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A district sectorization for water network protection from intentional contamination

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Abstract

The introduction of cyanide with a backflow attack into a water system was studied. The recent development of techniques for water network sectorization, aimed to improve the management of water systems, represents also an efficient way to protect networks from intentional contamination. The possibility of closing gate valves by a remote control system to create an i-DMA (isolated District Meter Area) can reduce the risk of contamination and thus the extent of damage of a terroristic attack. The study proposes a novel technique for designing i-DMAs compatible with hydraulic performance and optimized for water network protection.

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Keywords: water network protection, district metering, water contamination, malicious attack, sectorization.

1. Introduction

Water distribution networks are exposed to different potential sources of accidental and intentional contamination (US EPA, 2003). The first one is related essentially to problems of occasional bad source water quality, dysfunction of chlorine stations or pipe breaks; while the second one concerns malicious attacks

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represented by intentional introduction of a contaminant at the network sources or contaminant injection in a network pipe (Nilsson et al., 2005; Clark et al., 2006) or by a backflow that occurs when a pump system is utilized to overcome the pressure gradient of network pipes (Kroll, 2010). Water contamination by terrorist attacks is a major risk for society and can have serious consequences such as poisoning and infectious diseases; after September 11, 2001 many countries adopted guidelines for water quality monitoring and emergency action plans (HSPDs, 2002; US EPA, 2003, 2009; CER, 2005).

A malicious act may consist of introduction of chemical, biochemical or radioactive contaminants in the water supply network. Sabotage is most effective when the hazardous substance is injected as a concentrated liquid or powder. The most hazardous substances are biotoxins (organic substances that can cause serious poisoning) and biological agents (viruses and/or bacteria).

Studies available in the literature have been focused on the ability of common sensors to detect noticeable changes in water quality when a contaminant is present (USEPA, 2005; Hall et al., 2007), especially by monitoring parameters such as pH, conductivity, Total Organic Carbon (TOC), turbidity and residual chlorine, coupled with interpretive algorithms (McKenna et al., 2007; Umberg, 2008; Kroll and King, 2010). Other studies are focused on the optimal positioning of measurement stations and identification of point source contamination (Rico-Ramirez et al., 2007; Ostfeld et al., 2008; Chang et al., 2011). These techniques are very helpful to develop Early Warning Systems (EWS) but they are not so effective in assessing the impact of actions to be taken to guarantee safety and security of users.

When a water supply network contamination incident is identified, two main actions should be carried out: a) alert users not to use water and b) close the sector of the network in order to limit health risks.

Early warning is crucial for the first action to be successful, while the effectiveness of the second one depends on the possibility of closing pipes to disconnect network sectors. Early warning requires a good distribution of fast warning sensors over the network (Kroll and King 2010); pipe closing can only be done if network sectorization (or partitioning) has been envisaged in the planning phase.

The recent development of techniques for Water Network Partitioning (WNP) that divides the water network in District Meter Area (DMA) (Wrc/WSA/WCA 1994), directed to improve the management of water systems (Di Nardo and Di Natale, 2011; Di Nardo et al., 2013c), represents also an efficient way to protect networks from biological agents (Grayman et al., 2009; Murray et al., 2010). More recently, in Di Nardo et al. (2013a), the authors proposed a methodology to reduce the risk of intentional contamination of a water supply network using the technique of Water Network Sectorization (WNS). Sectorization is achieved by closing gate valves in the network pipes that link the DMAs (Tzatchkov et al., 2006). In this condition, wherein each district in the system is completely separated (or isolated) from all other districts, the isolated district can be named i-DMA, as proposed in Di Nardo et al. (2012) and in Di Nardo et al. (2013c).

A study for water network protection with WNS carried out by Di Nardo et al. (2013a) showed that: a) DMA isolation is more effective than only water network partitioning, b) the higher the number of DMAs in a WNP, the better the protection for the users; c) WNP reduces the extent of risk because several introduction points are needed to have a wide negative impact on the network; d) WNP allows to activate easier protection measures because it is possible to disconnect a small part of the network; e) the methodology respects the criteria of *dual-use value* (Kroll and King 2010).

In this paper different WNPs, obtained with a recent methodology in compliance with hydraulic performance, based on graph partitioning techniques (Di Nardo et al., 2011) were investigated in order to evaluate the effects of different WNPs for water network protection. In this way the study analysed the benefits of defining i-DMAs compatible with hydraulic performance using different weights on pipes and nodes.

The intentional contamination was modelled as proposed in Di Nardo et al. (2013a) by the introduction of cyanide at a reservoir and with a backflow attack into a real-water system defining the most dangerous points for a deliberate contaminant delivery.

The analysis was carried out with different partitioning and sectorization scenarios on a real multiple source water distribution network in Italy. The results show a significant reduction of risk for users.