



Editorial Advances in Modeling and Management of Urban Water Networks

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Abstract: This Editorial presents a representative collection of 15 papers, presented in the Special Issue on Advances in Modeling and Management of Urban Water Networks (UWNs), and frames them in the current research trends. The most analyzed systems in the Special Issue are the Water Distribution Systems (WDSs), with the following four topics explored: asset management, modelling of demand and hydraulics, energy recovery, and pipe burst identification and leakage reduction. In the first topic, the multi-objective optimization of interventions on the network is presented to find trade-off solutions between costs and efficiency. In the second topic, methodologies are presented to simulate and predict demand and to simulate network behavior in emergency scenarios. In the third topic, a methodology is presented for the multi-objective optimization of pump-as-turbine (PAT) installation sites in transmission mains. In the fourth topic, methodologies for pipe burst identification and leakage reduction are presented. As for the Urban Drainage Systems (UDSs), the two explored topics are asset management, with a system upgrade to reduce flooding, and modelling of flow and water quality, with analyses on the transition from surface to pressurized flow, impact of water use reduction on the operation of UDSs and sediment transport in pressurized pipes. The Special Issue also includes one paper dealing with the hydraulic modelling of an urban river with a complex cross-section.

Keywords: water distribution system modeling; urban drainage system modeling; asset management; emergency scenarios; leakage; demand; energy; water quality; sediment transport

1. Introduction

The technical progress in sensors, control systems and computational resources have recently breathed new life into the research on urban water networks (UWNs), which has broadened from the well-established topics of simulation and design to aspects of optimization, real-time monitoring and management, and water quality.

As regards water distribution systems (WDSs), the aging of the system causes the deterioration of elements, thus resulting in such problems as the increase in pipe bursts and the decrease in hydraulic capacity. Therefore, the asset management for WDS renewal has been the subject of much research, e.g., [1–4]. In this context, there is still curiosity about the application of single-and multi-objective optimization techniques to new case studies. Sticking to WDSs, the increasing availability of data measured at high frequency at flow meters and smart meters installed in WDSs has supplied researchers with numerous and large databases for the set-up and calibration of demand modelling/forecast methodologies, e.g., [5–8]. The abundance of methodologies in the scientific literature calls for comparative studies and for sensitivity analysis of such parameters as the forecast lead time. Another well-established research topic in the scientific literature of the most recent decade

is the modelling of WDS hydraulics, which has seen the development of numerous algorithms able to model the behavior of WDSs with increasing computational efficiency, e.g., [9–12]. However, the matching of these algorithms to the real behavior of WDSs, with special focus on emergency scenarios, requires further investigation. The potential of energy recovery through the installation of pumps operating as turbines (PATs), able to convert pressure surpluses into electric energy, has also attracted the attention of numerous researchers, e.g., [13–16]. In this context, the application of multi-objective techniques for the identification of optimal sites for PAT installation has been explored in few works to date. Finally, the need to reduce water waste and to keep a high efficiency of service has spurred researchers to develop methodologies for fast pipe-burst identification, e.g., [17–19], and for effective leakage reduction, e.g., [20–22]. Though numerous works in the scientific literature have dealt with these topics, there is still need for more effective and efficient algorithms for application in real case studies.

As for UDSs, asset management is focused not only on the replacement of old and deteriorated elements, but also on updating the system to tackle the increase in peak water discharges under wet weather conditions, caused by urbanization processes and climate change in progress worldwide. Therefore, to prevent the occurrence of flooding in urban areas, methodologies have recently been developed to plan interventions of pipe replacement and storage tank installation, e.g., [23–25]. However, there is curiosity about the results obtainable in this field through the application of modern optimization techniques, such as those based on the multi-objective approach. Other research was carried out to analyze flow conditions in sewer channels, with specific focus on localized phenomena such as the transition from free surface to pressurized flow, e.g., [26–28]. Nevertheless, some problems of numerical instability have not yet been fully solved, calling for more research efforts. Finally, numerous experimental and numerical works have focused on water quality, e.g., [29–31], and sediment transport, e.g., [32–34], in sewers. However, some aspects, such as the sediment transport in pressurized pipes and the impact of water use reduction on the operation of UDSs, need to be analyzed in more depth.

