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Procedia Engineering 119 (2015) 347 – 351

Procedia Engineering

www.elsevier.com/locate/procedia

13th Computer Control for Water Industry Conference, CCWI 2015

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.

Peer-review under responsibility of the Scientific Committee of CCWI 2015

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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Peer-review under responsibility of the Scientific Committee of CCWI 2015
doi:10.1016/j.proeng.2015.08.894

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.

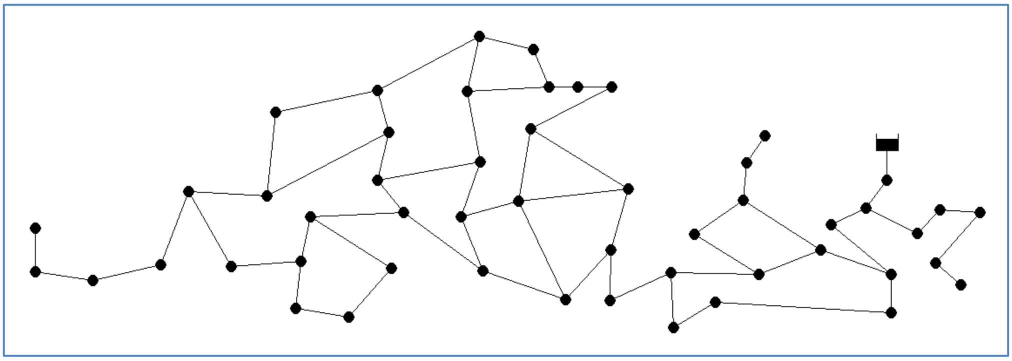

Fig. 1: Sample application layout

The sample network resembles a district metering area (DMA) which was said to be contaminated and now needs to be disinfectant. The network is made of 31 pipes and 51 junctions. It is controlled by a constant head source at its inlet with a total head of 65 meters. The disinfection method selected is the "fill and wait" method with disinfectant concentration spread requirement throughout the system of 50 mg/L.

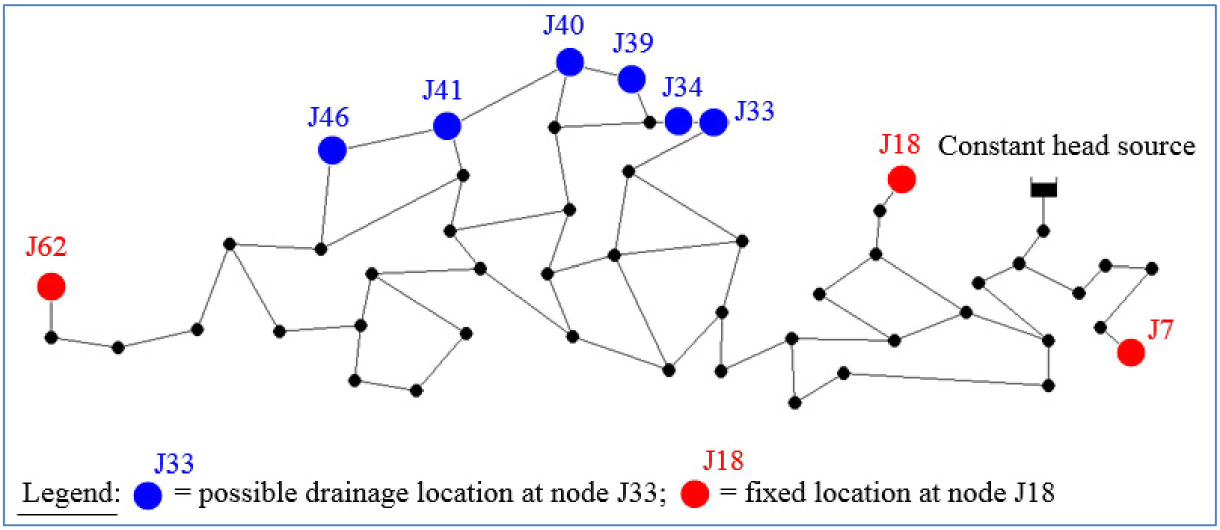

Fig. 2: Drainage locations

Fig. 2 show the drainage locations in the Network. There are three "dead-end" pipes were drainage valves must be opened in order to allow the disinfectant to fill these pipes (J7, J18 and J62 marked in red circles in Fig. 2). At these 3 locations the drainage flows should be determined. There are additional 6 possible drainage locations (J33, J34, J39, J40, J41 and J46 marked in blue circles in Fig. 2) out of which two locations should be selected, due to the water utility limited resources, and their drainage flows are to be determined.

Results

Running the model with a population of 100 strings and 100 generations resulted in the Pareto-front presented in Fig. 3. Each point in Fig. 3 represents a set of drainage locations and their flow rates. By the definition of the Pareto-front there is no one points which dominates any of the others (gives better results for both objective functions). It is up to the system operator, the decision maker, to select the desired solution for implementation. The common practice would be to select a solution which will results in a shorter "return to normal operation" duration.

