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Towards More Efficient Hydraulic Modeling of Water Distribution Networks Using the EPANET Software Engine †

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Abstract: Hydraulic modeling of Water Distribution Networks (WDNs) is a vital for all water related professionals towards the development of management practices and strategies, which aim at the reduction of water losses and the associated financial cost and environmental footprint. In the current work we develop an easy to implement methodology for the effective modeling of WDNs, which seeks to minimize the computational load without undermining the analysis' accuracy, using the open access EPANET software package. The effectiveness of the proposed methodology is tested via a large-scale, real-world application to the city of Patras.

Keywords: hydraulic modeling 1; hydraulic network 2; EPANET 3; computational nodes 4; junctions 5; sensitivity analysis 6; leakage allocation 7

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1. Introduction

Today, the problem of the continuing decrease of the available freshwater reserves is a fact, which is significantly magnified, if one considers the effects of climate change on the spatial and temporal distribution of water resources [1–5]. Consequently, there is an urgent environmental and societal need to implement efficient management practices to water distribution networks (WDNs), which constitute the core infrastructure for drinking water supply to users.

The first step towards developing efficient management strategies, is accurate hydraulic modeling of WDNs using a dedicated software package (e.g., EPANET), in order to identify their weaknesses and evaluate their overall operational condition. To do so, one needs to develop a detailed representation (i.e., a model) of the pipeline grid using appropriate hydraulic objects (e.g., pipes, pumps, valves, junctions, reservoirs, tanks etc.). The effectiveness of the modeling procedure is mainly determined by the modeling accuracy, which is significantly affected by the density of the computational nodes (i.e., junctions). Although a high nodal density model produces more accurate results, it also dramatically increases the computational requirements, leading to time consuming solutions. Under this setting, the current work focuses on developing a practical methodology for the optimal allocation of computational nodes, in terms of modeling accuracy and computational cost.

2. Area of Application

We apply the analysis that follows to the 4 largest and most highly populated Pressure Management Areas (PMAs) of the water distribution network of the city of Patras, in western Greece (namely Boud, Kentro, Panachaiki and Prosfygika, see Figure 1). The corresponding PMAs, which share similar characteristics regarding the population density as well as land uses and topography, consist of over 200 kilometers of HDPE and PVC pipes, and cover most of Patras' city center (about 4 km^2), providing water to more than 58,000 customers as reported by the associated public competent authorities (see Table 1).

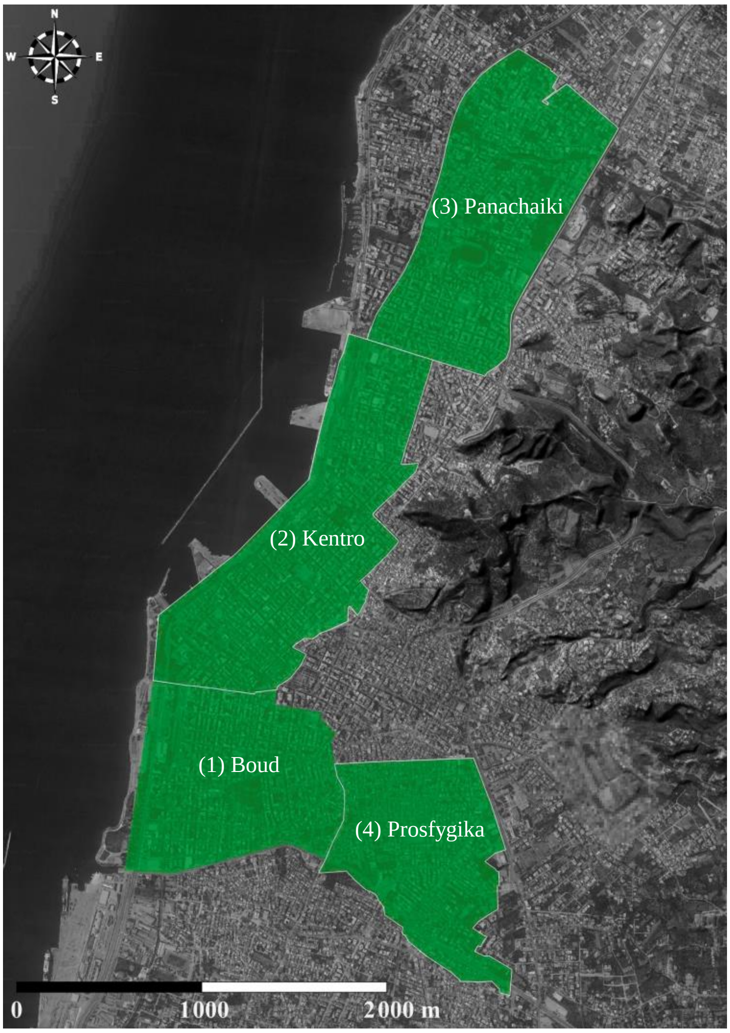

Figure 1. Map showing the position of the 4 largest pressure management areas located in the central region of Patras. Numbers are linked to the entries listed in Table 1.

