**ARTICLE**

# Challenges of monitoring losses in the water distribution network through two measurement and control districts in the metropolitan region of Aracaju, Sergipe (Northeast Brazil)

Wendell Valença Bittencourt de Jesus & Marcos Luciano Alves Barroso [ID]

Instituto Federal de Educação, Ciências e Tecnologia de Sergipe, Avenida Engenheiro Gentil Tavares do Mota 1166, Cirurgia 49050-250, Aracaju, Sergipe, Brasil. E-mail: marcos.barroso@ifs.edu.br

**Abstract**: Real losses in water distribution are inevitable; however, efficient network management can lead to acceptable minimum loss values. Leaks, on the other hand, indicate a lack of pipeline maintenance, inadequate installations, and large variations in pressure and flow within the network. Therefore, this study aims to compare data from Measurement and Control Districts (MCD's) 32 and 33, which are part of the water distribution network of the Aracaju Metropolitan Region (State of Sergipe), with regional and national data, in order to identify improvements in reducing loss rates. Data available in reports on water loss quantities from the Sergipe Sanitation Company (DESO) were used, examining seven parameters from 2017 to 2022, with the goal of identifying significant trends and correlations. The correlation matrix for Measurement and Control District (MCD) 32 showed a high level of agreement (66.66%) as well as a strong correlation between the parameters studied. The correlation matrix for MCD 33 showed low agreement (42.85%). The loss index values in the MCD's (31.82% and 40.82%) presented an unsatisfactory average variation during the period, compared to 37.78% (Brazil), 46.67% (Northeast), and 57.60% (Sergipe) in 2022, which are lower, but not ideal. The studied MCD's reflect how distribution management operates, and the parameters considered can estimate operational losses in water distribution networks as well as guide the actions of sanitation companies.

**Key words**: Water supply, sanitation companies, metering, sanitation, water losses.

### Desafios do monitoramento de perdas na rede de distribuição de água por meio de dois distritos de medição e controle na região metropolitana de Aracaju, Sergipe (Nordeste do Brasil)

**Resumo:** Perdas reais na distribuição de água são inevitáveis, entretanto, uma gestão eficiente da rede pode levar a valores mínimos de perdas que são aceitáveis. Já a ocorrência de vazamentos indica uma ausência de manutenção das tubulações, instalações inadequadas bem como grandes variações de pressão e vazão na rede. Assim, o estudo tem como objetivo comparar os dados de Distritos de Medição e Controle (MCD's) 32 e 33, que fazem parte da rede de distribuição de água da Região Metropolitana de Aracaju (Estado de Sergipe) com dados regionais e nacionais, visando identificar melhorias na redução dos índices de perdas. Dados disponíveis nos relatórios sobre quantitativos de perdas hídricas da Companhia de Saneamento de Sergipe (DESO) foram utilizados, sendo examinados sete parâmetros no período de 2017 a 2022, tendo em vista identificar tendências e correlações significantes. A matriz de correlação do Distrito de Medição e Controle (MCD) 32 demonstrou uma elevada concordância (66,66%) bem como forte correlação entre os parâmetros estudados. Já a matriz de correlação do MCD 33 demonstrou baixa concordância (42,85%). Os valores dos índices de perdas nos MCD's (31.82 e 40.82%) apresentaram uma variação média não satisfatória no período, em comparação aos 37.78% (Brasil), 46.67% (Nordeste) e 57.60% (Sergipe) no ano de 2022, os quais são menores, porém não ideais. Os MCD's estudados refletem

como as gestões de distribuição atuam e os parâmetros levados em consideração podem estimar as perdas operacionais em rede de distribuição de água bem como direcionar as ações das companhias de saneamento.

**Palavras chave**: Abastecimento, companhias de saneamento, medição, saneamento, perdas de água.

## Introduction

Water is an essential resource for life, but its availability is increasingly threatened (Brito *et al*. 2007). Historically, the growing demand for water, coupled with water pollution and climate change, are some of the factors contributing to the constant vigilance regarding the vastness of water resources and, at the same time, its scarcity (Ferreira & Garcia 2017). Given this scenario, it becomes vital to promote research whose results lead to efficient water resource management processes in supply systems, as good management of water distribution is fundamental to guaranteeing its availability for future generations, protecting the environment, and promoting sustainable development.

Many strategies can be adopted to reduce water waste and promote proper water resource management; however, the study must be based on analyses and discussions of water control and security, parameters for loss analysis, and the identification of the most appropriate opportunities to reduce or even mitigate this waste. The management of this essential resource for society becomes as important regarding distribution challenges as one might think (Pereira 2018).

Despite being a matter of great importance and concern for the whole society, in recent years, there have not been many published works on this aspect so relevant to the community. Barroso (2019), in his studies, argues that, despite the existence of a certain level of planning for distribution management, many factors are still not considered. In the parameter of equity of access, management fails in terms of assertiveness between repair and increased distribution (Fritz *et al*. 2020).

Poor management of the distribution network can lead to significant losses of potable water through leaks and damaged pipes (Castro 2022). The most frequent causes of leaks are the lack of pipe maintenance, as well as inadequate installation and pressure variations in the water distribution network (Pereira 2018).

Another implicitly related aspect that further increases the cost of water distribution is energy loss. The water distribution system consumes a lot of energy in its treatment and pumping process from reservoirs to the final consumer, due to the long distances traveled and the higher altitude areas that often require the placement of auxiliary pumps along the routes to ensure the supply reaches the entire required distance. Poor distribution can further increase this energy consumption and consequently waste.

For loss control planning, water distribution companies use Measurement and Control Districts (MCD's), which are delimited and isolated sub-areas of the network with flow control at the entrance. MCD's are important for more efficient distribution because, with the help of equipment and trained personnel, they allow for faster leak identification, more thorough analysis of water consumption in the delimited area through macro and micro-metering, control of water pressure in the network, and improved monitoring of losses (real and apparent). This facilitates the control of a specific area and allows the company to develop more focused actions on the problem.

