water

Editorial

Advanced Hydroinformatic Techniques for the Simulation and Analysis of Water Supply and Distribution Systems

Manuel Herrera [1,*], Silvia Meniconi [2], Stefano Alvisi [3] and Joaquín Izquierdo [4]

1 Department of Architecture & Civil Engineering, University of Bath, Claverton Down, Bath BA2 7AZ, UK
2 Department of Civil and Environmental Engineering, University of Perugia, via G. Duranti 93, 06125 Perugia, Italy; silvia.meniconi@unipg.it
3 Department of Engineering, University of Ferrara, via Saragat, 1, 44122 Ferrara, Italy; stefano.alvisi@unife.it
4 Institute for Multidisciplinary Mathematics, Universitat Politècnica de València, Cno. de Vera, s/n, 46022 Valencia, Spain; jizquier@upv.es
* Correspondence: A.M.Herrera.Fernandez@bath.ac.uk; Tel.: +44-1225-38-4440

Received: 21 March 2018; Accepted: 4 April 2018; Published: 8 April 2018

Abstract: This document is intended to be a presentation of the Special Issue "Advanced Hydroinformatic Techniques for the Simulation and Analysis of Water Supply and Distribution Systems". The final aim of this Special Issue is to propose a suitable framework supporting insightful hydraulic mechanisms to aid the decision-making processes of water utility managers and practitioners. Its 18 peer-reviewed articles present as varied topics as: water distribution system design, optimization of network performance assessment, monitoring and diagnosis of pressure pipe systems, optimal water quality management, and modelling and forecasting water demand. Overall, these articles explore new research avenues on urban hydraulics and hydroinformatics, showing to be of great value for both Academia and those water utility stakeholders.

Keywords: water distribution design; water network performance; pressure pipe system; water quality; water demand

1. Introduction

One of the most complex structures that an intelligent city has to manage is its water distribution system (WDS), which must provide water to citizens in adequate quantity and quality. This complexity is twofold. On the one hand, it is well known that the classical hydraulic models that describe the phenomena that take place in a WDS are of a complex nature, given the characteristics of the equations that describe these phenomena and their eminently distributed nature. On the other hand, the galloping recent need to handle large amounts of data obtained from the monitoring of systems has brought classical complexity to new paradigms that need new ways of addressing the problems of Urban Hydraulics. In this regard, special attention should be given to the achievement of an adequate digital connection related to the availability of data in real time, which allows effective solutions for demand prediction and other water utilities operations.

In essence, WDSs must be adequately designed (in the case of new systems) and adequately rehabilitated (extensions, renovation, restoration, etc., in later stages) so that they supply the user at all times and places under given satisfactory conditions. WDSs must be adequately monitored in order to obtain quality data in real time that allows an efficient control of the system. In addition, suitable (optimal) operation for the quality service to be provided continuously, without interruption, is essential. Finally, intelligent management that is capable of reconciling conflicting objectives such as economic benefit and social satisfaction, among others, must be an inescapable condition for ruling a WDS.

To achieve these objectives, efficient techniques are necessary to overcome the complexity of the associated problems. For example, in the tasks of design and rehabilitation, optimization algorithms are needed that are capable of manipulating nonlinearity, the coexistence of variables of different types, the discrete nature of some processes, etc.; these requirements impose the need to transcend classical optimization and to use modern techniques of evolutionary optimization. The real-time monitoring of the quality of the service will be greatly benefited by efficient time series processing techniques and several other forms of intelligent data manipulation. The operation of a system can be defined in terms of certain operators and variables of Boolean type, which must be optimally defined and integrated into the models and data structures in an appropriate manner; again, efficient techniques of optimization and fusion of methodologies that are able to work with data in real time will be necessary. Finally, the management of WDSs is currently carried out through a wide range of elements, such as demand prediction, network sectorization, leak detection, system maintenance through appropriate policies, control of transients, evaluation of user satisfaction, etc. Moreover, some of the elements that intervene in decision-making are quantifiable, while others must be classified as intangible; therefore, it is crucial to have adequate techniques for handling the information to be manipulated, which will frequently be affected by uncertainty and subjectivity.

In the water supply industry, as in other fields, any improvement that can occur in the treatment and handling of big data will produce considerable and obvious benefits. For example, through the installation of advanced measurement infrastructure (AMI) and the more efficient treatment of the data obtained, it will be possible to reduce more effectively the unaccounted-for water in the short term. More generally, in the long term, a more efficient operation that is expected from such improvements will contribute to the excellence of the urban water cycle, one of the objectives of an intelligent city. The idea is to promote the implementation of the smart city concept from the perspective of water supply.

