Water in Circular Economy and Resilience (WICER)

The Case of São Paulo, Brazil

Optimizing Wastewater Treatment Plants in the Metropolitan Area of São Paulo

This case study is part of a series prepared by the World Bank's Water Global Practice to highlight existing experiences in the water sector. The purpose of the series is to showcase one or more of the elements that can contribute toward a Water in Circular Economy and Resilience (WICER) system. This case focuses on the experience of São Paulo, Brazil.

Context

SABESP (Companhia de Saneamento Básico do Estado de São Paulo S.A.) is the state owned water utility for São Paulo state. As such it is responsible for public water supply and sanitation services in more than 370 cities, including 36 of the 39 municipalities that make up the Metropolitan Region of São Paulo (MRSP). In the MRSP, a vast urban swath of more than 21 million residents, public water supply has been practically universalized.

Under the Tietê River recovery project in SABESP’s concession area, the volume of wastewater collected for treatment rose from 24 percent in 1992 to 78 percent in 2018. But despite São Paulo’s extensive efforts to improve and expand sanitation services throughout the region, many residents—especially in informal urban settlements—remain unconnected to the public network. In fact, the exceptionally high pollution levels in the urban tributaries of the Upper Tietê River Basin are caused mainly by household sewage. On the one hand, CETESB (São Paulo’s environmental agency) has been implementing monitoring-and-control procedures to de-industrialize the Tietê River Basin since the 1970s. But on the other hand, despite great efforts and investments to achieve de-industrialization, the river basin remains severely polluted. Not even the peak rainy season can dilute wastewater in natura or mitigate pollution flows from urban tributaries.

Accordingly, using loans from the Inter-American Development Bank and other resources from the
World Bank, SABESP has been expanding wastewater collection networks in the region’s poorest neighborhoods. Greater volumes of wastewater flows are being directed to the main wastewater treatment plants (WWTPs). Improved water quality can already be detected in the Pinheiros and Tietê rivers and their tributaries. The Pinheiros River recovery program has overseen infrastructure upgrades in informal urban settlements—improvements that have increased collection of sewage in the Pinheiros watershed for transfer to the Barueri WWTP. Also, in 2019, SABESP won the water supply and sanitation services concessions for three more municipalities in the MRSP, including Guarulhos, a city of 1 million inhabitants and deficient wastewater treatment. In addition to the ever-increasing need for services, SABESP has also been handed the mission to universalize wastewater collection and treatment by 2033 (see the section on “Policy, institutional, and regulatory environment”). SABESP therefore faces the urgent need to expand its wastewater treatment capacity and improve the quality of the effluents ultimately discharged into the Upper Tietê. Most of the wastewater collected by SABESP in the MRSP is sent to five WWTPs, which are also operated by SABESP (figure 1; table 1). It is hard to find available land in the MRSP at affordable prices and at suitable locations for building treatment plants. The existing plants, originally conceived in the 1970s, were therefore designed to allow future expansion for receiving and treating increased volumes of wastewater. Traditional solutions for expanding treatment capacity and improving efficiency in WWTPs WWTPs usually

**FIGURE 1.** The Main WWTPs in São Paulo’s Metropolitan Region

![Map of São Paulo's Metropolitan Region with WWTP locations](image_url)

Legend

- **Wastewater treatment plant**
- ABC sewer system
- Barueri sewer system
- Parque novo mundo sewer system
- São miguel sewer system
- Sizano sewer system
- Municipal boundaries

Source: SABESP.
TABLE 1. The MRSP’s Main Wastewater Treatment Plants (WWTPs): Nominal Capacity and Population Served, 2019

<table>
<thead>
<tr>
<th>WWTP</th>
<th>Nominal capacity (in m³/s)</th>
<th>Nominal population served (inhabitants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barueri</td>
<td>16.0</td>
<td>7,680,000</td>
</tr>
<tr>
<td>ABC</td>
<td>3.0</td>
<td>1,400,000</td>
</tr>
<tr>
<td>Parque Novo Mundo</td>
<td>2.5</td>
<td>1,200,000</td>
</tr>
<tr>
<td>São Miguel</td>
<td>1.5</td>
<td>720,000</td>
</tr>
<tr>
<td>Suzano</td>
<td>1.5</td>
<td>720,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>24.5</strong></td>
<td><strong>11,720,000</strong></td>
</tr>
</tbody>
</table>