Given this, the study aims to collect data from the water distribution network of the Metropolitan Region of Aracaju, Sergipe, in two MCD's, and compare it to regional and national data, seeking to identify opportunities for improvement, strengthen practices aimed at reducing water loss rates in the distribution network, maintain a commitment to the environment aiming for the greatest possible sustainability, and ensure the responsible management of this resource so essential to human development.

## Material and Methods

### Study characterization

In December 2023, the planning for the bibliographic survey of this research was carried out at the *Coordenadoria do Curso Superior de Tecnologia em Saneamento Ambiental do Instituto Federal de Educação, Ciência e Tecnologia de Sergipe* (TSA/IFS) [Coordination Office of the Higher Technology Course in Environmental Sanitation of the Federal Institute of Education, Science and Technology of Sergipe (TSA/IFS)]. Based on the chosen theme, the planning involved selecting databases for the bibliographic research, defining thematic inclusion/exclusion criteria, and reading the obtained texts. In addition, reports on the quantities of water losses in the water distribution system were obtained from the *Diretoria de Operação e Manutenção, órgão técnico da Companhia de Saneamento de Sergipe* (DESO) [Operation and Maintenance Directorate, a technical body of the Sergipe Sanitation Company (DESO)], which handles information on the water distribution network of the Aracaju Metropolitan Region. The reports included consolidated data from two MCD's, covering the period from 2017 to 2022.

### Aracaju and the water distribution network

In the city of Aracaju, Sergipe State, essential services such as piped water and sewage systems were implemented at the beginning of the 20th century. According to SEPLAG (2023), the city has 602.757 inhabitants and a Human Development Index (HDI) of 0.770. The service and industrial sectors represent the predominant economic activities, accounting for one-third of the State's Gross Domestic Product (GDP).

The water distribution network in focus encompasses the cities of Aracaju, Nossa Senhora do Socorro, Barra dos Coqueiros, and part of the city of São Cristóvão. The existing network is part of the cities' public water supply system, fed by four water treatment plants and consisting of pipes, valves, and accessory components. The network is recognized as being predominantly of mixed layout and physically divided and interconnected by 10 maneuvering sectors, which are smaller networks accommodating more decisive management and focused operations (**Figure 1**).

The network also has 10 reservoirs that supply the sectors, with a pipeline that carries water to the reservoirs through a main network conductor of up to 800 mm, made of cast iron. This network is further complemented by different types of interconnected pipelines, the sub-pipelines and secondary conductors (made of polyvinyl chloride, asbestos and cast iron), from 50 to 200 mm, installed in the streets with one or two distribution conductors that serve the various consumption points.

### Characterization of MCD's

For monitoring and controlling the water flow in the distribution network, the utility uses MCD's, which are specific sub-areas for maneuvers and small networks, delimited within the distribution network. These areas contain "macrometers" to measure the amount of water entering that region, and pressure reducing valves to protect the pipes from high pressure, preventing ruptures and thus enabling leak detection, pressure and flow control of the distributed water. This allows for management through more precise parameters and optimizes the entire system.

One of the most striking characteristics of pressure reducing valves technology is that its implementation requires a well-defined operating area in the water distribution network, isolated by boundary valves, configuring a subsector (pressure zone) or a Measurement and Control District (DMC) (Zaniboni 2009). Sectorization or re-sectorization should seek the hydraulic balance of the distribution system, aiming to obtain a system with controlled pressures to minimize losses and energy expenditure in serving the area covered by the distribution sector (Motta 2010).

The water distribution network in the Aracaju Metropolitan Region has 59 registered MCD's. These were defined by the company after a technical evaluation considering aspects, such as: diameter and material of the inlet pipe, length, number of connections and monthly consumption of customers within the delimited area. Additionally, perimeter, number of house-

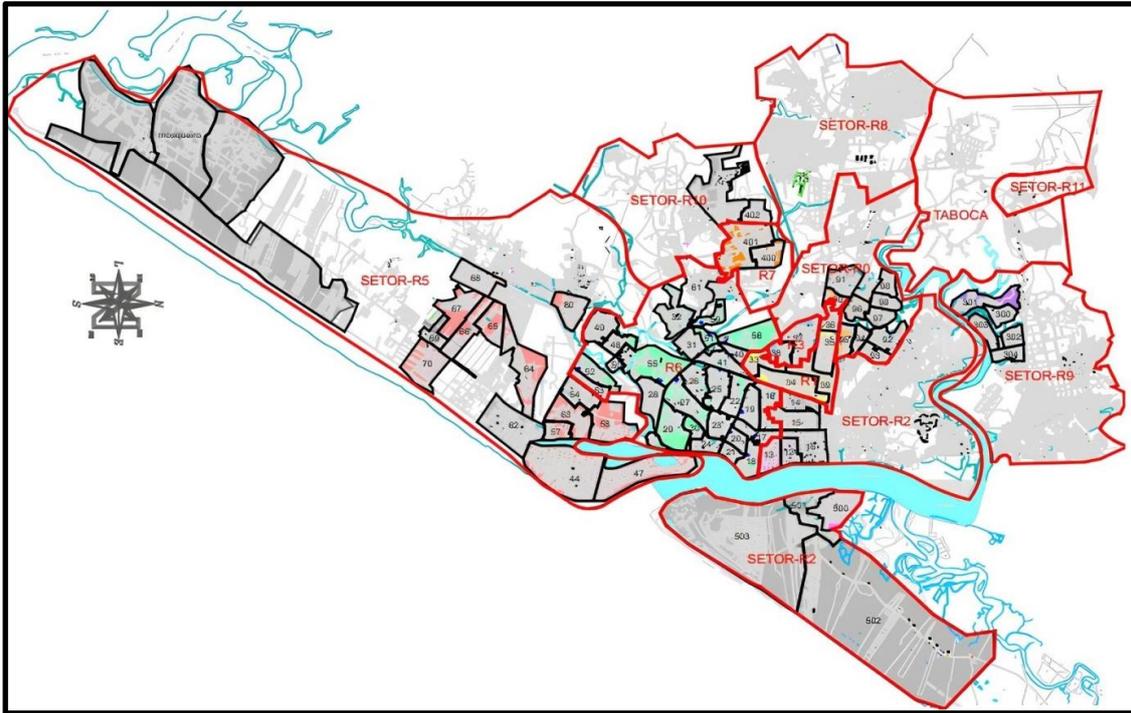holds, distributed volume, and micrometered volume were evaluated.