2. Overview of This Special Issue

This issue contains 18 papers which focus on some of the mentioned problems of water distribution system management. The key points are: (i) design of water system [1–4]; (ii) optimization of network performance assessment [5–8]; (iii) monitoring and diagnosis of pressure pipe system [9–11]; (iv) optimal water quality management [12–14]; and (v) modelling and forecasting of water demand [15–18].

2.1. Design of Water System

Four papers of this issue examine the first key point that is design of water system. Firstly, Mala-Jetmarova et al. present a systematic literature review of optimization of WDS design since the end of the 1980s [1]. The review classifies the examined papers by the following issues: the type of design problems (i.e., static or dynamic), the application area (i.e., new or existing systems, with the optional inclusions of system operations), the optimization model (i.e., objective functions, constraints, and decision variables), and the analysed networks. It pinpoints trends and limits and suggests further research directions. Specifically, it reveals that there is not a consensus about the best WDS design optimization model, and consequently, researchers would force themselves to compare and validate different methods on real case studies.

Secondly, different multiobjective evolutionary algorithms (MOEAs) are compared in [2] on four well-known benchmark networks (i.e., two loop, Hanoi, Fossolo, and Balerma irrigation networks), by taking into account two objective functions: cost minimization and resiliency index maximization. A new hybrid algorithm that combines differential evolution and harmony search algorithm has been proposed for WDS design and compared with five MOEAs (i.e., NSGA2, AMALGAM, Borg, "ε-MOEA", and "ε-NSGA2"): the comparison shows that the new approach outperforms the previous MOEAs.

Thirdly, in [3] a new approach has been developed: to reduce the search space it bounds the pipe diameter values by analysing two opposite extreme flow distribution scenarios (i.e., uniform and maximum flow distribution) and applying velocity constraints. This model has been coupled to a genetic algorithm (GA) to improve its performance. The approach is applied to two benchmark networks (i.e., again two-loop network and Hanoi networks) by taking into account the cost minimization as objective function. By means of the new approach, the search space is reduced to less than 3% of the total search space for both the analysed networks. The results are compared to the classical GA: the comparison shows that the new approach is much faster and more accurate.

Finally, Zheng et al. describe experimental tests aimed at the optimal design of circular drop manholes in urban drainage networks [4]. Particularly, free, pressurized, and constrained outflow conditions have been tested for different manhole heights. Tests show that the local head loss coefficient of the manhole strictly depends on the outflow conditions. As a concluding remark, some empirical equations have been proposed to evaluate this coefficient.

2.2. Optimization of Network Performance Assessment

Four papers refer to the second key point that is optimization of network performance assessment. First, Sadatiyan and Miller [5] introduce a multiobjective version of the Pollution Emission Pump Station Optimization tool (PEPSO). It can be used to find a pump schedule of a WDS to reduce both the electricity cost and pollution emissions, by measuring the Undesirability Index in a nondominated sorting genetic algorithm. Tests carried out on the WDS of Monroe City (MI, USA) and Richmond (UK) show that PEPSO can optimize and provide useful information in a very limited amount of time.

Second, the main aim of the paper by Zischg et al. [6] is to assist decision makers in testing various planning options and design strategies during long-term city transitions. The procedure consists of the automatic creation, simulation, and analysis of different WDS scenarios. The pressure head, water age, and pressure surplus have been taken into account. Moreover, if data are not available, the approach uses alternative systems with strong similarity to WDSs. The proposed methodology is applied to the Swedish town Kiruna, in which it allows understanding the lack of the sole design at the final-stage WDS for most of the future scenarios and planning options.

Third, a procedure has been developed by Ilaya-Ayza et al. [7] to define district metered areas (DMAs) in WDSs with intermittent supply. The chosen objective function is the water supply equity. The approach uses soft computing tools from graph theory and cluster analysis and both the company expert opinions and adequate supply times for each DMA have been taken into account. The considered case study is the water supply network of Oruro (Bolivia), for which the proposed sectorization allows a clear improvement of the resilience index of the entire network.

