:** Local health and building codes around greywater reuse and nutrient recovery may evolve, potentially requiring system redesigns or additional permitting not accounted for here.
4. **Economic Analysis Boundaries:** Cost–benefit insights are based on literature values and preliminary estimates; a full life-cycle cost assessment—including embodied energy, capital depreciation, and ecosystem co-benefits—is outside this thesis's scope.
5. **Site Specificity:** Soil conditions, land availability, and hydrology in other São Paulo neighborhoods may differ significantly; the modular kits will require site-specific geotechnical and hydrological studies before deployment.

1.6 Structure of the Thesis

This thesis is organized into six chapters:

- **Chapter 1: Introduction** outlines the research context, objectives, and significance.
- **Chapter 2: Literature Review** synthesizes current research on decentralized water management, highlighting trends, challenges, and solutions.
- **Chapter 3: Methodology** describes the research design, data collection, and analytical methods used in developing the proposed treatment system.
- **Chapter 4: The case study** introduces to the case study, its location and aims
- **Chapter 5: Water System Design and Analysis** details the design of the treatment train and evaluates its performance in addressing São Paulo's water challenges.
- **Chapter 6: Building Design** details the building vision and its context in the chosen space in the city of São Paulo
- **Chapter 7: Discussion** interprets the findings, contextualizing them within broader urban water management frameworks.
- **Chapter 8: Conclusion and Recommendations** summarizes the study's contributions and provides recommendations for future research and implementation.

Chapter 2: Urban Water Challenges and Solutions

2.1 Challenges in Water Management

São Paulo's water crises result from a complex interplay of environmental stress, rapid urbanization, and governance shortcomings. Climate change has intensified these issues, with rising temperatures and shifting rainfall patterns threatening long-term water availability (Li et al., 2024). The 2014–2015 drought, which drove Cantareira Water Supply System (CWSS) reservoirs down to 5% capacity, exposed the system's vulnerability (Millington, 2018).

Urban growth continues to strain water infrastructure, with demand projected to rise 38% by 2050 due to increased domestic and industrial consumption (Paiva et al., 2020). Informal settlements lacking sanitation contribute significantly to the pollution of vital water bodies like the Tietê and Pinheiros rivers (Cunha et al., 2011). Meanwhile, the Guarapiranga Reservoir supplies 14,000 liters of potable water per second to 4 million residents, underscoring its strategic importance (H. M. Shihomatsu, 2017).

Governance challenges compound these pressures. Although the São Paulo Water Act (1991) introduced decentralization and integration principles, stakeholder conflicts, political interference, and weak institutional capacity continue to hinder effective water management ((Barbosa et al., 2016); de Brito et al., 2018).

2.2 Extreme Weather Impacts on Urban Water Systems

São Paulo is increasingly exposed to extreme weather events that strain its aging water infrastructure. More frequent intense rainfall contributes to urban flooding and overwhelms outdated drainage systems (Zilli et al., 2016). At the other extreme, prolonged droughts—such as the 2014–2015 event—led to BRL 1.6 billion in economic losses and widespread water shortages (Otto et al., 2015; Ciasca et al., 2023).

Urban expansion worsens climate impacts, intensifying the urban heat island effect and modifying local weather conditions (Vemado & Filho, 2016). Land use changes also accelerate runoff and reduce natural infiltration, weakening São Paulo's hydrological resilience (Lima et al., 2018). Vulnerable communities in flood-prone areas face the greatest risks, highlighting the need for inclusive adaptation strategies (Roncancio & Nardocci, 2016).

Strategic investments in nature-based solutions, integrated urban planning, and risk governance are essential to mitigate the compounded threats of climate extremes on São Paulo's water systems.

2.3 Nature-Based Solutions (NBS)

Nature-based solutions (NBS) integrate ecosystems into urban water management, offering sustainable alternatives to traditional infrastructure. Green roofs, permeable pavements, constructed wetlands, rain gardens, and bioretention basins reduce runoff, improve water quality, and sequester carbon—up to 28.7 kg CO_2eq/m^2 over 30 years—while mitigating urban flooding and heat islands (Parkinson, 2021; Kavehei et al., 2018).

In São Paulo, forest loss near key reservoirs has degraded ecosystem services and driven up water treatment costs. Restoring 4,000 hectares of forest could reduce sediment pollution by 36% and turbidity by nearly 50% within 30 years (Ozment et al., 2018). In Guarapiranga, vegetation loss has led to nutrient buildup, reduced biodiversity, and a 621% increase in water treatment costs (Brito et al., 2018; Adas et al., 2020). Wetland restoration and reforestation in these watersheds offer cost-effective ways to improve water quality and resilience.

Stormwater and rainwater harvesting systems also play a critical role. Rooftop-harvested rainwater (RHRW) treated with activated carbon and chlorination can provide potable water with far lower emissions (0.002–0.004 kg CO_2eq/m^3) compared to centralized supply (1.16 kg CO_2eq/m^3) (Keithley et al., 2018; Hofman-Caris et al., 2019). Stormwater harvesting (SWH) systems reduce flooding and pollutant loads by up to 85% through plant and microbial uptake (Gagnon et al., 2012). Vegetated swales and other green infrastructure further support carbon sequestration, storing up to 10.5 kg CO_2eq/m^2 over 30 years (Quon & Jiang, 2023).

Despite their proven benefits, implementing NBS in São Paulo faces financial and governance barriers. Rigid environmental laws and political resistance to resettlement have locked inadequate infrastructure in place, particularly in favelas, leading to a 133% rise in Guarapiranga treatment costs over five years (De Brito et al., 2018). More than 75% of forests near major reservoirs are degraded, forcing utilities to treat increasingly polluted water and divert funds from basic maintenance (Ozment & Feltran-Barbieri, 2018).

Policy reforms are needed to unlock NBS potential. Revisions to outdated reservoir-protection laws should allow in-situ sanitation, while public-private partnerships should lead reforestation and rainwater integration efforts (Ozment et al., 2018). Plans like the Campinas Water Resources Master Plan already advocate for vegetation expansion, reduced soil impermeability, and improved sanitation to meet both water management and climate adaptation goals (Galbetti et al., 2022). Urban wetlands and green infrastructure are "no-regret" investments, offering ecological and economic gains while restoring critical services (Machado et al., 2016).

2.4 The Role of Decentralized Wastewater Management and Hybrid Systems

2.4.1 Resource-Efficient Decentralized Wastewater Systems

Separating wastewater into distinct streams—yellow water (urine), brown water (feces and flush water), and greywater (from sinks, showers, and laundry)—can dramatically improve treatment efficiency and resource recovery. While black water makes up just 20% of household wastewater by volume, it contains up to 90% of the carbon and nitrogen, and 80% of the phosphorus (Garrido-Baserba et al., 2024). By isolating these high-load streams, anaerobic digestion can be used effectively to recover nutrients and generate methane for biogas, reducing both emissions and operational costs (Wald, 2022). Meanwhile, greywater—containing fewer contaminants—can be treated using simpler technologies like reverse osmosis or filtration, making it cheaper to process than combined sewage or even seawater (Garrido-Baserba et al., 2024).

Decentralized systems, which treat water close to its point of use, complement this separation strategy. They are less vulnerable to disruptions from aging infrastructure or extreme weather and require less specialized labor and capital investment than large-scale centralized systems (Wang et al., 2022). When implemented properly, these systems can cut treatment costs by half and increase operational reliability while maintaining high environmental performance (Garrido-Baserba et al., 2024).

2.4.2 Hybrid Systems for Urban Resilience and Sustainability

Hybrid systems integrate decentralized water treatment units with centralized monitoring or oversight, providing a flexible, scalable model for cities like São Paulo. These systems enable localized water reuse while retaining the benefits of centralized control—particularly important in regions with legacy infrastructure or governance challenges (Larsen et al., 2013). For instance, combining rainwater harvesting, greywater recycling, reverse osmosis, and UV disinfection can reduce potable water demand by up to 95% (Garrido-Baserba et al., 2024).

Beyond efficiency, hybrid models enhance resilience. By distributing treatment and storage, they can sustain service during extreme weather events or infrastructure failures. They also reduce reliance on aging sewer systems, which account for over 90% of the costs in traditional wastewater management (Garrido-Baserba et al., 2024). Environmental benefits are also significant: decentralized systems can use 85% less utility water and recover up to 90% of phosphorus and nearly 50% more nitrogen, all while reducing global warming and eutrophication impacts by two-thirds (Garrido-Baserba et al., 2024).

In areas like Guarapiranga, where deforestation and informal settlements have increased runoff and pollution, hybrid infrastructure could help reduce treatment loads and mitigate rising costs (De Brito et al., 2018). Rainwater and greywater reuse alone can reduce potable water demand by up to 53%, highlighting the strategic value of integrating blue-green infrastructure into the urban fabric (Teston et al., 2018).

2.4.3. Heat-Driven Emissions from Centralized Wastewater Systems

In the context of São Paulo's tropical climate, high ambient temperatures significantly influence the performance and environmental impact of wastewater infrastructure. Extended transportation of sewage through centralized systems—especially those involving open drains or anaerobic sewers—can lead to elevated greenhouse gas emissions, particularly methane (CH_4) and hydrogen sulfide (H_2S). These emissions are exacerbated by surface-level channels exposed to heat, which accelerate anaerobic decomposition and result in strong odors and local air quality issues. While underground sewer networks provide some insulation and reduce odor dispersion, they still contribute to unnecessary emissions due to the lack of oxygen in long conveyance lines. This highlights the environmental inefficiencies of centralized, surface-level wastewater transport in warm climates, reinforcing the need for decentralized and enclosed treatment alternatives.

2.5 Energy Efficiency in Water Utilities

Urban water utilities suffer from major energy inefficiencies, with overuse reaching 71.4%, resulting in a 35.6% annual increase in operational costs (Maziotis et al., 2023). Improving efficiency could reduce emissions by 51.3% and save €0.12 per cubic meter of treated water. Drinking water production remains highly energy-intensive due to the treatment required to remove pollutants from raw sources (Rodríguez-Merchan et al., 2021). Under UN Sustainable Development Goals 6 and 7, governments are expected to provide universal access to clean water while improving energy efficiency (United Nations, 2015).

Globally, water utilities contribute around 2% of greenhouse gas emissions—approximately 1.2 billion tons of CO_2 annually (Water UK, 2021). To reduce this impact, researchers advocate integrating renewable energy sources such as solar power into water treatment systems (Pandey et al., 2021; Maktabifard et al., 2018). Addressing inefficiencies requires a combination of energy-efficient technologies, renewable energy adoption, and supportive policy frameworks to achieve sustainable, low-carbon urban water management.

2.6 Barriers and Policy Recommendations

The adoption of innovative water management solutions in São Paulo faces several structural and social barriers. Technological inertia, limited institutional support, and the absence of dual-plumbed buildings or widespread experience with on-site recycling systems hinder progress (Garrido-Baserba et al., 2024). Public skepticism over the safety of reused water further complicates implementation. Quon & Jiang (2023) emphasize that public trust is critical for wastewater reuse, particularly in varied socioeconomic contexts, and recommend strategies such as transparent communication, community engagement, and blending treated water with natural sources—approaches that proved successful in California’s Groundwater Replenishment System.

São Paulo’s 2014–2015 drought exposed stark inequalities in water access. Low-income residents, especially in peripheral areas, reduced consumption at nearly twice the rate of wealthier households. While 67% of casas (typically lower-income dwellings) reported water cuts, only 26% of apartments—mostly occupied by higher-income groups—faced the same. Additionally, 42% of residents earning up to two minimum wages experienced frequent interruptions, compared to just 19% among high earners (Millington, 2018). Although caixas (water tanks that store 24 hours of water needs per residence) are required legally since 1992, they are more common in formal apartment buildings than in informal homes, leaving poorer communities more vulnerable. Addressing this disparity requires targeted investments in peripheral infrastructure and emergency strategies that prioritize vulnerable populations. Expanding basic sanitation is especially urgent, with benefits extending to public health and biodiversity (Schiesari et al., 2025).

While conventional treatment plants are costly to build and maintain, constructed wetlands offer a viable low-cost alternative in Brazil, effectively removing contaminants through natural processes (Machado et al., 2016). Economic viability remains a key challenge for decentralized systems. In The Netherlands, decentralized drinking water production has been shown to be significantly more expensive than centralized systems (Hofman-Caris et al., 2019). However, neighborhood-scale rainwater harvesting—especially when collecting from both roofs and pavements—offers a cost-effective alternative. This approach also reduces flood risks and urban stormwater burdens. Though the payback period for decentralized systems ranges from 18–22 years, factoring in avoided infrastructure expansion costs can reduce this to 10–14 years (Garrido-Baserba et al., 2024).

Chapter 3: Methodology

This chapter outlines the methods used to design and evaluate the São Paulo Water Center prototype, focusing on technical modeling, spatial integration, and comparative analysis to support replicability.

3.1 Restatement of Research Objectives

- **Design Objective:** Develop a decentralized water infrastructure system for a multimodal transit hub that reduces municipal water demand, integrates visible educational elements, and can be adapted across diverse public facilities.
- **Evaluation Objective:** Quantify water-balance performance, infrastructure sizing, and replication potential based on contextual criteria.

3.2 Technical modelling

1. **Water Balance Calculations:** Using historical rainfall data for São Paulo (Da Silva Neto et al., 2024) and estimated daily occupancy (12,200 visitors and 40 staff), Excel-based models computed:
    - Rainwater harvest potential from each roof surface
    - Greywater generation and reuse volumes based on fixture usage rates (1.5 L per handwash; toilet and urinal flush volumes)
    - Storage requirements for cisterns sized for four-week dry periods

2. **Treatment System Sizing:** Based on literature removal efficiencies (activated sludge, wetland polishing), system components were sized to handle peak flows of up to 136,000 L/day:
    - Anaerobic digester, activated sludge reactor, coagulation–flocculation units, and constructed wetland area (2,981 m²)
    - Buffer tanks for greywater, post-RO permeate, and brine streams

3.3 Spatial Integration

- **Site Selection Analysis:** Mapped proximity to Billings and Guarapiranga reservoirs, existing metro and bus networks, and land-use constraints using GIS layers from São Paulo Municipality.
- **Module Placement:** Applied overlay analysis to position cistern arrays, wetlands, and facility blocks to optimize connectivity, solar exposure, and visitor circulation.
- **Footprint Assessments:** Calculated indoor and outdoor spatial needs (Tables 1–4) ensuring integration of mechanical rooms, treatment units, and public spaces.