**Figure 1**. Map showing the 10 sectors in the water distribution network of the cities of Aracaju, Nossa Senhora do Socorro, Barra dos Coqueiros and part of the city of São Cristóvão. Source: DESO (2022).

Two MCD's were randomly selected for this research, designated MCD 32 and MCD 33. MCD 32 is located in the Santa Lúcia housing complex (Aracaju/SE) (**Figure 2**) and is part of sector 6 of the network that supplies approximately 16.000 people. It is supplied by the reservoir designated R6, which is of the supported type, with a network perimeter of approximately 16.105 m, only one pressure reducing valve, and a relatively flat topography. DMC 33 is located in the Siqueira Campos neighborhood (Aracaju/SE) (**Figure 3**), comprising sector 1. It is supplied by the reservoir designated R1, which is of the supported type, with a perimeter of 10.859 m, a quite irregular topography, no pressure reducing valve, and supplies 6.000 people. In both cases, the calculation was based on an estimate of four people per property.

The water inlet to a MCD, whether supplied by gravity, pumping, or pressure valve areas, must have a flow meter to quantify the volumes supplied (water inlet to the MCD). From the inlet volume, it is possible to make a comparison with the micrometered volumes (volumes used by customers), in order to calculate the volumes of water lost in the MCD (Júnior & Vatavuk 2023).

The monitoring of the MCD's is carried out daily by company professionals using the GRAFANA software, which receives data from the large flow meter via pulses converted into flow rate, sent from the datalogger, generating reports.

## Statistical treatment and evaluation parameters

For this study, information from reports on water loss quantities in the water distribution system was used, with monthly data for seven parameters from the two MCD's being segregated for the period from 2017 to 2022, totaling 1.008 data points. The following evaluation parameters were adopted, according to the description in SNIS (BRASIL 2022):

● Number of water savings: Quantity of active water savings that were fully operational on the last day of the reference year;

● Number of connections: Quantity of active water connections to the public network, whether or not equipped with a water meter, that were fully operational on the last day of the reference year;

● Distributed volume: Value of the sum of annual water volumes measured by means of permanent macro-meters;

● Micrometered volume: Annual volume of water measured by water meters installed in active water connections;

● Billed volume: Annual volume of water charged to total savings (metered and unmetered) for billing purposes;

● Billed days: Measurement monitoring period;

● Loss Index (LI): Percentage of water lost that leaves the reservoir and reaches the MCD inlet, but after macro-metering, this volume of water does not financially return to the company. The LI was calculated using the difference between the distributed volume (Vd) by the micro-metered volume (Vm) and the ratio of the distributed volume (Vd) (**Equation 1**):

$$LI = \frac{V_d - V_m}{V_d} \qquad\qquad \textbf{\textit{Equation 1}}$$
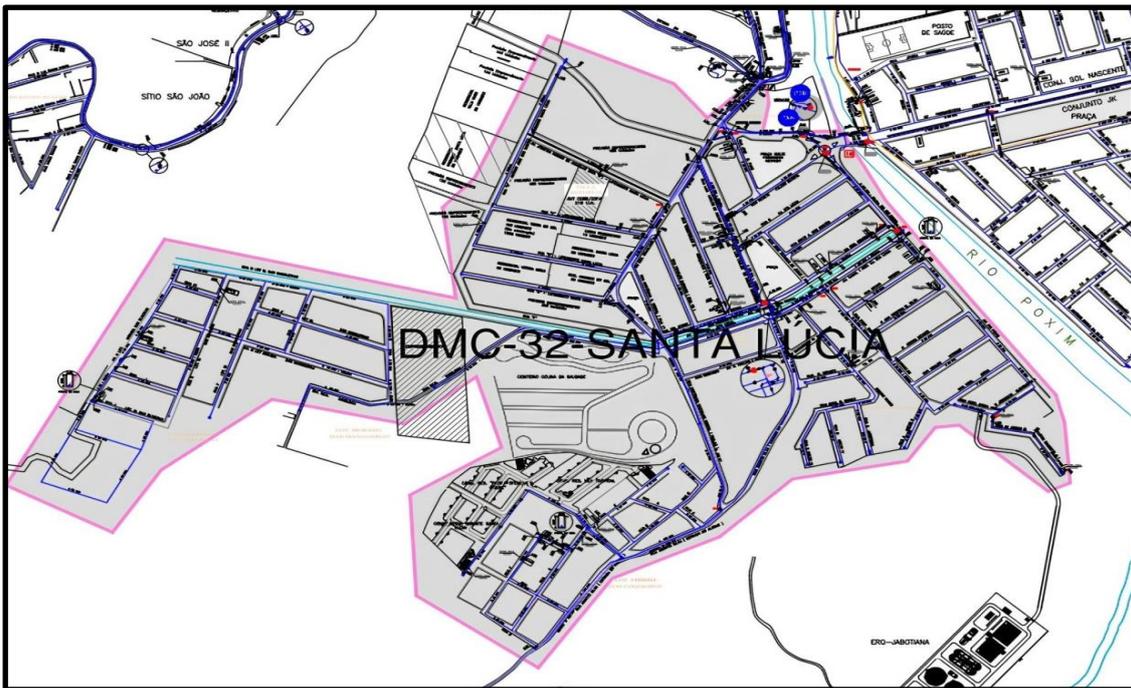


**Figure 2**. Map of the delimitation of Sector 6 and extension of MCD 32 in the water distribution network, located in the Santa Lúcia housing complex (Aracaju/SE). MCD = DMC. Source: DESO (2022).