Fourth, di Nardo et al. [8] propose the application of graph spectral theory (GST) for the optimal network sectorization. The approach is applied to two case studies (i.e., the well-known C-Town network and a real small WDS of Parete, Italy), and GST allows ranking WDS nodes and selecting the most important nodes for monitoring water quality, flow, or pressure, and for defining the DMAs. The main advantage of such an approach is that this is based only on topological and geometric information and no hydraulic data—often not available—are required.

2.3. Monitoring and Diagnosis of Pressure Pipe System

Three papers are part of the third key point that is monitoring and diagnosis of pressure pipe systems. First, Duan [9] investigates analytically and numerically the impact of nonuniformities of pipe diameter on transient wave behavior. Specifically, it demonstrates the dependence of wave scattering on the relationship between the incident wave frequency and nonuniform pipe diameter frequency, and nine numerical tests have been carried out by varying the pipe diameter nonuniformities (i.e., regular or random) and this relationship. As a result, the wave scattering has a nonnegligible effect on wave reflections and attenuation, and, consequently, it has to be taken into account in transient modelling—along with both the unsteady friction and viscoelasticity—and in the application of Transient Test-Based Techniques (TTBTs) for the diagnosis of pressure pipe systems.

Second, Lin [10] presents a hybrid heuristic optimization approach called leak detection ordinal symbiotic organism search (LDOSOS) for locating and sizing leaks in a WDS. This approach combines the ordinal optimization algorithm (OOA) and the symbiotic organism search (SOS) in an inverse transient analysis (ITA). Moreover, the problem of generation of pressure waves is discussed and SOS is used to determine the optimal transient generation point. The procedure is tested on two numerical case studies: a two-loop network with a constant head supply reservoir and two very closed leaks, and a more complex network with a supply node with a constant inflow rate, a larger range of pipe diameters and lengths, and two distant leaks. Tests show that the LDOSOS has the ability to detect leak number, location, and size, by speeding up the ITA convergence and improving the reliability of the results.

Third, in Meniconi et al. [11] TTBTs are used to detect system defects and characteristics by monitoring the pressure waves at key points. The transmission main of the city of Trento (I) was analysed and transient tests were executed by pump shutdown. By means of the comparison of the numerical model and the acquired pressure signal, the relevance of the topology, pipe material characteristics, transient energy dissipation, and defects has been explored. Specifically, two malfunctioning valves have been detected and a preliminary criterion for the skeletonization of the transmission mains has been proposed.

2.4. Optimal Management of Water Quality

Three papers of this issue analyse the optimal management of water quality. Specifically, in Meyers et al. [12] a long-term continuous study of discolouration mobilisation is presented along with a methodology to determine the approximate amount and origin of hydraulically mobilised turbidity in trunk mains. The methodology is validated on three UK trunk main networks, observed over a period of about three years. The results show that the mobilisation of discolouration material is mainly determined by hydraulic forces, and consequently can be modelled and predicted, and its origin can be approximately determined.

Furthermore, in de Melo et al. [13], the factors that influence the water quality of the Jucazinho reservoir in northeastern Brazil have been pointed out by a data base of nine years of water quality reservoir monitoring and a multivariate statistical technique (i.e., the Principal Component Analysis, PCA). The study points out the connection between water quality parameters and the rainfall that has an annual or seasonal pattern. Precisely, two principal components of the water quality of this reservoir have been selected by PCA. The first, ranging from an annual basis, explains the increase in the concentration of dissolved solids and the cyanobacteria proliferation as a function of the drought period, during which the turbidity and the levels of total phosphorus decrease. The second, ranging from a monthly basis, indicates the connection between the process of photosynthesis performed by cyanobacteria with the percentage of the volume of the dam.

Finally, Reynoso-Meza et al. [14] have incorporated two decision-making methodologies (i.e., Technique for Order of Preference by Similarity to Ideal Solution—TOPSIS, and Preference Ranking Organisation Method for Enrichment of Evaluations—PROMETHEE) in a Multiobjective Evolutionary Algorithm (MOEA). The analysed multiobjective problems are two typical water quality problems: the dissolved oxygen problem for the activated sludge wastewater treatment process and the water quality of a river polluted by a cannery industry (Pierce-Hall Cannery) and the effluent from three treatment plants. The case studies have validated the reliability of such approaches for the degree of flexibility to capture designers' preferences.

