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Benchmark problem library for water distribution system modeling

Biblioteca de problemas para modelagem de sistemas de distribuição de água

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ABSTRACT

This technical note presents a benchmark problem library which compiles, classifies and makes available a series of examples for modeling and analyzing water distribution systems using EPANET. The project consolidates, currently, 44 benchmark problems, categorized by their topological complexity and operational features, besides other parameters of interest. An interactive web interface allows users to access and filter problems according to their research, teaching, or practical goals. By providing complete model examples the library supports learning and development of solutions for a wide variety of water network objectives. Additionally, for some of the main challenges the library facilitates the comparison between new methodologies and those previously published. We hope this resource may encourage the use of model supported analysis, and that contribute to improve the water networks management.

Keywords: Water distribution networks; Benchmark problems; EPANET; Optimization; Water resource management.

RESUMO

Esta nota técnica apresenta uma biblioteca de problemas de referência que compila, classifica e disponibiliza uma série de exemplos para a modelagem e análise de sistemas de distribuição de água por meio do EPANET. O projeto consolida, atualmente, 44 problemas de benchmark, categorizados por sua complexidade topológica e características operacionais, além de outros parâmetros de interesse. Uma interface web interativa permite aos usuários acessar e filtrar os problemas conforme seus objetivos de pesquisa, ensino ou aplicação prática. Ao fornecer modelos completos, a biblioteca apoia o aprendizado e o desenvolvimento de soluções para uma ampla variedade de demandas relacionadas às redes de abastecimento de água. Ademais, para alguns dos principais desafios, a biblioteca facilita a comparação entre novas metodologias e abordagens já publicadas. Espera-se que esse recurso incentive o uso de análises apoiadas em modelos e contribua para aprimorar a gestão de redes de distribuição de água.

Palavras-chave: Redes de distribuição de água; Problemas de referência; EPANET; Otimização; Gestão de recursos hídricos.

INTRODUCTION

Water supply remains a central issue on a global scale, highlighted by the United Nations' Sustainable Development Goals (United Nations, 2015). Although recognized as a fundamental human right, access to potable water remains unevenly distributed, including in Brazil, where many communities face persistent challenges in obtaining safe and reliable supplies (European Union, 2010). Such difficulties stem not only from budget limitations but also from the lack of better engineering applications, including sub-optimal projects, operational inefficiencies, and inadequate failure response planning.

Addressing these challenges is not an easy task, considering the complexity of the networks, so it often involves the application of mathematical models to represent and analyze water distribution networks, either for applying consolidated solutions or researching new ones. When considering the hydraulic behavior of those networks, the most widespread modeling tool is EPANET (Rossman et al., 2020). Developed by the United States Environmental Protection Agency (EPA), EPANET open access codes and libraries are also applied and modified as part of collaborative or particular projects and are the base for several other water modeling tools. In this work, however, we focus on the standard EPANET model.

As the extensive application of water network modeling is desirable, among the challenges faced in teaching and researching with models is the need for water network data to be used as examples. System examples, and their previous analysis, are useful for training users, supporting analysis, testing solutions, and comparing the results of different methodologies. For that, those examples should be complete and widely available, so they can be considered Benchmark Problems.

This technical note focuses on the development of a benchmark problem library designed to facilitate the study and comparison of methodologies involving water supply network models. These problems, varying in complexity and operational characteristics, provide a reference set for researchers, students, and practitioners interested in testing, validating, and improving strategies for network planning, operation, and management.

LIBRARY DESCRIPTION

The library compiles, currently, 44 selected problems, each with a base hydraulic model as a .inp EPANET file and other related data, besides the details about their main features. All the library information can be obtained through an interactive web at the Numerical Simulation Laboratory (LABSIN-EESC-USP) website (Universidade de São Paulo, 2025).

To enhance usability, the library is available at an interactive web interface that enables users to filter and select problems based on specific criteria. This structure supports more transparent comparisons and contributes to a shared framework for evaluating diverse approaches to water distribution system projects, operation, etc.