Table 1. Name, total area, length of the pipeline grid and population of the 4 largest pressure management areas (PMAs) of the city of Patras. Numbers reflect the encompassed areas in Figure 1.

PMA	Area (km^2)	Length of the Pipeline (m)	Population (cap.)
(1) Boud	0.95	44,953	15,361
(2) Kentro	1.21	62,175	13,991
(3) Panachaiki	1.18	51,704	18,002
(4) Prosfygika	0.80	43,246	10,657

3. Methodology

3.1. Hydraulic model design

To realistically describe a WDN, the nodal density should be high enough as to effectively describe both the area's topographic variability as well as the original connectivity of the network, while considering all necessary hydraulic parameters (e.g., pipe material and diameter). Under this concept, we choose to place computational nodes at: a) intersections between two or more pipes, b) changes in pipes' diameters and/or material, c) fire hydrant locations, d) dead ends, and e) at the locations of high-water demand consumers [6].

To take into account the area's topographic variability (which highly affects the analysis' pressure outcome; see [7–9]), we use sensitivity analysis to determine an appropriate nodal density. Figure 2 summarizes the corresponding EPANET simulations time complexity (i.e., the computational time), in terms of network's nodal density (i.e., number of nodes per km). One sees that time complexity increases almost exponentially with increasing nodal density for all 4 cases, as a result of the heavier computational load. Selection of a proper solution (i.e., nodal density) is achieved through an optimal trade-off between time complexity and the required accuracy of the simulation, tailored to each specific case, as a function of topographic variability. For the purposes of the current study, we select to incorporate 10 nodes per km (i.e., at least one computational node per 100 m), as for larger nodal densities the computational time increases significantly.

