XXVI SIMPÓSIO BRASILEIRO DE RECURSOS HIDRÍCOS

ANALYZING DEEP WELLS NETWORK EXPANSION FOR URBAN WATER SUPPLY UNDER DATA LIMITATIONS: A CASE STUDY OF ALTO DA BOA VISTA CONDOMINIUM, SOBRADINHO/DF

Cássio Guilherme Rampinelli [1]; Magno Gonçalves da Costa [2]; Carlos Henrique de Assis do Carmo[3]; Ivana Santos Guimarães [4]

Abstract: The overexploitation of groundwater is a critical global issue, particularly in rapidly urbanizing regions with increasing water demands. In the federal capital, unplanned urban growth mirrors challenges faced by other major cities, where indiscriminate drilling of deep tubular wells often occurs without proper hydrogeological assessments. This study addresses the frequent reliance on expanding well-based water supply systems. By conducting hydraulic analysis and network optimization, existing systems can be enhanced to improve flow output. However, data limitations often impede these analyses. This case study evaluates a well intake system, exploring network expansion with new wells and optimizing layouts for efficiency. The findings offer valuable insights for diagnosing and expanding water supply systems in developments under data constraints, emphasizing cost-effective and timely solutions.

Resumo: A superexploração de águas subterrâneas é uma questão crítica global, especialmente em regiões de urbanização rápida com demandas crescentes de água. Na capital federal, o crescimento urbano desordenado reflete desafios enfrentados por outras grandes cidades, onde a perfuração indiscriminada de poços tubulares profundos muitas vezes ocorre sem avaliações hidrogeológicas adequadas. Este estudo aborda a frequente dependência da expansão de sistemas de abastecimento com base em poços. Ao realizar análises hidráulicas e otimização da rede, sistemas existentes podem ser aprimorados para melhorar a vazão. No entanto, limitações de dados frequentemente dificultam essas análises. Este estudo de caso avalia um sistema de captação de poços, explorando a expansão da rede com novos poços e otimizando layouts para eficiência. Os resultados oferecem insights valiosos para o diagnóstico e expansão de sistemas de abastecimento em desenvolvimentos com limitações de dados, enfatizando soluções econômicas e oportunas.

Palavras-Chave – poços, sistemas de abastecimento de água, águas subterrâneas.

Keywords – Wells, water supply systems, groundwater.

1) Infrastructure Analyst, PhD. in Water Resources Engineering, ANA, SPO, Área 5, Quadra 3, Bloco O, Sala 206, Brasília/DF, 61-2109-5335, cassiorampinelli@gmail.com
2) Infrastructure Analyst, MsC. in Water Resources Engineering, Casa Civil da Presidência da República, Palácio do Planalto, Anexo III, sala 202ª, Praça dos Três Poderes, Brasília/DF, 61-3411-3379, magnogc@gmail.com
3) Undergraduate Student in Civil Engineering, UDF-Centro Universitário, SEP SUL, EQ 704/904, Conj. A – Asa Sul – Brasília/DF, carlosprojetoeng@gmail.com
4) Civil Engineer, COPENGE, R. das Orquídeas, 777 - Vila Bergamo, Indaiatuba - SP, 13345-040, guimaraesisg@gmail.com

1. INTRODUCTION

The overexploitation of groundwater has become an increasingly concerning topic worldwide in water resource management, as indicated by declining groundwater levels in various studies (Bierkens et al., 2021; Döll et al., 2014a; Jasechko et al., 2024b; Rodell et al., 2018; Uchôa et al., 2024; Wada et al., 2010a). Recently, an analysis of over 17,000 wells in Brazil (Uchôa et al., 2024) revealed that the majority (55%) showed water levels below those of nearby rivers and streams, indicating infiltration and the risk of reduced river flow. The imbalanced infiltration of river water into the ground can decrease stream flow, impacting human supply and aquatic ecosystems.

The anticipated increase in water demand due to human consumption and the rise in energy and agricultural production (Uchôa et al., 2024), along with uncertainties about the impacts of climate change (ANA, 2024; Ballarin et al., 2023), is a concern for organizations and sectors managing water resources. This has led to a pursuit of effective groundwater management and control mechanisms (Jasechko et al., 2024b; Scholten et al., 2025; Wada et al., 2010b). In the federal capital, the reality of unplanned urban growth and pressure on water sources mirrors that of other major cities in the country. The Planning Company of the Federal District (CODEPLAN) released a study showing that the region continues to expand, with the urban area growth rate increasing from 12 km²/year to 20 km²/year since 2013 (Chelotti & Sano, 2021). This growth has been accompanied by a significant decline in the efficiency of government tools since the same year.