Other research has been carried out on the topic of urban rivers, with special focus on the restoration of natural water courses, e.g., [35–37]. However, few works have dealt with the flow characteristics of the urban channelized rivers with complex cross-sections.

The papers in this Special Issue attempt to find an answer to some open questions in the research topics presented above. In the following section, the main novelties of these papers are presented. The paper continues with a discussion to comment the results achieved, followed by the conclusions.

2. Overview of the Special Issue

The Special Issue was established to point out the recent trends in UWNs, with emphasis on the opportunities introduced by technical progress for modelling, management, forecast, and performance improvement. The collected papers are grouped in the following subsections, related to the research topics inherent to WDSs, UDSs and urban rivers.

2.1. Water Distribution Systems

2.1.1. Asset Management

Nafi and Brans [38] predict the potential costs and benefits of a combination of asset management actions of maintenance and renewal in the WDS. The actions are treated as decisional variables in a bi-objective optimization aimed at finding solutions in the trade-off between cost and efficiency, to be minimized and maximized, respectively. Both objective functions are calculated through an artificial neural network (ANN) trained on real data. The selection of the ultimate solution in the Pareto front is made based on budget constraints or efficiency targets. The applications to a French WDS show that the methodology can effectively help decision-makers in selecting the most suitable interventions in the WDS.

2.1.2. Modelling of Demand and Hydraulics

Yousefi et al. [39] propose the simulation of urban water consumption using chaos theory, with the aim to help optimize system management. They test consumption forecast models optimized through chaos theory techniques against an urban consumption dataset obtained from the City of Kelowna (British Columbia, Canada). The analysis of the results proves that the non-linear local approximation model performs best, and the phase space reconstruction improves the accuracy of the models.

Mentes et al. [40] develop an extended period simulation model for the WDSs of the Thessaloniki city in Greece to model the current operating state of the networks, as well as its response to emergency conditions resulting from failure in one of them. The model is calibrated under both normal and critical operating conditions. Failure in the WDSs is analyzed through the model in five emergency scenarios of network operation, two of which consider possible interconnections of the studied WDSs. The results of the work prove the model is able to give reliable insights into the management of limited water reserves in some areas of the network when considering the interconnections.

2.1.3. Energy Recovery

Creaco et al. [41] investigate the benefits associated with the installation of PATs in systems of transmission mains, which convey water from source(s) to WDS tanks at an almost constant rate. They apply their bi-objective methodology to an Italian case study made up of nine systems of transmission mains, to find solutions in the trade-off between installation costs and generated hydropower, to be minimized and maximized, respectively. Due to the large geodesic elevation variations available in the case study, the post processing of solutions in terms of long-life profit show that, in all systems, the optimal solution with the highest values of installation cost and generated electric power, which can be as high as 83 KW, is the most profitable under usual economic scenarios. Furthermore, payback periods lower than 3 years are always obtained for these solutions.

2.1.4. Pipe Burst Identification and Leakage Reduction

Mirshafiei et al. [42] present a Geospatial Information System (GIS)-based methodology for partially isolating a leaking pipeline from the remainder of a WDS. Specifically, a web GIS application based on the traceability concept is developed to find the optimal valves close around the pipeline. The algorithm is applied and tested against one of the districts of the Teheran WDS, proving to be accurate and handy.

Manzi et al. [43] present a methodology aimed at processing transient signals for the detection and location of bursts in WDSs. Disaggregation, ANN, and clustering techniques are the methodological elements. The application to two real WDSs proves the methodology to be accurate and effective at locating pipe bursts and at characterizing them in terms of leaked flow.

By making use of a calibrated numerical model, Bosco et al. [44] investigate the potential of rehabilitation measures and active pressure control strategies for leakage reduction in a water distribution system (WDS) in southern Italy. Three different scenarios, namely pipe rehabilitation (S1), implementation of pressure local control (S2), and introduction of remote real-time pressure control (RTC) (S3), are analyzed and compared with the current operational scenario (S0). The results point out that 16.7%, 35.0%, and 37.5% leakage reductions (as compared to S0) can be obtained under scenarios S1, S2, and S3, respectively.