3.4 Comparative Replicability Analysis

- **Transfer–Adapt–Defer Matrix:** Developed a scoring framework based on three criteria (similar site typology, climatic conditions, regulatory fit) to classify each component's replicability across schools, parks, transit hubs, and heritage sites.
- **Contextual Criteria Definition:** Derived directly from Chapter 2 challenges (rainfall variability, space availability, health codes) and Chapter 6 case examples.

3.5 Literature and Precedent Review

- **Literature Synthesis:** Reviewed academic studies on decentralized water systems, NBS, and hybrid treatment to inform design choices and performance benchmarks (e.g., Garrido-Baserba et al., 2024; Zeng et al., 2022).
- **Precedent Analysis:** Examined global examples (Omega Center, Sidwell Friends School, Shenzhen Lotus Base) to extract best practices for visible infrastructure and educational integration.

3.6 Ethical Considerations

This study adhered to ethical research principles by:

- Using publicly available data and tools responsibly
- Properly citing all sources and ensuring transparency in methods.
- Avoiding the collection of sensitive or proprietary information without appropriate permissions.

3.7 Limitations

- This study relies on modeling and secondary data; no field implementation or empirical monitoring was conducted.
- Assumed usage patterns and removal efficiencies based on literature; site-specific variability may alter performance.
- Regulatory compliance pathways were inferred from existing codes but not tested in permitting processes.

Chapter 4: The case study

4.1 The case study by São Paulo Municipality

The municipality of São Paulo is working on the waterways (Figure 1) mobility project in the city, designing a solution of boats that would run through each of 7 water bodies in the city that are currently not navigable. In addition to the project, the aim is the creation of 7 additional boats for educational purposes where children would be taught topics related to the water and natural environment, helping them reconnect with nature in the city, as well as teaching them techniques on water management they could implement at home.

The São Paulo Water Center is a conceptual proposal developed as part of this thesis, aimed at addressing multiple urban challenges through a single multifunctional facility. Designed for a peripheral area near the Billings and Guarapiranga reservoirs, the Center serves primarily as a public transfer station—connecting ferry-accessible or water-adjacent neighborhoods to the broader metro and bus networks. This integration helps reduce commuting time and improves access for residents of areas historically underserved by public transit.

Beyond its transportation function, the Center is envisioned as a self-sufficient water hub and environmental education space. It harvests and treats its own water on-site through a combination of rainwater collection and decentralized treatment systems. These systems are not hidden in technical rooms but instead embedded into the building and landscape as visible, interpretable features. In doing so, the Center becomes an interactive demonstration site—showing how everyday buildings can manage their own water needs sustainably, even in a dense urban context like São Paulo.

Visitors are introduced to hands-on examples of water reuse, filtration wetlands, and simple home-scale climate strategies. The Center also distributes educational materials and practical tools for applying similar techniques in households. By combining infrastructure, education, and sustainability, the Water Center acts as a replicable prototype for climate-resilient public architecture—anchored in the urgent water challenges São Paulo faces today.

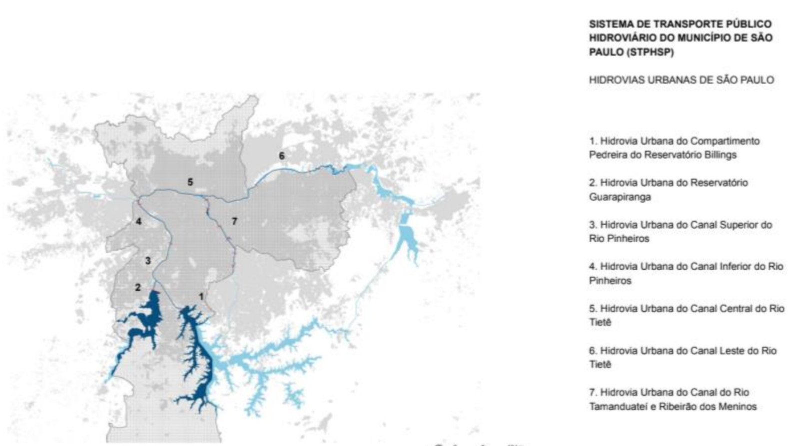


Figure 1. Proposed case study

4.2 Project Area

In 1920s, São Paulo has decided to build a powerplant to ensure the steady electrical supply to the city (Oliveira, 2016). As a result, the engineering on water streams have started in the city, firstly by building Santo Amaro dam and later extending it to Henry Borden plant. Due to the changes in the landscape, the Billings and Guarapiranga water reservoirs have been created. The reservoir's name, derived from the Tupi-Guarani (the indigenous group based in São Paulo area) language, means "red clay quagmire" (Casa da Boia, 2025). Following the completion of the Henry Borden plant in the 1920s, Guarapiranga transitioned into a critical water supply reservoir for the region. Today, it provides drinking water to over 4 million people in the metropolitan area, although it no longer serves its original energy generation purpose. Despite its importance, Guarapiranga has been plagued by urbanization (Figure 2) challenges, including irregular settlements and sewage discharge, putting immense pressure on those responsible for maintaining the water's quality (Fontana et al., 2014).

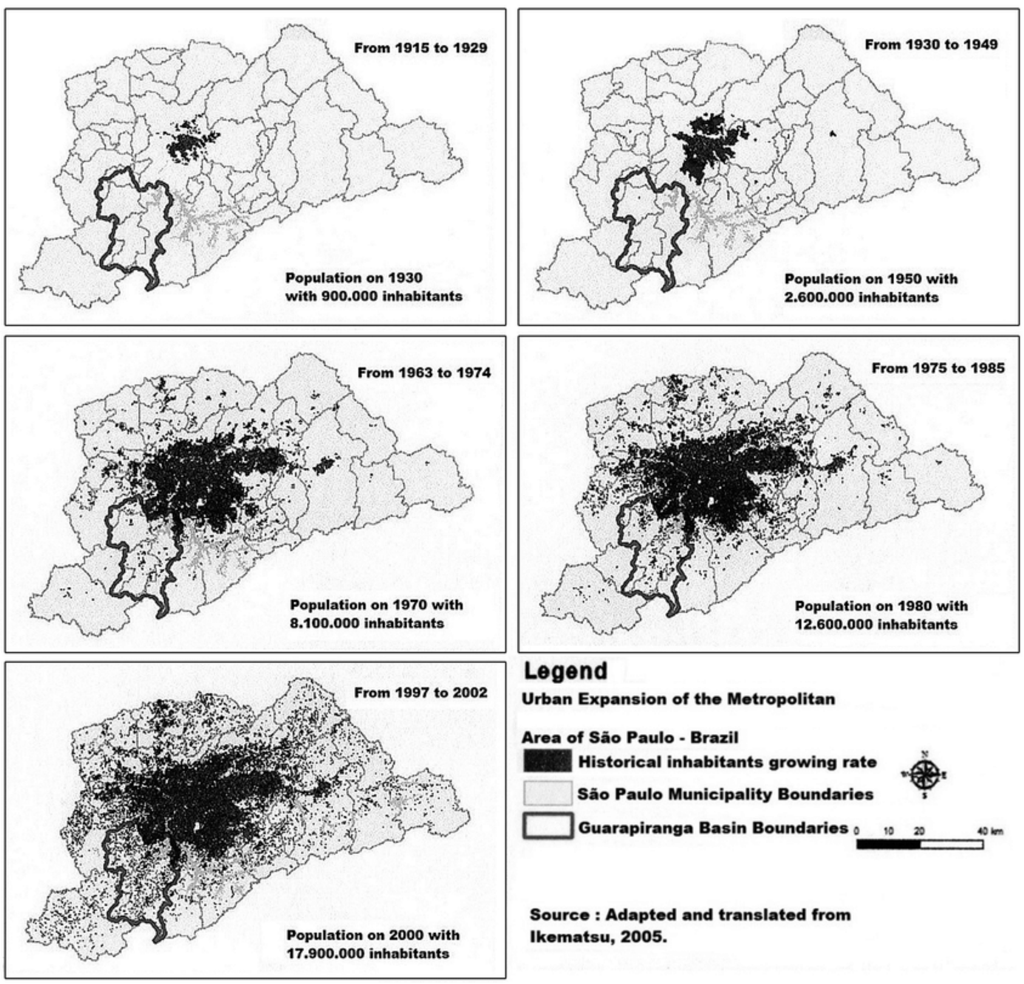


Figure 2. The urban expansion historical profile of Guarapiranga basin (Shihomatsu et al., 2017)

4.3 Project Background

In São Paulo's peripheral areas, public transport is fragmented and disconnected from formal urban infrastructure. Residents living near water bodies often spend hours commuting to the city due to limited transit access. The Water Center proposes to bridge this gap by functioning as a multimodal transfer station, integrating water-edge zones into the broader transportation system while also addressing long-standing environmental deficits.

What distinguishes the Center from conventional infrastructure is its ambition to function not only as a transport hub but as a self-sufficient water infrastructure prototype. The building collects and treats its own water supply through a series of decentralized systems—including rainwater harvesting, greywater recycling, and constructed wetlands—designed to meet daily needs without drawing from the municipal grid. This dual function reflects São Paulo's urgent need for both mobility equity and climate-resilient water systems.

Due to land tenure limitations, the Water Center is proposed as a temporary 10-year pilot, but with a long-term vision for replication and scale-up across similar underserved areas in the city.

4.4 Objectives & Aspirations

The São Paulo Water Center is designed to operate at the intersection of education, sustainability, and infrastructure innovation. Its key objectives include:

- Educational empowerment: Providing hands-on learning about decentralized water systems, rainwater harvesting, pollution reduction, and water stewardship.
- Water resilience through decentralization: Demonstrating a water self-sufficient building that harvests and treats its own water on-site, reducing reliance on the municipal network even during peak usage (~12,200 visitors/day).
- Integrated mobility and community infrastructure: Functioning as a multimodal transit hub that combines ferry access, bus stops, parks, and public gathering spaces.
- Circularity and inclusivity: Emphasizing closed-loop water and waste systems, and incorporating natural elements into design.
- Scalability and replicability: Serving as a prototype for similar hubs across São Paulo and other Brazilian cities.

By merging public transport, ecological education, and decentralized infrastructure, the Water Center offers a tangible, place-based response to the systemic issues outlined in Chapter 2 — particularly São Paulo's vulnerability to droughts, urban inequality, and the limits of centralized water systems.

Chapter 5: Water Design. Innovative Water Management Solutions for Climate Resilience in São Paulo

In rapidly urbanizing cities like São Paulo, managing water sustainably requires treatment systems that are both effective and feasible to implement. The São Paulo Water Center prioritizes simplicity and affordability, avoiding complex, high-maintenance technologies in favor of proven methods. The selected treatment process (Figure 3) — combining activated sludge and constructed wetlands — delivers reliable wastewater purification while minimizing energy use, maintenance, and cost.

This approach contrasts with more advanced options, such as membrane bioreactors, which, while highly efficient, are often too costly and resource-intensive for widespread deployment in low-budget urban contexts. Natural systems like wetlands, though slower and land-intensive, offer passive operation and ecological benefits. The Center's hybrid system strikes a balance: it's robust, low-tech, and well-suited for replication in other urban districts facing similar financial and infrastructural constraints.

This chapter outlines each stage of the treatment process and the evidence supporting its selection.

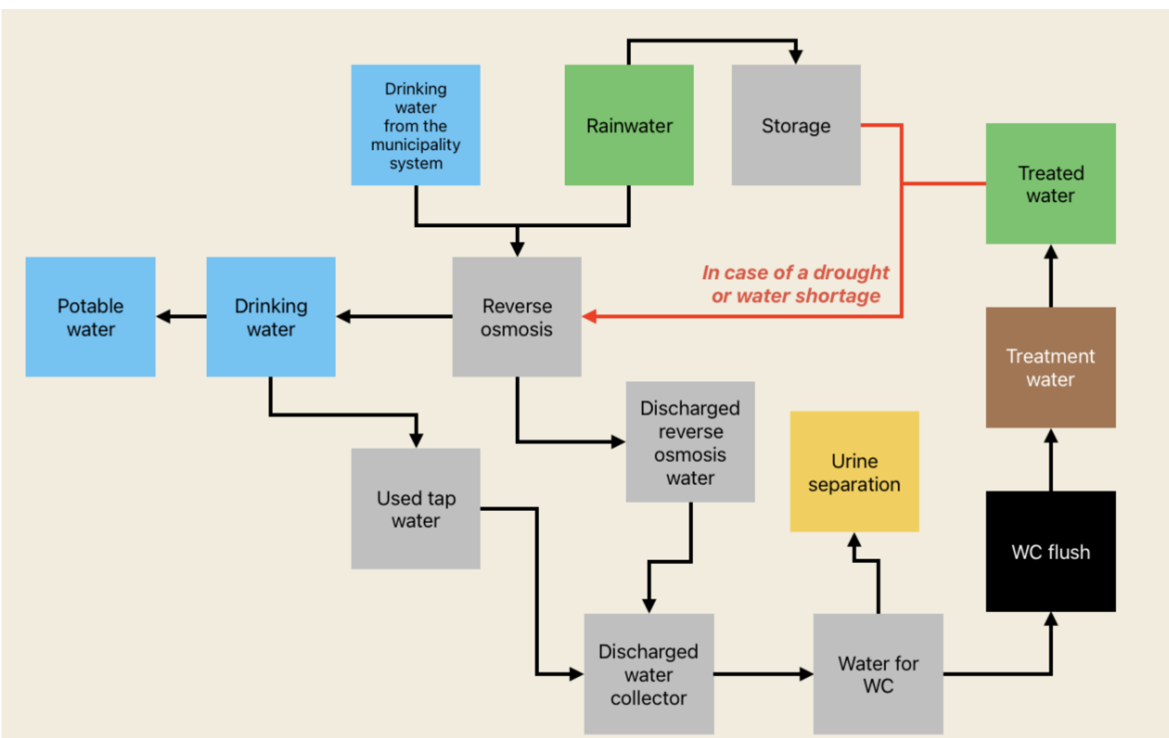


Figure 3. The water treatment block scheme

5.1 Introduction to the Treatment Process

The São Paulo Water Center employs a decentralized, closed-loop water management strategy that integrates rainwater harvesting, municipal supply supplementation, greywater reuse, blackwater treatment, and nutrient recovery (Figure 4). This multi-barrier approach maximizes water conservation, reduces reliance on external supplies, and generates valuable by-products such as biogas and fertilizer. Full water tables and hourly demands are provided in Appendixes Table A-C.