Although originally planned for 500,000 inhabitants, the capital has faced typical issues of unplanned cities since the 1990s, such as irregular urban settlements, slums, and water resource shortages (Chelotti et al., 2019). The water crisis in the Federal District between 2016 and 2018 (Lima et al., 2018) highlighted the vulnerability of the capital due to significant population growth, disorganized urbanization, and high susceptibility to climate conditions (Torres et al., 2012). The increased water demand in the Federal District is largely linked to the expansion of urban areas, especially in unestablished regions like Jardim Botânico, Sobradinho, and Planaltina (Torres et al., 2012). Urbanization is progressing particularly in areas at high risk of aquifer recharge loss, intensifying the need for water resources, especially during dry periods (Chelotti & Sano, 2021).

In many private residential developments in the Federal District, water supply solutions often involve the indiscriminate drilling of deep tubular wells without proper hydrogeological assessments or alternative supply studies. In response, the Regulatory Agency for Water, Energy, and Basic Sanitation of the Federal District (ADASA) has intensified its control and monitoring of drilling permits, and is promoting the training and development of various stakeholders and water users involved (ADASA, 2020). The lack of control and studies in groundwater exploration is linked to numerous issues, such as aquifer depletion(Döll et al., 2014b; Jasechko et al., 2024a), saltwater intrusion in coastal areas (Werner et al., 2013), land subsidence (Herrera-García et al., 2021; Shirzaei et al., 2021), reduction in river levels (M de Graaf et al., 2019; Uchôa et al., 2024), and the exhaustion of wells designed for water supply (Jasechko & Perrone, 2021). Locally, unplanned drilling to meet rising demand makes communities entirely dependent on well-based supplies in a few areas of the city. Intensified occupation and soil impermeabilization reduce aquifer recharge and, along with groundwater overexploitation, can lead to well collapse during periods of high demand and drought.

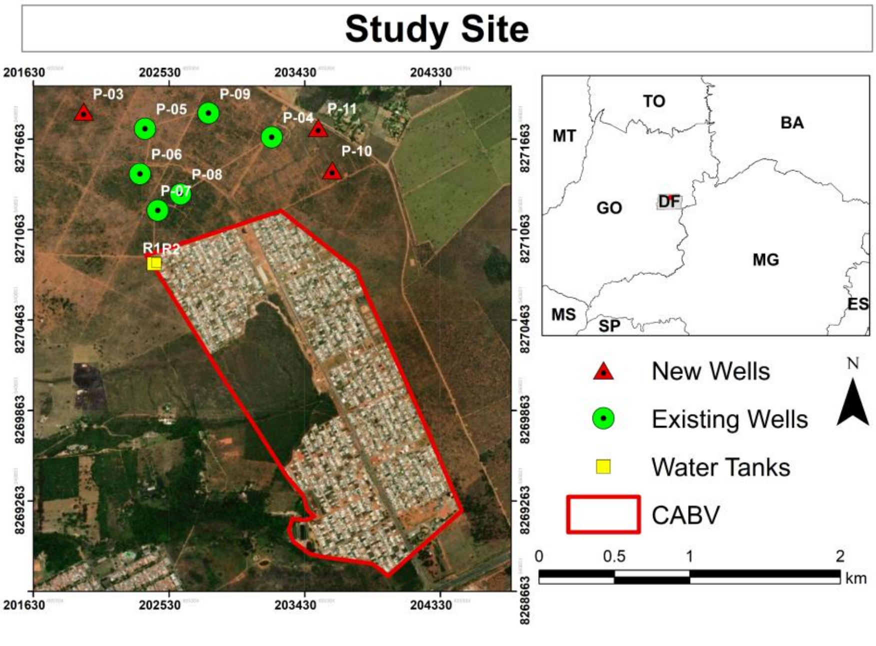
Frequently, increasing water supply through wells can be avoided by conducting a hydraulic analysis of the existing system, optimizing the network to enhance final flow output. However, designers often face data limitations hindering this analysis. This work examines a case study aimed at evaluating an existing well intake system, exploring network expansion with new wells, while optimizing layouts for greater efficiency. It provides valuable insights to the technical community on diagnosing existing water supply systems in these condominiums and analyzing alternatives for water supply expansion under data constraints, with an emphasis on delivering a high-quality study within budgetary, technical, and time limitations.

2. STUDY SITE

The study area is located within the Alto da Boa Vista Condominium (CABV), situated in the satellite city of Sobradinho, Brasília/DF, along the BR-020 highway at kilometer 12.5. The CABV features a set of six deep tubular wells positioned in the highest, uninhabited part of the condominium. These wells connect to a water intake network that conveys water to two reservoirs (R1 and R2) located at the northwest edge of the area. From these reservoirs, water is distributed throughout the condominium.