The collected data were tabulated and aligned in a spreadsheet (Excel), in which the parameters were examined year by year. Partial averages for the years were calculated, followed by consolidated averages. Significant trends and correlations between parameters were identified based on the observed intervals. The indicators are presented by year to mitigate the effect of seasonality on supply and the differences between the reading periods of the volumes supplied and consumed in the area (Santos 2013).
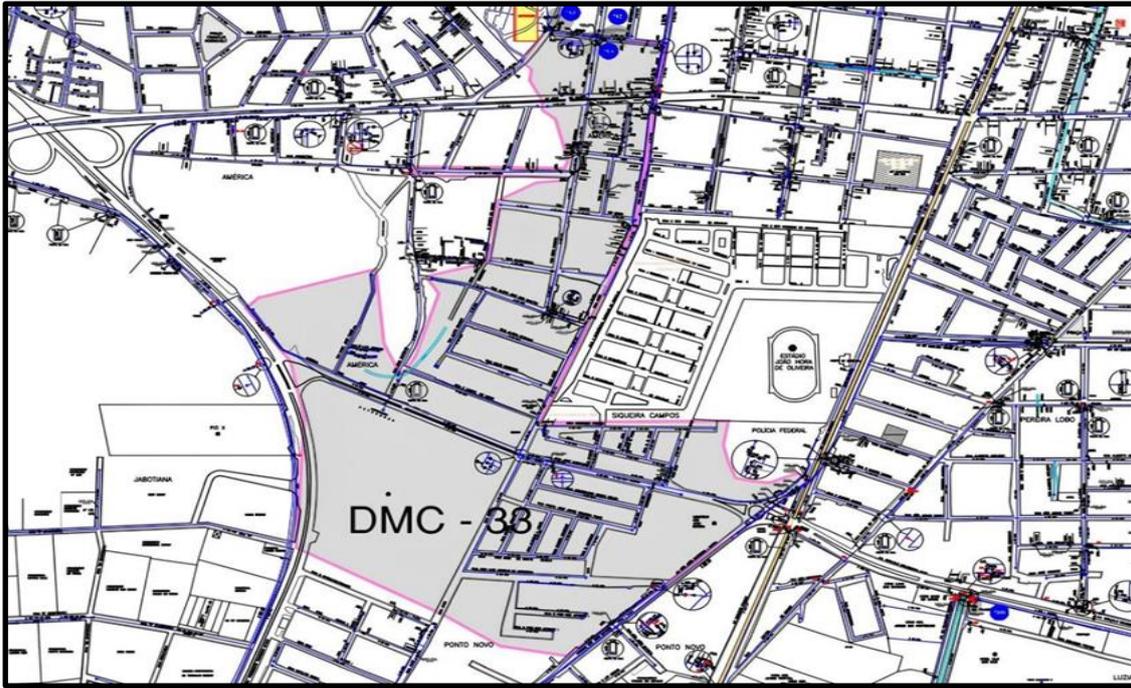
**Figure 3**. Map of the delimitation of Sector 1 and extension of MCD 33 in the water distribution network, located in the Siqueira Campos neighborhood (Aracaju/SE). MCD = DMC. Source: DESO (2022).

## Results and Discussion

This study presents the variation in the number of water savings in MCD's 32 and 33, from the Santa Lucia housing complex and the Siqueira Campos neighborhood, respectively, from 2017 to 2022, based on the metropolitan region of Aracaju water distribution network (**Table 1**). The results demonstrate a different behavior between the MCD's over the years, where in MCD 32, there was an increase of 12.75% between 2017 and 2018 and an even greater increase (20.20%) between 2018 and 2019. In subsequent years, the increase did not exceed 6.59%, representing less than 150 connections installed for consumers in the Santa Lucia housing complex. The result found is consistent with the weak growth in the implementation of new households. The MCD 33 from consumers in the Siqueira Campos neighborhood, showed a slight decrease between 2017 and 2020 (4.0%), with no change in subsequent years, as it represents a consolidated area with few areas to be occupied, i.e., without major changes. The average number of savings in the MCD 32 was around 3.524 units, while in MCD 33 the average was 1.507 units, with practically double the number of installed units. In order to improve the accounting of the volume consumed, it is recommended that all connections be metered, and that the period for accounting for the volume produced coincide with the period for reading the water meters, thus allowing for coherent comparisons (Gonçalves 1998).

**Table 2** presents data on the number of active connections in the MCD's. The data shows an increase in the number of active connections in DMC 32 over the years in the housing complex, mainly between 2017 and 2018 (18.87%) and 2018 and 2019 (23.18%). This may be linked to the growing number of properties in the region, as it is an area of expansion and shows a large increase in the number of new homes, with an increase in the number of connections of more than 52.63% and an average of 3.188 active connections. Lambert & Taylor (2010) and Gomes (2011) reported that in urban areas, the average size for MCD's should be between 500 and 3.000 connections, although there may be a reduction in values to the order of 500 to 1.000 connections in older systems. These authors did not recommend values above 5.000 connections because it makes locating leaks more difficult. Distribution networks in urban centers with accelerated population growth have expanded to meet new occupations without concern for the sectorization of water systems (Motta 2010).

