



Rethinking the Coupled Operation-Design Optimisation Problem in Water Distribution Systems under Deep Uncertainties

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The management and strategic planning of urban Water Distribution Systems (WDS) face new challenges indicative of a more profound transformative shift across all dimensions of urban life.

External factors and environmental influences on the urban context have expanded significantly. Historically, fluctuations in water demand and urban development were primarily driven by localised system dynamics. Today, however, the reliability of WDS is shaped by (i) deep uncertainties spanning national and continental scales and (ii) considerations for both short- and long-term horizons. These include persistent trends such as demographic and migration shifts, evolving climatic conditions, and transient events with varying levels of predictability, including seasonal droughts, abrupt changes in governmental policies, and economic volatility, particularly in the transitioning energy sector.

Consequently, there has been a shift towards a more holistic perspective of the urban WDS. New approaches encompass the WDS infrastructure along with its operation, management, and integration with the wider energy grid, representing a significant paradigm change from the traditional approaches focusing primarily on the network of pipes.

As the problem's description complexity increases, the development and use of benchmarks become more relevant. These tools are essential for rigorous and reproducible testing of our solutions and to guide an evidence-based decision-making process. Historically, the academic research field of urban WDS design optimisation has been a prime testing ground. Numerous open problems have been introduced in the literature since the late '80s/early '90s, with notable examples being Anytown, Hanoi, and the New York Tunnels. However, the evolving complexity of the problem indicates that historical benchmarks may no longer suffice, while their adapted versions lack a unified framework, with multiple problem formulations scattered across the literature.

In this work, we explore the coupled operation-design optimisation problem for Water Distribution Systems (WDS). Building on a critical review of the literature, we identify the strengths and limitations of existing benchmark formulations, paving the way for a discussion on the key attributes that next-generation benchmarks should embody. Our work aims to establish a

comprehensive problem framework for joint operation and staged design (planning) optimisation, ensuring it addresses the complex and evolving challenges faced by WDS globally. Particular emphasis is placed on capturing the dynamic interplay between viable policy interventions and the variability of critical factors, such as water demand, electricity prices, energy mix, and timing.