The existing wells provide sufficient water supply for most of the year. However, during the dry season (particularly from July to October), water demand increases, and the current wells are unable to meet the demand, necessitating rationing measures. To enhance water availability, the CABV has drilled three additional wells to integrate into the existing system. Figure 1 illustrates the location of the six existing wells (P-04 to P-09), the three newly drilled wells (P-03, P-11, and P-10), the existing water tanks, and the boundary defining the condominium area.

Figure 1 – Study area indicating existing wells with green circular markers, newly drilled wells with red triangular markers, water tanks with yellow squares, and the condominium boundary outlined in red

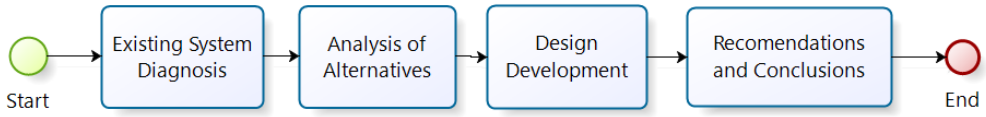


3. METHODOLOGICAL APPROACH

The methodological approach aimed at achieving the following objectives: (a) Conduct a diagnosis of the existing system; (b) Evaluate alternatives for integrating the newly drilled wells into the existing water supply system; (c) Specify and develop the project for the optimal solution; (d) Provide recommendations and suggestions for future improvements to the system.

Figure 2 provides a general summary of the main stages we believe are applicable to any analysis aimed at evaluating deep tubular well water supply distribution systems similar to those found in CABV.

Figure 2 – Main methodological framework considered in the study



In the following subsections, we describe the main methodological steps summarized in Figure 2. We provide an overview encompassing aspects we consider relevant for any study aimed at re-evaluating water supply systems that rely on deep tubular wells in similar condominiums. Additionally, we include specific details of the case analyzed in this work, which may be useful for technicians and designers dealing with similar issues.

3.1 Existing System Diagnosis

The first step before assessing any improvement or expansion of a system is conducting a diagnosis. The diagnostic stage aims to thoroughly understand the system's operating conditions. This requires gathering all existing technical data of the system, such as designs, technical specifications, descriptive reports, graphical documents, operational rules, monitoring data, conversation with technicians that operate the system and any aspect that might support the system's understanding.

Commonly, practical cases lack a robust design, or even with a good design, numerous modifications, expansions, improvements, and adjustments may have been made over time without detailed documentation or specification of the original design. In such cases, the following are suggested: (a) Catalog all existing system components; (b) Carry out measurements and monitoring, considering constraints like budget, available technical staff, and timeline for the study; and (c) Implement a hydraulic model using available software, aiming to calibrate it as accurately as possible to represent the existing system.

For the case study, there was a well-designed project; however, a series of modifications and expansions were carried out, and a cadastral survey of all information materialized in an as-built was conducted. The types and dimensions of pipelines (material, length, and diameters), connections, pumps, and equipment were detailed. Given the absence of systematic monitoring of flow rates and pressures in the network, an expedited flow measurement campaign was proposed for wells equipped with flow meters, along with some pressure readings in the reservoirs. Based on this data, an estimate of per capita flow rates and peak day/hour consumption coefficients was made. These findings were then incorporated into a hydraulic model to represent conditions closest to the system's actual operation. The following subsections summarize the steps taken for the diagnosis.