The library's database is structured into four main sections: General Problem Information, Simulation Data, Physical System Characteristics, and Additional Information. Below is a brief description of each section and its respective columns:

1. General Problem Information:

Network Name: Provides a direct identification of the case study.

Problem Description: Summarizes the original scenario proposed for the network model, helping users select appropriate cases for specific analyses.

2. Simulation Data:

Problem Type: Categorizes problems based on the nature of the challenge (e.g., expansion, optimization, forecasting). This helps users align problems with their research or operational goals.

Simulation Type: Indicates whether the model is configured for static (fixed conditions) or dynamic (time-varying conditions) simulations.

Demand Pattern: Specifies whether the demand is fixed (DDA) or pressure-dependent (PDA), influencing the hydraulic behavior of the system.

Controls and Rules: Indicates the presence of operational controls, such as pump scheduling or valve operations, which are essential for complex management strategies.

Emitters: Identifies if the model includes emitters to represent leaks or discharges, relevant for pressure-dependent demand analysis.

Water Quality: Specifies whether the model includes water quality parameters, such as chlorine concentration or water age, critical for assessing potability and system safety.

3. Physical System Characteristics:

Number of Junctions: Represents the connection points in the network, indicating the system's topological complexity.

Fixed Reservoirs: Indicates the number of reservoirs with constant water levels, essential for ensuring continuous supply.

Variable Reservoirs: Indicates the number of reservoirs with variable water levels, important for dynamic balancing of supply and demand.

Number of Pipes: Total count of pipes in the network, reflecting the system's size and extent.

Minimum Diameter: The smallest pipe diameter in the network, useful for identifying potential flow restrictions.

Maximum Diameter: The largest pipe diameter in the network, relevant for determining maximum flow capacity.

Total Pipe Length: The combined length of all pipes, crucial for hydraulic simulations and cost calculations.

Total Demand: The total water demand the system must meet, critical for proper sizing of pipes and reservoirs.

Flow Unit: The unit of measurement for flow (e.g., LPS, CFS), ensuring consistency in simulations.

Number of Valves: Indicates the presence and quantity of valves, essential for flow control and system flexibility.

Minimum Elevation: The lowest elevation point in the network, important for gravity and pressure calculations.

Maximum Elevation: The highest elevation point in the network, critical for modeling systems in hilly or mountainous areas.

4. Additional Information:

Data Source: Provides the origin of the data, such as links to .inp files or references to original studies.

Bibliographic Reference: Lists the academic or technical sources related to the problem.

Inclusion Date: The date the problem was added to the library.

Original Publication Year: The year the problem was first published.

Comments/Notes: Additional observations or notes about the problem.

EPANET File: Provides the link or path to the EPANET (.inp) file for the problem.

Although the hydraulic models available in the library could be used to support a range of analytical, educational, and operational applications, they were originally analyzed as part of a specific research problem, such as expansion or optimized operation. One of the potential uses of the library is the research of better solutions for general problems, given that the application on benchmark problems and comparison with previous results allows a more interesting evaluation and more robust conclusions.

The library currently contains 44 benchmark problems, including the data and references related to the solution developed originally for them. These problems span several categories based on the primary objective or focus, as listed below. This distribution highlights that the majority of the library targets optimization-related analyses, reflecting a central theme in water distribution research and practice. However, the inclusion of expansion, diagnosis, and forecasting scenarios ensures broader applicability across different research and operational needs.

- Expansion: 2 problems (approximately 4.5% of the total) focused on designing cost-effective additions to existing networks.
- Optimization: 34 problems (about 77%) aimed at improving network performance, such as reducing costs, meeting pressure requirements, and handling variable demands.
- Optimization and Diagnosis: 7 problems (nearly 16%) combining optimization tasks with diagnostic challenges, for example, leakage detection or response to system disturbances.
- Forecast: 1 problem (about 2.5%) dedicated to planning upgrades under future demand scenarios.

The library database structure allows new problems to be easily added anytime, by library managers. Moreover, further parameters such as water quality-related or advanced control features could be included with reasonable effort, offering pathways for future expansions.