Source: SABESP.

calls for building new civil infrastructure alongside existing facilities and installing tertiary treatment systems, such as ultrafiltering membranes or membrane bioreactors. These solutions imply, however, high capital and operating expenditures—costs that cannot always be justified in the face of other higher-priority investment demands like expanding sewage collection in poor neighborhoods. To achieve the same outcome, more innovative, efficient solutions had to be identified.

**Solution: The MRSP WWTP Optimization Program**

International experience with WWTPs, along with greater operational efficiency, has shown that conventional (secondary) treatment processes can reach performance goals that exceed nominal design settings. Certain plant processes—such as primary and secondary clarifiers and aeration tanks—have treatment capacities that outperform nominal capacities foreseen by the original design. Sanitation utilities often assume that the real capacity of all plant processes equals the nominal capacity. So, they tend to expand an entire WWTP by “mirroring” the plant without considering each plant’s actual capacity. This approach leads to overexpansion of infrastructure (and its subsequent depreciation). By way of contrast, optimizing conventional wastewater treatment postpones the need to invest in expanding facilities or in tertiary treatment systems. Resources can be applied to other purposes and achieve better outcomes, such as an expanded network for wastewater collection.

A joint initiative between SABESP and the 2030 Water Resources Group (WRG), São Paulo, created an optimization program for the MRSP WWTPs. The program defined high-priority actions and investments to maximize the treatment capacity of existing infrastructure. The program can be understood as a circular economy program because it makes the most of resources, designs out waste and pollution, and regenerates natural systems. In particular, the program aims to:

- Maximize the use of materials and infrastructure already in place and increase assets’ efficiency and life cycles by recovering damaged or inactive structures and equipment and postponing the need for further investments in expansion works or tertiary treatment systems.
- Reduce the generation of waste and pollution by improving both wastewater treatment processes and the quality of the final effluent. The program will also allow SABESP to adopt a “from waste to resource” strategy and recover and reuse wastewater treatment byproducts (water, energy, biosolids) in the future.
- Regenerate natural systems by improving the quality of the effluent discharged into the Upper Tietê River.

The purpose of the MRSP WWTP optimization program is to generate specific recommendations for performance improvements in four plants operated by SABESP: Barueri, Parque Novo Mundo, São Miguel, and ABC. One of the five main WWTPs operated by SABESP, the Suzano plant, was not covered by the program because it already showed good performance indicators.

The methodology begins with data collection and analysis through “process auditing” at each treatment phase.
The audits identify operational bottlenecks and offer technical recommendations to eliminate them. For each of the four plants, the audit will specify the maximum potential treatment capacity in liters per second (L/s). And because current legislation requires 80 percent efficiency removal of biochemical oxygen demand (BOD), the audits will recommend actions (and investments) to improve effluent quality to reach at 80 percent, 90 percent, and 95 percent efficiency removal of BOD—at current and projected flows for 2030. Total savings on operating expenses and investments (capital expenditures delayed or canceled) are calculated by comparing the investment needed for performance optimization with the traditional alternative of expanding the WWTPs. Lowering operational costs through power cogeneration with biogas in the WWTPs will also be evaluated, along with investments in other circular-economy interventions. With this knowledge, SABESP should be able to revise its expansion plans and invest in more cost-effective and sustainable solutions to achieve the desired effluent quality at each plant.

The Three Phases of the WWTP Optimization Program

Phase 1: Proof of Concept (March 2019 to April 2020)

In March 2019, 2030 WRG and SABESP Metropolitan Wastewater Division held a round of workshops and field visits. These analyzed the possibilities surrounding circular-economy principles and technologies as they might apply to the MRSP treatment plants. 2030 WRG provided an international consultant, Daniel Nolasco, who has been working with the World Bank’s Water Global Practice on the “From Waste to Resource” initiative. He supported SABESP workshops and field visits.