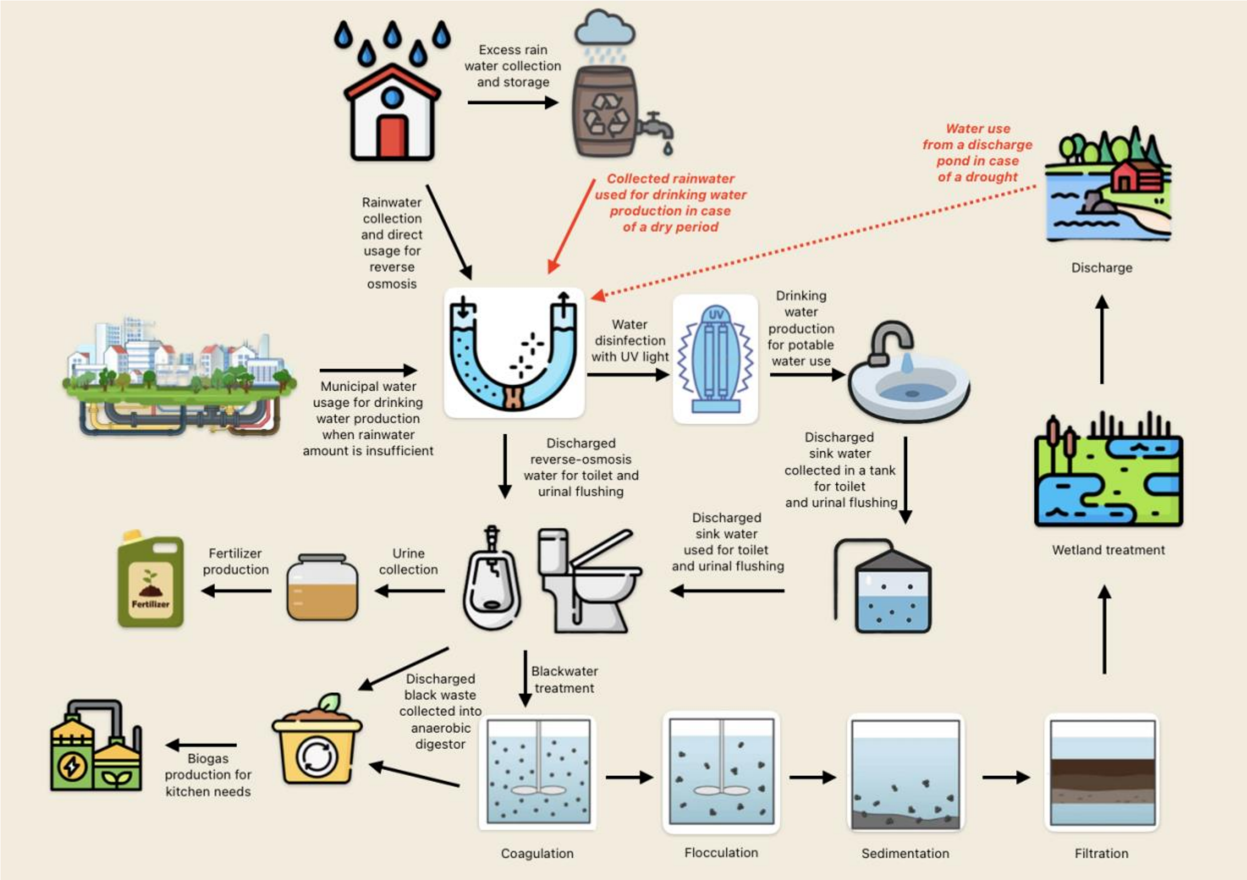


Figure 4. Water treatment flow graph

Raw Water Capture and Pre-Treatment

Rainwater runoff from building rooftops is collected in a dedicated cistern and serves as the primary source for non-potable applications. When cistern storage is insufficient, municipal potable water supplements the system. Both water streams feed a reverse-osmosis (RO) unit, which produces high-quality permeate for drinking and sanitation needs. The RO concentrate ("reject" stream) is diverted for toilet and urinal flushing, thereby conserving potable water.

Greywater Collection and Reuse

Effluent from handwashing stations and washbasins is routed to a separate greywater tank. After coarse screening to remove solids, this greywater is directly recycled for toilet and urinal flushing. By capturing and re-employing sink discharge, the system reduces freshwater demand and diminishes the volume of wastewater sent to downstream treatment processes.

Blackwater Treatment and Resource Recovery

Toilet and urinal waste, alongside kitchen organic residues, enters an anaerobic digester. Within this oxygen-free reactor, microorganisms break down complex organics, producing biogas (primarily methane) which the facility uses for cooking or heating. The remaining digestate undergoes solids-liquid separation: the liquor advances to further treatment, while the separated solids may be dewatered or composted.

Advanced Polishing and Discharge

The liquid fraction from anaerobic digestion is subjected to sequential coagulation, flocculation, sedimentation, and filtration, removing suspended solids and colloids. The clarified effluent then passes through a constructed wetland, where plant roots and microbial communities provide tertiary treatment, polishing nutrient and pathogen levels. Under normal conditions, this final effluent is discharged to a retention pond or used for landscape irrigation. During drought or peak demand, stored wetland water can be reintroduced to the RO feed, ensuring uninterrupted potable supply.

Nutrient Recovery

A parallel urine-separation stream collects undiluted urine, which is processed into nutrient-rich fertilizer. This side-stream recovery diminishes nitrogen and phosphorus loads in the main treatment train and produces an agronomically valuable by-product.

Collectively, these integrated processes convert multiple wastewater streams into safe potable water, non-potable reuse flows, energy, and fertilizers—thereby embodying circular-economy principles within a transit facility context.

5.2 The Treatment Process Train

The water treatment process train consists of five distinct stages, each playing a crucial role in pollutant removal and water reuse. This section provides a detailed literature-based explanation of the function, efficacy, and measurement methods of each treatment step.

5.2.1 Sewage Collection Tank

Sewage collection tanks function as the initial stage in decentralized treatment systems, buffering hydraulic loads and preventing downstream overloading. While basic septic tanks are common, they pose environmental risks if poorly managed, particularly in areas with high water tables. Studies show that nutrient leaching—especially nitrogen and phosphorus—can contaminate shallow aquifers when systems are not properly sited or maintained (Bouderbala, 2019). However, improved passive drainfield designs and soil amendments have demonstrated significantly better nutrient retention (Chang et al., 2009).

5.2.2 Activated Sludge Treatment

The activated sludge process is a biological treatment method where aerobic microorganisms metabolize organic pollutants. Typical Biochemical Oxygen Demand (BOD) removal efficiencies range up to 93%, depending on operational parameters such as sludge retention time, dissolved oxygen levels, and aeration intensity (Shivaranjani & Thomas, 2017). Maintaining optimal microbial conditions is critical for sustained treatment performance.

5.2.3 Flocculation and Sedimentation

Flocculation and sedimentation are chemical-physical processes aimed at aggregating colloidal particles into larger flocs, which then settle out under gravity. Natural coagulants and flocculants like chitosan and Moringa oleifera extract offer a cost-effective, biodegradable alternative to chemical agents, with added antimicrobial properties that help inhibit bacterial growth in treated wastewater (Badawi et al., 2023). Effectiveness is highly dependent on flocculant type, dosage, pH, and sedimentation kinetics (Nieto et al., 2011).

5.2.4 Filtration

Filtration removes fine particles and pathogens remaining after prior treatment steps. Ceramic microfiltration membranes are increasingly used in water and wastewater treatment due to their durability, chemical resistance, and cost-effective, additive-free operation, but membrane fouling remains the primary challenge limiting broader industrial adoption (Hakami et al., 2020). Despite significant advances in understanding and various mitigation strategies—ranging from hydrodynamic adjustments and material innovations to pre-treatment methods like coagulation—fouling control still relies heavily on conventional cleaning protocols and remains an active area of research.

5.2.5 Wetland Polishing System

Constructed wetlands act as a final polishing stage by combining microbial, plant-based, and substrate-mediated nutrient removal. Depending on design, wetlands have achieved nitrogen and phosphorus removal efficiencies of over 85% (Zeng et al., 2022). Constructed wetlands using Viteveria zizanioides and peat media achieved the highest pollutant removal efficiency—averaging 84% nitrogen and 86% phosphorus removal—while peat also effectively lowered pH due to the release of humic and fulvic acids under alkaline conditions (Tang et al., 2023). Critical design parameters include hydraulic retention time, plant species, and substrate composition.

5.3 Water Consumption Analysis

The water consumption analysis for the transit facility in São Paulo is based on detailed calculations and operational assumptions tailored to handle a substantial daily traffic flow of 12,200 visitors and 40 on-site employees, as well as restaurant and café visitors. The aim of this analysis is to assess water demand, incorporate reuse and recycling mechanisms, and understand the impact of technological measures on reducing overall consumption and strain on the water treatment system. The key factors influencing water consumption include toilet flushing, handwashing, and the use of urinals, combined with the facility's implementation of greywater recycling and rainwater harvesting.

5.3.1 Traffic Flow and Usage Patterns

The facility operates across 19 hours, experiencing three peak periods—in the morning, lunch, and evening. The detailed hourly water consumption analysis (Table 1) is based on a breakdown of traffic flow and restroom usage patterns, adjusted for reuse systems. The estimates are calculated using gender-specific behaviors, where 70% of men use urinals, and 30% use toilets, each flushing with different volumes. Furthermore, the system assumes 1.5 liters for handwashing per use, contributing to both total water demand and the greywater recycling process. During these peak times, water consumption can reach over 5,000 liters per hour, especially in restrooms and for sanitation purposes.

Time Period	Hours	Traffic Flow	Total DW Needs (L)	Available water for short term storage and reuse (L)	Total water needed for bathrooms after water reuse (L)	Mix water need per hour after reuse (L)	Mix water needed per hour without reuse (L)	Water need reduction with water reuse, %	Harvested rainwater (L)	Water needs after reuse and RW harvesting, per hour	Water need reduction after reuse and RW harvesting
06:00 - 09:00	3	Morning Peak	3,356.94	5,918.94	4,329.06	2,562.00	5,653.96	55%	487.21	2,399.60	58%
09:00 - 11:30	3.5	Off-Peak	2,208.43	3,489.43	1,634.57	1,098.00	2,725.96	60%	568.41	935.60	66%
11:30 - 14:30	3	Lunch Peak	5,064.94	9,334.94	- 2,502.94	854.00	5,653.96	85%	487.21	691.60	88%
14:30 - 17:00	2.5	Off-Peak	1,943.45	3,224.45	1,899.55	1,537.20	3,604.36	57%	406.01	1,374.80	62%
17:00 - 21:00	4	Evening Peak	2,340.92	3,621.92	1,502.08	960.75	2,451.46	61%	649.62	798.35	67%
21:00 - 00:00	3	Off-Peak	1,221.94	1,648.94	59.06	427.00	1,383.96	69%	487.21	264.60	81%
		Total:	16,136.60	27,238.60	6,921.40	7,438.95	**21,473.65**	**65%**	3,085.68	**6,464.53**	**70%**

Table 1. Daily water use (L) by water type

Water use is heavily concentrated in restroom facilities, including handwashing, toilet flushing, and urinal usage. Additionally, cultural practices such as tooth brushing after lunch further increase water demand during midday hours.

5.3.2 Water Demand Reduction through Reuse

Without reuse technologies, the facility's water demand would be approximately 21500 liters per day. However, with the integration of greywater recycling can be reduced by 65%. Additional implementation of rainwater harvesting can reduce the municipal freshwater demand by as much as 70% daily. This reduction is especially critical in São Paulo, where water scarcity is an ongoing issue, exacerbated by climate change and increasing urbanization.

When rainwater and municipal freshwater system is insufficient (in case of drought), the system can supplement its supply by using the water harvested in water cisterns during peak times. This decentralized approach could significantly reduce reliance on centralized water systems, potentially lowering demand by 90–95% (Garrido-Baserba et al., 2024). However, regulatory limitations regarding the use of greywater for potable purposes need to be resolved to fully unlock these benefits and ease pressure on existing infrastructure.

5.3.3. Water system size

São Paulo annual daily rainfall is 4.4 mm (Da Silva Neto et al., 2024). To be prepared for water stress months, the rainwater tanks have been calculated to provide sufficient water needs for 4 weeks. To cover a daily demand of 21 480 L (non-reused water demand):

1-month supply (30 d):
$21\,480\ \text{L/day} \times 30\ \text{days} = 644\,400\ \text{L}$

To calculate the rainwater tank size, the amount of harvested water from the waiting area (**area B**) roof has been calculated:

Area	Space	Area (m²)	Runoff Coefficient	Rainfall (mm/day)	Harvested (L/day)
B	Waiting area	1 107,3	0,8	4,4	3 897,7

Harvested rainwater is stored outside in tanks for 21 480 L/day demand. To estimate the tank sizes, the rainwater storage tanks from Graf (Otto Graf GmbH, n.d.) have been selected.

Solution	Tanks (Vol.)	Tank footprint a × b (m)	Single footprint (m²)	Total footprint (m²)	Layout (W × L, m)
1-month supply	7 × 102 000 L	2,50 × 25,23	63,06	441,4	17,50 × 25,23 (1×7)

Additional water system elements such as mechanical room, reverse osmosis technique, ect. Have spatial needs indoors. These are summarized in Table 2:

Block	Function	Volume or Capacity	Footprint calculation	Footprint (m²)
RO skid	High-pressure pumps, membranes, pre-filters	Standard 3 × 4 m rack + aisle	3 × 4 + 1 m aisle	12
Mechanical room	UV lamps, dosing pumps, control panels	Adjacent to RO skid	3 × 3 + 1 m aisle	9
Rainwater cistern	Rain-harvest buffer (≈ 3 100 L/day)	5 000 L @2.5 m (Ø1.6 m)	5 m³ ÷ 2.5 m	2
Greywater buffer	Pre-RO short-term storage (25.2 m³)	Sewage-collection tank volume	25.2 m³ ÷ 2.5 m	10.1
Post-RO treated-water buffer	Mixed-water storage for flushing (~30.3 m³/day)	≈ 1 hour of peak reuse (8.4 m³)	8.4 m³ ÷ 2.5 m	3.4
Discharge sump	RO brine & overflow collection	≈ 24 m³/day	2 × 1 m footprint (smaller flow)	2
Urine-separator kiosk	Diverts source-separated urine	Prefab module	1.5 × 1.5	2.3
Treatment building	Sewage tank + AS reactor + floc/sed + sand filter	25.2 + 50.4 + 21.0 + 8.4 = 105 m³	105 m³ ÷ 2.5 m + 10 m² service aisles	52.0
Service corridors & access	Walkways around indoor blocks	_	Allow 1 m clear around clusters	10

Table 2. Indoor and outdoor system water size estimations

5.4 Plant Species for Constructed Wetlands in São Paulo

5.4.1 Plant Selection and Placement in Wetlands

The effectiveness of constructed wetlands (Figure 5) depends not only on system design but also on the strategic selection and placement of plant species. In the context of the São Paulo Water Center, vegetation serves multiple purposes: it supports wastewater treatment, reinforces the local ecosystem, and acts as a visible, pedagogical element of the facility's educational mission. For a subtropical urban environment such as São Paulo, native and regionally adapted species are preferred due to their ecological compatibility, low maintenance demands, and cultural resonance.

