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A multi-objective approach for minimizing water network disinfection time and disinfectant quantity

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Abstract

Water distribution systems are liable to be contaminated. Depending on the nature of the contamination the cleaning process may include disinfection. The common requirement for disinfection is that the disinfectants will have a minimal contact time and a predefined minimum concentration with the pipe. The regulations consider disinfection of a single main but no specific procedures are given for larger portions of the network. This paper presents a multi-objective optimal operation plan for disinfection of water systems. The objective functions are to minimize the disinfection time and minimize the disinfectant quantities used while keeping the required regulations.

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Keywords: Water distribution system, disinfection, contamination

Introduction

Intentional or unintentional water systems contamination events are relatively rare but once in a while they do occur and reported. For instance, the 2000 Walkerton Canada E. coli outbreak were 7 people died and thousands were sickened (http://en.wikipedia.org/wiki/2000_Walkerton_E._coli_outbreak), the 2007 Nokia Finland drinking water supply contamination by sewage water with hundreds of people hospitalised (http://en.wikipedia.org/wiki/Nokia_water_supply_contamination) and lately in early January 2014 a chemical

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contamination of the Elk River in West Virginia left over 300,000 people without tap water for about five days (wikipedia.org/wiki/2014_Elk_River_chemical_spill).

As a contamination is located in the water distribution system by a warning system, actions need to be taken:

- Finding the contamination source
- Stopping additional pollutants from entering the system
- Evaluation of contamination spread in the system
- Isolating the contaminated section of the network
- Cleaning and disinfecting the contaminated system. In most cases the system is cleaned through mains flushing, but also through chemical treatment (e.g., the Elk River event in January 2014).

Current regulations of the Israeli Minister of Health [health.gov.il/hozer/bz22_2013.pdf (In Hebrew)] describe the instances in which flushing and disinfection are required. Those include new system installation, network opening, change of use, contamination, mains maintenance, and prevention works. The regulations also denote a suit of cleaning and disinfection methods. The disinfection efficiency is defined by CT, where C is the concentration of the disinfectant material, and T is the contact time of the disinfectant with the system components. All methods are subject to pH and temperature ranges. The minimum values of C and T are determined by the disinfection method which can be of continuous ("fill and wait", 25mg/L for 24 hours) or plug flow (100mg/L for 3 hours). Network flushing is required following any disinfection operation. Special attention should be given for the disposal of heavily Chlorinated water.

Currently, all regulations in Israel (and also the AWWA standards) are defined for a single water pipe. No regulations exist for disinfecting portions of the water distribution system, nor is there a method for efficiently performing this task.

To accomplish efficient and satisfactory disinfection of the water system in minimum time and/or through using minimum disinfectant amounts, one needs to determine the locations in which the disinfectant should be injected, locations where water should be drained, and drainage flows. Due to limited resources by the water utilities, constraints are posed on the number and locations of drainage locations, and on a minimum disinfectant concentration which should fill the entire system. Once the entire system is filled up with a required disinfectant concentration, drainage locations are closed, and the disinfectant resides in the system for a predefined duration ("fill and wait"), after which it is flashed out. This study is on optimizing drainage locations and flows for disinfecting the system at minimum time and minimum disinfectant dosage amounts.

Methodology

The methodology is a multi-objective genetic algorithm (MOGA) NSGA-II (Deb et al. 2000) scheme linked with EPANET hydraulic and water quality solver where the objective functions are the minimization of the disinfection system filling time and the disinfection amount. The constraints are on the number of drainage locations and minimum disinfection concentration. The decision variables are the drainage locations and drainage flows.

Sample application

The algorithm was tested on a portion of a real-world water distribution system which was somewhat changed due to data security limitations while keeping the network's main features. The sample application layout is shown in Fig. 1.