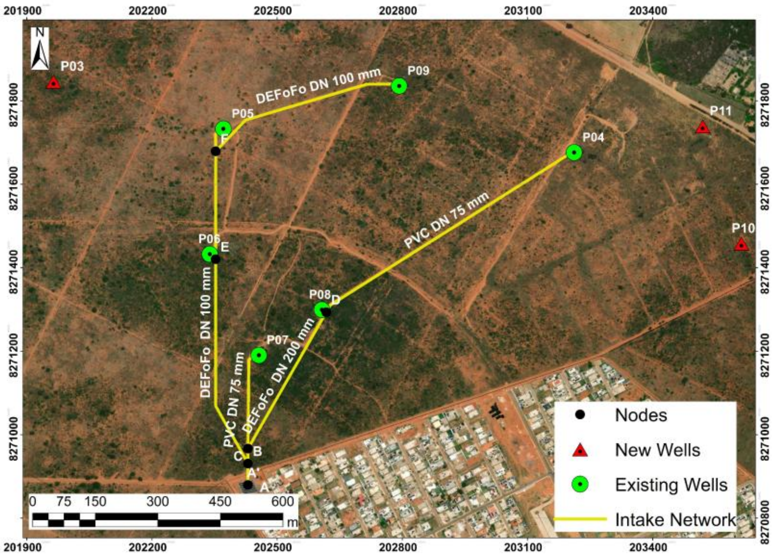
3.1.1 System layout

The diagnosis of the existing network began with a cadastral survey of existing conduits and identification of reference nodes in the system that are important for the implementation of a hydraulic model. These nodes were points of change in the pipe diameter, pipe junctions, or exit points from the deep tubular wells to the network. Main components of the wells and the topography were identified. An updated layout was created based on previous designs, in-situ inspections, and staff input. Verification of buried pipelines required inspection trenches. This layout was then used in hydraulic simulations to evaluate the current state of the system and also for the analysis of alternatives. Additionally, the types of pumps, well configurations, and structures were surveyed.

Figure 3 shows an overview of the existing network layout. The six wells (P-04, P-05, P-06, P-07, P-08, and P-09) are connected by a branched conduit system. Each deep tubular well features a manifold with a flow meter, pressure gauge, air release valves, and check valves for system protection. Connection points (or nodes) use the well number with an apostrophe, such as P9' for Well

P09 and P6' for Well P06. Other network points, like junctions or diameter changes, are identified by letters. The conduit paths and points are mapped approximately.

Figure 3 – System layout



3.1.2 Flows

According to NBR 12.211/92 (ABNT, 1992; Tsutiya, 2006) , the design of water supply systems should based on existing measured data, ideally over a five-year period. This allows determination of the average daily flow and the peak day coefficient, crucial for designing reservoirs and intake systems. However, the CABV lacks daily consumption flow measurements. While equipment exists for measuring flow at the main reservoirs' intake and outlet points, the exit meter has been compromised, and there's no automatic data recording.

To estimate daily system flow, readings from installed well meters could be used, but there's no systematic historical record. A quick data measurement campaign has been proposed to estimate the daily flow magnitude. Ideally, flow records at reservoir outlet would be used, but only household meter readings were available, which are not recommended for daily average estimates according to NBR 12.211/92. Despite this, these readings provide some insight into annual consumption variation and total measured use due to their extended temporal range. Spreadsheets with records from January 2022 to June 2024 were used. The per capita consumption from meter readings were estimated using the following Equation (1) (Tsutiya, 2006):

$$q = \frac{q_e}{1 - I} \quad (1)$$

Where: q per capita water consumption; q_e effective per capita water consumption; I loss index. The effective consumption q_e is obtained from the following Equation (2):

$$q_e = \frac{V_c}{NE\ .\ ND\ .\ \frac{NH}{L}} \quad (2)$$

Where: V_c Measured consumption, NE Number of economies, ND Number of days of meter readings; NH/L Number of inhabitants per connection. For new projects, a loss index of 20% is recommended as a target. For NH/L, 3.5 inhabitants per connection were considered based on the urban features. The remaining data was obtained from the measurement spreadsheets provided.

3.1.3 Hydraulic model, calibration e validation

To perform the hydraulic model, the EPANET software (Rossman, 2000), a widely used tool for simulating pressurized water supply systems due to its versatility and simplicity. The model focused on simulating the wells and pipelines transporting water to the supported reservoirs, treating each well as a fixed-level reservoir. Input data from the diagnostic phase were incorporated, and the system's components were configured to calculate its operation. Without pressure measurements along the pipelines, calibration relied on adjusting roughness coefficients using flow measurements, with a separate dataset used for validation.

Boundary conditions, including water levels at the wells and downstream reservoir conditions, were defined based on diagnostic data. The water level in the reservoirs was assumed to be 1.5 meters or more; otherwise, the pipelines operated with free discharge at a set elevation. Calibration was performed across three scenarios: two with low reservoir levels and one nearly full. Each scenario employed average pumping flows and reservoir levels, iteratively adjusting roughness coefficients to minimize discrepancies. The model's performance was evaluated using the root mean square error (RMSE) was used to assess the performance of the calibration given by Equation (3):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Q_{ci} - Q_{oi})^2} \quad (3)$$

Where: n – number of measurements; Q_{ci} – calculated flow in pipe i; Q_{ci} – observed flow in pipe i.

3.2 Analysis of Alternatives

After calibrating and validating the hydraulic model, an analysis of alternatives was performed to determine the most efficient connection layout for new wells to the existing system. Efficiency was evaluated based on energy consumption, increased flow, and cost reduction. Three alternatives were developed, each with a variant for a near-term scenario, adding 50 m³/h to the system. These alternatives were compared in terms of implementation costs, energy consumption, systemic flow, head losses, and versatility. The same calibrated roughness coefficients were used when connecting new wells, considering a maximum increase of up to 50 m³/h. Iterative simulations were performed using EPANET to calculate flows, head losses, and pressures in the system. Pressure classes for the pipes were defined based on the analyses, taking into account maximum pressures, including transient pressure computed with . For cost analysis, CABV provided construction budget for the alternatives. The following briefly describes each alternative.