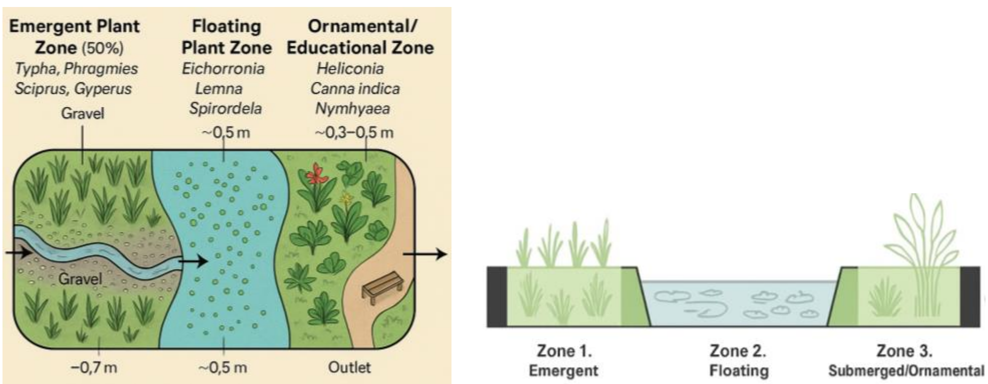


Figure 5. The layout of the constructed wetland

In designing the wetland system, three plant zones were considered—emergent, floating, and submerged—each contributing distinct ecological functions. Combining plant species into layered zones—beginning with hardy emergent macrophytes, transitioning to floating absorptive species, and culminating in educational or decorative wetland beds—ensures both technical performance and public engagement. This design not only treats greywater and stormwater on-site but also transforms the treatment process into a learning experience, consistent with the Center's broader mission. The list of suitable plants for the wetlands is described in Table D in the Appendixes.

5.4.2 Wetland Area Calculation Methodology

To determine the appropriate size for the constructed wetland, several technical parameters were considered, including the expected wastewater inflow, desired retention time for effective treatment, substrate porosity, and a safety margin for operational variability. The goal was to ensure that the wetland could reliably treat greywater and stormwater on-site, even under fluctuating conditions, while maintaining sufficient hydraulic retention time (HRT) for pollutant removal.

The daily wastewater inflow to the wetland was calculated based on a steady flow rate of 5,664 liters per hour, resulting in a total daily volume of:

5,664 L/hour×24 hours/day=135,936 L/day

To achieve high treatment performance, a hydraulic retention time (HRT) of 6 days was selected, allowing adequate contact between wastewater, plant roots, and the microbial community in the substrate. This results in a base wetland volume requirement of:

120,960 L/day×6 days=815,616 L

To account for uncertainties such as peak inflows, plant growth cycles, and temporary reductions in treatment efficiency, a 15% safety buffer was added:

725,760 L×1.15=834,624 L

This total volume of approximately 835 cubic meters (m^3) defines the required internal capacity of the wetland. However, the actual surface area depends on the porosity of the wetland substrate and the depth of the wetland bed.

The substrate consists of coarse gravel, which has an estimated effective porosity of 0.4 to 0.5**,** meaning that only 40–50% of the total volume can be occupied by water. The average design depth was set at 0.7 meters, a standard value in horizontal subsurface flow wetland systems to balance oxygen transfer and root penetration.

To calculate the required surface area of the constructed wetland, the porosity of the gravel substrate plays a critical role. Porosity determines the proportion of the wetland volume that is available for water flow and treatment, excluding the space occupied by solids (gravel, roots, biofilm). Based on scientific literature, uniform sediments, such as gravel or sand composed of spherical grains, exhibit porosities ranging from 0.36 in closely packed arrangements to 0.40 in loosely packed arrangements (Allen, 1985).

This porosity range reflects real-world packing conditions of uniform granular media such as the gravel used in subsurface flow wetlands. To ensure conservative design and accommodate potential compaction or clogging over time, the upper-end porosity of 0.4 was selected. This allows for reliable hydraulic calculations while providing sufficient void space for water retention, microbial activity, and plant root development.

The surface area AA of the wetland was calculated using the formula:

$$A = \frac{V}{n \times d}$$

Where:

- A = wetland area (m^2)
- V = required volume (m^3)
- n = substrate porosity (dimensionless)

- d = wetland depth (m)

Applying this formula:

- For **porosity 0.4**:

$$A = \frac{835}{0.4 \times 0.7} = \frac{835}{0.28} \approx 2,981\,\mathrm{m}^2$$

Thus, the total required wetland surface area was calculated using this porosity value in conjunction with a design depth of 0.7 meters and a total storage requirement of 835 m^3, yielding a surface area of approximately **2,981 m^2**. The split between the plant zones and their sizes in provided in Table 3.

Zone	Function	Estimated %	Area (of 2,981 m^2)	Key Species
Zone 1: Emergent Plants (Inlet)	Sedimentation, nutrient uptake, root zone microbial activity	50%	≈ **1,490 m^2**	*Typha*, *Phragmites*, *Cyperus*, *Scirpus*, *Pontederia*, *Vetiver*
Zone 2: Floating Plants (Middle)	Nutrient polishing, algae control, surface oxygenation	30%	≈ **894 m^2**	*Lemna*, *Eichhornia*, *Spirodela*, *Pistia*, *Wolffia*
Zone 3: Submerged/ Ornamental (Outlet)	Visual appeal, biodiversity support, educational display	20%	≈ **596 m^2**	*Heliconia*, *Zantedeschia*, *Nymphaea*, *Canna indica*, *Thalia*

Table 3. Wetland Zonation Breakdown (Based on Porosity 0.4)

Chapter 6: São Paulo Water Center Design - Integrating Innovative Water Systems into Architecture

6.1 Site

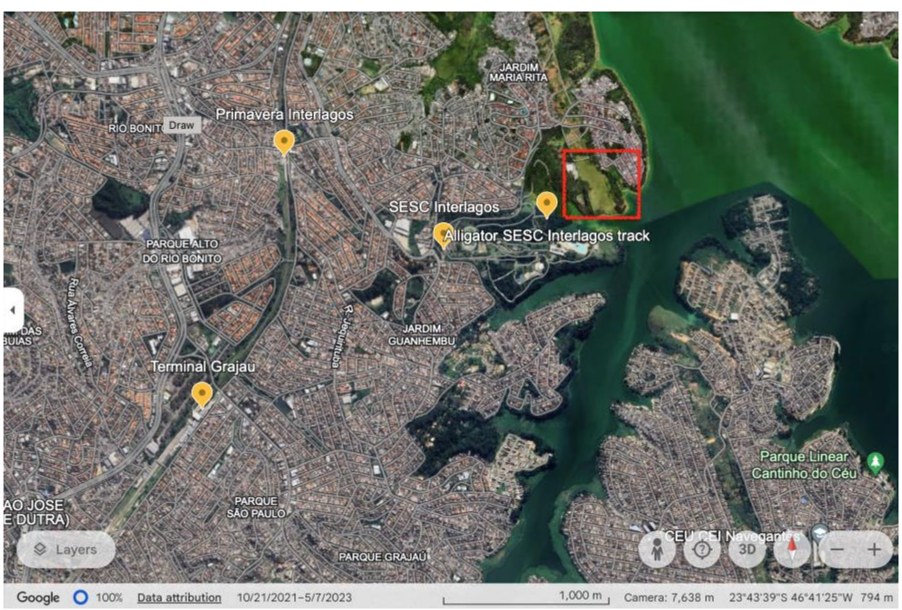
The São Paulo Water Center is strategically located at the edge of the Billings Reservoir—an urban-ecological threshold where city and water meet. This site offers a unique opportunity to embed public infrastructure within a functioning aquatic ecosystem. The reservoir serves as both an emergency buffer and a source of non-potable water for the Center, allowing the facility to operate independently of the city's overstressed mains network.

Connectivity is a key asset. The Center is accessible via a nearby metro station, with frequent electric or hydrogen-powered shuttles ensuring low-emission transit. A new pier links the facility to water taxis and educational boats, reinforcing the Center's role as a physical and symbolic bridge between land-based and water-based systems.

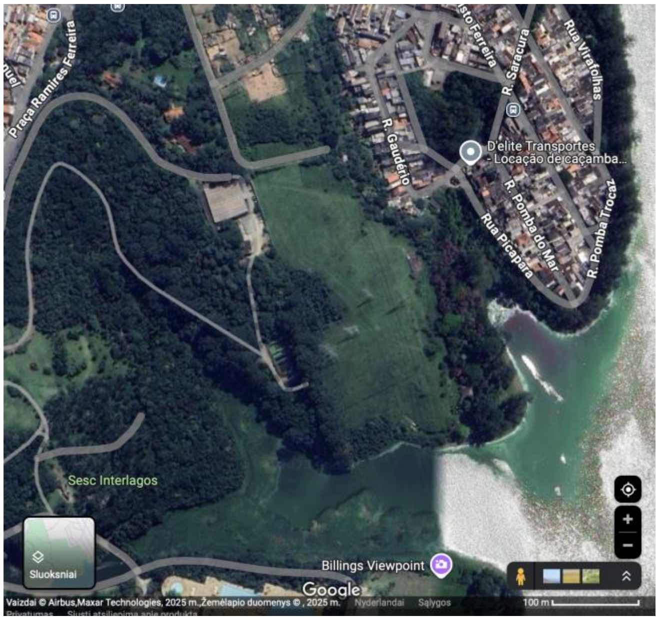
Its proximity to SESC Interlagos—a major public cultural hub—creates opportunities for collaboration. Shared programming can activate the district as a full-day destination, blending environmental education with leisure and community events.

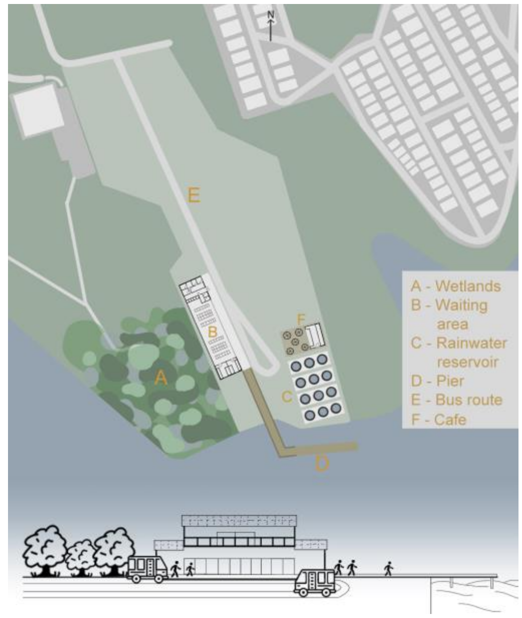
The masterplan includes visible, low-impact water systems: a rainwater pond, constructed wetlands, modular treatment units, and decentralized wastewater solutions. These are integrated into the landscape with clear signage and walkways, transforming infrastructure into public experience. Built with reusable and locally sourced materials, the Center is designed for a 10-year lifespan, with flexibility for dismantling or adaptation based on evolving needs.

This site selection reflects the project's core principle: infrastructure should be visible, adaptive, and fully embedded in the social and ecological life of the city.



Picture 1: proposed project site in the city of São Paulo





Picture 2: proposed project site (zoomed in)

Picture 3: proposed design of a project

6.2 Water as a Visible Design Concept

The São Paulo Water Center transforms urban water systems into a public experience. Designed in response to the city's water crises and climate challenges, the Center makes water infrastructure visible and educational—from rain capture to reuse—demonstrating how buildings can operate sustainably and transparently.

This project does not treat infrastructure as something to be hidden beneath the surface. Rainwater harvesting, greywater recycling, and wetland-based treatment are not concealed behind walls but expressed in form, space, and material. The design aspires to both meet technical needs—such as securing daily water supply for public usage of toilets and the daily needs of café and restaurant — and to educate visitors through spatial storytelling. In doing so, the Center aligns directly with São Paulo's municipal ambitions for decentralized, participatory, and resilient water infrastructure, as outlined in Chapter 2 and Chapter 4. The satellite image and spatial overlay reveal a carefully choreographed composition, where each design element—wetlands, transportation paths, public plazas, and water systems—intertwines with the surrounding landscape to tell a compelling story of water, movement, and resilience.

Rather than functioning as a static facility, the Center acts as an interactive circuit. It draws people through systems and spaces that reveal São Paulo's hydrological challenges and possibilities. Designed to follow natural topography and enhance local ecology, the site is both a regenerative public space and a living narrative of water in the urban environment.

Visitors arrive at the **bus terminal (E)**, strategically placed along the main access road to ensure seamless connection with the city's public transport network. The terminal is sheltered under a long-span roof structure, designed to accommodate frequent electric bus departures and arrivals with minimal environmental impact. Pedestrian paths, protected from sun and rain, allow for safe and direct movement toward the building and onward to other features.

Adjacent to the bus terminal is the **waiting area (B)** – a shaded, open-air space that serves as both a transition zone and gathering point. From here, visitors encounter didactic signage introducing the water systems at play. This space is designed for orientation and reflection, where groups can pause before entering the heart of the site.

To the east, a cluster of **modular rainwater reservoirs (C)** occupies a sunlit open zone. These tanks collect and store rainwater from surrounding surfaces, making the process of urban water management legible and accessible. Their geometric layout forms an interactive field that doubles as a visual demonstration space. Visitors can walk among the tanks, observing water levels and learning about São Paulo's rainfall cycles and reuse strategies.