**Table 1**. Number of savings in the MCD's 32 and 33, from 2017 to 2022. Source: DESO (2022).

| Year | Number of savings (units) | |
|------|------|------|
| | DMC's | |
| | 32 | 33 |
| 2017 | 2.744 | 1.533 |
| 2018 | 3.094 | 1.512 |
| 2019 | 3.719 | 1.507 |
| 2020 | 3.786 | 1.487 |
| 2021 | 3.839 | 1.503 |
| 2022 | 3.964 | 1.503 |
| Mean | 3.524 | 1.507 |

**Table 2**. Number of active connections in MCD's 32 and 33, from 2017 to 2022. Source: DESO (2022).

| Year | Number of connections | |
|------|------|------|
| | DMCs | |
| | 32 | 33 |
| 2017 | 2.337 | 1.321 |
| 2018 | 2.778 | 1.305 |
| 2019 | 3.422 | 1.301 |
| 2020 | 3.482 | 1.287 |
| 2021 | 3.543 | 1.302 |
| 2022 | 3.567 | 1.313 |
| Mean | 3.188 | 1.305 |

On the other hand, in MCD 33 there was a slight decrease in the number of connections (2.64%) between 2017 and 2020, probably due to water disconnections without reconnection requests. The region is characterized by already being densely populated, with limited areas for growth, yet it showed growth in the number of connections (2.02%), on average, with 1,305 active connections in the period. Farley *et al.* (2008) and Sabesp (2008) stated that the ideal size for a MCD depends on the type of use found in the area under study, and can vary between 500 and 2.500 connections, with studies actually carried out by the company using 2.000 connections for each DMC. Regarding the savings/connections in the two MCD's, there are 1.10 savings/connection (Santa Lúcia housing complex), which is slightly below the national average of 1.28 savings/connection. (BRASIL 2022) and, in the same year, there are 1.54 savings/connection for DMC 32 (Siqueira Campos neighborhood), which is above the national average.

MCD 32 presented an average inflow of 95.90 m³/h (DESO 2022). Although this MCD showed a 2.25% decrease in distributed volume between 2017 and 2018 (**Table 3**), overall, from 2018 onwards, there was an increase, with an average increase of 5,000 m³ per year. Between 2018 and 2019, the distributed volume was the most pronounced, totaling 7.125 m³ (15.40%), in contrast to being lower between 2019 and 2020 (1.887 m³ - 3.53%). These variations are likely related to the increasing number of connections linked to new residences (Santa Lúcia housing complex) as well as the peak of the Pandemic (COVID-19), where there was greater water consumption for hygiene purposes, consequently resulting in possible losses in distribution, with an average distributed volume of 54.577 m³ and an increase of 17.687 m³.

MCD 32 showed an increase in distributed volume (29.64%) between 2017 and 2018; however, between 2018 and 2020, a reduction in volume (15.16%) was observed, followed by a 17.09% increase between 2020 and 2021. MCD 33, in the Siqueira Campos neighborhood, presented an average inflow of 40.55 m³/h (DESO 2022). The peak of the COVID-19 pandemic, as well as possible leaks, caused a reduction in the distributed volume between 2021 and 2022, which reached an average of 28.112 m³ of water distributed between 2017 and 2022 to consumers in the neighborhood. Farley *et al.* (2008) highlighted the issue of minimum flow during the night, which is less than the inflow to the MCD, during a 24-hour period. The minimum flow occurs, in urban areas, generally between 2 and 4 am, when consumption is minimal and losses due to leaks reach maximum levels.

**Table 3**. Variation in the volume of water distributed in MCD's 32 and 33, from 2017 to 2022. Source: DESO (2022).

| Year | Distributed volume (m³) | |
| --- | --- | --- |
| | DMCs | |
| | 32 | 33 |
| 2017 | 47.320 | 23.849 |
| 2018 | 46.253 | 30.919 |
| 2019 | 53.378 | 27.816 |
| 2020 | 55.265 | 26.229 |
| 2021 | 60.237 | 30.712 |
| 2022 | 65.007 | 29.145 |
| Mean | 54.577 | 28.112 |

Regarding the micrometered volume of water (measured by water meters installed in building connections), an increase of 13.402 m³ (46.08%) was observed in the micrometered volume and distributed volume of MCD 32 over the study period. The micrometered volume showed a considerable increase between 2017 and 2018 (2.724 m³), 2018 and 2019 (6.367 m³), and 2019 and 2020 (3.051 m³), with less significant increases in other years (< 950 m³) (**Table 4**). In MCD 33, there were no major changes in the micrometered volume of water (471–817 m³). However, it is worth noting that the distributed volume increased between 2017 and 2018 (29.64%) and between 2020 and 2021 (17.09%), while the micrometered volume decreased to 4.61% and 2.88%, respectively. This likely caused a loss for the company due to a drop in revenue. On the other hand, between 2018 and 2019 and between 2021 and 2022, there was a decrease in the distributed volume (10.04%; 5.10%) and an increase in the micrometered volume (5.06%; 4.77%), increasing revenue and reducing company losses. According to the diagnosis of the *Sistema Nacional de Informações Sobre Saneamento* (SNIS) [National Sanitation Information System (SNIS)], the average per capita water consumption in Brazil was 148.20 l/inhabitant/day. In the city of Aracaju, the average water consumption was 133.57 l/inhabitant/day (BRASIL 2022).

