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Flushing planner: a tool for planning and optimization of unidirectional flushing

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Abstract

Unidirectional flushing is a technique for periodic cleaning of water supply pipes to remove deposits and may also be an important response to contamination of drinking water networks. For unidirectional flushing the defined flushing path is fed by clean water at an entrance point. The development of an efficient flushing strategy is not straight forward. The objective is to minimize the effort of operating staff. The flushing plan consists of a well-defined series of flushing actions in which the current flushing path is always connected to previously cleaned sections. The paper describes the software tool referred to as Flushing Planner.

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1. Introduction

Unidirectional flushing (UDF) campaigns for cleaning of pipes to remove sediment are implemented by many water supply utilities on a regular basis (Korth et al., 2011). The sediments consist of corrosion by-products or particles that enter the system at the treatment plant (Korth et al., 2008). In order to prevent discoloration of the drinking water by resuspension the sediments have to be removed from time to time. Another important application for UDF concerns the cleaning of the pipe system as a response to deliberate or accidental contamination. In this case the primary goal is to minimize the impact of the contamination on public health by

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public notification and isolation of contaminant in the pipe system that has been affected. The cleaning of the affected pipes is essential before recommissioning of the supply.

The security of public water supply has been a big concern since the events of September, 11, 2001. An extensive research effort has been undertaken for the development of optimal sensor networks and contaminant warning systems including software solutions for detection and source identification. However, there is little literature on planning of optimized unidirectional flushing campaigns. Baranowski and LeBoeuf (2008) and later Haxton and Uber (2010) used Genetic Algorithms for minimizing the impact of contamination events by selection of most appropriate nodes for flushing. However, the approach assumes that each node is a possible hydrant location for flushing by alteration of the demand and doesn't take into account the actual location of hydrants and valves. Poulin et al. (2010) describe different flushing methods as well as an algorithm for selection of flushing path that steps forward loop by loop. The algorithm is similar to the one proposed in this paper. However, the method described here is not restricted to flushing of subnetworks that have been isolated due to a contamination event.

In general, Periodical Unidirectional Flushing (P-UDF) has to be distinguished from flushing as a response to a contamination event. Response Unidirectional Flushing (R-UDF) is targeted at minimizing the impact of the contamination on public health and must be implemented with strict time constraints. In contrast, P-UDF is part of the regular maintenance of the system and consists of a planned and well-arranged sequence of single flushings. For both applications the flushing plan addresses a preselected subsection of the total water supply system that is denoted here as the flushing area. In the case of a flushing as a response to contamination the flushing area is determined by the contaminated subsection of the network whereas for routine flushing the identification of the flushing area is based on the network characteristics like network topology and the decomposition of the pipe system into transport, main distribution, secondary distribution and house connection pipes. For each flushing action one or more flushing hydrants, the flushing path (series of pipes) and an arbitrary number of isolation valves have to be defined. The optimal flushing plan consists of a structured sequence of actions for the cleaning of the pipes of the flushing. The optimal flushing plan should minimize the effort for valve manipulations, which are required for the temporal isolation of the flushing path, while guaranteeing an appropriate flow velocity in the flushing path and maintaining an sufficient supply pressure in the rest of the system (at least for P-UDF). The minimization of the effort is crucial for minimizing the exposure time of the population and to quickly resume the supply. Under normal conditions minimizing the effort is a matter of economic efficiency and minimization of cost. The method described in the following is more related to P-UDF and does not consider simultaneous flushing using different hydrants at the same time or flushing without valve manipulations. These methods can be necessary in case of contamination with highly toxic material in order to prevent the population from getting into contact with the substances.

The paper is organized as follows. After a brief description of the design criteria of the flushing program, modifications of network topology are discussed that are necessary to integrate the valves and hydrants into the network graph. The valves and hydrants are normally assigned to pipes and are not normally included in the network graph as additional nodes and links. Here, valves and hydrants and additional nodes are included to form a "full graph". This "full graph" including valves and hydrants and links and nodes is then decomposed into different connectivity components which are the basis for the further steps of the identification of the flush plan. In the first step, the pipes of the graph theoretical forest that cannot be flushed due to absence of hydrants at extremities are identified and added to the non-flushable subgraph. In the next step the remaining graph is further subdivided into flushing areas. For that purpose, the pipes that meet some user defined criteria like maximal flushable diameter or minimum flow velocity that prevents sedimentation are additionally excluded from the graph. The flushing areas are then the maximal connected components that result from connectivity analysis of the reduced graph.

In the next step, the flushing areas are further decomposed into flushing paths. A flushing path consists of a series of pipes that are, besides the entrance point at the beginning of the path, isolated during flushing. Different user-defined criteria like the above mentioned optimal path length or the maximal allowable difference in pipe diameter/flushing velocity of pipes are considered as constraints. For the identification of flushing paths a greedy algorithm has been implemented that is similar to the approach presented by Poulin et al. (2010) and proceeds loop by loop through the subgraph of the flushing area. Eventually, the final flush plan contains the ordered sequence of flushing paths including valve operations.