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Editorial

Urban Water Networks Modelling and Monitoring, Volume II

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1. Introduction

Innovation in information and communication technologies has greatly impacted the production of goods and service provision. Urban water research and practice have been boosted thanks to the availability of new and advanced numerical models, increased computing resources (especially distributed in clouds), and cheap and reliable sensors that can be deployed through the system to trace its evolution. This Special Issue is focused on new technologies and models to monitor and manage urban water distribution networks and drainage systems. Monitoring and managing urban water distribution networks and drainage systems play an important role in research for the innovation of methods and technologies in use. The wide availability of numerical models and low-cost sensors has allowed us to make great strides in finding applications in various fields. However, there are still many critical issues to be overcome, such as reducing water losses or improving water quality; these are aspects that have been addressed in this Special Issue.

The Special Issue includes six articles, with contributions from twenty-six authors. From a geographical point of view, the case studies concern four countries (Italy, Greece, Florida and Portugal) spread over two continents (Europe and America) with very different characteristics. In particular, the topics covered by the contributions collected in this Special Issue concern water saving through the reduction of losses with different techniques, the acoustic one, one through pressure control valves, and the one concerning partitioning, the topic of water quality potable water and system operation. The Special Issue offers an overview of the wide range of urban water systems modelling techniques that have applications in different aspects. However, the common goal remains to test new methodologies and approaches to find optimal solutions or provide indications to direct future research.

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Citation: Sambito, M.; Freni, G. Urban Water Networks Modelling and Monitoring, Volume II. *Water* **2023**, *15*, 1086. https://doi.org/10.3390/w15061086

Received: 2 March 2023
Accepted: 9 March 2023
Published: 12 March 2023

2. Overview of the Contributions of the Special Issue

As part of managing and monitoring a water distribution system, losses have a strong impact on costs and resources; research was implemented using various techniques. Among the most innovative technologies are the Digital Twins (DT) discussed in the paper of Ramos et al. [1]. This research defines a new methodology for an efficient application of DT expertise within water distribution networks. Assuming a DMA of a real water distribution network as a case study, it was demonstrated that a fast detection of leakage along with an optimal set of pressure control valves by means of DT together with an optimisation procedure could ensure high water savings, contributing to significantly increase the efficiency of the whole system.

The proposed approach combines virtual network models, optimisation algorithms, real-time data collection, and smart actuators' information with Geographic Information System (GIS) data aggregated in a Digital Twin (DT). The real-time monitoring of the DT results in fast loss or burst detection and repair, allowing the achiement of significant water savings. This result is enormous advantages, such as reduced water losses and operational costs, as well as contained social and environmental impacts. In this study, a DT implementation has been simulated by performing an optimisation procedure, searching for optimal valve regulations to minimise water leakage within the analysed network. The need for optimisation arises as soon as the leakage is detected, and a strategy to contain the amount of leaked water is required. Once the leakage is detected, the search for the optimal settings, as well as the intervention, can require a few hours. As highlighted in this study, the potential benefit of Digital Twin in the water sector towards digital transition and system efficiency improvement is significant, directly impacting on water economy, improving customer experience, and ensuring better maintenance and environmental protection. DT technology also allows for consumption prediction during peak demands, providing better pressure and flow management, and significantly enhancing the system's reliability and operational flexibility. Moreover, it is worth underlining that DT reduces maintenance costs, energy operations, and unexpected water main breaks. In conclusion, the increased water efficiency resulting from loss (leakages and frauds) control represents a positive economic impact on both water-energy nexus and systems reliability.

However, one of the main problems in the search for leaks in water pipes is the ability to probe long stretches for long periods; for surveys in large stretches of pipeline and over the long term, the analysis of acoustic emissions is one of the most efficient. The paper by Zagretdinov et al. [2] proposes applying the fractal theory to determine pipeline leaks. One of the most accurate methods for determining the fractal dimension of time series is R/S analysis using the Hurst exponent. An experimental stand has been developed and created, including a steel pipeline with water circulating. Water leakage from the pipeline was simulated by installing discs with holes of different diameters. The discs were placed in a special fitting on the surface of the pipeline. Acoustic signals recorded from the pipeline surface at different leakages and water pressure were analysed. A relationship has been established between the size of the leak and the Hurst exponent of acoustic signals. The proposed method is compared with spectral analysis. Empirical experience has proven that R/S analysis can be used to determine pipeline leaks and their classification by size. The research discovered that liquid flowing turbulently through a hole in the pipe wall produces pulsations of liquid density. The appearance of such pulsations is manifested in the form of elastic waves in the liquid itself and the walls of the pipe. The determining parameters of these pulsations are the liquid's flow rate and the hole's size. In addition, the presence of leaks leads to a change in the flow rate in the pipe itself. With an increase in the size of the leak, the flow rates in the hole and pipeline decrease, which lead to a decrease in turbulence. In this case, the elastic vibrations of the pipeline wall acquire a deterministic character. The Hurst exponent allows for the identification of these changes in signals. As the pressure inside the pipe increases, the sensitivity of the method to small leaks decreases. This is due to an increase in vortex formation since the flow rate depends on the pressure drop at the inlet and outlet of the leak. Undoubtedly, the method requires further research using CFD modelling to establish the scope of its effective application. However, based on the research, an argument can be made for the high potential of using the proposed method for classifying leaks by size.

