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Feasibility of mass balance approach to Water Distribution Network model calibration

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Abstract

The increase of real water losses in water distribution networks (WDNs) is worrisome for social community and water utilities. Nowadays, enhanced WDN hydraulic models allow simulating pressure-dependent background leakages, thus, being of direct relevance to support water loss reduction actions. Unfortunately, traditional calibration approaches rely on demand-driven analyses and do not account for additional parameters of the pressure-dependent background leakage models. This work proposes a novel framework for calibrating enhanced WDN models which permits to pursue mass-balance (matching of flow observations at water sources) by accounting for pressure-dependent water demand components and demand patterns. At the same time, energy balance (matching of pressure observations) allows to get the realistic prediction of all water demands and background leakages. The novel calibration strategy involves the simultaneous estimation of pipe hydraulic resistances, parameters of the background leakage model and relevant customer demand patterns. The feasibility of the strategy is demonstrated on a real WDN located in Southern Italy.

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Keywords: Water distribution networks; WDN models; calibration; background leakages

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1. Introduction

Nowadays, leakages from water pipelines entail waste of water and energy resources and are a major issue in water distribution networks (WDNs) management, since they reduce system capacity under normal operating conditions and

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exacerbates possible water scarcity scenarios, e.g. due to socio-economic factors and/or climate changes. Besides, high rates of *background leakages*, representing the largest figure of annual water loss volume from WDN, are usually associated with increasing number of major pipe failures (i.e. *bursts*), which might cause service disruptions and third party damages. Accordingly, the effective management of WDNs for background leakage reduction is strategic for the social communities and water utilities.

In this context, WDN hydraulic models are crucial since they allow analysing the status of such systems in order to assess the impact of planning and management actions. Accordingly, the more accurate WDN hydraulic models, the more effective for supporting technical actions. The model calibration “consists of determining the physical and operational characteristics of an existing system and determining the data that when input to the computer model will yield realistic results” [1].

Traditionally, WDN models were mainly used to support the design of new water supply systems and/or to verify the WDN hydraulic capacity under some assigned service conditions (e.g. in order to verify sufficient pressure at hydrants for firefighting purposes). From such perspective, WDN model calibration mainly aimed at getting accurate prediction of pipe head-losses and the calibration “inverse problem” was originally formulated as the assessment of model parameters (i.e. pipe hydraulic resistances) that maximize the matching between pressure measured at sampling nodes and pressure values obtained from model run. Such approach exploited the classic demand-driven analysis (DDA) since the assigned service conditions were represented by nodal demands independent on current pressure status. A comprehensive literature review of the WDN model calibration methods based on such a traditional approach is reported in [2]. Unfortunately, all these methods completely neglected pressure-leakage relationship, thus making the resulting model not effective for supporting the management of existing WDNs.

Since the last decades of nineties, the main technical interest of water utilities moved from designing water supply systems *ex novo* to supporting management decisions on systems that were built right after the World War II and were progressively facing asset deterioration. In addition, the growing consideration of water and energy resources in recent years motivated the development of sustainable WDN operations in terms of environmental (i.e. carbon footprint), social and economic impact. This new technical context posed the challenge of more realistic hydraulic models that should overcome the limitations of classic WDN modelling, as mentioned in the special session “The Open Source Epanet project” at CCWI 2015 conference (www.water-system.org/ccwi2015). In fact, the WDN hydraulic models have to simulate both normal working conditions and pressure deficient scenarios that occur in real systems in consequence of increasing demands (e.g. due to socio-economic and climate changes), asset deterioration (e.g. increase of pipe hydraulic resistance due to ageing), system failures (e.g. pipe bursts) and/or background leakages (e.g. [3]).

Nowadays, a new generation of enhanced WDN models is available to perform pressure-driven analysis (PDA) (e.g. [4]) of all demand components including background leakages (e.g. [5][6]). Therefore, the calibration problem of the enhanced WDN models cannot be limited to estimating pipe hydraulic resistances, but should include the assessment of additional parameters, like those of the *background leakage* model.

In fact, differently from DDA where pipe flow rates are determined by fixed nodal demands, in PDA flow rates depends on current nodal pressure according to the pressure-dependent relationships used for modelling customer demand and *background leakages*. Consistently, the accurate prediction of head-losses along pipes depends on both pipe hydraulic resistances and nodal water demands that, in turns, depends on pressure. Consequently, the calibration of the enhanced WDN models should pursue both energy balance, i.e. the matching between measured and simulated nodal pressures, and mass-balance, i.e. matching between measured and simulated pipe flow rates due to the pressure-dependent demand components and demand patterns.

From such perspective, pressure measurements are used to get the realistic simulation of *background leakages and demand patterns*, besides providing information for estimating pipe hydraulic resistances; flow measurements allow driving the realistic prediction of water volumes circulating through the system. The latter aspect is actually of primary importance for understanding current system behaviour, identify areas with higher background leakages for allocating works and, eventually, use the calibrated model for prompt detection and identification of pipe bursts.

As reported for traditional calibration of hydraulic models [7], in order to increase the robustness of the calibration procedure and avoid a mere error-compensation, it is mandatory to consider a set of several independent steady-state observations of flow and pressure as well as the extended period simulation (EPS) of the network [8]. Therefore, the mass-balance calibration presented herein is based on the EPS using some time patterns of customer demands. Actually, the distribution of customers’ demands in space and time is a major driver of WDN hydraulic status but