3.2.1 Alternative 1.1 (current scenario)

Alternative 1.1 aimed to preserve the existing system as much as possible and connects wells P11 and P10 near the P04 area. This alternative involved replacing approximately 700 meters of existing pipeline that connects well P04, between nodes P04' and D (near well P08), with a 150 mm diameter PVC DEFoFo pipeline (PN = 1.25 MPa).

3.2.2 Alternative 1.2 (future scenario)

Alternative 1.2 shared the same characteristics as Alternative 1.1, with the difference of considering the addition of wells in the future, near the P10 and P11 area. For modeling purposes, the additional flow was represented by a single representative well with a maximum of 50 m³/h and connected to the system through a new pipeline section.

3.2.3 Alternative 2.1 (current scenario)

Alternative 2.1 aimed to configure an independent complementary system by connecting wells P10 and P11 directly to the storage center. It included a connection between wells P10 and P11 using a 75 mm diameter PVC pipeline over approximately 300 meters. From well P10 to the reservoir, a new pipeline was planned along the condominium boundaries, made of 150 mm diameter PVC DEFoFo, with a length of about 1,600 meters.

3.2.4 Alternative 2.2 (future scenario)

Alternative 2.2, similar to how 1.2 relates to 1.1, maintained the main features of Alternative 2.1 but considered the potential addition of new wells near the P10 and P11 area. The model represented the additional flow with two representative wells, each with a maximum flow of 50 m³/h.

3.2.5 Alternative 3.1 (current scenario)

In Alternative 3.1, an adaptation of Alternative 1.1 was considered by creating a new independent pipeline while maintaining the current path. The 75mm pipeline between P04 and P08, which was to be replaced with a 150mm line, could not be used between the new wells and P04 due to pressure class incompatibility. However, it could be used to create a parallel pipeline beyond P08, where lower pressures exist. Thus, Alternative 3.1 involves connecting wells P10 and P11 immediately downstream of P04 and creating a fully independent pipeline to the reservoir. This new pipeline would make use of the existing 150mm pipe connecting P08 to point C and extend with a new 150mm line approximately 150m long from point C to the reservoir. Well P08 would reconnect to the current system using part of the existing 75mm pipe that would be replaced.

3.2.6 Alternative 3.2 (future scenario)

Similar to the other alternatives, Alternative 3.2 incorporates future incremental flow into the pipeline system, maintaining the same design as Alternative 3.1. The model represents the additional flow with two representative wells, each with a maximum of 50 m³/h.

3.3 Design Development

After analyzing the alternatives, the most energy-efficient option with the highest system flow at the lowest cost is determined. For this alternative, the engineering technical project is detailed, including technical specifications and detailed design. It's important to note that the chosen solution may not be the optimal one in terms of energy consumption, flow, and cost due to constraints such as licensing and property issues. Therefore, the next best option that fits these constraints may be selected.

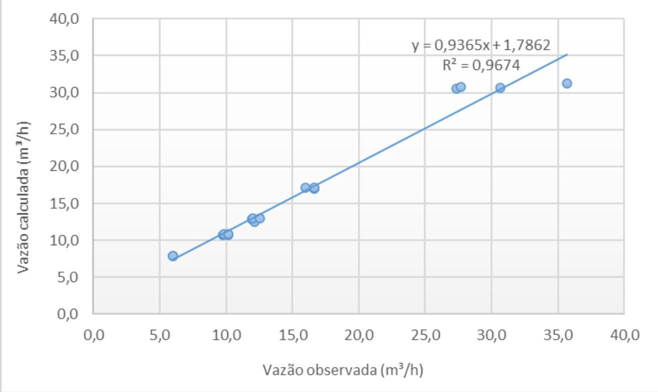
3.4 Recommendations and Conclusions

At this stage, after detailing the selected alternative's project, recommendations should highlight any limitations encountered during the project's completion. Additionally, aspects related to potential future increases in flow rates to meet system's demand should be considered, including the possibility of adding new wells or accessing water from other resources.

4. RESULTS AND DISCUSSIONS

RMSE results for calibration (2.08, 0.99, and 1.45), and validation (1.62) were deemed satisfactory. However, it should be noted that there are several errors involved in data measurement and the variables used. Direct measurement of head loss was not possible, and this should be taken into account when comparing observed values with model responses. Figure 4 illustrates a comparison between observed and calculated values, while Figure 5 displays the model's pressure and flow results for the validation data.