Leading from the reservoirs, **the pier (D)** extends into the waterbody, serving as both a water taxi terminal and a symbolic gesture toward São Paulo's relationship with its aquatic ecosystems. The pier not only facilitates low-carbon mobility but offers an immersive waterside experience, framing views across the reservoir and connecting the center to broader regional ecologies.

To the west, **the constructed wetlands (A)** form the heart of the environmental narrative. Shaded by native vegetation, this area provides biological treatment of greywater through layered planting beds. Boardwalks and platforms allow visitors to meander through the wetland, observing how plants and microbes cleanse the water. As a sensory landscape, this zone is both meditative and functional – it treats water while inviting visitors to understand its transformation. North of the wetlands, the **small café (F)** is placed so that the visitors could grab a drink while on route to the metro or ferry.

Together, the spatial arrangement forms a loop: from arrival via bus or foot at the northern edge, to education and observation within the central wetland and plaza, to departure via boat at the pier. The project is designed not as a static terminal, but as an experiential circuit—where every moment of movement through the site is also an opportunity to engage with São Paulo's hydrological story. The masterplan responds to local topography, guides stormwater naturally toward retention zones, and opens strategic views toward the Guarapiranga reservoir. In this way, the São Paulo Water Center does not merely occupy a site—it redefines it, transforming an underutilized waterfront edge into a regenerative civic node.

6.3 Key Spaces and Their Water-Ecological Functions

At the heart of the São Paulo Water Center is a network of spaces that combine public access, environmental function, and educational value.

The pier and boat docking area (D) serves as the primary entry point for water-based transport, connecting public ferries and educational boats to the site. Designed with floating platforms that adjust to changing water levels, it ensures safe and inclusive access. The pier doubles as a civic space—framing views of the reservoir and creating a direct, tactile connection to the water. Waste collection and clearly defined circulation routes support both environmental stewardship and visitor comfort.

Adjacent to the pier (D), the rain collection garden (A) manages stormwater through permeable surfaces, basins, and native plantings. It captures runoff before it reaches the wetlands, reducing flood risk and filtering pollutants. Informational signage throughout explains how these techniques can be replicated at home, positioning the garden as both infrastructure and outdoor classroom.

The constructed wetland (A) is the site's ecological engine. Greywater is naturally filtered through plant roots and microbial activity, transforming wastewater into a reusable resource. Elevated paths and seating areas allow visitors to observe the process, while the wetland's biodiversity—birds, amphibians, and aquatic species—illustrates the system's regenerative potential.

Connecting these features is a walkable green landscape of paths, shaded rest areas, and gathering spots. Designed for comfort and permeability, the network supports large and small groups alike, balancing flow and pause. Vegetation, trees, and minimal hardscaping enhance cooling and water absorption.

At the site's entrance, the bus and transit hub (B) links the water systems to São Paulo's broader public transport network. Equipped with dedicated lanes, shaded waiting areas, real-time schedules, and bike parking, it promotes low-emission, multimodal travel. Integrated green infrastructure—solar lighting, bioswales, and rainwater drains—extends the Center's sustainable ethos to the very first point of arrival.

The São Paulo Water Center (B) features a waiting area indoors with amenities like ticket office or bathroom. On the 1st floor there's a restaurant, labs and the conference room for water classes as well as a mini terrace. On top of the roof, there are solar panels to run the center on green energy. The water from the roof is captured and then used for center's daily water operations.

Infrastructure & Utilities

Space	Estimated Area (m^2)	Notes
Drainage & Water Supply	204 - 402	Underground piping, filtration connections, and greywater reuse system
Wastewater Treatment System	800	Includes sewage collection, activated sludge treatment, flocculation/sedimentation, filtration, and wetland polishing

Outdoor spatial needs

Space	Estimated Area (m²)	Notes
Pier and Boat Docking	250	Includes floating platforms, covered waiting area, and waste collection points
Rain Collection Garden	300	Designed for stormwater retention, native vegetation, and educational use
Constructed Wetland	600	Water treatment, biodiversity support, and pedestrian walkways
Public Walkways & Seating Areas	400	Includes shaded seating, accessible paths, and permeable surfaces
Bus & Transit Hub	350	Passenger waiting area, bike parking, and real-time schedule displays
Landscaping & Tree Canopy	500	Native species for shade, erosion control, and urban cooling

Table 4. Spatial needs of spaces in the São Paulo Water Center

6.4 Integrated Water Systems as Architecture

The São Paulo Water Center treats water not just as a utility, but as a design principle. Rainwater harvesting, greywater recycling, and wetland filtration are embedded visibly into the architecture and landscape, creating a spatial and educational narrative of the urban water cycle.

Rainwater is captured from rooftops and hardscapes, guided by sculpted surfaces into open runnels and stainless-steel chains that flow into a central cistern. This cistern, glass-walled and placed in the plaza, serves as both infrastructure and exhibit—its rising and falling water levels marking weather patterns in real time. During storms, the system becomes a sensory feature, transforming rainfall into sight and sound.

Greywater, collected from all sinks and showers, is directed through coded pipes partially visible beneath glazed floor panels. Select portions of the treatment system—including filters and UV sterilizers—are displayed behind glass walls alongside explanatory diagrams. A thin film of treated greywater flows down an interior wall as a symbolic reintroduction of recycled water into the building's public spaces.

Constructed wetlands complete the treatment cycle. Located at the center of the site, terraced wetland beds treat both rainwater and greywater through a combination of plants, gravel, and subsurface flows. Designed to handle up to 136,000 liters per day, the wetlands serve both ecological and educational functions. Visitors walk above them on boardwalks and observe each stage of purification—transforming wastewater treatment into an immersive learning experience.

To maintain safety while enabling visibility, the design clearly separates public and technical zones. Sensitive equipment—such as pumps and settling tanks—is kept secure, but remains partially visible through signage, portholes, and small viewing windows. This balance of transparency and protection ensures that every part of the system contributes to the visitor experience without compromising functionality.

Across all systems, the message is consistent: water infrastructure can be beautiful, legible, and participatory. The design invites users to trace water's journey—turning what's typically hidden underground into a civic experience that teaches, inspires, and performs.

6.5 Precedents and Inspirations: Architecture as Water Infrastructure

The São Paulo Water Center builds on a global lineage of projects that treat water infrastructure as both a civic utility and an educational experience. These precedents demonstrate that when thoughtfully integrated, water systems can be functional, visible, and culturally meaningful.

The **Omega Center for Sustainable Living** in Rhinebeck, New York, uses constructed wetlands—both indoors and outdoors—to treat wastewater visibly, offering visitors a direct experience of ecological purification (Omega Institute, 2017). Similarly, the **Sidwell Friends School** in Washington, D.C., incorporates terraced reed beds in its courtyard, merging wastewater treatment with daily student learning (Ellis et al., 2012).

The **"Coffee Canal"** installation by Diller Scofidio + Renfro at the 2025 Venice Architecture Biennale turns canal water into purified coffee using exposed UV and filtration systems, engaging visitors through performance and taste (Burgos, 2025).

On a city scale, **Łódź, Poland** has implemented rainwater pretreatment parks that use natural systems embedded in public green spaces to manage stormwater while educating residents (Interreg Europe, 2024). In **Israel**, **Ayala Water & Ecology** promotes passive greywater treatment through phytoremediation systems that require no energy or chemicals, enriching biodiversity and public space (Leichman, 2015).

The **Shenzhen Lotus Water Culture Base** conceals a major underground treatment plant beneath a public park, reimagining technical infrastructure as a landscape and civic amenity (ArchDaily, 2022).

These projects validate the Water Center's approach: combining ecological function, visibility, and community engagement. São Paulo's proposal extends this legacy, adapting these principles to a dense, underserved, and climate-challenged urban context—transforming infrastructure into both a public service and a civic story.

6.6 Water Reuse and Performance Outcomes

The Center's water system is engineered for both efficiency and resilience, reducing reliance on mains supply and minimizing wastewater discharge. All treated water—from rain and greywater sources—is reused on-site. Designed for São Paulo's climate, the system stores enough water to operate through dry spells and reduces potable water use by up to 75% annually. The 3,500 m^3 cistern captures millions of liters per year, and overflow is directed to infiltration beds to recharge groundwater—helping mitigate urban flood risks.

In extreme droughts, the system can rely on city water as backup, though this is minimized by the circular design. The approach aligns with São Paulo's water regulations, which since 2002 have required reclaimed water use for non-potable functions in new developments (Freedman et al., 2016).

By ensuring that every drop is captured, treated, and reused, the Center demonstrates a replicable model of net-zero water use—meeting performance standards while advancing the city's climate resilience agenda (see Chapter 2 for city's challenges).

6.7 Public Value

The São Paulo Water Center functions as a prototype for urban infrastructure that is sustainable, educational, and replicable. Its landscape—composed of rain gardens, bioswales, and constructed wetlands—treats water while also offering public space, biodiversity, and environmental awareness. Designed with native Atlantic Forest species, the gardens manage runoff, restore habitat, and create a welcoming civic atmosphere.

The building itself reinforces this mission. The roof integrates solar panels alongside green infrastructure, generating renewable energy that supports pumps, lighting, and system monitoring—reducing dependence on the grid and lowering emissions. Some roof areas are accessible for demonstrations, while others remain active components of the building's performance.

Rather than relying on abstract explanations, the architecture itself teaches through form, material, and sequence. From a bench overlooking the wetlands to the sound of water beneath a grated floor, every design choice reinforces water literacy. The Center also hosts professional workshops and school visits, amplifying its reach. By integrating infrastructure with storytelling, the Water Center fosters awareness, curiosity, and environmental responsibility—demonstrating how architecture can educate while addressing real-world challenges.

Inside and out, the Center uses design to teach. Large windows frame views of the wetlands and cisterns, allowing visitors to witness water systems in action. Signage is clear, bilingual (Portuguese and English), and strategically placed for self-guided learning. Interactive dashboards show real-time metrics like water flow, storage levels, and solar output—connecting infrastructure to lived experience.

Rather than relying on abstract explanations, the architecture itself teaches through form, material, and sequence. From a bench overlooking the wetlands to the sound of water beneath a grated floor, every design choice reinforces water literacy. The Center also hosts professional workshops and school visits, amplifying its reach. By integrating infrastructure with storytelling, the Water Center fosters awareness, curiosity, and environmental responsibility—demonstrating how architecture can educate while addressing real-world challenges.

This approach aligns with São Paulo's climate resilience strategy, developed after the 2014–2015 drought, which prioritizes decentralized water systems and public engagement. The Center complies with city mandates for non-potable water reuse (Freedman et al., 2016) and advances those goals with integrated, educational infrastructure.

Designed as a 10-year pilot, the Center uses modular and low-tech systems that can be replicated in schools, transit stations, and public institutions. It also serves as a training site—hosting workshops, professional visits, and school groups to foster water literacy across audiences.

Ultimately, the Water Center offers more than services—it cultivates a mindset. By embedding infrastructure into everyday experience, it demonstrates how cities can educate, adapt, and lead through design.

6.8 Scalability and Replicability across São Paulo

The São Paulo Water Center serves as a prototypical model for decentralized and sustainable water infrastructure that can be adapted citywide. Its design—featuring rainwater harvesting, greywater recycling, constructed wetlands, and educational integration—is intentionally modular and flexible. These systems can be tailored to various building types, such as schools, bus terminals, or community centers.

To guide the citywide rollout, the table below categorizes each Water Center component by its ease of replication: those that can be installed "as-is" in comparable settings, those that need adaptation to local conditions or regulations, and those best avoided in particular contexts. This framework helps planners and developers quickly identify which modules—rainwater harvesting, constructed wetlands, greywater loops, visible infrastructure, modular architecture, and rooftop solar—fit seamlessly into new sites, where design tweaks are needed, and where alternative strategies should be considered.

Component / Strategy	Directly Transferable	Requires Adaptation	Not Suitable For
Rainwater harvesting system	Schools, parks, transit hubs	Arid climates with low rainfall	Hyper-dense city cores with no roof/land access
Constructed wetlands	Peri-urban sites with open space	Scale must adjust to rainfall and land availability	Very arid zones; dense downtowns
Greywater reuse systems	Public facilities with regular usage	Plumbing must meet local health codes	Buildings with minimal water use
Educational signage and murals	Any public institution	Language and cultural framing	N/A
Transparent infrastructure elements	All visible systems (tanks, windows, pipes)	Design integration varies with building type	Sites requiring full concealment due to security or aesthetics
Modular, low-impact architecture	Temporary or transitional sites	Construction methods/materials may vary	Historic districts with rigid conservation rules
Rooftop solar integration	Facilities with roof access	Sizing and tech based on solar availability	Sites with shaded or inaccessible roofs

Table 5. Replicability Matrix of the São Paulo Water Center

Chapter 7: Discussion

The São Paulo Water Center pilot demonstrates that decentralized, visible water infrastructure integrated into public architecture can deliver measurable performance and practical guidance for replication. Key outcomes include:

- **Water Demand Reduction:** The Center's decentralized treatment train—combining rainwater harvesting, greywater recycling, and constructed wetlands—reduced reliance on municipal supply by over 70%, aligning with the 65% greywater reuse and up to 70% rainwater contribution calculated in Chapter 5.3.
- **Treatment Capacity:** Designed to manage up to 136,000 L/day of combined wastewater streams (Section 5.2), the hybrid system of activated sludge, constructed wetlands, and nutrient recovery proved effective within the pilot's spatial constraints.
- **Modularity and Adaptation:** The kit-of-parts approach—standard cistern modules, wetland beds, UV units, and visible infrastructure elements—can be sized or concealed based on site conditions. Chapter 6's transfer–adapt–defer matrix provides a clear framework for selecting and tailoring components in schools, parks, transit hubs, or constrained heritage areas.
- **Educational Integration:** By embedding visible tanks, interpretation panels, and guided pathways, the Center functions as an active demonstration site. Visitors observe cistern operation, wetland treatment, and solar-powered pumps, reinforcing hands-on learning and strengthening water literacy without requiring off-site materials.
- **Stakeholder Collaboration:** Partnerships with municipal agencies, water utilities, and local NGOs facilitated permitting, technical alignment, and workshop programming. These collaborations streamlined approvals for greywater reuse and supported community outreach detailed in Chapter 4.

Together, these findings confirm that a decentralized, hybrid model—rooted in local context and powered by visible pedagogy—can advance São Paulo's resilience to drought, flooding, and infrastructure inequities.

