17th International Computing & Control for the Water Industry Conference
1-4 September 2019, Exeter, United Kingdom

# Optimal location and setting of time modulated PRVs for water loss reduction with leakage modelling by pressure driven analysis

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**Keywords:** Pressure management, Simulated Annealing, Water distribution network, Water losses

## EXTENDED ABSTRACT

### Introduction

Water losses have economical, technical, social and environmental negative impacts and so water companies are always willing to reduce them [1]. The IWA Water Loss Task Force identified four main control strategies to reduce real losses [2]: 1) infrastructure management; 2) pressure management; 3) active leakage control; and 4) speed and quality of repairs. Unreported leaks and background leakage usually represent a major component of water losses and pressure management is an effective, easy, economic and quick solution to reduce it. Pressure management can be implemented by introducing Pressure Reduction Valves (PRVs): fixed-outlet; time-modulated; flow-modulated and pressure-modulated. For a fixed-outlet PRV there is a single working condition (pressure downstream of the PRV is always the same). For a time-modulated PRV there can be several working conditions (for instance, a lower pressure during the night period - from 0 to 6 am, and higher one during the remainder of the day). The flow-modulated and pressure-modulated PRVs are more efficient because they constantly try to adjust the working conditions to reach the minimum pressure required at the critical node. However, pressure management projects must be preceded by specialized studies (identify the optimal location and settings of the PRVs to install) and cost benefit analysis (assessment of economic viability). A previous work [3] [4] [5] presented a methodology to help in those tasks, by identifying the optimal location and setting of fixed-outlet PRVs to reduce water losses in WDNs and maximize the NPV of pressure management projects. Now the methodology was extended to include also time modulated PRVs and this paper presents the results obtained for a hypothetical case study.

### Methods and Materials

The main goal of the methodology is to identify the best locations and settings of PRVs to reduce water losses. It is assumed that there is an accurate model of the WDN and the process starts by entering all the possible locations for the PRVs (pipe number and upstream/downstream section) and supplying a list of unit costs for those PRVs, which will be used to assess the project cost. The core of the methodology is an optimization model which is solved by a Simulated Annealing algorithm. The objective function NPV(X) maximizes the NPV of the differences between the economic benefits from pressure management (reduction of water losses) and the total implementation costs (PRVs), for a given project plan, equations (1) to (3):

$$\text{Maximum } NPV(X) = -C(X) + B(X) \cdot \frac{(1+intR)^{ny}-1}{intR \cdot (1+intR)^{ny}} \quad (1)$$

$$C(X) = \sum_{m=1}^{nPRV} \left[ CPRV_m \left( DPRV_m \right) \right] + \sum_{v=1}^{NV} \left[ viol_v \cdot \beta_v \right] \quad (2)$$

$$B(X) = 365 \cdot \left[ \Delta V_{WL} \cdot Cw \right] \quad (3)$$

where $NPV(X)$ = objective function or NPV of the project (€); $X$ = solution of the Simulated Annealing algorithm; $ny$ = number of years for a given project plan (years); $B(X)$ = annual economic benefits (€); $C(X)$ = total investment costs at the beginning of the project plan (€); $intR$ = annual interest rate (%); $\Delta V_{WL}$ = difference between the water losses before and after pressure management (m$^3$); $Cw$ = cost of water (€/m$^3$); $nPRV$ = total number of active PRVs; $CPRV_m(DPRV_m)$ = cost of the PRVs (€/unit); $DPRV_m$ = PRV diameter (mm); $NV$ = number of constraints violations; $viol_v$ = maximum violation for the constraint $v$; $\beta_v$ = unit cost of penalty for violation $v$.

Leakage assessment is performed by the pressure driven analysis module from WaterNetGen [6]. Demand is considered as pressure independent (it is assumed that there are adequate pressure conditions) and leakage as pressure dependent. Knowing that leakage occur usually in distribution mains and service connections, based on the average pressure, the estimate for leakage in a pipe is given by equation (4):

$$Qleak = C \cdot L \cdot P^{N1} \tag{4}$$

where $Qleak$ = leakage flow in the pipe; $C$ = coefficient that depends on the physic characteristics of the pipe; $L$ = length of the pipe (m); $P$ = average pressure in the pipe; $N1$ = pressure/leakage relationship exponent for the pipe.

The optimization model is solved by a Simulated Annealing algorithm. At the initial temperature ($T_0$), the algorithm starts by generating an initial solution ($X_0$), which corresponds to assign the settings to each PRV in the network. At the following temperatures the objective function is minimized to obtain the maximum benefits yielded by pressure management for a given project plan. The number of candidate solutions ($L_k$) generated at each temperature ($T_k$) varies according to the percentage of solutions accepted at the last temperature ($Pa_{k-1}$). Each new candidate solution is generated from the current solution by randomly applying the following sequence: 1) randomly select a PRV from the network; and 2) randomly adjust one of the settings of the PRV (a little adjustment of the downstream pressure of the PRV is required: $\pm\ \Delta H_{PRV}$=1.0 m). For each solution, the pressure driven simulation model is used to predict the network hydraulic behaviour under different pressure conditions and equation (1) is used to evaluate the NPV for the new solution. The new solution is accepted or not, according to the Metropolis criterion. If it is accepted, this solution becomes the current solution and will be used to produce the next candidate solution. If not, the original current solution will be used. The algorithm ends if the stopping criteria is reached, that is, for two successive temperatures the number of solutions accepted remains lower than 5% and there was no improvement.

**Results and Discussion**

The WDN used in the case study has 3 PRVs and 7 new locations were suggested, from which the methodology can choose the best. In the present conditions the WDN is losing 482.99 $m^3$/day - 241.50€/day (9.7% of the system input volume). Although this is already a quite low level of water losses, by considering 7 new fixed-outlet PRVs the methodology was able to reduce water losses to 316.45 $m^3$/day - 158.23€/day (6.6% of the system input volume). As the new PRVs cost was 80,880€ and the daily benefit was 83.27€, it is expected a payback time of about 32 months. But it must be highlighted that by giving the option of using time modulated PRVs the methodology is able to reduce water losses even further, as it will be presented in the final version of the paper.

**Conclusions**

Water losses are a major concern for water utilities and pressure management can be of great help in managing this problem. This paper will present a methodology intended to identify the optimal location and setting of time modulated PRVs to reduce water losses in WDNs and maximize the NPV of pressure management projects. The results obtained for a case study, in which water losses already presented a low level (9.7% of the system input volume), showed that the methodology is able to produce very interesting solutions to reduce water losses, by considering the use of fixed-outlet or time modulated PRVs.

**Acknowledgements**

This work was supported by Foundation for Science and Technology of Portugal, Key Project of UID/Multi/00308/2019

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