The preliminary findings from the phase-one workshops suggested that, in order to introduce circularity into wastewater treatment systems, SABESP needs to prioritize investments that eliminate performance-impairing operational bottlenecks. In this way, each WWTP could achieve treatment capacity and efficiency goals that surpassed the nominal outcomes, or original design standards. It was also found that these actions could be carried out with lower capital expenditures and operational costs compared with other solutions defined in the company’s expansion plans—postponing or avoiding unnecessary costs.

The impetus for this approach arose from early discussions hosted by 2030 WRG. Leverage for the project came from SABESP’s metropolitan board and presidency, which understood the project’s strategic importance for the MSRP’s goal of reaching universal wastewater collection and treatment. In fact, SABESP decided to expand the program to four treatment plants, adding Barueri and the Parque Novo Mundo to the two originally anticipated. The consultant prepared a new audit action plan and timeline to cover all four facilities and presented the specific equipment and human resources that SABESP would require for the audit. Meanwhile, SABESP arranged to contract the consultancy for the second phase (see below).

In summary, phase 1 included the program conception and structure; the optimization goals; mobilization of SABESP’s Metropolitan Wastewater Division teams (management and operations); technical visits, workshops, and meetings; the consultant’s preliminary analysis and recommendations on the two additional treatment plants; and preparation for continuing the program through a pilot application of the process audit methodology.

Phase 2: Audit Processes at Four WWTPs (May 2020 to November 2021)

This second phase began on May 4, 2020, when SABESP and ANDILET entered into an agreement. ANDILET is a private consulting firm, hired to conduct the process audits of the four selected WWTPs. The following actions have been completed or are underway:

- Analysis of historical performance data for each plant (sewage inflows, BOD levels, solid material removed, sludge production, etc.).
• Installation and calibration of new online monitoring equipment at each plant to obtain data from various locations inside the WWTPs;
• Field tests and laboratory analysis deemed necessary to understand treatment capacity and quality parameters under stressed conditions; and
• Discussions of hydraulic measures to address exceptional flows and protect plant operations.

At the end of this phase, ANDILET will deliver an optimization plan for each plant. The plans will identify bottlenecks and list recommendations. They will also include an analysis of potential capital expenditures delayed or canceled, investments needed, and the estimated operating expenditures required to reach each one of the BOD-removal performance scenarios described above (80 percent, 90 percent, or 95 percent).

The information obtained through the audit tools should feed a dynamic model of each wastewater treatment plant. Modeling should simulate the behavior of the station operating at current and higher flow rates and confirm the treatment plant’s maximum treatment capacity; the BOD-removal performance scenarios for the final effluents; the future generation of sludge; demand for aeration (and electricity for blowers); biogas production and the potential for energy cogeneration (heat and electricity); the most efficient and effective way to operate the WWTP; and the necessary expansion based on likely future demand.

Phase 3: Implementation of the Audit Results
(Expected to Start in 2022)

In phase 3, SABESP will incorporate the audit recommendations regarding the company’s investment plan to increase capacity and improve treatment of wastewater in the MRSP over the next years. As part of the process, key performance indicators (KPIs) will be monitored to measure the evolution of the efficiency parameters and analyze the impact of implementing the audit findings. The indicators are:

• Effluent quality: \( \text{BOD}_5 \) in mg/L and removal percentages
• Screening and sand removal: material removed in tonnes per month (t/month)
• Sludge treatment and disposal cost: USD/t of treated and removed sludge (costs may rise as the quality of the effluents improves but may drop after the digesters’ heating systems are installed)
• Demand and energy consumption: in kW and kWh
• Electricity cost: in USD/month
• Unit cost of electricity: USD/m³ of treated wastewater and USD/kg of BOD removed

The Policy, Institutional, and Regulatory Environment

SABESP did not foresee the WWTP optimization program for the MRSP in any previous plan, nor was it responding to any specific new demands from a regulatory institution. However, some aspects of São Paulo’s policy, institutional, and regulatory environment have indirectly fostered this program.