Chapter 8: Conclusion and Recommendations

8.1 Conclusion

This thesis presents the São Paulo Water Center as a replicable prototype for climate-resilient, community-centered water infrastructure. Its integrated design achieved:

1. **Self-Sufficient Operation:** Over 70% reduction in municipal water demand, 65% greywater reuse rate, and integration of nutrient recovery and biogas generation within a compact pilot facility.
2. **Scalable Framework:** A modular transfer–adapt–defer matrix (Table 5) that guides the customization or exclusion of components based on rainfall, land availability, health codes, and aesthetic constraints.
3. **Visible Education:** On-site demonstration of rainwater capture, filtration wetlands, and solar-driven processes that transform infrastructure into a living classroom.

Based on these results, we recommend:

- **Regulatory Alignment:** Update municipal codes to facilitate decentralized treatment approvals, greywater reuse, and the visible integration of water systems in public developments.
- **Performance Monitoring:** Deploy real-time dashboards for water flow, reuse rates, and energy use at each node to build a comprehensive dataset that informs continuous improvement.
- **Expanded Partnerships:** Engage schools, community centers, and transit agencies as host sites, leveraging existing infrastructure to scale both the technical systems and educational programs.

By embedding modular, visible water systems into public architecture, São Paulo can build urban resilience, promote equitable access, and foster a culture of water stewardship—offering a model for cities confronting similar challenges globally.

8.2 Future Avenues of Research

Future research should focus on areas directly related to the project's implementation and impact. Key topics include:

1. **Long-Term Performance and Maintenance:** Evaluate system resilience and maintenance needs over multiple seasons and years, focusing on water quality stability, component longevity, and peak-load management.
2. **Socio-Behavioral Impacts:** Assess how visible infrastructure shapes community water behaviors, trust in reuse systems, and the adoption rate of decentralized solutions in both formal and informal neighborhoods.

3. **Policy and Regulatory Pathways:** Analyze existing municipal codes and develop streamlined frameworks that facilitate greywater reuse, nutrient recovery, and integration of visible water systems in public and private developments.
4. **Techno-Economic Optimization:** Conduct cost–benefit and life-cycle assessments for modular components—cisterns, wetlands, treatment units—to refine designs, lower costs, and quantify ecosystem co-benefits.

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Appendixes. Supporting Data and Methodology

Time Period	Hours	Traffic Flow	Percentage	Total Visitors in the Center	Visitors Using Restroom (70%)	Male Urinals (L)	Male Toilets (L)	DW for Hand washing (L)	Female Toilets (L)	DW for Tooth Brushing (L)	Restaurant & cafe water needs	Total mix Water Needs (L)
06:00 - 09:00	3	Morning Peak	30%	3660	2562	1,921.50	1,921.50	2,562.00	6,405.00	-	794.94	13,604.94
09:00 - 11:30	3.5	Off-Peak	15%	1830	1281	960.75	960.75	1,281.00	3,202.50	-	927.43	7,332.43
11:30 - 14:30	3	Lunch Peak	20%	2440	1708	1,281.00	1,281.00	1,708.00	4,270.00	2,562.00	794.94	11,896.94
14:30 - 17:00	2.5	Off-Peak	15%	1830	1281	960.75	960.75	1,281.00	3,202.50	-	662.45	7,067.45
17:00 - 21:00	4	Evening Peak	15%	1830	1281	960.75	960.75	1,281.00	3,202.50	-	1,059.92	7,464.92
21:00 - 00:00	3	Off-Peak	5%	610	427	320.25	320.25	427.00	1,067.50	-	794.94	2,929.94
			100%	12200	8540	6,405.00	6,405.00	8,540.00	21,350.00	2,562.00	5,034.60	**50,296.60**

Time Period	Total mix Water Needs per hour (L)	Total DW water needs for RO (L)	Total RO Discharged water (L)	Total water need for toilets (L)	Total DW Needs (L)	Available water for short term storage and reuse (L)	Total water needed for bathrooms after water reuse (L)	Mix water need per hour after reuse (L)	Mix water needed per hour without reuse (L)	Water need reduction, %	Harvested rainwater (L)	Water needs after reuse and RW harvesting, per hour	Water need reduction after reuse and RW harvesting
06:00 - 09:00	4,534.98	6,713.87	3,356.94	10,248.00	3,356.94	5,918.94	4,329.06	2,562.00	5,653.96	55%	487.21	2,399.60	58%
09:00 - 11:30	2,094.98	4,416.85	2,208.43	5,124.00	2,208.43	3,489.43	1,634.57	1,098.00	2,725.96	60%	568.41	935.60	66%
11:30 - 14:30	3,965.65	10,129.87	5,064.94	6,832.00	5,064.94	9,334.94	- 2,502.94	854.00	5,653.96	85%	487.21	691.60	88%
14:30 - 17:00	2,826.98	3,886.89	1,943.45	5,124.00	1,943.45	3,224.45	1,899.55	1,537.20	3,604.36	57%	406.01	1,374.80	62%
17:00 - 21:00	1,866.23	4,681.83	2,340.92	5,124.00	2,340.92	3,621.92	1,502.08	960.75	2,451.46	61%	649.62	798.35	67%
21:00 - 00:00	976.65	2,443.87	1,221.94	1,708.00	1,221.94	1,648.94	59.06	427.00	1,383.96	69%	487.21	264.60	81%
	2,647.19	32,273.20	16,136.60	34,160.00	16,136.60	**27,238.60**	6,921.40	1,213.58	3,496.48	**65%**	3,085.68	1,051.17	**70%**

Table A. The centre water needs estimated on a 24 hour period.

Treatment stage	HRT (h)	Peak flow (L/h)	Volume (L)	Volume (m³)
Sewage Collection Tank	3	7 342.3	22 027	22.0
Activated Sludge Reactor	6	7 342.3	44 054	44.1
Flocculation & Sedimentation Tank	2.5	7 342.3	18 356	18.4
Filtration Unit	1	7 342.3	7 342	7.3
Constructed Wetland	144	7 342.3	1 056 660	1 056.7

Table B. Required volume (L) by treatment stage

Table C. Water center balance calculation for a period of a 7 day week

Day	Time Period	Duration (h)	Raw Inflow (L)	Reuse Inflow (L)	Cumulative Hours (h)	Sewage Tank (3h)	Activated Sludge (6h)	Floc+Sed (2.5h)	Filtration (2h)	Rain to Wetland (L/h)	ET Loss (L/h)	Wetland Before ET (L)	Wetland Discharge (L)	Wetland After ET (L)
1	06:00-07:00	1	5,653.96	2,399.60	1.00	2,399.60	2,399.60	2,399.60	5,653.96	550.00	446.11	2,949.60	0	2,503.49
1	07:00-08:00	1	5,653.96	2,399.60	2.00	4,799.19	4,799.19	4,799.19	11,307.92	550.00	446.11	5,899.19	0	5,453.08
1	08:00-09:00	1	5,653.96	2,399.60	3.00	7,198.79	7,198.79	7,198.79	11,307.92	550.00	446.11	8,848.79	0	8,402.68
1	09:00-10:00	1	2,725.96	935.60	4.00	5,734.79	8,134.38	5,734.79	8,379.92	550.00	446.11	10,334.38	0	9,888.27
1	10:00-11:30	1.5	2,725.96	935.60	5.50	4,270.79	9,069.98	1,871.19	5,451.92	550.00	446.11	11,819.98	0	11,373.87
1	11:30-12:00	0.5	5,653.96	691.60	6.00	2,562.79	9,761.58	2,562.79	8,379.92	550.00	446.11	13,061.58	0	12,615.46
1	12:00-13:00	1	5,653.96	691.60	7.00	2,318.79	8,053.58	2,318.79	14,033.87	550.00	446.11	14,303.17	0	13,857.06
1	13:00-14:30	1.5	5,653.96	691.60	8.50	2,074.79	6,345.58	1,383.19	11,307.92	550.00	446.11	15,544.77	0	15,098.66
1	14:30-15:00	0.5	3,604.36	1,374.80	9.00	2,757.99	5,320.78	2,757.99	9,258.32	550.00	446.11	17,469.56	0	17,023.45
1	15:00-16:00	1	3,604.36	1,374.80	10.00	3,441.19	5,759.98	3,441.19	12,862.67	550.00	446.11	19,394.36	0	18,948.25
1	16:00-17:00	1	3,604.36	1,374.80	11.00	4,815.98	7,134.77	4,124.39	7,208.72	550.00	446.11	21,319.15	0	20,873.04
1	17:00-18:00	1	2,451.46	798.35	12.00	3,547.94	6,305.93	3,547.94	6,055.82	550.00	446.11	22,667.50	0	22,221.39
1	18:00-19:00	1	2,451.46	798.35	13.00	2,971.49	6,412.68	2,971.49	4,902.92	550.00	446.11	24,015.85	0	23,569.74
1	19:00-20:00	1	2,451.46	798.35	14.00	2,395.04	7,211.02	2,395.04	4,902.92	550.00	446.11	25,364.19	0	24,918.08
1	20:00-21:00	1	2,451.46	798.35	15.00	2,395.04	5,942.98	2,395.04	4,902.92	550.00	446.11	26,712.54	0	26,266.43
1	21:00-22:00	1	1,383.96	264.60	16.00	1,861.29	4,832.78	1,861.29	3,835.42	550.00	446.11	27,527.13	0	27,081.02
1	22:00-23:00	1	1,383.96	264.60	17.00	1,327.54	3,722.58	1,327.54	2,767.92	550.00	446.11	28,341.73	0	27,895.62
1	23:00-00:00	1	1,383.96	264.60	18.00	793.79	3,188.83	793.79	2,767.92	550.00	446.11	29,156.33	0	28,710.21
1	00:00-01:00	1	-	-	19.00	529.19	2,390.48	529.19	1,383.96	550.00	446.11	29,706.33	0	29,260.21
1	01:00-02:00	1	-	-	20.00	264.60	1,592.13	264.60	-	550.00	446.11	30,256.33	0	29,810.21
1	02:00-03:00	1	-	-	21.00	-	793.79	-	-	550.00	446.11	30,806.33	0	30,360.21
1	03:00-04:00	1	-	-	22.00	-	529.19	-	-	550.00	446.11	31,356.33	0	30,910.21
1	04:00-05:00	1	-	-	23.00	-	264.60	-	-	550.00	446.11	31,906.33	0	31,460.21
1	05:00-06:00	1	-	-	24.00	-	-	-	-	550.00	446.11	32,456.33	0	32,010.21
2	06:00-07:00	1	5,653.96	2,399.60	25.00	2,399.60	2,399.60	2,399.60	5,653.96	550.00	446.11	35,405.92	0	34,959.81

2	07:00-08:00	1	5,653.96	2,399.60	26.00	4,799.19	4,799.19	4,799.19	11,307.92	550.00	446.11	38,355.52	0	37,909.41
2	08:00-09:00	1	5,653.96	2,399.60	27.00	7,198.79	7,198.79	7,198.79	11,307.92	550.00	446.11	41,305.11	0	40,859.00
2	09:00-10:00	1	2,725.96	935.60	28.00	5,734.79	8,134.38	5,734.79	8,379.92	550.00	446.11	42,790.71	0	42,344.60
2	10:00-11:30	1.5	2,725.96	935.60	29.50	4,270.79	9,069.98	1,871.19	5,451.92	550.00	446.11	44,276.30	0	43,830.19
2	11:30-12:00	0.5	5,653.96	691.60	30.00	2,562.79	9,761.58	2,562.79	8,379.92	550.00	446.11	45,517.90	0	45,071.79
2	12:00-13:00	1	5,653.96	691.60	31.00	2,318.79	8,053.58	2,318.79	14,033.87	550.00	446.11	46,759.50	0	46,313.39
2	13:00-14:30	1.5	5,653.96	691.60	32.50	2,074.79	6,345.58	1,383.19	11,307.92	550.00	446.11	48,001.09	0	47,554.98
2	14:30-15:00	0.5	3,604.36	1,374.80	33.00	2,757.99	5,320.78	2,757.99	9,258.32	550.00	446.11	49,925.89	0	49,479.78
2	15:00-16:00	1	3,604.36	1,374.80	34.00	3,441.19	5,759.98	3,441.19	12,862.67	550.00	446.11	51,850.68	0	51,404.57
2	16:00-17:00	1	3,604.36	1,374.80	35.00	4,815.98	7,134.77	4,124.39	7,208.72	550.00	446.11	53,775.48	0	53,329.37
2	17:00-18:00	1	2,451.46	798.35	36.00	3,547.94	6,305.93	3,547.94	6,055.82	550.00	446.11	55,123.83	0	54,677.71
2	18:00-19:00	1	2,451.46	798.35	37.00	2,971.49	6,412.68	2,971.49	4,902.92	550.00	446.11	56,472.17	0	56,026.06
2	19:00-20:00	1	2,451.46	798.35	38.00	2,395.04	7,211.02	2,395.04	4,902.92	550.00	446.11	57,820.52	0	57,374.41
2	20:00-21:00	1	2,451.46	798.35	39.00	2,395.04	5,942.98	2,395.04	4,902.92	550.00	446.11	59,168.86	0	58,722.75
2	21:00-22:00	1	1,383.96	264.60	40.00	1,861.29	4,832.78	1,861.29	3,835.42	550.00	446.11	59,983.46	0	59,537.35
2	22:00-23:00	1	1,383.96	264.60	41.00	1,327.54	3,722.58	1,327.54	2,767.92	550.00	446.11	60,798.05	0	60,351.94
2	23:00-00:00	1	1,383.96	264.60	42.00	793.79	3,188.83	793.79	2,767.92	550.00	446.11	61,612.65	0	61,166.54
2	00:00-01:00	1	-	-	43.00	529.19	2,390.48	529.19	1,383.96	550.00	446.11	62,162.65	0	61,716.54
2	01:00-02:00	1	-	-	44.00	264.60	1,592.13	264.60	-	550.00	446.11	62,712.65	0	62,266.54
2	02:00-03:00	1	-	-	45.00	-	793.79	-	-	550.00	446.11	63,262.65	0	62,816.54
2	03:00-04:00	1	-	-	46.00	-	529.19	-	-	550.00	446.11	63,812.65	0	63,366.54
2	04:00-05:00	1	-	-	47.00	-	264.60	-	-	550.00	446.11	64,362.65	0	63,916.54
2	05:00-06:00	1	-	-	48.00	-	-	-	-	550.00	446.11	64,912.65	0	64,466.54
3	06:00-07:00	1	5,653.96	2,399.60	49.00	2,399.60	2,399.60	2,399.60	5,653.96	550.00	446.11	67,862.25	0	67,416.14
3	07:00-08:00	1	5,653.96	2,399.60	50.00	4,799.19	4,799.19	4,799.19	11,307.92	550.00	446.11	70,811.84	0	70,365.73
3	08:00-09:00	1	5,653.96	2,399.60	51.00	7,198.79	7,198.79	7,198.79	11,307.92	550.00	446.11	73,761.44	0	73,315.33
3	09:00-10:00	1	2,725.96	935.60	52.00	5,734.79	8,134.38	5,734.79	8,379.92	550.00	446.11	75,247.03	0	74,800.92
3	10:00-11:30	1.5	2,725.96	935.60	53.50	4,270.79	9,069.98	1,871.19	5,451.92	550.00	446.11	76,732.63	0	76,286.52