2.5. Modelling and Forecasting of Water Demand

Four papers of this issue examine the last key point, modelling and forecasting of water demand. Firstly, Letting et al. [15] present a water demand calibration approach. The approach is aimed at estimating the water demand multiplier at each node of a water distribution system model by minimizing the error between observed and simulated nodal head and pipe flow rates. An optimization approach based on Particle Swarm algorithm is used. Application to a simple case study (Epanet example Net1) and a medium-sized real network highlights that the approach can provide an accurate water demand multiplier estimation by using data observed in a limited number of properly placed sensors.

Secondly, Pastor-Jabaloyes at al. [16] present an automatic tool for smart metered water demand time series disaggregation into single-use events. The tool is based on a filter automatically calibrated by using NSGA-II algorithm, and on a cropping algorithm. Furthermore, a semiautomatic classification is subsequently performed in order to categorize the obtained single-use events into different water end uses in a household such as shower, toilet, etc. The tool is applied to water demand time series collected from 20 households featuring very different characteristics in terms of geographical location, number of inhabitants, and average daily consumptions.

Thirdly, Anele et al. [17] provide an overview of some methods for short-term water demand forecast pointing out their pro and cons. The methods considered are univariate time series, time series regression, artificial neural network, and hybrid methods (i.e., a combination of two or more of the previous methods). The methods are applied to a case study highlighting that univariate time series, time series regression, and hybrid models may be accurate and appropriate for short-term water demand forecast. However, these methods are not applicable in more general decision problem frameworks. Indeed, these methods cannot be used to understand and analyse the overall level of uncertainty in future demand forecasts and thus much more attention needs to be given to probabilistic forecasting methods for short-term water demand forecast.

Finally, and strictly related to the previous considerations, a Markov-chain-based approach for probabilistic short-term water demand forecasting is presented by Gagliardi et al. [18]. In particular, two models based on homogeneous and nonhomogeneous Markov chains are proposed. The models are capable of providing both a deterministic forecast of the future values of water demand, and a characterization of the stochastic behaviour of the forecasted values. The models are applied to water demand time series of three district metered areas in the UK, and the deterministic forecast compared with those provided by neural network-based and naïve forecasting models, highlighting that the homogeneous Markov chain model provides both an accurate deterministic forecast and useful information regarding the probability distribution of the forecast itself.

3. Conclusions

In addition to the complexity inherent to WDS management, there often is a need for online actions to accomplish decision-making processes in real time. Another challenge that water companies should face nowadays is handling the huge amount of data generated by supervisory control and data acquisition (SCADA) systems, smart water meters, and other cyber–physical systems. This Special Issue on "Advanced Hydroinformatic Techniques for the Simulation and Analysis of Water Supply and Distribution Systems" presents a number of powerful techniques able to cope with such a complexity associated with: the nature of the hydraulic models, real-time requirements, and large scale databases. Bio-inspired and evolutionary algorithms play an important role in dealing with these issues. This is the reason why various contributions presented herein are based on these techniques. Overall, the Special Issue encompasses a collection of proposals that can be classified as follows:

- optimization, both classical and evolutionary;
- definition of structures and tools for big data;
- neural networks, support vector machines, and other Machine Learning techniques;

- graph theory and methods for complex networks;
- efficient treatment of time series;
- agent-based systems;
- multi-attribute decision-making techniques;
- transient test-based techniques for the diagnosis of pressure pipe systems; and
- other mathematical and computational tools and techniques

These techniques have been developed within the field of the so-called Hydroinformatics in Urban Hydraulics, that is, with application to problems such as:

- smart water networks (intelligent measurement, intelligent analysis of measurement data, ...);
- online analysis of WDSs (prediction of online demand, estimation of states, ...);
- water quality aspects (water quality characterization, prediction of discolouration, ...);
- reduction of unaccounted-for water and optimization of operation (sectorization, leak detection, operation indicators, water balance, and benchmarking, ...);
- optimal operation (of pumping stations, scheduling, transient control, ...);
- efficient utilization of real-time monitoring signals through smart treatment of online raw data using suitable learning approaches

Contributions to this Special Issue, exploring those new research avenues on urban hydraulics and hydroinformatics, are expected to be of great value for both Academia and all water utility stakeholders. On top of this, important social benefits are expected from a number of research objectives that ultimately aim to guarantee a regular supply of clean water at the pressure and quality required at the network consumption points.

Author Contributions: Each of the authors contributed to the design, analysis and writing of the manuscript.