Figure 4 – Comparison between computed and observed discharges



Since the calibration was done by adjusting only the roughness coefficient, all errors, uncertainties, and potential issues in the supply system were transferred to this parameter. Therefore, it cannot be stated that the current pipe roughness matches the previously informed values. However, it is clear that the system is not operating as expected. The theoretical roughness coefficients for new PVC pipes are around 130 to 140. For old material, values near 100 are acceptable. To match measured flow rates, the section should have a friction loss equivalent to a roughness coefficient of 30, an unreasonable value for unobstructed pipes.

The calibration results have indicated severe performance issues in the system, likely due to factors like air pockets, leaks, and blockages. Proper identification and improvement would require a comprehensive testing campaign, including installation of additional measuring equipment and system modifications according to technical standards. Such investigation were beyond the initial scope and impractical in this study context, and was considered as recommendations. As an emergency measure, it was suggested to install a triple-function air valve at the highest point of the pipeline near the reservoir to address these issues.

During the study of alternatives, Alternative 2 was deemed the best option to accommodate current and future water flows. Table 2 presents the results for the three alternatives, evaluating total system discharge, energy consumption, cost, and the incremental cost to transition from the current to future scenarios. The final column summarizes the cost/benefit metric used to compare these alternatives. This metric considers the cost per m³/h and kWh, calculated by dividing the incremental cost by the product of the average discharge and energy for both current and future scenarios. The alternative with the lowest value in this metric is considered the optimal choice.

The selected option (Alternative 2) was defined with a maximum flow potential of 136 m³/h, and an operational flow of 102 m³/h (assuming well operation of 18/24 hours) for the current scenario (Alternative 2.1). It allows for a maximum increase of 50 m³/h for a future scenario.

Although the proposed methodology was successfully applied to define the best alternative for this case, to enhance the system's efficiency, it is recommended to implement a monitoring system using strategically placed hydrometers and piezometers within the water collection network. Conducting systematic monitoring over a suitable period is crucial for accurate diagnosis and optimization of the network. Additionally, installing an air valve where the pipeline reaches the reservoirs will improve performance. Developing a hydrogeological model for the area of the existing deep wells can help evaluate aquifer behavior and assess the potential for new well installations. Future flow projections should be estimated, considering full occupancy of the condominium, which includes both residential and commercial units. It's important to examine the anticipated demands of these units. Furthermore, a study should be conducted to explore the expansion of the system's storage capacity.

Figure 5 – Pressures computed in the EPANET model under steady state for validation.

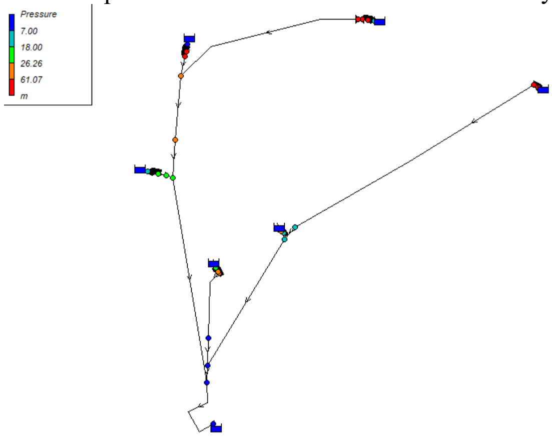


Table 2 – Results for roughness coefficient after calibration

Alternative	Discharge (m^3/h)	Energy (kWh)	Cost (R$)	Incremental Cost (R$)	Cost/Benefit [R$/ ($m^3$/h kWh)]
1.1	134.8	34,950.40	94,815.89	105,863.40	0.024
1.2	121.9 + 50	35,126.10	200,679.29		
2.1	136	33,766.60	181,377.13	39,091.80	0.009
2.2	136 + 50	33,766.60	220,468.93		
3.1	139.8	35,170.00	158,138.54	90,570.30	0.019
3.2	134.4 + 50	35,618.00	248,708.84		

5. CONCLUSIONS

This study demonstrates valuable guidance for diagnosing and expanding water supply systems for condominiums needing to increment their water supply systems based on deep wells. Through a case study at Alto da Boa Vista Condominium in Sobradinho/DF, the proposed steps for expanding the water network were applied. This network, initially consisting of six deep tubular wells, was evaluated for the integration of three additional wells.

A hydraulic model was calibrated and validated using data from the existing network's diagnostic phase. This model evaluated expansion alternatives integrating three new wells. Among the three options, Alternative 2 was chosen for its cost-benefit efficiency, offering a maximum flow potential of 136 m^3/h and an operational flow of 102 m^3/h for the current scenario, with a future increase of up to 50 m^3/h.