**Table 4**. Variation in micromeasured volume in MCD's 32 and 33, from 2017 to 2022. Source: DESO (2022).

| Year | Micromeasured volume (m³) | |
| --- | --- | --- |
| | DMC's | |
| | 32 | 33 |
| 2017 | 29.082 | 16.912 |
| 2018 | 31.806 | 16.132 |
| 2019 | 38.173 | 16.949 |
| 2020 | 41.224 | 16.356 |
| 2021 | 41.545 | 15.885 |
| 2022 | 42.484 | 16.643 |
| Mean | 37.386 | 16.480 |

The behavior of the billed volume in the two MCD's (as per measurements shown in **Table 5**) proved to be realistic, as the values are higher than the micrometered volume. This is related to the minimum or average consumption parameters adopted by the companies, which may be higher than the volumes actually consumed. Over the years, MCD 32 showed an increase (15.357 m³) in the billed volume from the annual volume of water delivered to the total number of households, with the largest increases between 2017 and 2018 (4.003 m³) and between 2018 and 2019 (7.506 m³). Subsequent years did not show increases in the billed volume (<2.200 m³), with an average of 44.246 m³. The period showed a significant increase of 44.59%, representing the fraction of the water volume made available and billed (volume used by consumers). No major changes were observed in MCD 33, including in the micrometered volume, with a slight decrease (1.10%) and an average of 20.333 m³ in the analyzed period. There were no major fluctuations in relation to the billed days. In most years, MCD 32 showed an average consumption of 31 days. In MCD 33, the average consumption was 30 days (**Table 6**). Overall, these data do not influence the

other parameters. Freire (2017) pointed out that the unbilled volume is different from the loss component, because within the unbilled volume there is a portion that is authorized and is not an integral part of the sanitation company's billing. Part of this volume is made available for social purposes, representing a large portion of unbilled water, and is not characterized as a loss. Water losses occur in all supply systems. The amount of water lost is variable and dependent on the physical characteristics of the supply system, local factors and customs, operational practices, and the level of technology applied for its control (Melato 2010).

**Table 5**. Variation in billed volume in MCD's 32 and 33, from 2017 to 2022. Source: DESO (2022).

| Year | Billed volume (m³) | |
| --- | --- | --- |
| | DMC's | |
| | 32 | 33 |
| 2017 | 34.440 | 20.772 |
| 2018 | 38.443 | 20.176 |
| 2019 | 45.946 | 20.784 |
| 2020 | 48.113 | 19.968 |
| 2021 | 48.737 | 19.757 |
| 2022 | 49.797 | 20.543 |
| **Mean** | **44.246** | **20.333** |

**Table 6**. Variation in billed days in MCD's 32 and 33, from 2017 to 2022. Source: DESO (2022).

| Year | Billed days | |
| --- | --- | --- |
| | DMC's | |
| | 32 | 33 |
| 2017 | 31 | 30 |
| 2018 | 30 | 30 |
| 2019 | 30 | 30 |
| 2020 | 31 | 30 |
| 2021 | 31 | 30 |
| 2022 | 31 | 31 |
| **Mean** | **31** | **30** |

In MCD 32, there was a considerable reduction in losses between 2017 and 2020 (37.98% to 25.40%), resulting in less waste of water, electricity, and treatment products. Between 2020 and 2022, the loss rate increased again (8.75%), reaching 34.15%, resulting in an average value of 31.82% for the period. Between 2017 and 2022, the loss rate decreased to 3.83 percentage points. In MCD 33, there was a rise in losses between 2017 and 2018 (32.70% to 44.03%), followed by reductions between 2018 and 2020 (5.56 percentage points). Between 2020 and 2021, there was a sharp increase (9.74 percentage points) followed by a decrease of 5.70 percentage points, ending 2022 with 42.51% losses and an average of 40.82% (**Table 7**). In quantitative terms, for every 100 liters made available, only 59.18 liters were accounted for as being used by consumers in the Siqueira Campos neighborhood. Actions to reduce losses involve various departments of a sanitation operator (e.g., purchasing, maintenance, billing, marketing, etc.) and the presence of a unit not only focused on structuring and monitoring an energy reduction and efficiency program (Salamoni 2013). Real losses (physical losses) and apparent losses (commercial or administrative losses) have synergistic and negative impacts on the overall performance of the utility. While real losses lead to increased operating costs and higher investments, apparent losses reduce public service revenues (Silva 2014). Real losses are those where water leaves the reservoirs but does not reach the end consumer due to leaks in pipes (**Figure 4**), connections, and/or overflows in the reservoirs. Apparent losses are those where volumes of water are consumed but are not accounted for or billed by the company, which can occur due to failures in macro or micro-metering, commercial failures (e.g., lack of property registration), which allow water consumption without charge, as well as theft through clandestine connections (Santos 2013) (**Figure 5**).

**Table 7**. Performance of the Loss Index in MCD's 32 and 33, from 2017 to 2022. Source: DESO (2022).

| Year | Percentage loss index (%) | |
|---|---|---|
| | DMC's | |
| | 32 | 33 |
| 2017 | 37,98 | 32,70 |
| 2018 | 34,10 | 44,03 |
| 2019 | 28,36 | 38,98 |
| 2020 | 25,40 | 38,47 |
| 2021 | 30,99 | 48,21 |
| 2022 | 34,15 | 42,51 |
| Mean | 31.82 | 40.82 |



**Figure 4**. Evidence of a water leak in a pipe in the distribution network, located in the Siqueira Campos neighborhood (Aracaju/SE). Source: DESO (2022).



**Figure 5**. Prominent theft through illegal connections and a building without a water meter, located in the Siqueira Campos neighborhood (Aracaju/SE). Source: DESO (2022).