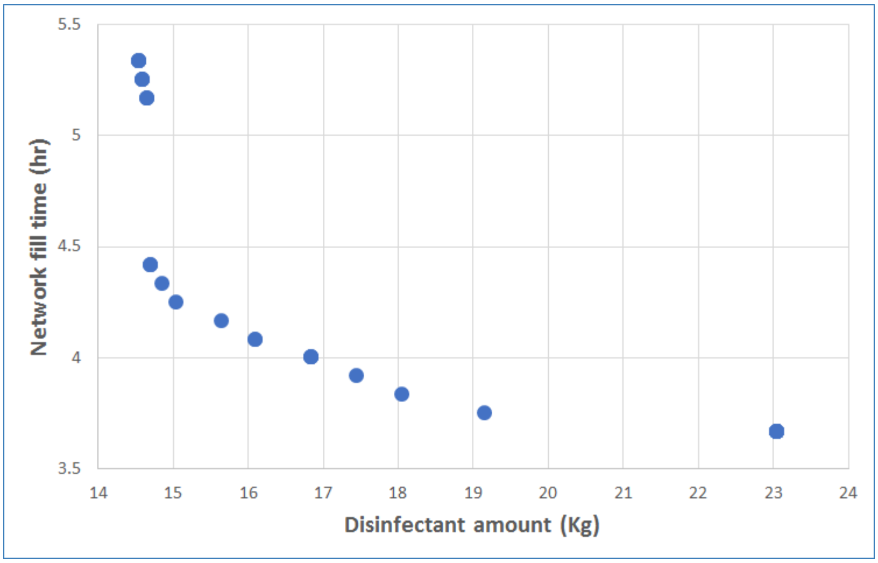

Fig. 3: Pareto-front result for the sample network

In an earlier study, Ostfeld and Salomons (2014) solved the network disinfection problem using a single objective approach. They considered the same two objectives as presented in this study (minimum network fill time and minimum disinfectant amount. Their solution for the two different objectives are shown in Fig. 4 compared to the results obtained in this study. For the minimum network fill time they have found a solution of 4.75 hours with 23.9 Kg of disinfectant. This solution is dominated by the results in this study. This may be caused be a poor run of the single objective Genetic Algorithm's run. For the second objective, minimum disinfectant amount, the solution found in the single objective found was 13.37 Kg with a network fill time of 17.83 hours. This solution is on the Pareto-front of the current study which is the result expected.

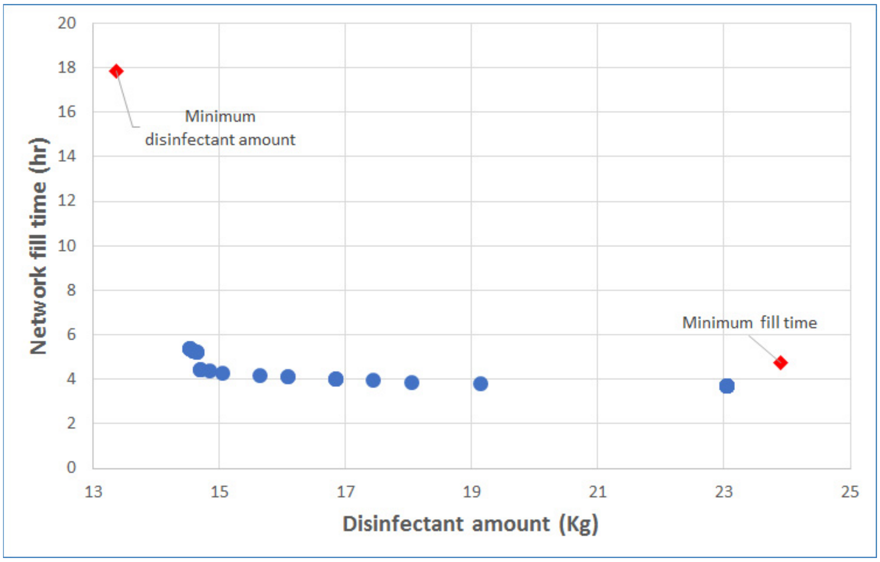

Fig. 4: Comparison to the single objective solution

Conclusions

This study presented a MOGA model for drainage locations and flow rates decisions for optimizing disinfection actions in water distribution systems following a contamination event. Two objective functions were minimized: network fill time and disinfectant amounts. A real-world illustrative sample network was used for demonstrating the model capabilities. Results show a clear Pareto-front which better or equal in performance compared to previouse work utilizing single objective optimization. Further research is ongoing through decisions on disinfectant injection locations, more complex drainage operation actions and other disinfection methods such as the plug flow method.

Acknowledgements

This study was supported by the joint Israeli Office of the Chief Scientist (OCS) Ministry of Science (MOST), and by the Germany Federal Ministry of Education and Research (BMBF), under project numbers WT1304 (MOST) and 02WA1298 (BMBF).

References

[1] A. Ostfeld and E. Salomons, “Optimal disinfection of water distribution networks following a contamination event,” in *Proc. 16th Water Distribution Systems Analysis Conference (WDSA 2014)*, Bari, Italy: ELSEVIER, Volume 89, 2014, Pages 168–172.
[2] USEPA, “Drinking Water Software: EPANET,” *view-source: http://www.epa.gov/nrmrl/wswrd/dw/epanet.html*, Jan. 2015.
[3] Deb, K., Agrawal, S., Pratap, A., and Meyarivan, T., “A fast elitist nondominated sorting genetic algorithm for multi-objective optimization: NSGA-II.” Proc., Parallel Pr, 2000