The study highlighted the need for a robust monitoring system to optimize system performance, focusing on measuring flow and pressure at strategic network points. The existing system operates under non-ideal conditions, potentially limiting flow capacity despite available wells. Model tests suggested potential flow gains of up to 20 m^3/h through optimization, though data limitations pose challenges. Implementing systematic monitoring can improve both management and system operation, ensuring accurate future demand analyses. Accurate flow measurements throughout the year are essential to assess the need for increased storage.

The exploration of aquifer dynamics by the condominium administration is crucial. Successive deep well drilling without proper hydrogeological assessment brings risks to the system collapse, particularly if the dynamic depletion zones of wells overlap excessively. Although no technical data currently confirms this risk, a hydrogeological study is recommended before adding new wells, potentially supporting sustainable aquifer use and guiding future extraction limits. Such a study could help determine if supplemental water from the local water supply company (CAESB) is necessary, aligning operational strategies with sustainable water management objectives.

REFERENCES

ABNT (1992). *NBR 12211:1992 - Estudos de concepção de sistemas públicos de abastecimento de água*.

ADASA (2020). *Relatório de Análise do Impacto Regulatório Assunto: Cadastramento de Agentes Perfuradores de Poços no Território do Distrito Federal*. https://www.adasa.df.gov.br/images/storage/audiencia_publica/003-2021/AIR_AP_03_2021.pdf

ANA (2024). *Impacto da Mudança Climática nos Recursos Hídricos do Brasil*. https://metadados.snirh.gov.br/geonetwork/srv/api/records/31604c98-5bbe-4dc9-845d-998815607b33/attachments/Mudancas_Climaticas_25012024.pdf

BALLARIN, A. S.; UCHÔA, J. G. S.; SANTOS, M. S.; ALMAGRO, A.; MIRANDA, I. P.; SILVA, P. G. C.; SILVA, G. J.; GOMES JÚNIOR, M. N.; WENDLAND, E.; OLIVEIRA, P. T. S. (2023). "Brazilian Water Security Threatened by Climate Change and Human Behavior". *Water Resources Research* 59(7). https://doi.org/10.1029/2023WR034914

BIERKENS, M. F. P.; SUTANUDJAJA, E. H.; WANDERS, N. (2021). "Large-scale sensitivities of groundwater and surface water to groundwater withdrawal". *Hydrology and Earth System Sciences* 25(11), pp. 5859–5878. https://doi.org/10.5194/hess-25-5859-2021

CHELOTTI, G. B.; MARTINEZ, J. M.; ROIG, H. L.; OLIVIETTI, D. (2019). "Space-temporal analysis of suspended sediment in low concentration reservoir by remote sensing". *Revista Brasileira de Recursos Hídricos* 24. https://doi.org/10.1590/2318-0331.241920180061

CHELOTTI, G. B.; SANO, E. E. (2021). *Sessenta anos de ocupação urbana da capital do Brasil: padrões, vetores e impactos na paisagem*. https://www.codeplan.df.gov.br/wp-content/uploads/2020/07/TD-73-Sessenta-anos-de-ocupacao-urbana-da-capital-do-Brasil-padroes-vetores-e-impactos-na-paisagem-2021.pdf

DÖLL, P.; MÜLLER SCHMIED, H.; SCHUH, C.; PORTMANN, F. T.; EICKER, A. (2014a). "Global-scale assessment of groundwater depletion and related groundwater abstractions: Combining hydrological modeling with information from well observations and GRACE satellites". *Water Resources Research* 50(7), pp. 5698–5720. https://doi.org/10.1002/2014WR015595

DÖLL, P.; MÜLLER SCHMIED, H.; SCHUH, C.; PORTMANN, F. T.; EICKER, A. (2014b). [Same title as 2014a]. *Water Resources Research* 50(7), pp. 5698–5720. https://doi.org/10.1002/2014WR015595

HERRERA-GARCÍA, G.; EZQUERRO, P.; TOMÁS, R.; BÉJAR-PIZARRO, M.; LÓPEZ-VINIELLES, J.; ROSSI, M.; MATEOS, R. M.; CARREÓN-FREYRE, D.; LAMBERT, J.; TEATINI, P.; CABRAL-CANO, E.; ERKENS, G.; GALLOWAY, D.; HUNG, W.-C.; KAKAR, N.; SNEED, M.; TOSI, L.; WANG, H.; YE, S. (2021). "Mapping the global threat of land subsidence". *Science* 371(6524), pp. 34–36. https://doi.org/DOI: 10.1126/science.abb8549