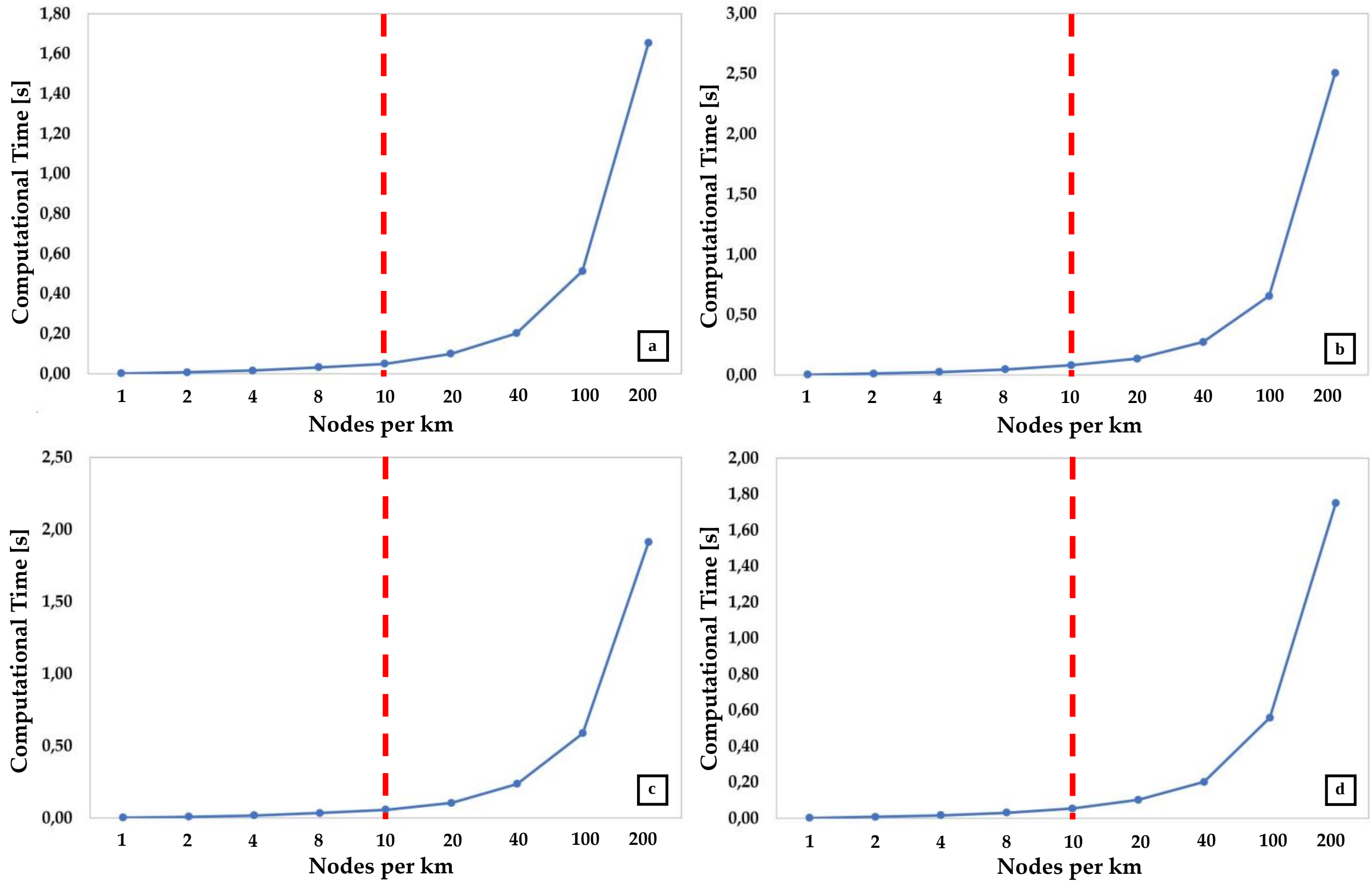

Figure 2. EPANET simulation time complexity for the 4 PMAs considered, in terms of network's nodal density: (**a**) Boud, (**b**) Kentro, (**c**) Panachaiki, and (**d**) Prosfygika.

3.2. Real Losses (RL, Leakages) Allocation

To perform the hydraulic simulation, firstly, we determine the total water demand at each network node, and divide it into two parts: a demand-driven component and a pressure-driven component. The former is based on the flow pattern, as consumers' usage varies throughout the day, while the pressure-driven component accounts for network leaks, which increase when the applied pressure increases. Modeling of leaks is done by assuming that the leakage rate is proportional to the square root of the difference between the actual nodal pressure and the minimum pressure necessary to fulfill consumption requirements. To do so, we multiply the initial leakage rates at each computational node by the parameter:

$$c_j = \textbf{Error!}, \text{ for } s_j > s_j^* \quad (1)$$

where s_j is the numerically simulated head at node $j = 1, \ldots, n$ (i.e., the sum of nodal elevation and pressure head), and s_j^* is the minimum threshold head at node j (i.e., the sum of nodal elevation and the minimum required pressure head). The hydraulic simulation is repeated until convergence (see [9]).

4. Results

We implement the proposed hydraulic modeling methodology (see Section 3) to the 4 largest pressure management areas of the water distribution network of the city of Patras, based on their geometric characteristics and hydraulic parameters as well as the area's altitudinal variation. In order to estimate the water consumption, we use flow-pressure data at 1 min temporal resolution for the 4-month long summer period from 1 June 2019–31 August 2019, which have been collected from the pressure regulation stations of the water distribution network (WDN) of the City of Patras in Western Greece. Flow and pressure data were obtained from the Municipal Enterprise of Water Supply and Sewerage of Patras (DEYAP), for each of the 4 stations, and were quality checked as to identify and eliminate errors resulting from communication issues and other data transmission malfunctions.

Figure 3 illustrates the Nodal pressures and water velocity results for PMAs Boud (Figure 3a), Kentro (Figure 3b), Panachaiki (Figure 3c) and Prosfygika (Figure 3d), obtained through hydraulic simulations using the EPANET 2.x solver for water networks' design and analysis. It is noted that in all cases the minimum pressure requirements (21 m in PMA Boud, 24 m in PMAs Panachaiki and Prosfygika, and 28 m in PMA Kentro) and maximum speed requirements are met (based on pipe diameters; for more info see [6]).

In order to test the accuracy of the proposed methodology, we use on-site pressure data obtained by DEYAP through smart pressure meters located at the most distant nodes of PMAs' pressure regulating valves (i.e., the points in Figure 3. marked in blue). Table 2 summarizes the calculated pressures obtained from the smart metering system and the corresponding ones by the EPANET solver.

Table 2. Modeled and on-site metered pressure of the 4 largest pressure management areas (PMAs) of the city of Patras. Numbers are linked to the positions in Figure 1.