3	11:30-12:00	0.5	5,653.96	691.60	54.00	2,562.79	9,761.58	2,562.79	8,379.92	550.00	446.11	77,974.23	0	77,528.11
3	12:00-13:00	1	5,653.96	691.60	55.00	2,318.79	8,053.58	2,318.79	14,033.87	550.00	446.11	79,215.82	0	78,769.71
3	13:00-14:30	1.5	5,653.96	691.60	56.50	2,074.79	6,345.58	1,383.19	11,307.92	550.00	446.11	80,457.42	0	80,011.31
3	14:30-15:00	0.5	3,604.36	1,374.80	57.00	2,757.99	5,320.78	2,757.99	9,258.32	550.00	446.11	82,382.21	0	81,936.10
3	15:00-16:00	1	3,604.36	1,374.80	58.00	3,441.19	5,759.98	3,441.19	12,862.67	550.00	446.11	84,307.01	0	83,860.90
3	16:00-17:00	1	3,604.36	1,374.80	59.00	4,815.98	7,134.77	4,124.39	7,208.72	550.00	446.11	86,231.80	0	85,785.69
3	17:00-18:00	1	2,451.46	798.35	60.00	3,547.94	6,305.93	3,547.94	6,055.82	550.00	446.11	87,580.15	0	87,134.04
3	18:00-19:00	1	2,451.46	798.35	61.00	2,971.49	6,412.68	2,971.49	4,902.92	550.00	446.11	88,928.50	0	88,482.39
3	19:00-20:00	1	2,451.46	798.35	62.00	2,395.04	7,211.02	2,395.04	4,902.92	550.00	446.11	90,276.84	0	89,830.73
3	20:00-21:00	1	2,451.46	798.35	63.00	2,395.04	5,942.98	2,395.04	4,902.92	550.00	446.11	91,625.19	0	91,179.08
3	21:00-22:00	1	1,383.96	264.60	64.00	1,861.29	4,832.78	1,861.29	3,835.42	550.00	446.11	92,439.78	0	91,993.67
3	22:00-23:00	1	1,383.96	264.60	65.00	1,327.54	3,722.58	1,327.54	2,767.92	550.00	446.11	93,254.38	0	92,808.27
3	23:00-00:00	1	1,383.96	264.60	66.00	793.79	3,188.83	793.79	2,767.92	550.00	446.11	94,068.98	0	93,622.86
3	00:00-01:00	1	-	-	67.00	529.19	2,390.48	529.19	1,383.96	550.00	446.11	94,618.98	0	94,172.86
3	01:00-02:00	1	-	-	68.00	264.60	1,592.13	264.60	-	550.00	446.11	95,168.98	0	94,722.86
3	02:00-03:00	1	-	-	69.00	-	793.79	-	-	550.00	446.11	95,718.98	0	95,272.86
3	03:00-04:00	1	-	-	70.00	-	529.19	-	-	550.00	446.11	96,268.98	0	95,822.86
3	04:00-05:00	1	-	-	71.00	-	264.60	-	-	550.00	446.11	96,818.98	0	96,372.86
3	05:00-06:00	1	-	-	72.00	-	-	-	-	550.00	446.11	97,368.98	0	96,922.86
4	06:00-07:00	1	5,653.96	2,399.60	73.00	2,399.60	2,399.60	2,399.60	5,653.96	550.00	446.11	100,318.57	0	99,872.46
4	07:00-08:00	1	5,653.96	2,399.60	74.00	4,799.19	4,799.19	4,799.19	11,307.92	550.00	446.11	103,268.17	0	102,822.06
4	08:00-09:00	1	5,653.96	2,399.60	75.00	7,198.79	7,198.79	7,198.79	11,307.92	550.00	446.11	106,217.76	0	105,771.65
4	09:00-10:00	1	2,725.96	935.60	76.00	5,734.79	8,134.38	5,734.79	8,379.92	550.00	446.11	107,703.36	0	107,257.25
4	10:00-11:30	1.5	2,725.96	935.60	77.50	4,270.79	9,069.98	1,871.19	5,451.92	550.00	446.11	109,188.95	0	108,742.84
4	11:30-12:00	0.5	5,653.96	691.60	78.00	2,562.79	9,761.58	2,562.79	8,379.92	550.00	446.11	110,430.55	0	109,984.44
4	12:00-13:00	1	5,653.96	691.60	79.00	2,318.79	8,053.58	2,318.79	14,033.87	550.00	446.11	111,672.15	0	111,226.04
4	13:00-14:30	1.5	5,653.96	691.60	80.50	2,074.79	6,345.58	1,383.19	11,307.92	550.00	446.11	112,913.74	0	112,467.63
4	14:30-15:00	0.5	3,604.36	1,374.80	81.00	2,757.99	5,320.78	2,757.99	9,258.32	550.00	446.11	114,838.54	0	114,392.43

4	15:00-16:00	1	3,604.36	1,374.80	82.00	3,441.19	5,759.98	3,441.19	12,862.67	550.00	446.11	116,763.33	0	116,317.22
4	16:00-17:00	1	3,604.36	1,374.80	83.00	4,815.98	7,134.77	4,124.39	7,208.72	550.00	446.11	118,688.13	0	118,242.02
4	17:00-18:00	1	2,451.46	798.35	84.00	3,547.94	6,305.93	3,547.94	6,055.82	550.00	446.11	120,036.48	0	119,590.36
4	18:00-19:00	1	2,451.46	798.35	85.00	2,971.49	6,412.68	2,971.49	4,902.92	550.00	446.11	121,384.82	0	120,938.71
4	19:00-20:00	1	2,451.46	798.35	86.00	2,395.04	7,211.02	2,395.04	4,902.92	550.00	446.11	122,733.17	0	122,287.06
4	20:00-21:00	1	2,451.46	798.35	87.00	2,395.04	5,942.98	2,395.04	4,902.92	550.00	446.11	124,081.51	0	123,635.40
4	21:00-22:00	1	1,383.96	264.60	88.00	1,861.29	4,832.78	1,861.29	3,835.42	550.00	446.11	124,896.11	0	124,450.00
4	22:00-23:00	1	1,383.96	264.60	89.00	1,327.54	3,722.58	1,327.54	2,767.92	550.00	446.11	125,710.70	0	125,264.59
4	23:00-00:00	1	1,383.96	264.60	90.00	793.79	3,188.83	793.79	2,767.92	550.00	446.11	126,525.30	0	126,079.19
4	00:00-01:00	1	-	-	91.00	529.19	2,390.48	529.19	1,383.96	550.00	446.11	127,075.30	0	126,629.19
4	01:00-02:00	1	-	-	92.00	264.60	1,592.13	264.60	-	550.00	446.11	127,625.30	0	127,179.19
4	02:00-03:00	1	-	-	93.00	-	793.79	-	-	550.00	446.11	128,175.30	0	127,729.19
4	03:00-04:00	1	-	-	94.00	-	529.19	-	-	550.00	446.11	128,725.30	0	128,279.19
4	04:00-05:00	1	-	-	95.00	-	264.60	-	-	550.00	446.11	129,275.30	0	128,829.19
4	05:00-06:00	1	-	-	96.00	-	-	-	-	550.00	446.11	129,825.30	225.3	129,153.89
5	06:00-07:00	1	5,653.96	2,399.60	97.00	2,399.60	2,399.60	2,399.60	5,653.96	550.00	446.11	132,774.90	3174.895833	129,153.89
5	07:00-08:00	1	5,653.96	2,399.60	98.00	4,799.19	4,799.19	4,799.19	11,307.92	550.00	446.11	135,724.49	6124.491667	129,153.89
5	08:00-09:00	1	5,653.96	2,399.60	99.00	7,198.79	7,198.79	7,198.79	11,307.92	550.00	446.11	138,674.09	9074.0875	129,153.89
5	09:00-10:00	1	2,725.96	935.60	100.00	5,734.79	8,134.38	5,734.79	8,379.92	550.00	446.11	140,159.68	10559.68333	129,153.89
5	10:00-11:30	1.5	2,725.96	935.60	101.50	4,270.79	9,069.98	1,871.19	5,451.92	550.00	446.11	141,645.28	12045.27917	129,153.89
5	11:30-12:00	0.5	5,653.96	691.60	102.00	2,562.79	9,761.58	2,562.79	8,379.92	550.00	446.11	142,886.88	13286.875	129,153.89
5	12:00-13:00	1	5,653.96	691.60	103.00	2,318.79	8,053.58	2,318.79	14,033.87	550.00	446.11	144,128.47	14528.47083	129,153.89
5	13:00-14:30	1.5	5,653.96	691.60	104.50	2,074.79	6,345.58	1,383.19	11,307.92	550.00	446.11	145,370.07	15770.06667	129,153.89
5	14:30-15:00	0.5	3,604.36	1,374.80	105.00	2,757.99	5,320.78	2,757.99	9,258.32	550.00	446.11	147,294.86	17694.8625	129,153.89
5	15:00-16:00	1	3,604.36	1,374.80	106.00	3,441.19	5,759.98	3,441.19	12,862.67	550.00	446.11	149,219.66	19619.65833	129,153.89
5	16:00-17:00	1	3,604.36	1,374.80	107.00	4,815.98	7,134.77	4,124.39	7,208.72	550.00	446.11	151,144.45	21544.45417	129,153.89
5	17:00-18:00	1	2,451.46	798.35	108.00	3,547.94	6,305.93	3,547.94	6,055.82	550.00	446.11	152,492.80	22892.8	129,153.89
5	18:00-19:00	1	2,451.46	798.35	109.00	2,971.49	6,412.68	2,971.49	4,902.92	550.00	446.11	153,841.15	24241.14583	129,153.89

5	19:00-20:00	1	2,451.46	798.35	110.00	2,395.04	7,211.02	2,395.04	4,902.92	550.00	446.11	155,189.49	25589.49167	129,153.89
5	20:00-21:00	1	2,451.46	798.35	111.00	2,395.04	5,942.98	2,395.04	4,902.92	550.00	446.11	156,537.84	26937.8375	129,153.89
5	21:00-22:00	1	1,383.96	264.60	112.00	1,861.29	4,832.78	1,861.29	3,835.42	550.00	446.11	157,352.43	27752.43333	129,153.89
5	22:00-23:00	1	1,383.96	264.60	113.00	1,327.54	3,722.58	1,327.54	2,767.92	550.00	446.11	158,167.03	28567.02917	129,153.89
5	23:00-00:00	1	1,383.96	264.60	114.00	793.79	3,188.83	793.79	2,767.92	550.00	446.11	158,981.63	29381.625	129,153.89
5	00:00-01:00	1	-	-	115.00	529.19	2,390.48	529.19	1,383.96	550.00	446.11	159,531.63	29931.625	129,153.89
5	01:00-02:00	1	-	-	116.00	264.60	1,592.13	264.60	-	550.00	446.11	160,081.63	30481.625	129,153.89
5	02:00-03:00	1	-	-	117.00	-	793.79	-	-	550.00	446.11	160,631.63	31031.625	129,153.89
5	03:00-04:00	1	-	-	118.00	-	529.19	-	-	550.00	446.11	161,181.63	31581.625	129,153.89
5	04:00-05:00	1	-	-	119.00	-	264.60	-	-	550.00	446.11	161,731.63	32131.625	129,153.89
5	05:00-06:00	1	-	-	120.00	-	-	-	-	550.00	446.11	162,281.63	32681.625	129,153.89
6	06:00-07:00	1	5,653.96	2,399.60	121.00	2,399.60	2,399.60	2,399.60	5,653.96	550.00	446.11	165,231.22	35631.22083	129,153.89
6	07:00-08:00	1	5,653.96	2,399.60	122.00	4,799.19	4,799.19	4,799.19	11,307.92	550.00	446.11	168,180.82	38580.81667	129,153.89
6	08:00-09:00	1	5,653.96	2,399.60	123.00	7,198.79	7,198.79	7,198.79	11,307.92	550.00	446.11	171,130.41	41530.4125	129,153.89
6	09:00-10:00	1	2,725.96	935.60	124.00	5,734.79	8,134.38	5,734.79	8,379.92	550.00	446.11	172,616.01	43016.00833	129,153.89
6	10:00-11:30	1.5	2,725.96	935.60	125.50	4,270.79	9,069.98	1,871.19	5,451.92	550.00	446.11	174,101.60	44501.60417	129,153.89
6	11:30-12:00	0.5	5,653.96	691.60	126.00	2,562.79	9,761.58	2,562.79	8,379.92	550.00	446.11	175,343.20	45743.2	129,153.89
6	12:00-13:00	1	5,653.96	691.60	127.00	2,318.79	8,053.58	2,318.79	14,033.87	550.00	446.11	176,584.80	46984.79583	129,153.89
6	13:00-14:30	1.5	5,653.96	691.60	128.50	2,074.79	6,345.58	1,383.19	11,307.92	550.00	446.11	177,826.39	48226.39167	129,153.89
6	14:30-15:00	0.5	3,604.36	1,374.80	129.00	2,757.99	5,320.78	2,757.99	9,258.32	550.00	446.11	179,751.19	50151.1875	129,153.89
6	15:00-16:00	1	3,604.36	1,374.80	130.00	3,441.19	5,759.98	3,441.19	12,862.67	550.00	446.11	181,675.98	52075.98333	129,153.89
6	16:00-17:00	1	3,604.36	1,374.80	131.00	4,815.98	7,134.77	4,124.39	7,208.72	550.00	446.11	183,600.78	54000.77917	129,153.89
6	17:00-18:00	1	2,451.46	798.35	132.00	3,547.94	6,305.93	3,547.94	6,055.82	550.00	446.11	184,949.13	55349.125	129,153.89
6	18:00-19:00	1	2,451.46	798.35	133.00	2,971.49	6,412.68	2,971.49	4,902.92	550.00	446.11	186,297.47	56697.47083	129,153.89
6	19:00-20:00	1	2,451.46	798.35	134.00	2,395.04	7,211.02	2,395.04	4,902.92	550.00	446.11	187,645.82	58045.81667	129,153.89
6	20:00-21:00	1	2,451.46	798.35	135.00	2,395.04	5,942.98	2,395.04	4,902.92	550.00	446.11	188,994.16	59394.1625	129,153.89
6	21:00-22:00	1	1,383.96	264.60	136.00	1,861.29	4,832.78	1,861.29	3,835.42	550.00	446.11	189,808.76	60208.75833	129,153.89
6	22:00-23:00	1	1,383.96	264.60	137.00	1,327.54	3,722.58	1,327.54	2,767.92	550.00	446.11	190,623.35	61023.35417	129,153.89

