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# A Simulation-Optimization Approach for Reducing Background Leakage in Water Systems

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**Abstract**

This paper forms an entry to the battle of background leakage assessment for water networks (BBLAWN). The proposed methodology for this problem is a sequential assessment of intervention types. In an initial stage, a diagnosis of the network is performed through simulating its hydraulic behaviour with no infrastructure or operational modifications. An optimization technique is developed to recommended improvements of a particular type, such as pipes to replace. These techniques are applied sequentially to yield a list of suggested improvements for the network. Our approach requires a hydraulic model that simulates background leakage, custom implementations of heuristic algorithms and optimization solvers.

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*Keywords:* water networks; background leakage; optimization

## 1. Introduction

Water loss from leaking pipes is a growing problem for aging infrastructure systems. As pipe networks within cities reach the end of their useful life, utilities face complex decisions about investment and operation for these systems. An especially pressing problem for older water networks is background leakage–a pressure dependent loss of water from the system that is always present. In an effort to assemble methods for controlling background leakage, the Water Distribution Systems Analysis Conference held in Bari, Italy, July 2014 is hosting the "Battle of background leakage assessment for water networks (BBLAWN)'. This paper and related materials comprise an entry to the competition.

The BBLAWN problem is to propose a methodology for recommending changes to the design and operation of a water distribution system to minimize total expenditure while meeting service requirements. Operational costs include energy for pumping on a time of use tariff and a penalty for water lost to background leakage. Design options include replacing or paralleling existing pipes, installing pressure reducing valves, adding storage capacity, and adding pumps. A summary of the problem statement is given in Table 1; complete information is provided in [1].

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The following sections describe a method to assess and control background leakage on water networks. The methodology is first described at a high level and then individual elements are treated in more detail. One notable contribution is a new simulation approach for water networks with background leakage based on fixed-point iteration. A simulator implementing this technique is combined with an optimizer to set tank levels and to choose pipes for replacement. A mixed-integer non-linear programming formulation of the PRV placement problem is given. Results obtained by applying the methodology on the challenge problem are described next. Through a combination of operational and design changes, the annual cost of the C-Town network is reduced from 3.9 to 1.45 million Euro.

**Nomenclature**

| | |
|---|---|
| $d_i$ | water demand at node i [L/s] |
| $e_i$ | elevation at node i [m] |
| $h_f$ | frictional head loss [m] |
| $h_p$ | head added by a pump [m] |
| $p_i$ | pressure at node i [m] |
| $v_k$ | valve indicator for pipe $k$ [$\in \{0, 1\}$] |
| $Cd$ | Epanet emitter discharge coefficient |
| $d_k^{\text{leaks}}$ | background leakage along pipe $k$ |
| $\alpha_k$ | Leakage coefficient of pipe $k$ [-] |
| $\beta_k$ | Leakage coefficient of pipe $k$ [$m^{2-\alpha/s}$] |
| $D_k$ | Pipe diameter [m] |
| $L_k, L$ | Pipe length [m], or the set of links |
| $M$ | Big M constant |
| $N_n$ | Number of nodes in the network |
| $N_p$ | Number of pipes in the network |
| $N_v$ | Number of valves in the network |
| $P$ | set of pumps |
| $Q$ | Flow rate [$m^3$/s] |

## 2. Methods

### 2.1. Overall solution methodology

The solution methodology proposed here decomposes the overall problem into smaller more tractable problems aimed at a single type of decision. Examining each problem individually has the advantages of simplifying implementation of software and interpretation of results and allowing parts of the problem to be examined in parallel. The disadvantage of such a decomposition is that interactions between decisions may not be optimal. The proposed solution methodology proceeds through several steps:

1. Simulate the network using pump control levels based on engineering judgement
2. Select locations for new pressure reducing valves using mixed integer non-linear programming
3. Choose pipes to replace or re-size by simulation-optimization
4. Adjust pump control levels by simulation-optimization
5. Manually check pump replacements and tank additions
6. Re-run the level control optimization to ensure feasibility
7. Perform a final feasibility check

These steps examine design and operational changes to reduce the long-term cost of water distribution. In the existing system, background leakage comprises the majority of costs and so leakage reduction is prioritized. Pressure reducing valves, being inexpensive relative to pipe replacements are treated first. Next, the replacement and resizing of