Between 2021 and 2022, water distribution loss rates in the state of Sergipe were 57.6% and 48.4%, respectively, with an absolute variation of 9.2 (BRASIL 2022). The document shows parity with the regional average, given similar socioeconomic challenges (Silva 2014). Loss rates are directly associated with the quality of infrastructure and system management. Hypotheses can be

raised to explain water losses at above acceptable levels: failures in leak detection, distribution networks operating at very high pressure, problems in the quality of system operation, difficulty in controlling illegal connections and in the verification/calibration of water meters, absence of a loss monitoring program, etc. (Morais *et al.* 2010). Controlling pressure in the distribution network has an immediate impact on loss volumes (Motta 2010). Preventive maintenance and the adoption of operational procedures and personnel training for carrying out appropriate maneuvers are also vital to avoid ruptures caused by sudden increases in pressure which, in cascade, cause multiple ruptures in distribution networks (Salamoni 2013).

The correlation matrix of the average DMC 32 data (**Table 8**) generally demonstrated high agreement in terms of signs (+, -), particularly showing 14 values out of 21, representing 66.66%, indicating a strong correlation (> 0.50) between the parameters. From the matrix, a significant positive correlation (> 0.88) is observed between billed volume and the parameters number of savings, number of connections, distributed volume, and micromeasured volume. This reflects the importance of monitoring billed volume, as there is a very broad association between them, since when billed volume increases, the other parameters have a strong tendency to increase, indicating that they are related, but can also vary together.

**Table 8**. Correlation matrix of parameters based on average MCD 32 data.

| DMC 32 | Number of savings | Number of connections | Distributed volume | Micromeasured volume | Billed volume | Billed days | Loss rates |
|---|---|---|---|---|---|---|---|
| Number of savings | 1 | | | | | | |
| Number of connections | 0.9956943 | 1 | | | | | |
| Distributed volume | 0.8754953 | 0.8332077 | 1 | | | | |
| Micromeasured volume | 0.9875349 | 0.9786852 | 0.9031343 | 1 | | | |
| Billed volume | 0.9968859 | 0.9917520 | 0.8870240 | 0.99656955 | 1 | | |
| Billed days | 0.0212627 | -0.0328591 | 0.3696542 | 0.15262126 | 0.0825138 | 1 | |
| Loss rates | -0.6668382 | -0.7162438 | -0.2687742 | -0.64894643 | -0.6663048 | 0.3503853 | 1 |

The strong correlation between distributed volume and micrometered volume (> 0.90) indicated that, in most cases, there is an increase in both dDistributed volume and micrometered volume. This means that one parameter can be used to predict the other, but one variable will not necessarily influence the other. The significant negative correlations (< -0.64) of the loss indices with the parameters number of savings, number of connections, micrometered volume, and billed volume indicated a shift in opposite directions, highlighting that when the Loss Index increases, the other four parameters tend to decrease, resulting in fewer properties being served, less water being distributed, micrometered, and billed, representing a major challenge for improving the water distribution system. The correlation matrix originating from the average data of MCD 33 (**Table 9**) generally showed low agreement in terms of signs (+, -), particularly showing 9 values out of 21 (42.85%).

A strong negative correlation (< -0.81) was observed between the Loss Index and micromeasured volume, demonstrating that the larger the micromeasured water, the lower the loss. When compared to other parameters, the Loss Index showed a negative correlation (with varying intensity) with virtually all of them, except distributed volume, showing an inverse relationship.

The Loss Index and distributed volume showed a strong positive correlation (> 0.95), indicating that the more water distributed, the more water was lost by the company. Despite a higher distributed volume, there was no contribution to the increase in billed volume, as it only increased when compared to the micromeasured volume (high correlation: > 0.94). Therefore, pressure management is the only method that has a positive impact on all three components of actual water losses: visible leaks, non-visible (detectable) leaks, and inherent (undetectable) leaks.

**Table 9**. Correlation matrix of parameters based on average MCD 33 data.

| DMC 33 | Number of savings | Number of connections | Distributed volume | Micromeasured volume | Billed volume | Billed days | Loss rates |
|---|---|---|---|---|---|---|---|
| Number of savings | 1 | | | | | | |
| Number of connections | 0.8635312 | 1 | | | | | |
| Distributed volume | -0.3700231 | -0.2138052 | 1 | | | | |
| Micromeasured volume | 0.4291956 | 0.4277748 | -0.6966519 | 1 | | | |
| Billed volume | 0.5993748 | 0.6185473 | -0.5148708 | 0.9475834 | 1 | | |
| Billed days | -0.4145780 | -0.0233152 | 0.2674593 | -0.0817899 | -0.0587257 | 1 | |
| Loss rates | -0.4703762 | -0.2977106 | 0.9510190 | -0.8115598 | -0.690001 | 0.195023 | 1 |

## Final considerations

After evaluating the reports on water loss quantities from DESO (2022) in two MCD's of the water distribution system in the Metropolitan Region of Aracaju/SE, it is concluded that the installation of MCD's 32 and 33 does not cause any harm to the water supply network in the Metropolitan Region of Aracaju/SE; the studied MCD's reflect how distribution management operates and what parameters are taken into account to estimate operational losses; it is important to update the consolidated data on loss percentages and stratification of breakdowns, whether in revenue, in volume of water distributed, in the face of increased savings and social dynamics; water losses in these locations represent a significant portion of the total losses, which negatively impacts the operational and financial efficiency of the company; water losses in the measurement and control districts are attributed to a variety of factors, including leaks in metering equipment, valve and register failures, as well as calibration problems and inadequate maintenance. The lack of advanced monitoring and leak detection technologies hinders the quick and efficient identification and correction of these problems. Finally, the low reduction in water losses in metering districts requires greater joint efforts from public authorities, water companies, and local communities. By adopting effective monitoring, maintenance, and awareness measures, the efficiency and sustainability of water distribution systems can be improved, ensuring access to this vital resource for future generations.

