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Finding economic optimality in leakage reduction: a cost-simulation approach for complex urban supply systems

D. Deidda[a], G. M. Sechi[b*], R. Zucca[b]

[a]Abbanoa s.p.a., viale Diaz 77, Cagliari, 09125, Italy
[b]University of Cagliari, via Marengo 2, Cagliari,09123, Italy

Abstract

The optimal economic level in leakage reduction must be defined when reaching equilibrium between marginal costs of saved water and marginal costs of achieving additional reduction in leakage (Farley and Trow, 2003). This concept is used to deal with the question of what the target in reducing leakage should be and how related costs can be justified. Nevertheless, when negotiating for optimal decisions considering complex multi-centre (or multi-district) supply systems, subject to reduced water resources and reduced funds, the problem could be much more difficult to define and analyze. Mainly, in this situation, the optimal economic problem can be modified in finding the priorities in investment for leakage reductions between the centres in the supply network. This paper is related to these aspects; it mainly focuses on finding a reliable and correctly justified cost-function attribution for the water in multi-source and multi-centre systems.

Keywords: Leakage reduction; Complex supply systems; Cost-simulation.

1. Introduction

As is well known, the concept of optimal economic levels in leakage reduction can be defined when reaching equilibrium between marginal costs of the saved water and marginal costs of achieving an additional reduction in leakage (Farley and Trow, 2003). This economic level of leakage is that at which any further reduction would incur costs in excess of the benefits derived from the savings (Lambert and Lalonde, 2005). The current thinking on

* Tel.: +39 070 6755314; fax: +39 070 6755314.
E-mail address: sechi@unica.it

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optimal economic level is that each and every activity aimed at reducing leakage follows the *law of diminishing returns*, meaning 'the greater the level of resources employed, the lower the additional marginal benefit which results' (Pearson and Trow, 2005). The optimal level must consequently be settled within the context of the supply–demand balance for water. Frequently, the optimal-level concept is used to deal with the question of what the target should be in reducing leakage and how related costs can be justified. Nevertheless, when negotiating optimal decisions considering complex multi-centre (or multi-district) supply systems, the problem could be much more difficult to define and analyse, particularly if the system is constrained by reduced water resources and reduced funds. All in all, in this situation, the optimal economic problem can be modified in finding the priorities in investment for leakage reductions between centres in the supply network.

This paper is related to these aspects; it mainly focuses on finding a reliable and correctly justified cost-function definition for the supplied water in real and complex multi-centre systems. A graph-optimization approach is used to define optimal flows of water from sources to demand nodes in the supply system (Ahuja et al., 1993, 1999). The demand nodes can represent homogeneous district-distribution systems, or even different urban centres, connected in the supply system represented by the graph. A Cost-Simulation procedure is then developed, in order to define the incremental behaviour of water cost along the paths connecting each demand node to supply nodes. This procedure can be considered as a development for multi-centre urban supply systems with the approach used in Deidda (2003) to determine cost-flows in multi-reservoir systems. To optimize flows in the network and retrieve the min-cost flow distribution, the Cost-Simulation procedure is linked to the WARGI optimization DSS (Sechi and Zuddas, 2000; Manca et al., 2004; Sulis and Sechi 2012).

2. The Cost-Simulation procedure in water supply systems

Finding a reliable and correctly justified cost function of the water and dealing with optimization of economic levels of leakage in complex multi-centre systems is the main aim of this work. Using flows retrieved by the simulation model, the incremental cumulative evaluation of water costs are estimated along the paths coming from supply nodes to demand nodes in the graph of the supply system. At the end, it is possible to evaluate the water production costs related to each demand and to define the marginal benefits in saving water in order to find priorities in leakage reduction investments between demand centres.

Synthetically, the Cost-Simulation procedure can be summarized in four steps:

1. Water system definition and analysis;
2. Graph-based simulation modelling using WARGI;
3. Cumulative cost evaluation in the supply graph;
4. Incremental benefits and investment priorities evaluation for leakage reductions.

In the first step the hydrological, hydraulic, infrastructural, economic and functional features of the water-supply system are defined. Then, in the second step, the supply system is represented as an oriented graph using the input graphical interface of the simulation model WARGI-SIM (Sechi and Zuddas, 2000; Manca et al., 2004; Sulis and Sechi, 2012). WARGI-SIM retrieves optimal flows in the graph by considering the water system's priority and preference management rules. From simulation output and the economic data of water infrastructures, the procedure's third step evaluates the incremental cumulative of water costs along the paths connecting each supply-node to each demand-node. In this way, the water unitary production cost related to each demand node is retrieved. In the final step, priorities in investment are defined for leakage reductions in the supply system. Each step of the procedure will be described hereafter.

2.1. Water system definition and analysis

The hydrological, hydraulic and infrastructural features of the water system must first be identified. The analysis takes place in a management optimization context for the supply system and no new transfer works, treatments or special repairing expenses are considered, so no more than the usual management and ordinary repair