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

References

1. Mala-Jetmarova, H.; Sultanova, N.; Savic, D. Lost in Optimisation of Water Distribution Systems? A Literature Review of System Design. *Water* **2018**, *10*, 307. [CrossRef]
2. Yazdi, J.; Choi, Y.H.; Kim, J.H. Non-Dominated Sorting Harmony Search Differential Evolution (NS-HS-DE): A Hybrid Algorithm for Multi-Objective Design of Water Distribution Networks. *Water* **2017**, *9*, 587. [CrossRef]
3. Reca, J.; Martínez, J.; López, R. A Hybrid Water Distribution Networks Design Optimization Method Based on a Search Space Reduction Approach and a Genetic Algorithm. *Water* **2017**, *9*, 845. [CrossRef]
4. Zheng, F.; Li, Y.; Zhao, J.; An, J. Energy Dissipation in Circular Drop Manholes under Different Outflow Conditions. *Water* **2017**, *9*, 752. [CrossRef]
5. Sadatiyan A., S.M.; Miller, C.J. PEPSO: Reducing Electricity Usage and Associated Pollution Emissions of Water Pumps. *Water* **2017**, *9*, 640. [CrossRef]
6. Zischg, J.; Mair, M.; Rauch, W.; Sitzenfrei, R. Enabling Efficient and Sustainable Transitions of Water Distribution Systems under Network Structure Uncertainty. *Water* **2017**, *9*, 715. [CrossRef]
7. Ilaya-Ayza, A.E.; Martins, C.; Campbell, E.; Izquierdo, J. Implementation of DMAs in Intermittent Water Supply Networks Based on Equity Criteria. *Water* **2017**, *9*, 851. [CrossRef]
8. Di Nardo, A.; Giudicianni, C.; Greco, R.; Herrera, M.; Santonastaso, G.F. Applications of Graph Spectral Techniques to Water Distribution Network Management. *Water* **2018**, *10*, 45. [CrossRef]
9. Duan, H.-F. Transient Wave Scattering and Its Influence on Transient Analysis and Leak Detection in Urban Water Supply Systems: Theoretical Analysis and Numerical Validation. *Water* **2017**, *9*, 789. [CrossRef]
10. Lin, C.-C. A Hybrid Heuristic Optimization Approach for Leak Detection in Pipe Networks Using Ordinal Optimization Approach and the Symbiotic Organism Search. *Water* **2017**, *9*, 812. [CrossRef]
11. Meniconi, S.; Brunone, B.; Frisinghelli, M. On the Role of Minor Branches, Energy Dissipation, and Small Defects in the Transient Response of Transmission Mains. *Water* **2018**, *10*, 187. [CrossRef]

12. Meyers, G.; Kapelan, Z.; Keedwell, E. Data-Driven Study of Discolouration Material Mobilisation in Trunk Mains. *Water* **2017**, *9*, 811. [CrossRef]
13. De Melo, R.R.C.; Rameh Barbosa, I.M.B.; Ferreira, A.A.; Lee Barbosa Firmo, A.; da Silva, S.R.; Cirilo, J.A.; de Aquino, R.R.B. Influence of Extreme Strength in Water Quality of the Jucazinho Reservoir, Northeastern Brazil, PE. *Water* **2017**, *9*, 955. [CrossRef]
14. Reynoso-Meza, G.; Alves Ribeiro, V.H.; Carreño-Alvarado, E.P. A Comparison of Preference Handling Techniques in Multi-Objective Optimisation for Water Distribution Systems. *Water* **2017**, *9*, 996. [CrossRef]
15. Letting, L.K.; Hamam, Y.; Abu-Mahfouz, A.M. Estimation of Water Demand in Water Distribution Systems Using Particle Swarm Optimization. *Water* **2017**, *9*, 593. [CrossRef]
16. Pastor-Jabaloyes, L.; Arregui, F.J.; Cobacho, R. Water End Use Disaggregation Based on Soft Computing Techniques. *Water* **2018**, *10*, 46. [CrossRef]
17. Anele, A.O.; Hamam, Y.; Abu-Mahfouz, A.M.; Todini, E. Overview, Comparative Assessment and Recommendations of Forecasting Models for Short-Term Water Demand Prediction. *Water* **2017**, *9*, 887. [CrossRef]
18. Gagliardi, F.; Alvisi, S.; Kapelan, Z.; Franchini, M. A Probabilistic Short-Term Water Demand Forecasting Model Based on the Markov Chain. *Water* **2017**, *9*, 507. [CrossRef]