

Practical Estimation of Minimum Night Flow in Water Distribution Networks: Large-scale Application to the City of Patras in Western Greece

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Abstract

In the present work we develop and test a non-parametric statistical methodology to obtain point estimates of Minimum Night Flow (MNF) in Water Distribution Networks (WDNs). The methodology constitutes a simplified version of the approach of Serafeim et al. (2021) for confidence interval estimation of background losses in WDNs, which simultaneously analyzes all night flow measurements, producing robust estimates independent of the nominal resolution of the available data.

In addition to being simpler to apply and computationally more efficient, the developed method can be applied to any WDN independent of its size, age and overall condition, its specific geometric characteristics (intensity of altimetry, average diameter etc.), inlet/operating pressures, and the nominal resolution of the flow data.

The effectiveness of the method is tested via a large-scale application to the WDN of the City of Patras in western Greece, which consists of 79 Pressure Management Areas (PMAs) with more than 700 km of pipeline grid. To do so, we use flow data at 1 min temporal resolution, provided by the Municipal Enterprise of Water Supply and Sewerage of the City of Patras, for the 4-month winter period from 01 November 2018 – 28 February 2019, which are progressively averaged to coarser temporal resolutions, in an effort to test the sensitivity of the developed method to the nominal resolution of the data.

The obtained point estimates of MNF are assessed on the basis of the confidence intervals obtained by the approach of Serafeim et al. (2021), highlighting the accuracy and robustness of a simple non-parametric approach in providing MNF point estimates at a minimum of effort.

1. Introduction

The most common approach for estimation of water losses in WDNs is that of the minimum night flow (MNF, see e.g. Liemberger and Farley, 2004). As human activity during late night and early morning hours is minimal, MNF estimates can be considered representative of the background losses in the network, as well as its overall condition.

Under this setting, in a previous work (see Serafeim et al., 2021) we developed two conceptually different probabilistic approaches for MNF estimation in WDNs, based on statistical metrics. The first approach is more elaborate, as it identifies a proper scale of temporal averaging to filter out noise effects in the estimation of MNF from the timeseries of night flow measurements during the low consumption period of the year, while the second is more intuitive, as it estimates MNF as the average flow of the most probable states of the night flows during the same period. The two approaches lead to very similar results, and are particularly suited to minimize noise effects, allowing for a better representation of the low flows during night hours, as well as the overall condition of the network.

This work introduces a simplification of the second method mentioned above, where all night flow data are analyzed simultaneously. MNF estimates are obtained independently of the nominal resolution of the available timeseries, in a rigorous statistical context.

2. Data and area of application

In the analysis that follows, we use flow data at 1-min temporal resolution for the 4-month long low consumption period from 01 November 2018 – 28 February 2019, which have been collected from the pressure regulation stations of the WDN of the City of Patras in Western Greece.

The network consists of more than 700 km of pipeline (mainly HDPE and PVC pipes) and 46 local pumping stations – pumping wells, covers an area of approximately 27 km², and serves approximately 213000 consumers, which correspond to more than 119000 authorized connections on the main network.

Flow data were acquired from DEYAP and were quality assessed to detect and remove errors related to communication glitches. Zones exhibiting prolonged periods of system malfunctioning and/or pressure regulation issues (i.e. due to topographic constraints) were excluded from the analysis. Under this setting, 62 PMAs with less than 8% of missing values during the 4-month long period were identified to be used for MNF estimation.

3. Methodology

We introduce a probabilistic MNF estimation method based on the concept of most probable states (see Serafeim et al., 2021). Figure 1 illustrates the empirical probability density functions (ePDFs) of the flow timeseries in PMA “Kentro” (the largest PMA of the Municipality of Patras) at different temporal resolutions $D = 5, 15, 30, 60$ and 120 min, within the timeframe from 00:00 am to 06:00 am of the 4-monthly low consumption period.

MNF estimates for the different temporal resolutions studied were obtained by calculating the lowest modal value (see black circle marks in Figures 1(a) – 1(f)) of each ePDF.

An important note to be made is that the obtained estimates are very similar independent of the temporal resolution of the flow timeseries and, also, are in good agreement with the MNF estimate (i.e. 69.85 l/s) obtained by applying the original approach of Serafeim et al. (2021), substantiating the robustness of the proposed simplification.

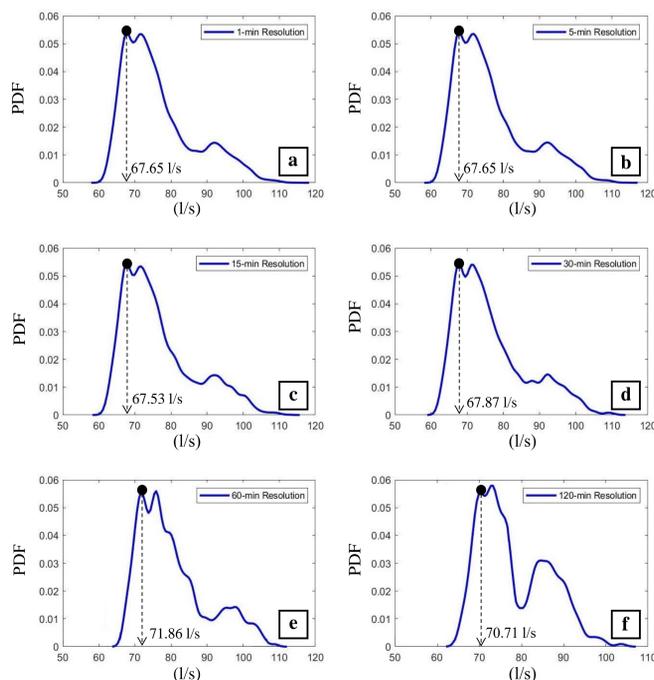


Figure 1. Illustration of the ePDFs obtained from the flow timeseries averaged at different temporal resolutions $D = 5, 15, 30, 60$ and 120 min (panels (a) – (f), respectively). Black circle marks highlight the lowest PDF modes.