PMA	Model Pressure (m)	On-Site Pressure (m)	Absolute Relative Difference (%)
(1) Boud	48.256	52.234	7.615
(2) Kentro	74.868	66.549	9.219
(3) Panachaiki	99.412	95.834	3.733
(4) Prosfygika	50.226	52.947	5.139

It is observed that the proposed methodology results in almost identical pressures as the on-site metering, with absolute relative deviations not exceeding 10% for all 4 cases (7.615%, 9.219%, 3.733% and 5.139% for PMAs Boud, Kentro, Panachaiki and Prosfygika, respectively), indicating the robustness of the proposed methodology.

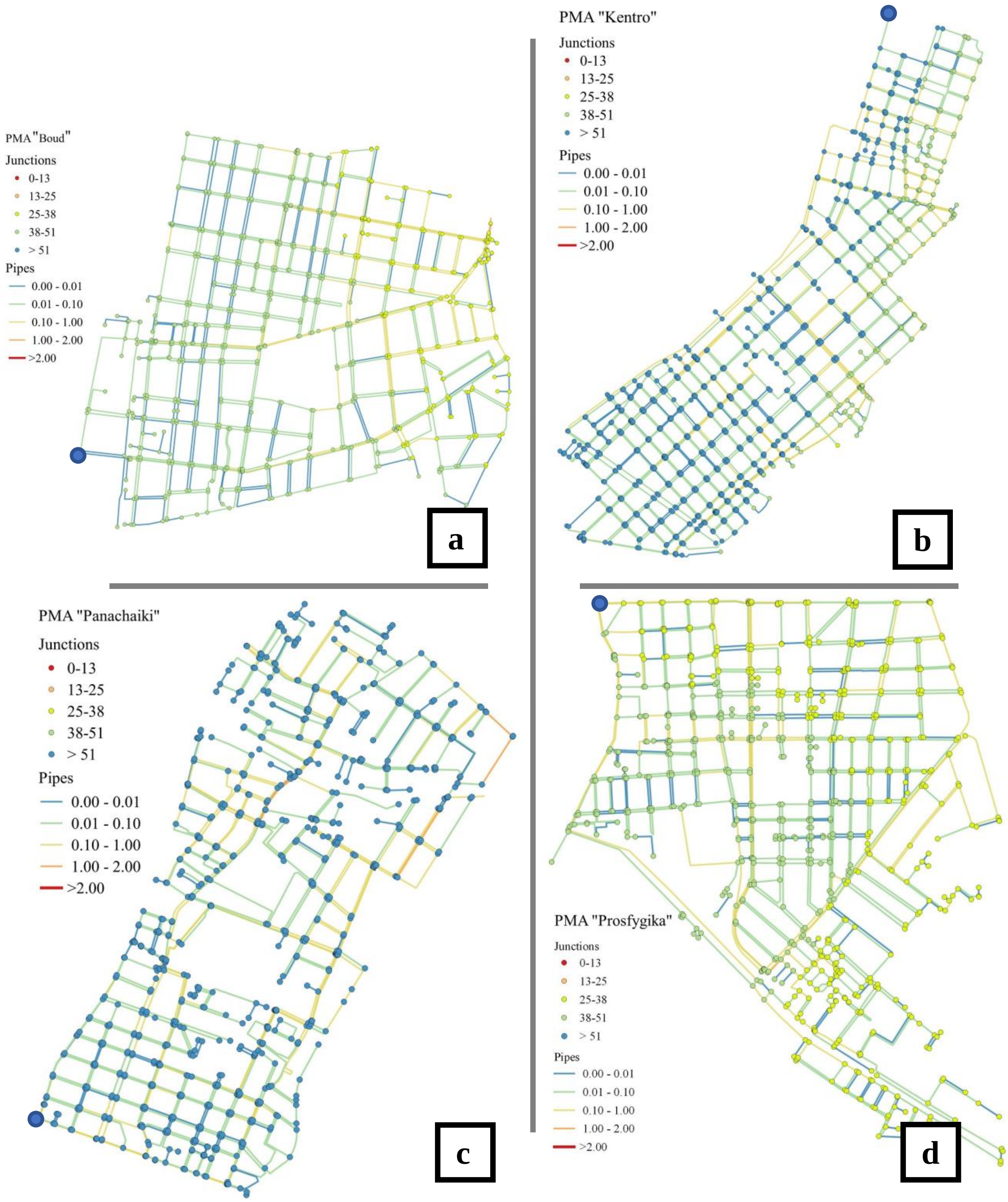

Figure 3. Nodal pressures and water velocity results for PMA: (**a**) Boud, (**b**) Kentro, (**c**) Panachaiki, and (**d**) Prosfygika, obtained through hydraulic simulations using the EPANET solver. PMA locations are illustrated in Figure 1.