Shao et al. [45] present a novel methodology to be used in the context of WDS partitioning, which is a management practice beneficial for consumption monitoring and leakage mitigation. Their methodology operates by identifying the optimal locations of flow meters and valves to separate the DMAs by means of an improved genetic algorithm, applied for minimizing the number of installed flow meters and the behavioral variations of the WDS in terms of hydraulics and water quality, in comparison with the unpartitioned WDS. The applications show the effectiveness of the methodology in a real WDS.

2.2. Urban Drainage Systems

2.2.1. Asset Management

Ngamalieu-Nengoue et al. [46] present a methodology to rehabilitate UDSs to cope with increased peak flows due to the development of urbanization and the climate change currently in progress. UDS rehabilitation is carried out by combining actions of pipe replacement and storm tank installation. The sites of intervention are the decisional variables of a pseudo-genetic heuristic algorithm aimed at minimizing the overall installation costs, while the UDS is modelled using the Storm Water Management Model (SWMM) model. The effectiveness of the methodology is applied to the UDS of Bogotà, Colombia.

Ngamalieu-Nengoue et al. [47] enhanced the methodology presented above by implementing multi-objective optimization, to obtain optimal solutions in the trade-off between installation costs and flooding damage, which are simultaneously minimized.

2.2.2. Modelling of Flow and Quality

Mao et al. [48] analyze the transition between free-surface and pressurized flow, which is a crucial phenomenon in UDSs. In the simulation of this phenomenon, severe numerical oscillations may appear behind filling-bores, causing unphysical pressure variations and computation failure. After reviewing various oscillation-suppressing methods, among which only one provides stable results under a realistic acoustic wave speed, the authors present a new oscillation-suppressing method with first-order accuracy based on two easily evaluable parameters. Besides being able to suppress numerical oscillations under an acoustic wave speed of 1000 ms⁻¹, it yields numerical results in good agreement with experimental data.

Bailey et al. [49] present the analysis of the impact of water use reduction on the operation of UDSs. The methodology used for the analysis is made up of two elements, namely SIMDEUM WW®and InfoWorks®ICM. The former is used for the generation of stochastic appliance-specific discharge profiles for wastewater flow and concentration, which are fed into the latter to quantify the impacts within the sewer network. After being calibrated by using measured field data from a sewer system in Amsterdam serving 418 households, the model is used to analyze the effects of three water conservation strategies (greywater reuse, rainwater harvesting and water-saving appliances) on flow, nutrient concentrations, and temperature in sewer networks. Results show both the reduction in sewer flow up to 62% and the increase in COD, TKN and TPH concentrations by up to 111%, 84% and 75%, respectively, offering more favorable conditions for nutrient recovery.

Rinas et al. [50] present the results of an experimental campaign on solids transport in a pressurized sewer pipe. Data with a very fine temporal resolution are obtained from the one year in-situ turbidity/total suspended solids (TSS) monitoring inside a pipe (600 mm diameter) in an urban region in northern Germany. This enables the determination of solid sedimentation (within pump pauses) and erosion behavior (within pump sequences). The measurements point out a change in the sedimentation and erosion behaviors as a function of the inflow rate, with faster settling solids as the inflow increases.

Rinas et al. [51] calibrate a numerical transport model to simulate the sedimentation and erosion behavior of solids in a pressurized sewer pipe, using the data collected in the work of Rinas et al. [50]. The model is applied to investigate sediments transport under low flow velocities (due to energy saving intentions). The simulation of the 30-day-long pumping operation shows that sediments can be transported even under variable inflow conditions with low flow velocities. As a result, low-energy pump operation can be applied without increasing the risk of deposition formation.

2.3. Urban Rivers

Wang et al. [52] present the application of the software MIKE21 FM for analyzing the flow in a planned urban river course with a complex cross-section. The first part of the work concerns

the verification of the rationality and feasibility of the planning scheme through a two-dimensional numerical model. The second part of the work is dedicated to the analysis of the river course, to give several suggestions and improvement measures for the follow-up of the river planning. The third and last part of the work derives some general rules to be followed for the modelling of rivers with a complex cross-section.

3. Discussion

All the papers of the Special Issue are focused on topics that are at the forefront of the research in Urban Water Networks. They are valuable contributions from the viewpoint of methodological development, objectives achieved and review of the scientific literature.

