Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 89 (2014) 118 – 125

Procedia Engineering

www.elsevier.com/locate/procedia

16th Conference on Water Distribution System Analysis, WDSA 2014

Evolutionary Computation-Based Decision-Making Framework for Designing Water Networks to Minimize Background Leakage

M.E. Shafiee[a], A. Berglund[b], E. Zechman Berglund[a]*, E. Downey Brill Jr.[a], G. Mahinthakumar[a]

[a]*Department of Civil, Construction, and Environmental Engineering, North Carolina State University, Raleigh, NC 27695*
[b]*Dewberry, 2301 Rexwoods Drive, Suite 200, Raleigh, NC 27607-3366*

Abstract

This research minimizes the impact of leaks on the operation of the system to reduce lost water while meeting typical management goals. A genetic algorithm approach is implemented within a high-performance computing platform to select tank sizes, pump placement and operations, placement of pressure control valves, and pipe diameters for replacing pipes. It identifies solutions that minimize water loss, operational costs, and capital costs, while maintaining pressure at nodes and operational feasibility for tanks. Multiple problem formulations are solved that use alternative objective functions and allow varying degrees of freedom in the decision space. The methodology is demonstrated to identify a water distribution system re-design for the C-Town case study.

Peer-review under responsibility of the Organizing Committee of WDSA 2014

Keywords: genetic algorithm; water distribution system design; rehabilitation; infrastructure management

---

1. Introduction

Water distribution systems are designed to deliver a reliable supply of water to meet the water demands of municipal customers. Frequent occurrence of leaks and bursts in a network can lead to significant water and revenue loss and may indicate overall poor health of a water system. Leakage typically leads to service interruptions, inefficient consumption of energy and water resources, and vulnerabilities in the network to pathogen intrusion [1]. Background leakages can be managed and minimized by replacing leaky pipes, optimizing tank and pump operations, and

---

* Corresponding author. Tel.: +1-919-515-2338; fax: +1-919-515-7908.
E-mail address: emily_berglund@ncsu.edu

Peer-review under responsibility of the Organizing Committee of WDSA 2014
doi:10.1016/j.proeng.2014.11.167

maintaining low pressures in a network through installing pressure control valves. Utility budgets, however, may limit the design of infrastructure improvements and the volume of non-revenue water that can be recovered. This research develops an evolutionary algorithm-based approach to explore tradeoffs among municipal water infrastructure management goals, including minimization of water loss, energy consumption, and costs of capital improvements. A genetic algorithm is coupled with a water distribution system model and implemented within a high performance computation platform. The methodology is applied to explore infrastructure designs for an illustrative case study, C-Town.

2. Methodology

This research explores a genetic algorithm-based approach to minimize water loss by extending a simulation-optimization framework that was developed to explore infrastructure improvements for network expansion [2]. The original framework is based on a genetic algorithm that is written in Java and calls functions from the EPANET toolkit [3] to simulate hydraulics in a network. The framework is implemented on a parallel cluster and was modified in this research. Research efforts incorporated additional functions from the EPANET toolkit for manipulating pressure control valves and created new functions for calculating hydraulics based on leakage across pipes.

2.1. Problem formulation: Objective function

The design problem is formulated as an optimization problem as follows:

$$Minimize\ C_{Tot} = \alpha C_{WL} + \beta C_c + \gamma C_E + V \tag{1}$$

$$V = \begin{cases} +\infty\ if\ violations > 0 \\ 0\ otherwise \end{cases} \tag{2}$$

where C_{Tot} is the total cost that should be minimized. Variables α, β, and γ are weights that are applied to three performance measures, cost of water loss (C_{WL}), cost of capital improvements (C_c), and cost of energy for pumping water (C_E). Each cost is represented as an annual cost (€). The variable *violations* is the number of violations that occur in a one-week hydraulic simulation of one solution, and violations are tallied based on pressure and tank constraints. Violations occur if nodal pressure falls below 20 *m* at nodes where demands are exerted, and if nodal pressure falls below 0.0 *m* at zero-demand nodes. Tank constraints specify that at the last time step of the one-week simulation, the level of water in each tank should be at or above the initial tank level at the first time step of the simulation; otherwise, a violation occurs. A violation is also triggered if a tank drains completely during a simulation. If the number of violations in the system is greater than zero, V is set to a large number.

The cost of energy is calculated based on the amount of energy used to operate pumps and the hourly rate of electricity, provided in the problem description [4]. The annual cost is calculated as the product of the weekly cost and number of weeks per year (52). The cost of capital improvements is calculated based on the replacement of existing pipes, addition of new pipes parallel to existing pipes, expansion of elevated tanks, replacement of existing pumps, addition of new pumps at existing pump stations, and addition of pressure reducing valves (PRV). Cost data for capital improvements are provided by [4] as annual cost.

For any solution, water loss is calculated by executing hydraulic simulation of the network twice. In the first simulation, new demands are calculated for every hourly time step at each node to represent the effects of background leakage, using the approach specified by [4]. The second simulation sets the new hourly demands at each node to represent water lost to leakage and re-calculates the hydraulics in the network. Based on preliminary investigations, two executions of the hydraulic simulation are sufficient to accurately represent leakage as demands at nodes. The volume of water loss is simulated for one week and converted to an annual cost, based on a unit cost of 2 €/m^3.