By providing a diverse set of problems classified and documented through standardized parameters, the library enables detailed comparative studies. Whether a user aims to benchmark a newly developed optimization algorithm, teach fundamental principles of water distribution modeling, or evaluate management strategies under different demand conditions, the library's quantitative attributes ensure that suitable scenarios are readily available.

METHODOLOGY FOR LIBRARY DEVELOPMENT

The primary objective of this work was to establish a standardized reference set of benchmark problems for modeling water distribution systems. The process began with a targeted literature review, examining scientific articles, theses, dissertations, and existing benchmarking platforms.

Particularly relevant were previous efforts of benchmarking problems compilation and their application. The main problem compilations used were those from the University of Exeter, which provides a comprehensive set of over 20 benchmark problems for water distribution networks (University of Exeter, 2024), and the University of Kentucky, which offers a repository with more than 25 benchmark problems focused on water systems research (University of Kentucky, 2024).

Additionally, benchmark problem design and their application to compare solution approaches are notably present in the Battles of the Water Networks. The Water Distribution Systems Analysis (WDSA) conference, initiated in 2006, focuses on the latest challenges and innovations in water distribution systems. In 2018, WDSA joined forces with the Computing and Control in the Water Industry (CCWI), a conference series that has been held since 1991, to address broader themes in water systems modeling and control. The library includes benchmark problems from the following WDSA/CCWI editions: WDSA 2010 in Tucson, Arizona (Ostfeld et al., 2012); WDSA 2012 in Adelaide, Australia (Marchi et al., 2013); WDSA 2014 in Bari, Italy (Berardi & Giustolisi, 2016); WDSA 2016 in Cartagena, Colombia (Saldarriaga et al., 2019); WDSA/CCWI 2018 in Kingston, Canada (Paez et al., 2020); WDSA/CCWI 2020 in Beijing, China (Vrachimis et al., 2022); and WDSA/CCWI 2022 in Valencia, Spain (Universitat Politécnica de València, 2025). These competitions have contributed significantly to the advancement of research in water distribution systems.

Currently, there are no Brazilian networks included, but they will be added soon. This is largely due to the research by Miranda (2024), which analyzed resilience metrics for real water distribution networks, including the system of a city located in the State of São Paulo. The study's detailed analysis makes it a fundamental reference for its future implementation in the benchmark database.

From this review, a long list of problems was identified and their data and features were obtained, also identifying duplication at several sources. For selecting the problems to be included in the library, standardized criteria were adopted to confirm that the problems encompassed a range of complexities, network configurations, and operational conditions The methodology applied in this task aimed to ensure that each benchmark problem could be effectively used to evaluate different modeling-dependent techniques for water distribution systems. Emphasis was placed on verifying the availability of reliable data suitable for EPANET modeling, considering only water quantity modeling, as quality analysis would be better detailed on future works.

The chosen problems encompass both extensive networks with numerous pipes and nodes, and more streamlined configurations, thus providing a balanced set of scenarios that can support diverse analytical and educational objectives.

Following selection, a validation phase was carried out. Each problem's input data were tested using EPANET simulations to confirm the accuracy of hydraulic parameters and the representativeness of the network conditions. In cases where inconsistencies were identified—such as missing information or unrealistic demand patterns—appropriate adjustments were made. This iterative process ensured that the finalized set of problems provided a robust foundation for comparative analyses.

Categorization, or feature description, played a central role in the methodology. Problems were described by simulation type, network elements, and all the parameters detailed in the 'library overview' section of this document. This systematic organization aims to help users select problems aligned with specific research goals, avoiding redundancy and promoting targeted analyses.

To manage these problems efficiently and make their features straightforwardly reached, an internal spreadsheet was built to serve as the central database of the library. Not directly accessible to users, this spreadsheet consolidates key parameters of each problem, and also allows effortless inclusion of new problems, and complementation or correction of existing information. The data from this internal resource underpins the library's interactive web interface, where researchers, students, and professionals can browse, filter, and select benchmark scenarios best suited to their modeling needs.

