Chapter 16
Evolutionary Computation for Single and Multiobjective Water Distribution Systems Optimal Design:
Review of Some Recent Applied Methodologies

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ABSTRACT

Water distribution systems least cost pipe sizing/design is probably the most explored problem in water distribution systems optimization. Attracted numerous studies over the last four decades, two main approaches were employed: decomposition in which an “inner” linear programming problem is solved for a fixed set of flows/heads, while the flows/heads are altered at an “outer” problem using a gradient or a sub-gradient type technique; and the utilization of an evolutionary optimization algorithm (e.g., a genetic algorithm). In reality, however, from a broader perspective the design problem is inherently of a multiobjective nature incorporating competing objectives such as minimizing cost versus maximizing reliability. This chapter reviews some of the literature on single and multiobjective optimal design of water distribution systems and suggests a few future research directions in this area.

INTRODUCTION

A water distribution system (WDS) is a collection of hydraulic control elements connected together to convey quantities of water from sources to consumers. Such a system can be described as a graph with the nodes representing the sources and consumers, and the links - the connecting elements: pipes, pumps, and valves. The behavior of a WDS is governed by: (1) the physical laws which describe flow and pressure distributions; (2) the consumer’s demands; and (3) the system layout.

The common definition of the single objective optimal design problem of a WDS is to find its component characteristics (e.g., pipe diameters, pump heads and maximum power, reservoir stor-
age volumes, etc.) which minimize the systems capital and operational costs such that the system hydraulic laws are maintained (i.e., Kirchoff’s Laws No.1 and 2.), and constraints on quantities and pressures at consumer nodes are fulfilled.

From a wider perspective the design problem of a WDS involves competing objectives, such as minimizing cost, maximizing reliability, minimizing risks, minimizing deviations from specific targets of quantity, pressure, and quality, etc. The design problem is thus inherently of a multiobjective nature. In a multiobjective optimization framework there is not a single optimal solution but a set of compromised solutions which form a Pareto optimal solution set. Incorporating multiple objectives in the optimal design of water distribution systems provides an improvement compared to using a single design approach as a larger range of alternatives is explored, thus making the design outcome more realistic.

The problem of water distribution systems optimal design has attracted numerous studies over the last four decades concentrating mainly on the single least cost objective problem. Only recently multiobjective schemes have been proposed to tradeoff competing objectives for water distribution systems optimal design.

This chapter reviews some of the literature on single and multiobjective optimal design of water distribution systems and suggests some future research directions in this area.

**BACKGROUND**

This section is a brief literature review on a number of single and multiobjective optimal design studies of water distribution systems.

**Single Objective Water Distribution Systems Optimal Design**

Water distribution systems design is the phase in which the sizes and characteristics of the components of a water distribution system are selected for a given system layout. The single objective design problem is commonly defined as finding the water distribution systems component characteristics: pipe diameters, pump heads and maximum power, and tanks storage which minimize the total system cost, such that constraints at the consumer nodes are fulfilled and hydraulic laws are maintained.

Numerous models for least cost design of water distribution systems have been proposed during the last four decades. A possible classification for those is into four major categories:

**Decomposition**

Methods based on decomposing the problem into an “inner” linear programming problem which is solved for a fixed set of flows (heads), while the flows (heads) are altered at an “outer” problem using a gradient or a sub-gradient optimization technique (e.g., Alperovits & Shamir, 1977; Quindry et al., 1979, 1981; Kessler & Shamir, 1989; Eiger et al., 1994; Ostfeld & Shamir, 1996).

Mathematically, decomposition is the split of an optimization problem as described in Equation (1) to the form presented in Equation (2):

\[
\min_{x \in \mathbb{R}^n, y \in \mathbb{R}^m} f(x, y) : x \in X, y \in \Omega(x) \tag{1}
\]

\[
\min_{x \in X} h(x) = \min_{y \in \Omega(x)} f(x, y) \tag{2}
\]

where: \(x \in \mathbb{R}^n, y \in \mathbb{R}^m\) = decision variables; \(f(x, y), h(x)\) = objective functions; \(X\) = a nonempty subset of \(\mathbb{R}^n\); \(\Omega(x)\) = a nonempty subset of \(\mathbb{R}^m\) defined in Equation (3), where \(g_i(x, y) = \text{the } i\text{-th constraint, and } p = \text{total number of constraints.}\)

\[
\Omega(x) = \left\{ y \in \mathbb{R}^m : g_i(x, y) \leq 0 \quad i = 1, \ldots, p \right\} \tag{3}
\]