In the field of WDSs, all works are numerical analyses, though most of them, i.e., [38–40,43,44], present models calibrated on the basis of experimental data. The methodologies adopted are multi-faceted, ranging from physically based modelling, [40,41,44,45], to GIS algorithms, [42], data-driven techniques, [38,39,43], graph-theory, [43], and optimization algorithms, [38,41,45].

In the field of UDSs, almost all the works, i.e., [46–49,51], are numerical. In this context, the methodologies adopted include physically based modelling, [46–49,51], stochastic, [49], and empirical, [51], modelling, optimization algorithms, [46,47]. The only experimental work [50] reports on and analyses the data of a measurement campaign on hydraulics and sediment transport in a pressurized pipe.

The paper on the topic of urban rivers, i.e., [52], makes exclusive use of the physically based numerical modelling.

The kinds of paper published in this Special Issue are representative of current research trends in the scientific literature of urban water systems, which features an evident prevalence of numerical over experimental works. In fact, although most papers use literature data for the validation of numerical models, only one of fifteen papers reports novel experimental results. Indeed, this represents a drawback of the current trends in research. In fact, data obtained through the modern and reliable measurement devices available nowadays could significantly enrich the literature, as they could enable the more exhaustive validation of models and the development of more refined numerical models. As a result, new experimental campaigns both in laboratories and in the field are needed in the future.

4. Conclusions

The Editorial presents an analysis of the papers published in the Special Issue on Advances in Advances in Modeling and Management of Urban Water Networks.

Starting with WDSs, the first analyzed topic is asset management, which was dealt with by Nafi and Brans [38] by applying the bi-objective optimization to find optimal solutions in the trade-off between costs and efficiency in the WDS to a French WDS. ANNs trained on real data are used for the assessment of both objective function within the optimization process. The second analyzed topic is the modelling of demand and hydraulics. As for demand, Yousefi et al. [39] propose simulation of urban water consumption in a Canadian city using chaos theory, with the aim to help optimize system management. As for the modelling, Mentes et al. [40] show the extent to which a well-calibrated extended period simulation model can reproduce the hydraulics of real WDSs in Greece, while giving reliable insights into WDS management in emergency scenarios. The third explored topic lies in the exploitation of WDSs for energy recovery. In this context, Creaco et al. [41] show that transmission mains in a real Sicilian case study featuring large geodesic elevation variations can be used to generate electric powers up to 83 KW. The fourth explored topic concerns operational management in terms of pipe burst identification and leakage reduction. In this context, Mirshafiei et al. [42] present a Geospatial Information System (GIS)-based methodology for partially isolating a leaking pipeline from the remainder of a WDS and its application to an Iranian WDS. Manzi et al. [43] present a methodology based on disaggregation, ANN, and clustering techniques for the identification and location of bursts in real WDSs. Thanks to the well-calibrated model of a WDS in Southern Italy, Bosco et al. [44] show the extent to which WDS rehabilitation and active pressure control can help in reducing leakage. Finally, Shao et al. [45] improves a genetic algorithm present in the scientific literature to optimize the positions of flow meters and valves in the context of WDS partitioning, which is a management practice beneficial for consumption monitoring and leakage mitigation.

In the field of UDSs, the first explored topic is asset management, in which Ngamalieu-Nengoue et al. [46,47] show how optimization can help decision-makers in selecting the most suitable sites for pipe replacement and storage tank installation, with the objective to improve UDS performance during intense rain events. In the context of the modelling of flow and quality, second topic for the UDSs, Mao et al. [48] propose an effective oscillation-suppressing method to be used for simulating the transition between free-surface and pressurized flow in sewer channel. Through the stochastic simulation of users' water and pollutant discharges and through the hydraulic modelling of sewer channels, Bailey et al. [49] present the analysis of the impact of water use reduction on the operation of UDSs. The results in a real Dutch case study point out the reduction in water discharges and the increase in pollutant concentrations, which are favorable conditions for nutrient recovery. Finally, Rinas et al. [50,51] present experiments and numerical simulations on solids transport in a pressurized sewer pipe, providing valuable results for a topic that is probably underrepresented in the scientific literature.

The Special Issue also includes a paper, i.e., [52], on the analysis of the flow in a planned urban river course with a complex cross-section, offering some general modelling rules to be followed in this context.

Each of these papers is a valuable contribution to the research on urban water networks and paves the way for further developments in the future.

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