CCWI 2023 (Extended Abstract Submission Form)

Title

Operational considerations for the long-term design of Water Distribution Systems

Keywords

Control, Design, Optimization, Water Distribution Systems, Deep Uncertainty, Literature Review

Highlights

Please enter the highlights of your paper
(the total character limit is 450 characters, please include 3-5 bullet points, with each one having no more than 90 characters)

- We highlight the gap between the design and operation of WDS in the current literature
- We suggest how controllable elements offer flexibility in the long-term design of WDSs
- We show potential future directions and required work

Purpose

Water Distribution Systems (WDS) are complex systems that play a critical role in supplying water while satisfying the required levels of service (expressed as objectives and constraints). The effective interaction and execution of numerous levels of optimal control, design, and monitoring of the associated components are necessary for these massive infrastructures to operate properly. This necessitates finding solutions to a number of issues with objectives spanning vastly diverse time horizons: the long-term infrastructure design [1], the daily and sub-daily system operations [2], and the real-time control of the active elements [3].

Traditionally, these tasks have been considered separately. Yet, the centralization and coordination of the optimization of all processes provide several advantages [4]. For example, design limitations can restrict the system's operational performance. On the other hand, a system designed without taking operations into account ignores important uncertainties and flexibility afforded by installed controllable elements.

There has been an increasing interest in WDS's flexible and adaptive design [5]. However, those studies concentrated on introducing long-term design uncertainties, limited to pipe sizing, rehabilitation, and strengthening, and have not taken into account the effect of control elements on the network.

This literature review investigates the shortcomings of current methodologies and highlights how they may be improved to consider uncertainties and opportunities during the long-term design of WDS that are provided by control elements. The ultimate goal is to develop robust and flexible strategies in support of the decision-making processes capable of coping with deep uncertainties associated with WDS evolving in time.

Materials and Methods

The papers selected for this review have been identified from a number of recent and highly cited review papers that deal with several components of a WDS [1]–[3], [6]. This pool of papers was supplemented with results from popular scientific literature search engines with specific keywords: "optimization", and "water distribution system" (or "water distribution network"). An a-posteriori filtering process on keywords and abstracts narrows down the search to works that simultaneously consider the system's "operation" and "design" variables. An additional wealth of papers dealing with

them independently is also included to highlight the missing links between these two main types of WDS optimisation problems.

Results and Discussion

The optimisation of Water Distribution Systems (WDS) involves a multitude of decision variables that can be grouped into two main categories: (i) design, i.e., that can not be adjusted once a specific realisation of the uncertainties is observed and (ii) control, i.e., that are optimised based on the observed uncertain parameters and the selected design variables [7].

The different nature and the complex interplay between the variables, coupled with the limited computational resources, led to the natural division of the problem into two independent subproblems: the system's design and operations.

Planning and design of WDS deal with network elements (pipes, pumps, valves and tanks) positioning and dimensioning; present cost minimisation and network reliability are the most common objectives [1].

The optimisation of WDS operations is mainly concerned with pump scheduling and valve status control. These variables are usually optimised to minimise operational costs (e.g., electricity consumption) or to satisfy water quality criteria [2]. Controllable elements give an "operational flexibility" [4], however, these problems are usually solved with a given network design, limiting their effectiveness.

A handful of studies deal with mixed problems, generally, they optimise the net present value as a function of design and operation variables. A comprehensive trade-off analysis between costs and flexibility is missing, also because of the lack of a well-defined metric for the latter.

Moreover, these studies do not consider the evolution of the WDS over time and the associated uncertainties. Therefore, it is still unclear how active elements can be used during planning to enlarge the set of possible actions and flexibly deal with future scenarios. For example, achieving climate neutrality goals will change both the costs and timing of electricity generation, thus incentivising the use of active components and their use to reduce electricity consumption.

Conclusion and Perspectives

In this work, we have reviewed some of the most relevant publications on the optimisation of WDS. The focus has been placed on the interplay between design and control variables, highlighting the role of controllable components as an element of operational flexibility for long-term design.

The main challenge identified is the definition of suitable metrics to represent the operational flexibility of the networks, a limitation holding back the development of adaptive frameworks for the long-term planning of water infrastructures that consider operations as a tool to exploit.

References

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