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A two-stage calibration for detection of leakage hotspots in a real water distribution network

Sophocles Sophocleous[a*], Dragan A. Savić[a], Zoran Kapelan[a], Orazio Giustolisi[b]

[a]*Centre for Water Systems, University of Exeter, North Park Road, Exeter, EX4 4QJ, UK*
[b]*Dept. of Civil Engineering and Architecture, Technical Univ. of Bari, Via E. Orabona 4, 70125, Bari, Italy*

Abstract

The paper presents a two-stage approach for solving a calibration-based problem for the ultimate purpose of detecting leakage hotspots. This is compared with a one-stage approach. A Genetic Algorithm is used to solve optimization problems of searching for calibration parameters values, while minimizing the differences between observations and model predictions. The approach takes into account suspect valves with unknown status, as well as pipes with incorrect roughness values and nodal leakage. The methodology also takes advantage of a new approach to reducing solution search space size for the optimisation problems. These problems are then solved for different leakage scenarios. Artificial calibration data are generated by means of hydraulic modelling employed to mimic planned hydrant discharges during a low demand period, combined with step tests. The case study demonstrates the improved leakage detection and model calibration of the two-stage calibration approach relative to the one-stage approach, which considers all calibration parameters together. This can result in a useful practical network operation tool.

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1. Introduction

Leakage from Water Distribution Networks (WDNs) is becoming a great concern for water utilities around the

* Corresponding Author. Tel: +44(0)7927 928661.
E-mail address: ss694@exeter.ac.uk

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world. Quantifying and localizing leaks within WDNs is of significant importance to a water company. However, the whole leakage detection process may still have shortfalls in speed of detections with a significant volume of water being lost before the leak is found. To avoid these inconveniences, leakage detection based on mathematical models may be used by “comparing” and analysing the network monitoring data, with the network model simulated outputs.

Currently, the calibration of hydraulic models is based on trial-and-error adjustments for pipe friction factors and nodal demands, due to the lack of major advances from the practitioner’s perspective. This is to simulate pressures within an accuracy of ±1 metre relative to observations [1], which is too coarse criterion for supporting operational work at the distribution mains level. This is a result of system and data anomalies associated with accidentally left closed (or open) valves, which are unreported in the Geographic Information Systems, incorrect pipe state information and undetected leaks, which cause a considerable effect on how accurately can the model simulate WDN hydraulics. Sophocleous et al. [2] suggested that a calibration process combining smarter field testing along with staged optimization analyses can provide a promising solution to solving such complex problems. Here, an improved two-stage optimisation-based calibration approach is applied to a real WDN for the ultimate purpose of detecting leakage hotspots, supported by improved reconciliation of observed pressure and flow data collected during night fire flow field tests. The staged approach is then compared to a one-stage calibration method. Both approaches take into account candidate unknown status valves, pipes with incorrect roughness values and suspect leakage nodes. Different leakage scenarios are tested for each of the two approaches to determine the number of leaks that best represents losses within the WDN. Using a preliminary topological analysis and sensitivity-based methods the search for leakage hotspots in the network is reduced, simplifying the calibration problem. Then, optimisation analyses are carried out. The paper is organized as follows: section 2 provides literature review on calibration-based leakage detection, section 3 describes the two-stage calibration approach and the search space reduction method, section 4 presents the case study, section 5 discusses the calibration results and compares between the one- and two- stage approaches, followed by conclusions.

2. Background

Model-based studies for the detection of leakage hotspots in WDNs have always attracted significant attention in water systems research. A variety of techniques, including inverse transient analysis, Bayesian identification method and belief-rule-based expert system have been applied to locate leaks with inverse transient modelling being the most attractive research area. More recent developments include non-transient model-based leakage detection techniques, which analyse the difference between measurements and estimated values from leaky scenarios to signal the probability of a zone to contain leakage. However, some of these model-based methodologies assume the hypothesis of a single leak in the network [3]. Calibration-based methods can leverage steady state hydraulic models and optimisation tool technology, such as Genetic Algorithms (GAs), to improve on the detection of leaks. Wu et al. [4] calibrated leakage as a pressure-driven demand using a competent GA. Similarly, Sage [5] carried out leakage hotspot optimization analyses in a real system using a pressure-dependent calibration-based method, suggesting that leakage detection accuracy was significantly affected by the sizes and ranges of the demand, pipe roughness and valve status groups. This comes into opposition with the current modelling assumptions with respect to valve location and status, which compromise existing calibration methods. Traditional calibration methods assume that the network topology associated with closed/open valves is perfectly known, but in reality this is uncertain. Wu et al., [6] highlighted the imperative need of determining the status and/or settings of valves, in order to adequately calibrate a WDN model, especially for those valves on critical flow paths. Walski et al., [7] recommended practical methods for field measurements collection, in order to improve model calibration by finding leaks and the correct status of valves in the network. Furthermore, additional errors in model calibration for leakage detection can result from incorrect pipe roughness values, as a result of custom-and-practice approaches that do not take uncertainty into consideration (Alvisi and Franchini [8]). Sophocleous et al. [2] implemented a two-stage calibration-based approach on a real WDN model, considering unknown valve status detection and leakage localization. The inclusion of field test planned hydrant discharges and concurrent tactical valve operations demonstrated an improved detection of unknown status valves and subsequently more accurate pipe roughness values and leakage hotspots.