The first aspect concerns compliance with environmental regulations. SABESP’s wastewater treatment operations must comply with the statutory environmental standards on effluent discharge into water bodies and with the conditions set forth in each plant’s environmental operating licenses. In the State of São Paulo, conditions and standards for wastewater discharge are defined by art. 18, State Decree No. 8468/1976, and later amendments. According to item V, the treated effluent must have a maximum BOD of 60 mg/L), a threshold that can be exceeded only if the treatment guarantees a minimum BOD-removal efficiency of 80 percent. These requirements are stricter than those established at the federal level by CONAMA (The National Council of the Environment) Resolution No. 430/2011, art. 21, which requires a maximum BOD of 120 mg/L and a minimum BOD-removal efficiency of 60 percent. As the stricter norm prevails...
in Brazilian jurisprudence, SABESP’s operations in the MRSP must comply with the requirements of the state legislation, as well as with the conditions defined in the environmental operating licenses of the WWTPs. São Paulo’s environmental agency—CETESB—is in charge of licensing, monitoring, and supervising the compliance of SABESP’s operations.

The second aspect relates to universalizing services. SABESP operates water and sanitation services in 36 municipalities within the MRSP. It has a concession contract with each one of them. According to Brazil’s new federal sanitation law (No. 14,026/2020, art. 11-B), new contracts for basic public sanitation services must achieve universal service by 2033. Specifically, 99 percent of the population must have guaranteed water supply and 90 percent of the population must have guaranteed wastewater collection and treatment services by December 31, 2033. The contracts also must define quantitative goals for noninterruption of water supply, loss reduction, and improvement of treatment processes. Ongoing contracts that did not define universalization goals must comply by March 31, 2022.

Thirdly, the competitive environment for sanitation concession contracts, established in the new federal legislation, has led to greater willingness to accelerate investments in the efficiency of sewage treatment systems.

Lastly but not least, the regulatory implications of certain ancillary gains (related to commercialization of byproducts such as reusable water and biosolids) unforeseen by the concession contracts need to be addressed. Power cogeneration and direct nonpotable reuse of treated effluents are also regulated activities that must meet statutory requirements.

Benefits

The program is designed to yield the following benefits:

- **Improved water quality for the Tietê River:** As stricter scenarios for BOD removal are achieved through optimized WWTPs—and as larger volumes of wastewater are piped to the same plants—the MRSP expects significant improvements in the water quality of the Tietê River, and downstream, by 2030.

- **Investments delayed:** As the WWTPs’ optimization permits SABESP to postpone investments in tertiary treatment, and to reduce investments in physical expansion of treatment phases, significant savings from delayed investments are expected.

- **More resilience through implementation of circular-economy principles:** As SABESP expands capacity, effluents can be sold as reusable, nonpotable water while improving service resilience in a region marked by water stress. The sludge treatment process also can cogenerate enough power to meet the

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Having confirmed these resources, SABESP hired a team of international specialists (ANDILET S.A.) to perform a complete audit of the four WWTPs mentioned above for a fee that is less than 1% of the total investment needed to adequate the four plants to the universalization goals. Signed on January 2, 2020, the contract covers a period of 18 months. The final report, with recommendations for optimizing performance in all four plants, should be delivered by November 2021, a deadline that accounts for delays caused by the pandemic.

Financial and Contractual Agreement

Phase 1 of the program was financed by 2030 WRG, enabling the 2030 WRG consultant to conduct field visits and workshops, prepare preliminary technical reports for discussion with SABESP teams, and define strategies for the program’s continuation.

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operational needs of the WWTPs, thereby saving energy. Biosolids and nutrients can be recovered and sold.

- **Better protection against damage caused by climate change:** As intense rainfall events are expected to rise, the program will help SABESP to enhance stations’ operations when facing abrupt, increased inflows during exceptional weather events.

- **Greater financial sustainability of the concessionaire:** As the recommendations for optimization and circular-economy investments are implemented, SABESP will reap financial benefits, as set forth above. At the same time, lower operating costs are expected from improved, more rigorous operation and maintenance procedures.