## References

Barroso M.L.A. (2019) Avaliação de perdas nos sistemas públicos de abastecimento de água no Estado de Sergipe. *Pesquisa e Ensino em Ciências Exatas e da Natureza*, 3(1): 76–87. http://dx.doi.org/10.29215/pecen.v3i1.1150

BRASIL (2022) Ministério das Cidades. Secretaria Nacional de Saneamento Ambiental – SNSA. Sistema Nacional de Informações sobre Saneamento SNIS: Série Histórica. Disponível em: http://www.snis.gov.br/aplicacao-web-serie-historica (acessado: 26/03/2025).

Brito L.T.L., Silva A.S. & Porto E.R. (2007) Disponibilidade de água e a gestão dos recursos hídricos (p. 15–32.). *In*: Brito L.T.L., Moura M.S.B. & Gama G.F.B. (Eds). Potencialidades da água de chuva no semi-árido brasileiro. Petrolina: Embrapa Semi-Árido. 179 p.

Castro C.N. (2022) Água, problemas complexos e o Plano Nacional de Segurança Hídrica. Rio de Janeiro: Ipea. 281 p.

DESO (2022) Relatórios dos Quantitativos de Perdas Hídricas. Diretoria de Operação e Manutenção, Companhia de Saneamento de Sergipe. Aracaju: DESO.

Farley M., Wyeth G., Ghazali Z.B.Md., Istandar A. & Singh S. (2008) The Manager's Non Revenue Water: A Guide to Understanding Water Losses. Malaysia: Ranhill Utilities Berhad and the United States Agency for International Development (USAID). 98 p.

Ferreira M.P. & Garcia M.S.D. (2017) Saneamento básico: meio ambiente e dignidade humana. *Dignidade Re-Vista*, 2(3): 1–12.

Freire M.R. (2017) Modelo para setorização de redes de distribuição de água. Dissertação (Programa de Pós-Graduação em Ciências: Engenharia Hidráulica e Saneamento). Universidade de São Paulo, Escola de Engenharia de São Carlos, São Carlos.

Fritz R.T., Gimenes J.C. & Filho A.C.P. (2020) Um estudo da automação para redução de perdas na rede de distribuição de água. *Brazilian Journal of Development*, 6(8): 56408–56416. https://doi.org/10.34117/bjdv6n8-161

Gomes R.J. (2011) Modelação Matemática como Ferramenta de Gestão e Exploração de Sistemas de Distribuição de Água. Tese (Programa de Pós-Graduação em Engenharia Civil). Universidade de Coimbra, Coimbra.

Gonçalves E. (1998) Metodologia para controle de perdas em sistemas de distribuição de água – Estudo de casos da CAESB. Dissertação (Programa de Pós-Graduação em Tecnologia Ambiental e Recursos Hídricos). Universidade de Brasília, Departamento de Engenharia Civil e Ambiental, Brasília.

Júnior J.C.S. & Vatavuk P. (2023) Distritos de medição e controle como ferramenta de gestão de perdas em redes de distribuição de água. *Revista Delos*, 16(42): 445–470. https://doi.org/10.55905/rdelosv16.n42-029

Lambert A.O. & Taylor R. (2010) Water loss guidelines. Wellington: Water New Zealand.

Melato D.S. (2010) Discussão de uma metodologia para diagnóstico e ações para redução de perdas de água: aplicação no sistema de abastecimento de água da Região Metropolitana de São Paulo. Dissertação (Programa de Pós-Graduação em Engenharia Hidráulica). Universidade de São Paulo, Escola Politécnica, São Paulo.

Morais D.C., Cavalcante C.A.V. & Almeida A.T. (2010) Priorização de áreas de controle de perdas em redes de distribuição de água. *Pesquisa Operacional*, 30(1): 15–32. https://doi.org/10.1590/S0101-74382010000100002

Motta R.G. (2010) Importância da setorização adequada para combate de perdas reais de água de abastecimento público. Tese (Programa de Pós-Graduação em Engenharia). Universidade de São Paulo, Escola Politécnica. https://doi.org/10.11606/D.3.2010.tde-18082010-171334

Pereira S.F. (2018) Avaliação das perdas hídricas no sistema de abastecimento de água do setor Parque das Nações do município de Parnamirim/RN. Monografia (Graduação em Engenharia Civil). Universidade Federal do Rio Grande do Norte, Centro de Tecnologia, Departamento de Engenharia Civil, Natal.

SABESP (2008) Companhia de Saneamento Básico do Estado de São Paulo: Distrito de Medição e Controle (DMC). Distrito de Manobra (DM). São Paulo: Superintendência de Desenvolvimento da Metropolitana.

Salamoni S.S. (2013) Avaliação das Perdas na Distribuição de Água: Estudo de Caso em São Bento Baixo, Nova Veneza-SC. Monografia (Engenharia Civil). Universidade do Extremo Sul Catarinense, Criciúma, Santa Catarina.

Santos D.D. (2013) Avaliação da metodologia para controle e redução de perdas de água em sistemas de distribuição no Recife-PE. Dissertação (Programa de Pós-Graduação em Engenharia Civil). Universidade Federal de Pernambuco, Centro de Tecnologia e Geociências, Recife, Pernambuco.

SEPLAG (2023) Observatório de Sergipe. Secretaria Especial de Planejamento, Orçamento e Inovação. Disponível em https://observatorio.se.gov.br/aracaju-concentra-355-do-pib-sergipano/ (acessado: 02/12/2023).

Silva C.O. (2014) Modelagem de rede de distribuição de água com ênfase no controle de perdas. Dissertação (Programa de Pós-Graduação em Engenharia Urbana e Ambiental). Universidade Federal da Paraíba, João Pessoa.

Zaniboni N. (2009) Equipamentos e metodologias para o controle redução de perdas reais em sistemas de abastecimento de água. Dissertação (Programa de Pós-Graduação em Engenharia). Universidade de São Paulo, Escola Politécnica, Departamento de Engenharia Hidráulica e Sanitária. https://doi.org/10.11606/D.3.2009.tde-11082009-172644