WEBSITE INTERFACE

The website interface was developed to present the benchmark problems identified in the library in a user-friendly and accessible format. While the underlying data are stored in an internal spreadsheet not visible to end users, the interface dynamically retrieves and displays relevant information. This approach ensures that users—such as researchers, students, and practitioners—can efficiently locate problems that align with their analytical or operational goals. This interface is accessible at the LabSiN (Numerical Simulation Laboratory, Department of Hydraulics and Sanitation, EESC-USP) website (Universidade de São Paulo, 2025).

To facilitate navigation, the interface offers multiple search and filter options. Users can enter keywords to identify problems by name, purpose, or operational characteristics. In addition, selectable filters allow the refinement of search results according to simulation type (static or dynamic), demand pattern (demand-driven or pressure-dependent), as well as the number of network components like pumps and nodes. This combination of free-text search and targeted filters streamlines the selection process, enabling users to identify problems tailored to their specific needs.

Figure 1 shows the homepage of the benchmark problem library interface on the dedicated website. It presents a brief overview of the benchmark collection and potential applications, as well as six filtering tools: search bar, problem type, simulation type, demand pattern, number of pumps, and number of nodes. A main table displays all the problems fitting the filters, with each model's name, simulation type, number of pumps, and a representative image.

Upon selecting a problem, a dedicated problem detail page (Figure 2) provides comprehensive information about the chosen scenario, including the network layout, operational parameters (e.g., nodes, total demand, valves), and a summary of the original problem proposal. It also lists relevant bibliographic references and a download section containing ".zip" files with the EPANET (.inp) and complementary data.

Overall, this interactive website interface transforms a complex dataset into a navigable resource. By bridging the gap between the internal data repository and the end-user experience, it supports informed decision-making and enhances the utility of the benchmark library in educational and professional contexts.

EXPECTED APPLICATIONS

The benchmark problem library provides a structured resource that can be employed in both academic and professional