4. Results

We further investigate the robustness of the developed

approach via a thorough application to 62 PMAs of the WDN of Patras. Figure 2 illustrates the obtained point MNF estimates of the current method, plotted against those obtained in our previous work (Serafeim et al., 2021), which lie along the 1-1 line, indicating that the two methods converge to very similar results regardless the resolution of the available data.

Figure 3 presents a map of the 62 PMAs analyzed, where MNF estimates are illustrated using a color scale with 8 classes (the 8th class corresponds to PMA “Kentro”).

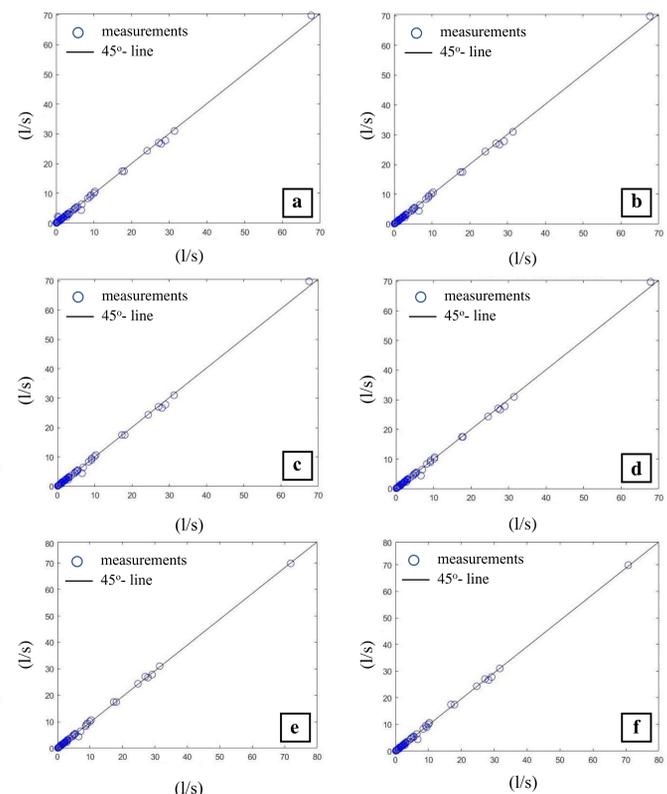


Figure 2. Scatter plot of the point MNF estimates, as obtained from Serafeim et al. (2021) (y - axis), and the current approach (x - axis) for different temporal resolutions $D = 5, 15, 30, 60$ and 120 min (panels (a) – (f)).

5. Conclusions

The proposed methodology produces robust MNF estimates independently of the nominal resolution of the flow data. It is intuitive and easy to implement, can be applied to any WDN (regardless of its condition and characteristics) and can serve as a useful engineering tool to estimate water losses in WDNs.

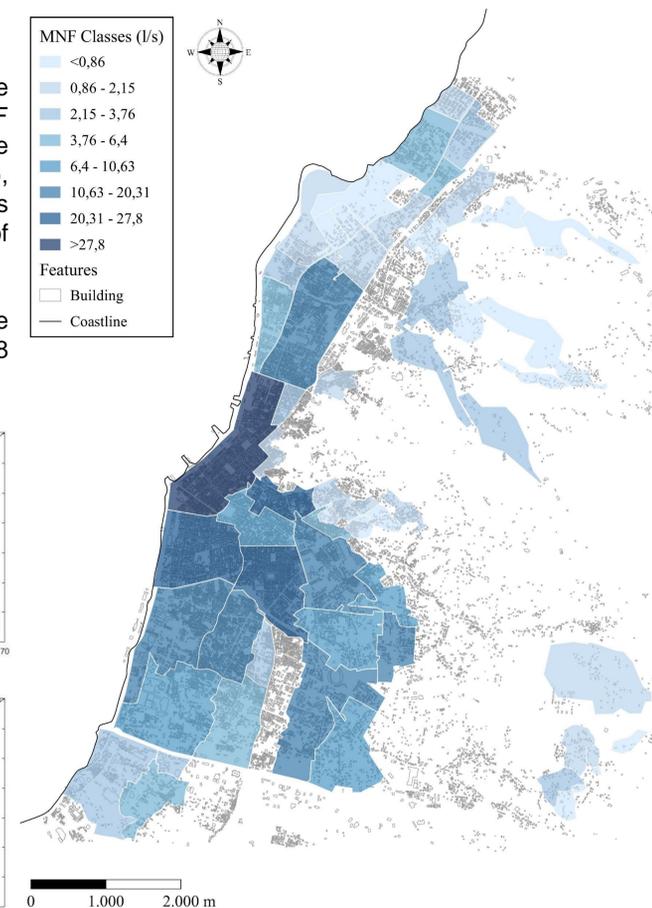


Figure 3. Map of the 62 PMAs analyzed, where MNF estimates calculated using the lowest mode approach are illustrated using a color scale with 8 classes.

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References

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