

# Speeding up stochastic analysis of bulk water supply systems using a compression heuristic

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## ABSTRACT

It is possible to analyse the reliability of municipal storage tanks through stochastic analysis, in which the user demand, fire water demand and pipe failures are simulated using Monte Carlo analysis. While this technique could in principle be used to find the optimal size of a municipal storage tank, in practice the high computational cost of stochastic analyses made this impractical. The purpose of this study was to develop a compression heuristic technique to speed up the stochastic analysis simulations. The compression heuristic uses a pre-run to characterise the failure behaviour of a tank under demand-only conditions, and the stochastic simulations are then only run for periods in which fire demand or pipe failures affect the tank. The compression heuristic method was found to be accurate to within 5% of the full stochastic analysis method. The compression heuristic was also found to be faster than the full stochastic method when more than 27 systems were analysed, and thus allowed genetic algorithm optimisation to be practical by reducing the optimisation simulation time by 75%.

**Keywords:** stochastic analysis; Monte Carlo; optimisation; genetic algorithm; reliability

## INTRODUCTION

Stochastic analysis is a technique whereby the deterministic and probabilistic parameters of a system are simulated to model its behaviour more accurately. Stochastic modelling is often used to analyse complex systems in which risk and uncertainty are significant, and where components are subject to stochastic failures (Yang et al., 1996). This technique is relatively new to water distribution systems, even though it has long been used in fields like hydrology (Thomson et al. 1997; Cui and Kuczera, 2003). Work on the application of stochastic analysis to water distribution systems has been done by Wagner et al. (1988), Yang et al. (1996), and Ostfeld et al. (2001).

Nel (1996) first applied stochastic analysis to estimate the reliability of municipal storage tanks. This work was later expanded by Van Zyl et al. (2008), where stochastic analysis was used to determine the failure characteristics of a tank in a bulk water supply system, which in turn is used as a measure of the bulk system's reliability. Van Zyl et al. (2008) proposed a criterion of 1 failure in 10 years at the most critical time of the year as the basis for sizing municipal storage tanks. Further work has been done to explore the effect of different user demand parameters on the reliability of bulk water supply systems (Van Zyl et al., 2012), as well as investigating the financial benefits of designing systems based on reliability criteria rather than design guidelines (Vlok, 2010).

In a recent study (Chang and Van Zyl, 2012), stochastic analysis was used in combination with genetic algorithms to optimise the design of bulk water supply systems. The optimisation variables were the storage tank capacity, feeder pipe configuration and feeder pipe diameter. Genetic algorithms

require a large number of system evaluations, each of which required stochastic analyses of the system to be conducted. Due to the high computation cost associated with stochastic analysis, this work would not have been practically possible without speeding up the stochastic analysis substantially, while retaining acceptable levels of accuracy. The aim of this paper is to describe the development, testing and application of the compression heuristic method used to achieve this aim. The motivation for using a compression heuristic is provided first, followed by a description of the method. The simulation times and accuracy of the compression heuristic are then compared to the full stochastic analysis.

## STOCHASTIC ANALYSIS MODEL

The stochastic analysis model presented by Van Zyl et al. (2008) uses reliability criteria for site-specific sizing of a storage tank in a bulk supply system. The reliabilities of different tank sizes are determined by simulating the system for an extended period of time (typically 10 000 years) in hourly intervals. Consumer demand, fire water demand and pipe failure states are estimated for each time step based on stochastic unit models. A failure is recorded whenever a tank runs dry, and the tank failure frequency is used as a measure of the tank reliability.

Unit models for calculating consumer demand, fire water demand and pipe failure events are summarised below, but more details can be found in Van Zyl et al. (2008).

Consumer demand was calculated in 2 steps, the first to determine the average daily demand and the second to calculate the hourly demands. Both steps included an average demand, day-of-week or hourly pattern, persistence (auto-correlation) and a random component.

The fire demand model considered 3 generic components: occurrence, duration and fire flow. The times between successive fires events were modelled using an exponential

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