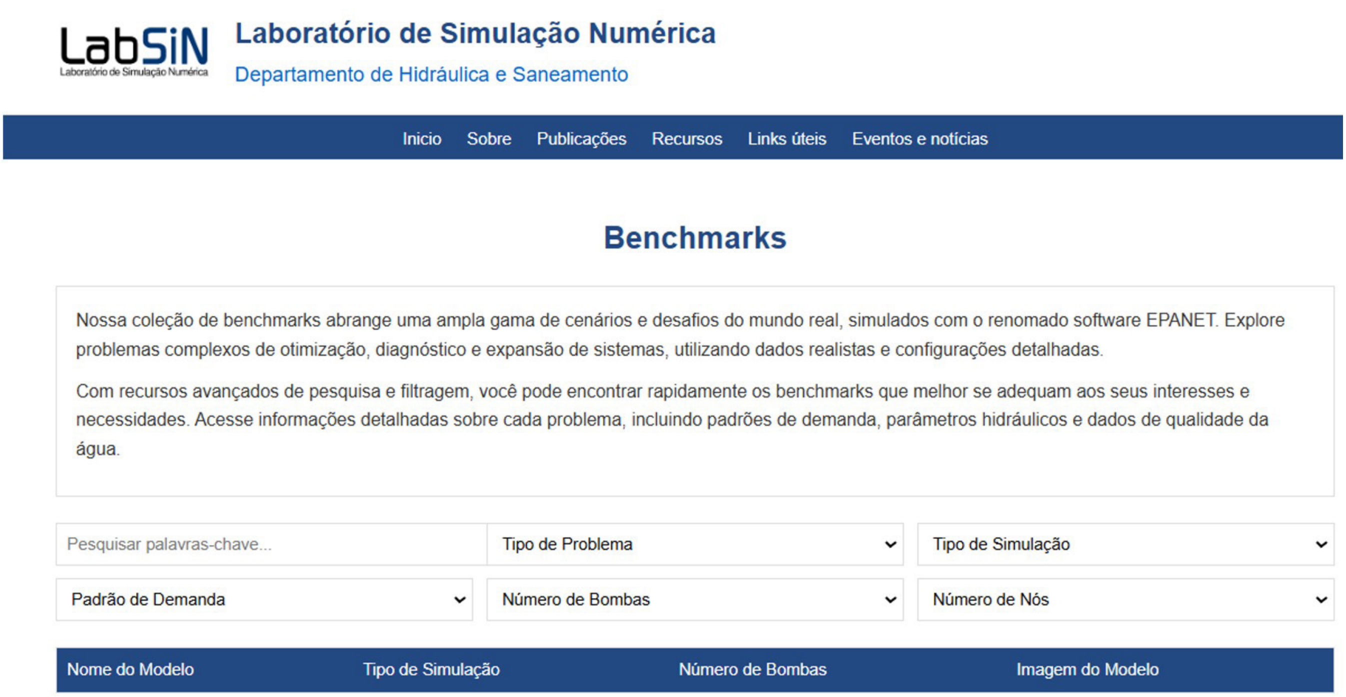

Figure 1. Homepage of the benchmark problem library interface.

Nome do Modelo	Tipo de Simulação	Número de Bombas	Imagem do Modelo
KY 01	Estático	1	

Tipo de Problema Proposto	Otimização
Nós/Junções	856
Reservatórios Fixos	1
Reservatórios Var	2
Tubulação (qtd)	984
Diâmetro Mínimo	0.75
Diâmetro Máximo	36
Comprimento Total da Tubulação	215282
Demanda Total	2000000
Unidade de Vazão	GPM
Válvulas	0
Alt. Mínima	63
Alt. Máxima	464
Controles e Regras	Sim
Emitters	Não
Qualidade	Não

Problema Proposto:

Otimizar um sistema de rede em Kentucky com ativos que incluem tanques, bombas e tubulações extensas, enfrentando uma perda de água estimada em 21%.

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Download de Arquivos Complementares

Figure 2. Detailed view of a selected benchmark problem, including network layout and key parameters.

contexts to examine and improve water distribution system modeling and optimization methods. In educational settings, the standardized problems can serve as illustrative case studies, assisting students in understanding concepts related to hydraulic modeling, network design, and system performance under varying conditions. By offering a range of scenarios with differing complexities and operational parameters, the library enables instructors to guide learners through progressive levels of difficulty, adapting the material to their particular course objectives.

In professional environments, the library can inform the development and testing of new modeling approaches, optimization algorithms, or operational strategies. Utilities, consulting firms, and other stakeholders may reference the benchmark problems when evaluating proposed solutions or training staff in the application of EPANET-based analyses. While the library does not provide prescriptive solutions to the challenges in water distribution management, it supplies a reference point that supports systematic comparisons, continuous improvement, and informed decision-making.

CONCLUSIONS

The development of this benchmark problem library represents a structured effort to support the analysis of water distribution systems and of solutions for its diverse challenges. By compiling 44 (so far) well-documented problems and providing an interactive web interface, the library offers a standardized reference that can inform both academic research and practical applications. Through a consistent set of criteria—encompassing network complexity, operational conditions, demand variability, etc.—users gain access to examples suited to their specific goals.

While the library itself does not prescribe solutions, it facilitates systematic comparisons and serves as a foundation for exploring diverse modeling approaches, optimization methodologies, and strategic interventions. The inclusion of data compatible with EPANET ensures that each benchmark problem can be readily simulated, enabling users to test hypotheses, refine techniques, and potentially adapt the models to evolving conditions or emerging technologies.

Looking ahead, the library may be expanded to incorporate additional parameters, such as water quality indicators or advanced control strategies. Although a few of the networks already include water quality data, most do not, so future work aims to integrate these indicators more broadly within the interface. As the library evolves, ongoing refinement and feedback from the research and professional communities will guide its development, ensuring it remains adaptable and increasingly valuable for future water distribution system challenges.

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João Vitor de Mendonça: Data curation, methodology, software, writing.

Maria Mercedes Gamboa Medina: Conceptualization, methodology, supervision, writing.

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