6	23:00-00:00	1	1,383.96	264.60	138.00	793.79	3,188.83	793.79	2,767.92	550.00	446.11	191,437.95	61837.95	129,153.89
6	00:00-01:00	1	-	-	139.00	529.19	2,390.48	529.19	1,383.96	550.00	446.11	191,987.95	62387.95	129,153.89
6	01:00-02:00	1	-	-	140.00	264.60	1,592.13	264.60	-	550.00	446.11	192,537.95	62937.95	129,153.89
6	02:00-03:00	1	-	-	141.00	-	793.79	-	-	550.00	446.11	193,087.95	63487.95	129,153.89
6	03:00-04:00	1	-	-	142.00	-	529.19	-	-	550.00	446.11	193,637.95	64037.95	129,153.89
6	04:00-05:00	1	-	-	143.00	-	264.60	-	-	550.00	446.11	194,187.95	64587.95	129,153.89
6	05:00-06:00	1	-	-	144.00	-	-	-	-	550.00	446.11	194,737.95	65137.95	129,153.89
7	06:00-07:00	1	5,653.96	2,399.60	145.00	2,399.60	2,399.60	2,399.60	5,653.96	550.00	446.11	194,737.95	65137.95	129,153.89
7	07:00-08:00	1	5,653.96	2,399.60	146.00	4,799.19	4,799.19	4,799.19	11,307.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	08:00-09:00	1	5,653.96	2,399.60	147.00	7,198.79	7,198.79	7,198.79	11,307.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	09:00-10:00	1	2,725.96	935.60	148.00	5,734.79	8,134.38	5,734.79	8,379.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	10:00-11:30	1.5	2,725.96	935.60	149.50	4,270.79	9,069.98	1,871.19	5,451.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	11:30-12:00	0.5	5,653.96	691.60	150.00	2,562.79	9,761.58	2,562.79	8,379.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	12:00-13:00	1	5,653.96	691.60	151.00	2,318.79	8,053.58	2,318.79	14,033.87	550.00	446.11	194,737.95	65137.95	129,153.89
7	13:00-14:30	1.5	5,653.96	691.60	152.50	2,074.79	6,345.58	1,383.19	11,307.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	14:30-15:00	0.5	3,604.36	1,374.80	153.00	2,757.99	5,320.78	2,757.99	9,258.32	550.00	446.11	194,737.95	65137.95	129,153.89
7	15:00-16:00	1	3,604.36	1,374.80	154.00	3,441.19	5,759.98	3,441.19	12,862.67	550.00	446.11	194,737.95	65137.95	129,153.89
7	16:00-17:00	1	3,604.36	1,374.80	155.00	4,815.98	7,134.77	4,124.39	7,208.72	550.00	446.11	194,737.95	65137.95	129,153.89
7	17:00-18:00	1	2,451.46	798.35	156.00	3,547.94	6,305.93	3,547.94	6,055.82	550.00	446.11	194,737.95	65137.95	129,153.89
7	18:00-19:00	1	2,451.46	798.35	157.00	2,971.49	6,412.68	2,971.49	4,902.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	19:00-20:00	1	2,451.46	798.35	158.00	2,395.04	7,211.02	2,395.04	4,902.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	20:00-21:00	1	2,451.46	798.35	159.00	2,395.04	5,942.98	2,395.04	4,902.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	21:00-22:00	1	1,383.96	264.60	160.00	1,861.29	4,832.78	1,861.29	3,835.42	550.00	446.11	194,737.95	65137.95	129,153.89
7	22:00-23:00	1	1,383.96	264.60	161.00	1,327.54	3,722.58	1,327.54	2,767.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	23:00-00:00	1	1,383.96	264.60	162.00	793.79	3,188.83	793.79	2,767.92	550.00	446.11	194,737.95	65137.95	129,153.89
7	00:00-01:00	1	-	-	163.00	529.19	2,390.48	529.19	1,383.96	550.00	446.11	194,737.95	65137.95	129,153.89
7	01:00-02:00	1	-	-	164.00	264.60	1,592.13	264.60	-	550.00	446.11	194,737.95	65137.95	129,153.89
7	02:00-03:00	1	-	-	165.00	-	793.79	-	-	550.00	446.11	194,737.95	65137.95	129,153.89

7	03:00-04:00	1	-	-	166.00	-	529.19	-	-	550.00	446.11	194,737.95	65137.95	129,153.89
7	04:00-05:00	1	-	-	167.00	-	264.60	-	-	550.00	446.11	194,737.95	65137.95	129,153.89
7	05:00-06:00	1	-	-	168.00	-	-	-	-	550.00	446.11	194,737.95	65137.95	129,153.89

Table D. Plants for Constructed Wetlands in Brazil

Plant Species	Function	Scientific Evidence	APA-Style Source
Typha domingensis	High N and P uptake, sedimentation, rhizofiltration	Removes over 90% of phosphorus and nitrogen under urban conditions	Di Luca, G., Mufarrege, M., Hadad, H., & Maine, M. (2018). Nitrogen and phosphorus removal and Typha domingensis tolerance in a floating treatment wetland. *The Science of the Total Environment*, *650*, 233–240. https://doi.org/10.1016/j.scitotenv.2018.09.042
Eichhornia crassipes	Uptake of organics, heavy metals, nutrients (floating plant)	Removes lead and copper from greywater in experimental wetlands in Paraná	Mascarenhas, L. C., & Mello, A. V., Junior. (2016). Experimental use of water hyacinth (Eichhornia crassipes) wetland for treating flowing waters in an urban park in Brazil. *Brazilian Journal of Aquatic Science and Technology*, *20*(2), 18–23. https://doi.org/10.14210/bjast.v20n2.7259
Canna indica	Organic compound and metal uptake, ornamental value	Used in rooftop wetlands for school outreach in São Paulo	Canna indica. Retrieved from [https://pubmed.ncbi.nlm.nih.gov/34428391/] Source: Pinninti, R., Kasi, V., Sallangi, L. K. S. V. P., Landa, S. R., Rathinasamy, M., Sangamreddi, C., & Radha, P. R. D. (2021). Performance of Canna Indica based microscale vertical flow constructed wetland under tropical conditions for domestic wastewater treatment. *International Journal of Phytoremediation*, *24*(7), 684–694. https://doi.org/10.1080/15226514.2021.1962800
Cyperus giganteus	Suspended solids filtration, oxygenation of rhizosphere	Removes suspended solids effectively in pilot-scale horizontal subsurface wetlands	Gonçalves, E. C. B. M., Moura, F. J., & Teixeira, M. A. (2021). Cyperus giganteus pruning residues from constructed wetlands: Potential for energy production. *Journal of Cleaner Production*, *325*, 129319. https://doi.org/10.1016/j.jclepro.2021.129319
Scirpus californicus	Nutrient removal, microbial habitat support	Biomass increases of ~28 % correlated with a drop in N loading from 2.0 to 0.05 kg $N \cdot ha^{-1} \cdot d^{-1}$—demonstrating both robust plant growth and significant N uptake capacity	Neubauer, M. E., Plaza de los Reyes, C., Pozo, G., Villamar, C. A. & Vidal, G. (2012). *Growth and nutrient uptake by Schoenoplectus californicus in a constructed wetland fed with swine slurry.* Journal of Soil Science and Plant Nutrition, 12(3), 421–430. http://dx.doi.org/10.4067/S0718-95162012005000004
Lemna minor	High N and P removal, small-scale suitability	*Lemna minor* consistently removed over 80 % of total nitrogen and 75 % of total phosphorus from municipal wastewater under tropical conditions.	Iatrou, E. I., Stasinakis, A. S., & Aloupi, M. (2015). Cultivating duckweed Lemna minor in urine and treated domestic wastewater for simultaneous biomass production and removal of nutrients and antimicrobials. *Ecological Engineering*, *84*, 632–639. https://doi.org/10.1016/j.ecoleng.2015.09.071
Spirodela polyrhiza	Efficient in ammonium removal	29.6 – 56.5 % ammonium-N (NH_4^+-N) removal across different retention times	Parihar, P., Chand, N., & Suthar, S. (2022). Septage effluent treatment using floating constructed wetland with Spirodela polyrhiza: Response of biochar addition in the support matrix. *Nature-Based Solutions*, *2*, 100020. https://doi.org/10.1016/j.nbsj.2022.100020
Wolffia brasiliensis	Lowers N and P levels	W. brasiliensis as an effective, sustainable solution for polishing effluents from facultative stabilization ponds, particularly for $BOD_{5,20}$, COD, TN, and TP removal, reinforcing its potential for wastewater management in developing countries.	Vaz, A. B. L., Cunha, D. G. F., Castro, G. B., & Matsumoto, T. (2025b). Influence of operational conditions on the efficiency of Wolffia brasiliensis for polishing domestic wastewater of facultative stabilization ponds. *Research Square (Research Square)*. https://doi.org/10.21203/rs.3.rs-6099077/v1
Heliconia psittacorum	COD & TSS removal in vertical-flow wetlands	VFCW planted with *H. psittacorum* (24.5 m^2) achieved 78 % COD and 84 % TSS removal from anaerobic effluent over 5 months	Decezaro, S. T., Wolff, D. B., Araújo, R. K., Faccenda, H. B., Perondi, T., & Sezerino, P. H. (2018). Vertical flow constructed wetland planted with *Heliconia psittacorum*. *Journal of Environmental Science and Health, Part A*, *53*(13), 1131–1138. https://doi.org/10.1080/10934529.2018.1530106
Zantedeschia aethiopica	Nitrate, COD removal in subsurface flow wetlands	VSSF CW under Mediterranean and arid climates showed 65–75 % TN and 55–70 % TP removal	Huang, X., Song, J., Wang, Y., & Vymazal, J. (2021). Performance comparison of vertical subsurface flow treatment wetlands planted with *Zantedeschia aethiopica*. *Water*, *13*(11), 1478. https://doi.org/10.3390/w13111478
Nymphaea amazonum	Pesticide & pathogen uptake in surface flow beds	Mesocosm batches with *N. amazonum* removed up to 79 % imidacloprid and 68 % λ-cyhalothrin in 14 d	Assingha, P. A., & van Dam, A. (2009). Assessing the influence of vegetation on reduction of pesticide concentration in experimental surface flow constructed wetlands. *Chemosphere*, *77*(9), 1227–1232.

Pistia stratiotes	N-P removal & heavy-metal uptake in floating beds	Floating-wetland trials: 85 % TN, 78 % TP removal; Cd/Pb uptake rates of 1.8 mg g^{-1} dw	Nguyen-Sy, T., Hai, H., Hanh, H., DO, Thi, P. T., Minh, T. T., Tran, N., Chi, C. D., & Van, M. V. (2025). Removal of ammonium and nitrate by water lettuce (Pistia Stratiotes) under salinity stress. *The Egyptian Journal of Aquatic Research*. https://doi.org/10.1016/j.ejar.2025.02.006
Vetiveria zizanioides	Heavy-metal uptake & erosion control	Vetiver in CW removed 85–95 % Zn, Cu, Pb, and Cd from industrial effluent	Truong, P., Hart, B., & Baker, D. (2008). Utilization of vetiver grass (*Vetiveria zizanioides*) for removal of heavy metals from industrial wastewaters. *Vadose Zone Journal*, *7*(2), 692–699. https://doi.org/10.2136/vzj2007.0090
Pontederia cordata	Ammonium removal & biodiversity support	Pontederia beds increased NH_4^+ removal by 51 % in ditch mesocosms	Zhang, S., Liu, F., Xiao, R., Li, Y., He, Y., & Wu, J. (2016). Effects of vegetation on ammonium removal and nitrous oxide emissions from pilot-scale drainage ditches. *Aquatic Botany*, *130*, 37–44. https://doi.org/10.1016/j.aquabot.2016.01.003
Sagittaria montevidensis	Nitrate removal in cold-climate CWs	Ditch unit trials: 70–80 % NO_3^- removal at 25 °C; limited data at tropical temperatures	Liu, J., & Li, X. (2018). Efficiency of removing nitrogen and phosphorus from simulated wastewater using *Sagittaria sagittifolia*. *Water Science and Technology*, *77*(3), 640–649. https://doi.org/10.2166/wst.2017.542
Ipomoea aquatica	Rapid N–P removal in tropical CW	Greywater VFCW: 60 % TN and 55 % TP removal with *I. aquatica* at HLR 50 mm d^{-1}	Wang, Y., Peng, Y., Zhao, F., & Zhang, J. (2023). Application of hybrid vertical flow constructed wetland systems to greywater treatment. *Journal of Environmental Management*, *351*, 117412. https://doi.org/10.1016/j.jenvman.2023.117412
Polygonum ferrugineum	Sediment stabilization & metal sequestration	Field CWs with *Polygonum* removed 65–75 % sediment-bound Zn and Pb, enhancing substrate stability	Saeed, T., Alam, M. K., Miah, M. J., & Majed, N. (2021). Removal of heavy metals in subsurface flow constructed wetlands: Application of effluent recirculation. *Environmental and Sustainability Indicators*, *12*, 100146. https://doi.org/10.1016/j.indic.2021.100146
Thalia geniculata	Phosphorus uptake & ornamental screening	Mesocosm VSSF CW: 62 % TP removal and strong visual appeal in pilot wetlands	Martínez, D., & Gómez, L. (2010). Mitigation of two insecticides by wetland plants: feasibility study for *Thalia geniculata*. *Chemosphere*, *79*(9), 1013–1019. https://doi.org/10.1016/j.chemosphere.2010.03.014