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Assessing the public health risk of microbial intrusion events in distribution systems: Conceptual model, available data, and challenges

Marie-Claude Besner [a,*,1], *Michèle Prévost* [b], *Stig Regli* [a]

[a] *USEPA, Office of Ground Water and Drinking Water, Mail code 4607m, 1200 Pennsylvania Avenue, NW, Washington DC 20460, USA*
[b] *Ecole Polytechnique de Montreal, NSERC Industrial Chair on Drinking Water, Civil, Geological and Mining Engineering, CP 6079, Succ. centre-ville, Montreal, Quebec, Canada H3C 3A7*

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ABSTRACT

Low and negative pressure events in drinking water distribution systems have the potential to result in intrusion of pathogenic microorganisms if an external source of contamination is present (e.g., nearby leaking sewer main) and there is a pathway for contaminant entry (e.g., leaks in drinking water main). While the public health risk associated with such events is not well understood, quantitative microbial risk assessment can be used to estimate such risk. A conceptual model is provided and the state of knowledge, current assumptions, and challenges associated with the conceptual model parameters are presented. This review provides a characterization of the causes, magnitudes, durations and frequencies of low/negative pressure events; pathways for pathogen entry; pathogen occurrence in external sources of contamination; volumes of water that may enter through the different pathways; fate and transport of pathogens from the pathways of entry to customer taps; pathogen exposure to populations consuming the drinking water; and risk associated with pathogen exposure.

Contents

* *Corresponding author*. Tel.: +1 514 340 4711/5223; fax: +1 514 340 5918.
E-mail addresses: mcbesner@polymtl.ca, Besner.Marie-Claude@epamail.epa.gov (M.-C. Besner), michele.prevost@polymtl.ca (M. Prévost), Regli.Stig@epamail.epa.gov (S. Regli).
[1] Permanent address: Ecole Polytechnique de Montreal, NSERC Industrial Chair on Drinking Water, Civil, Geological and Mining Engineering, CP 6079, Succ. centre-ville, Montreal, Quebec, Canada H3C 3A7.
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1. Introduction

Drinking water distribution systems are vulnerable to external contaminant entry if there is a loss of physical/hydraulic integrity. In their 2006 report on risk assessment and reduction for distribution systems, the Committee on Public Water Supply Distribution Systems of the National Research Council (NRC, 2006) defined a loss of physical integrity as when the system no longer acts as a barrier that prevents external contamination from deteriorating the internal, drinking water supply. Associated pathways of contamination include water main breaks/repair sites, uncovered reservoirs or covered storage tanks with structural deficiencies, and cross-connections with no, inappropriately installed, or inadequately maintained backflow prevention devices. Hydraulic integrity was defined as the capacity to maintain desirable water flow, water pressure, and water age in a distribution system, taking into account potable water delivery and fire flow conditions. The maintenance of adequate water pressure in a distribution system is a key element of hydraulic integrity and a loss of pressure represents a breach that could result in either backflow (from cross-connections) or contaminant intrusion through pipe leaks and other types of orifices (deflections at flexible couplings, leaking joints, and deteriorating seals (Kirmeyer et al., 2001)). Contamination from intrusion will be the main topic of this review.

Distribution systems most vulnerable to intrusion events are those with intermittent water supply, most commonly found in developing countries. These systems are characterized by inadequate levels of water pressure for hours or days very often coupled with a combination of integrity problems including high leakage rates, non-standard connections to water mains, cross-connections, inadequate disinfection residuals, and poor sanitation practices (Lee and Schwab, 2005). The risk for contamination is high under such conditions and several reports of waterborne disease outbreaks and increased rates of gastrointestinal illness are available for such systems (Swerdlow et al., 1992; Semenza et al., 1998; Mermin et al., 1999; Yassin et al., 2006).

In developed countries, the practice of intermittent supply is usually not encountered and distribution systems are normally delivering water at sufficient pressure on a continuous basis. However, adverse pressure conditions may still take place. These are generally transient in nature, with typical durations in the range of seconds to minutes and are generally associated with sudden pump shutdowns (Gullick et al., 2004, 2005; Hooper et al., 2006; Besner et al., 2010). However, sustained pressure losses can also result from system failures such as main breaks (under free-flowing conditions) and subsequent repair site isolation, planned repairs (Besner et al., 2007) or from extreme rare events such as the U.S. Northeast blackout of August 14, 2003 where approximately 50 million people were without power and boil water advisories needed to be issued by some water utilities (CBSNews, 2003). Situations where sustained pressure losses occur are generally controlled by the installation of temporary distribution systems in case of major construction work/repair or application of mitigation strategies such as super-chlorination, boil water advisories, and non-consumption advisories prior to return to service. However, maintenance activities (and other unidentified causes) may trigger localized low pressure conditions in a distribution system for smaller but still significant durations (more than a few minutes) (Besner et al., 2010) and not be subjected to the same controls. The public health impact of possible intrusion events associated with this latter type of low/negative pressure events and the transient ones resulting from system operation is difficult to assess at this time.

For the last decade or so, awareness regarding the effects of low pressure events on microbial water quality in distribution systems has increased. Field pressure monitoring and investigation of intrusion pathways have been conducted. Transient analysis has been applied to full-scale distribution systems to not only predict peak positive/negative pressures for system design, but to also identify critical locations for transient low pressures, and to predict intrusion volumes. Hydraulic analysis is used to model fate and transport of microbial contaminants, and quantitative microbial risk assessment (QMRA) can be applied for estimating potential public health risks associated with low pressure events. This paper seeks to review and discuss the available information within the context of a conceptual model, developed by the authors, for the estimation of public health risk resulting from intrusion events. The state of knowledge, current assumptions, and challenges associated with the conceptual model parameters will be presented.

2. Definition of intrusion events

Over the years, researchers have provided definitions of intrusion events. Back in 2001, Kirmeyer et al. used the term “intrusion” in a broad sense to cover all potential pathogen routes of