Nevertheless, in the field of water leak detection in distribution networks, partitioning (PMA, pressure management areas) remains the most used method. The paper by Serafeim et al. [3] uses hierarchical clustering enriched with topological proximity constraints to develop an approach for the optimal sizing and allocation of PMA, maintaining a sufficient level of hydraulic resilience. The study was applied to a real network in Greece, in Patras. It revealed better management and reduction of real water losses thanks to a simpler approach that contains objective criteria and few computational requirements. The study introduced a resilience index that accounts for water leakages and nodal heads in pressure-driven and mixed pressure-demand ways. The strong points of the introduced approach are that it uses the original pipeline grid as a connectivity matrix to avoid unrealistic clustering outcomes. Additionally, the study is statistically rigorous and user unbiased, based solely on statistical metrics, thus not relying on and/or being affected by user-defined weighting factors. The method is easy and fast to implement, requiring minimal processing power. The effectiveness of the developed methodology is tested in a large-scale application study in four PMAs of the city of Patras in western Greece, which cover the entire city centre and the most important part of the urban fabric of Patras, consisting of approximately 202 km of pipeline and serving approximately 58,000 consumers. Due to its simplicity, minimal computational requirements, and objective selection criteria, the suggested clustering approach for WDN partitioning can be an important step toward developing useful decision-making frameworks for water experts and officials, allowing for improved management and reduction of real water losses. The authors concluded that, due to its easiness, minimal computational requirements, and objective selection criteria, the suggested approach can serve as an important step towards developing useful decision-making frameworks for water experts and officials, allowing for improved management and the reduction of real water losses.

Another important aspect concerns the valves' inoperability because of which some segments of the network may need to be isolated even if this is not always easy; the paper by Abdel-Mottaleb et al. [4] proposes a multi-objective optimisation approach based on the Gomory–Hu tree to obtain the logical implications that determine the isolation of a segment due to the presence of critical valves. The study developed three multi-objective formulations: first, deterministic; second, accounting for uncertainty; and third, accounting for both uncertainty and the likelihood of failure of pipes within segments. Identified critical valves are compared between the three developed formulations and a method considering only a single objective. The optimisation took place through three formulations: the first of a deterministic type, the second, which took into account the uncertainty, and the third, which takes into account both the uncertainty and the probability of failure of the pipes inside the segments, but only the latter has provided the most insight without overwhelming decision-makers with a large number of identified valves. The proposed analysis can help identify critical valves without simulating many scenarios, including combinations of operable and inoperable valves. The Gomory–Hu tree may also be useful in the failure analysis of other flow-based infrastructure networks because it helps to ascertain the logical implications of component failure in a network. Further, this study evaluated the critical valves not only based on hydraulics, but also on social vulnerability. The identified critical valves differed when the social vulnerability was included as an objective function in the optimisation procedure—suggesting that social indicators (be they demographic or related to lifeline facilities) should be included in infrastructure criticality analyses. Another advance the study made is accounting for uncertainties (in water flow and social vulnerability) and the likelihood of failure of segments when identifying critical valves; the model accounting for uncertainties and the likelihood of failure was compared with the deterministic model.

Concerning instead, the modelling for the control of drinking water quality, the paper of Piazza et al. [5] proposes an implementation of the diffusion and dispersion equations in the hydraulic simulation model EPANET, to solve Advective–diffusive–dispersive transport equation in dynamic flow conditions, through the classical random walk method, implementing the diffusion and dispersion equations. The results of this study, obtained by applying the new model to a 1:1 scale laboratory network, demonstrated it could offer a better representation of the actual data than previous versions. The main conclusions of this study are as follows:

- The advective model works well only in locations close to the contamination node, where it can intercept the contamination's peak even for lower values.
- In all other cases, the contamination event was anticipated and had a shorter duration than that detected by the experimental campaign. As a result, much lower or even negative values of the three coefficients were obtained.
- The state-of-the-art models can represent the dispersive behaviour of the contaminant. Still, it poorly represents the experimental data regarding delay or anticipation of the contamination peak and overestimating the contaminant mass.

- The new model produced the best results in terms of adaptability with the experimental data. It simultaneously represented the peak time and provided better accuracy than the state-of-the-art models.

However, for water quality analysis in water distribution networks, diffusive transport is often neglected in turbulent flows, although this should not happen in loop systems. The study by Piazza et al. [6] compares the results obtained from three different numerical optimisation approaches for positioning water quality sensors with the results of an experimental campaign, demonstrating that a significant difference is obtained based on the numerical model used. This study solved the optimisation problem using the Monte Carlo method. Furthermore, three numerical models (a common EPANET advective model, a state-of-the-art Diffusive-Dispersive model, and a novel random walk advective-dispersive-diffusive-reactive model) have been considered to evaluate how they can influence the optimal positioning of water quality sensors in terms of the detection likelihood, detection time, and redundancy. The main conclusions of this study are summarised below:

- When the advective approach was used to solve the optimisation problem, the sensors were positioned in areas with high Reynolds numbers, where the flow regimes are predominantly turbulent and transition.
- The sensors were positioned in a linear pattern and covered most of the network using the dispersive state-of-the-art approach.
- The Random Walk model provided the best performance, with a contamination event detection likelihood of 95%, a redundancy of 70%, and a detection time of approximately 9 min.

Different configurations for sensor positions are obtained depending on the model used to solve the optimisation problem, as are different detection efficiencies for the objective functions. For example, the parameter values determined by the advective model are much lower than those determined by the dynamic dispersive random walk model.

Author Contributions: M.S. writing—orginal draft preparation; G.F. supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This study was carried out within the RETURN Extended Partnership and received funding from the European Union Next-GenerationEU (National Recovery and Resilience Plan—NRRP, Mission 4, Component 2, Investment 1.3—D.D. 1243 2/8/2022, PE0000005).

Conflicts of Interest: The authors declare no conflict of interest.

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