Although in the initial stages, the MRSP WWTP optimization program has already produced concrete outcomes:

- **Improved integration of SABESP’s internal departments:** The development and implementation of the program has been carried out in a participatory manner, so that technical meetings, workshops, and field visits involve management and operating teams and engineers from other SABESP areas. Each report was carefully discussed with the operation managers responsible for the treatment plants, as well as with the engineering and project teams. This dynamic has proved innovative, boosting interaction and integrating areas and people that previously had been isolated within SABESP—an important cultural change for the institution.

- **Increased technical knowledge:** The workshops held since the beginning of the program, in which consultants have presented the technical analysis from the audits, have built knowledge and motivation among SABESP teams responsible for wastewater management in the MRSP.

- **Improved performance at the Barueri WWTP:** During phase 1 and phase 2 of the program, SABESP took action to correct operational issues at the treatment plant, based on recommendations facilitated by the 2030 WRG consultant. From July to December 2019, SABESP invested B$ 3 million in the Barueri WWTP. In the first four months of 2020 SABESP installed new grating systems for solid removal, cleaned sand filters and aeration tanks, and implemented corrective maintenance procedures, avoiding discharges of 43,000 tons of BOD in the Tietê River. But only the final audit will tell SABESP precisely what actions are needed to eliminate bottlenecks to attain the full treatment capacity and efficiency at each facility.

### Lessons Learned

- The first step to develop a circular-economy program for wastewater treatment plants is to optimize the operations of the infrastructure already installed, so plants can reach maximum performance with the minimum capital and operational expenditure.

- Optimizing the existing infrastructure should be always considered before investing in new infrastructure to expand treatment capacity. The program presented in this study updates the logic underlying traditional expansion strategies, focusing instead on priority actions and investments to identify and eliminate bottlenecks and maximize efficient treatment processes at each plant.

- Participatory, technical workshops are an effective way to engage stakeholders in the water and sanitation utilities. Directors of units and operations teams have the opportunity to openly discuss technical issues, learn and retain new knowledge, and internalize best practices in current operations.

- Some aspects of the treatment process, during the project phase and during operations and maintenance, must be adapted to the type and quality of wastewater entering the stations, especially in regions where there are many informal households.
Discussions held throughout the program have strengthened the notion that SABESP must expand its monitoring-and-control authority over sewage networks in order to detect and minimize illegal sewage discharges, preserving the biota of the treatment plants and the networks as assets.

The methodology developed for this program can be replicated for countless WWTPs in the state of São Paulo and throughout the country. It should be understood as a true innovation based on a comprehensive and transformative vision for the management of public fixed assets for basic sanitation, grounded in an analysis of efficient process engineering and focused on results.

SABESP cannot clean up São Paulo’s rivers alone. Besides the utility’s efforts in expanding wastewater collection and treatment and improving treatment efficiency, the entire metropolitan region needs to contribute to these tasks. Municipalities must take more effective control of land division and use, soil loss, discharges of untreated wastewater, and solid waste disposal—tasks in which residents play vital roles. These issues are beyond the scope of the MRSP optimization program and in fact are beyond the capabilities of any single sanitation utility. Other projects, such as the SABESP’s sustainable sanitation program, which has received a World Bank loan, will be addressing some of these issues.²

Background Documents


Notes

1. Only the population living in SABESP’s concession area within the MRSP, which covered 33 municipalities in 2018, is reflected in this figure. The MRSP now consists of 39 municipalities.

2. The Tietê project consists of a large program of sanitation works aimed at improving wastewater collection and treatment services and at cleaning up the Tietê River. It was launched in 1992.

3. Daniel Nolasco is a civil engineer from the University of Buenos Aires and has a specialization at Harvard and MIT. He has been working as an international consultant in water and sanitation projects for over 25 years. He is also president of ANDILET S.A. and director of the International Water Association (IWA).

4. Some of the commonly used auditing tools are: review of historical data, flowmeter calibration, online monitoring, offline monitoring (laboratory analysis), jar tests, hydraulic modeling (for proper flow division), oxygen transfer tests, tracer tests (in clarifiers and digesters), stress tests, studies of the return currents of the sludge train, and dynamic simulation (frequently using a BioWin simulator).

5. For more information, see: http://site.sabesp.com.br/site/interna/Default.aspx?secaoId=710.