JASECHKO, S.; PERRONE, D. (2021). "Global groundwater wells at risk of running dry". *Science* 372(6540), pp. 418–421. https://doi.org/10.1126/science.abc2755

JASECHKO, S.; SEYBOLD, H.; PERRONE, D.; FAN, Y.; SHAMSUDDUHA, M.; TAYLOR, R. G.; FALLATAH, O.; KIRCHNER, J. W. (2024a). "Rapid groundwater decline and some cases of recovery in aquifers globally". *Nature* 625, pp. 715–721. https://doi.org/https://doi.org/10.1038/s41586-023-06879-8

JASECHKO, S.; SEYBOLD, H.; PERRONE, D.; FAN, Y.; SHAMSUDDUHA, M.; TAYLOR, R. G.; FALLATAH, O.; KIRCHNER, J. W. (2024b). [Same title as 2024a]. *Nature* 625(7996), pp. 715–721. https://doi.org/10.1038/s41586-023-06879-8

LIMA, J. E. F. W.; FREITAS, G. K.; PINTO, M. A. T.; SALES, P. S. B. (2018). *Gestão da Crise Hídrica 2016-2018. Experiências do Distrito Federal*.

RODELL, M.; FAMIGLIETTI, J. S.; WIESE, D. N. (2018). "Emerging trends in global freshwater availability". *Nature* 557, pp. 651–659.

ROSSMAN, L. A. (2000). *EPANET 2 User's Manual (2.2)*. U.S. Environmental Protection Agency.

SCHOLTEN, C.; KOTTARI, M.; PEREIRA, J. P.; ERVEN, C.; GUTIERREZ, J. G.; SIEME, O. G.; OOMENS, I.; DUIN, P. V.; LANEN, H. A. J. V.; ZEHNDER, A. (2025). *The future of water availability and use in the EU. A foresight study and policy options to address water scarcity*. https://doi.org/10.2861/6213761

SHIRZAEI, M.; FREYMUELLER, J.; TÖRNQVIST, T. E.; GALLOWAY, D. L.; DURA, T.; MINDERHOUD, P. S. J. (2021). "Measuring, modelling and projecting coastal land subsidence". *Nature Reviews Earth & Environment* 2, pp. 40–58.

TORRES, R. R.; LAPOLA, D. M.; MARENGO, J. A.; LOMBARDO, M. A. (2012). "Socio-climatic hotspots in Brazil". *Climatic Change* 115(3–4), pp. 597–609. https://doi.org/10.1007/s10584-012-0461-1

TSUTIYA, M. T. (2006). *Abastecimento de Água* (3a ed.). Escola Politécnica da Universidade de São Paulo.

UCHÔA, J. G. S. M.; OLIVEIRA, P. T. S.; BALLARIN, A. S.; MEIRA NETO, A. A.; GASTMANS, D.; JASECHKO, S.; FAN, Y.; WENDLAND, E. C. (2024). "Widespread potential for streamflow leakage across Brazil". *Nature Communications* 15(1). https://doi.org/10.1038/s41467-024-54370-3

WADA, Y.; VAN BEEK, L. P. H.; VAN KEMPEN, C. M.; RECKMAN, J. W. T. M.; VASAK, S.; BIERKENS, M. F. P. (2010a). "Global depletion of groundwater resources". *Geophysical Research Letters* 37(20). https://doi.org/10.1029/2010GL044571

WADA, Y.; VAN BEEK, L. P. H.; VAN KEMPEN, C. M.; RECKMAN, J. W. T. M.; VASAK, S.; BIERKENS, M. F. P. (2010b). [Same title as 2010a]. *Geophysical Research Letters* 37(20). https://doi.org/10.1029/2010GL044571

WERNER, D.; BAKKER, M.; POST, V. E. A.; VANDENBOHEDE, A.; LU, C.; ATAIE-ASHTIANI, B.; SIMMONS, C. T.; BARRY, D. A. (2013). "Seawater intrusion processes, investigation and management: Recent advances and future challenges". *Advances in Water Resources* 51, pp. 3–26.

ACKNOWLEGMENTS

The authors express their gratitude to the administration and technicians of the Alto da Boa Vista Condominium, in Sobradinho/DF, for providing the data and information essential for the development of this study. Special thanks are extended to the manager Eduardo Manso, the vice-manager Daniel Hott, and the technician Geovany Neres. We also extend our gratitude to the Regulatory Agency for Water, Energy, and Basic Sanitation of the Federal District (ADASA), particularly to the superintendent for Water Supply and Sewerage, Rafael Mello, for his support and sharing of valuable technical information.