5. Conclusions

Hydraulic modeling of WDNs is an important task towards the development of efficient water management practices and strategies, aiming at the reduction of water losses and the associated financial cost and environmental footprint. In the current work, we develop an easily applicable methodology for effective modeling of WDNs, which maintains a sufficient level of estimation accuracy with minimal computational load, using sensitivity analysis as to determine the appropriate nodal density, in order to effectively describe both topographic variability as well as the original connectivity of the network. Additionally, the water requirement at each node in the network was established by combining two factors, one being driven by demand and the other by pressure, resulting in more accurate depictions of the operational pressures.

The developed hydraulic models allowed us to implement and test a variety of methodologies regarding water losses estimation (see [7]), identification of pressure control failures and the release of notifications (see [5]) and the optimal partitioning of WDNs into PMAs, without undermining the overall hydraulic resilience of the network (see [9]). The developed approaches can significantly reduce the volume of lost water (30% on average in each PMA), which corresponds to approximately €300,000 of annual savings, based on the balance sheet of the fiscal year 2019 (see [10]).

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

References

1. Deng, Y.; Cardin, M.; Babovic, V.; Santhanakrishnan, D.; Schmitter, P.; Meshgi, A. Valuing flexibilities in the design of urban water management systems. *Water Res* **2013**, *47*, 7162–7174. https://doi.org/10.1016/j.watres.2013.09.064.
2. Rehan, R.; Knight, M.A.; Unger, A.J.A.; Haas, C.T. Development of a system dynamics model for financially sustainable management of municipal watermain networks. *Water Res* **2013**, *47*, 7184–7205. https://doi.org/10.1016/j.watres.2013.09.061.
3. Charalambous, B.; Foufeas, D.; Petroulias, N. Leak detection and water loss management. *Water Util J.* **2014**, *8*, 25–30.
4. Serafeim, A.V.; Kokosalakis, G.; Deidda, R.; Karathanasi, I.; Langousis, A. Probabilistic estimation of minimum night flow in water distribution networks: Large-scale application to the city of Patras in western Greece. *Stoch. Environ. Res. Risk. Assess.* **2021**, *36*, 643–660. https://doi.org/10.1007/s00477-021-02042-9.
5. Perdios, A.; Kokosalakis, G.; Fourniotis, N.T.; Karathanasi, I.; Langousis, A. Statistical framework for the detection of pressure regulation malfunctions and issuance of alerts in water distribution networks. *Stoch. Environ. Res. Risk. Assess.* **2022**, *36*, 4223–4233. https://doi.org/10.1007/s00477-022-02256-5.
6. Langousis, A.S.; Fourniotis, N.T. *Elements of Design of Water Supply and Sewerage Works*; In Greek; GOTSIS Publications, Greece, 2020; 722p. ISBN: 978-960-9427-89-0.
7. Serafeim, A.V.; Kokosalakis, G.; Deidda, R.; Karathanasi, I.; Langousis, A. Probabilistic Minimum Night Flow Estimation in Water Distribution Networks and Comparison with the Water Balance Approach: Large-Scale Application to the City Center of Patras in Western Greece. *Water* **2022**, *14*, 98. https://doi.org/10.3390/w14010098.
8. Serafeim, A.V.; Kokosalakis, G.; Deidda, R.; Karathanasi, I.; Langousis, A. Probabilistic framework for the parametric modeling of leakages in water distribution networks: Large scale application to the City of Patras in Western Greece. *Stoch. Environ. Res. Risk Assess.* **2022**, *36*, 3617–3637. https://doi.org/10.1007/s00477-022-02213-2.
9. Serafeim, A.V.; Kokosalakis, G.; Deidda, R.; Fourniotis, N.T.; Langousis, A. Combining Statistical Clustering with Hydraulic Modeling for Resilient Reduction of Water Losses in Water Distribution Networks: Large Scale Application Study in the City of Patras in Western Greece, *Water* **2022**, *14*, 3493. https://doi.org/10.3390/w14213493.
10. Serafeim, A.V.; Kokosalakis, G.; Deidda, R.; Karathanasi, I.; Langousis, A. Water Loss Estimation and Associated Financial Cost in Water Distribution Networks: Large Scale Application to the City of Patras in Western Greece. In Proceedings of the IWA World Water Congress & Exhibition 2022, Copenhagen, Denmark, 11–15 September, 2022.