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Short-term spatial and temporal variability of disinfection by-product occurrence in small drinking water systems

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HIGHLIGHTS

- The variability of 16 DBPs were evaluated in six small water systems (SWS).
- The daily variability of non-regulated DBPs in SWS was studied for the first time.
- On a daily basis, DBP levels can fluctuate from 22% to 96%.
- Spatial variations of DBPs along the system were high even if networks are small.
- Degradation of some DBPs was observed thanks to the numerous sampling locations.

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ABSTRACT

Disinfection by-products (DBPs) constitute a large family of compounds. Trihalomethanes and haloacetic acids are regulated in various countries, but most DBPs are not. Monitoring DBPs can be delicate, especially for small systems, because various factors influence their formation and speciation. Short-term variations of DBPs can be important and particularly difficult for small systems to handle because they require robust treatment and operation processes. According to our knowledge, for the first time, our study covers the short-term variability of regulated and non-regulated DBP occurrence in small systems in the summer. An intensive sampling program was carried out in six small systems in Canada. Systems in the provinces of Newfoundland and Labrador and Quebec were sampled daily at the water treatment plant and at six different locations along the distribution system. Five DBP families were studied: trihalomethanes, haloacetic acids, haloacetonitriles, halonitromethanes and haloketones. Results show that there were considerable variations in DBP levels from week to week during the month of study and even from day to day within the week. On a daily basis, DBP levels can fluctuate by 22% to 96%. Likewise, the large number of sampling locations served to observe DBP variations along the distribution system. Observations revealed some degradation and decomposition of non-regulated DBPs never before studied in small systems that are associated with the difficulty these systems experience in maintaining adequate levels of residual disinfectant. Finally, this study reveals that the short term temporal variability of DBPs is also influenced by spatial location along the distribution system. In the short term, DBP levels can fluctuate by 23% at the beginning of the system, compared to 40% at the end. Thus, spatial and temporal variations of DBPs in the short term may make it difficult to select representative locations and periods for DBP monitoring purposes in small systems.

1. Introduction

Disinfection by-products (DBPs) are potentially toxic substances generated by the reaction between a disinfectant, usually chlorine, and naturally organic matter (NOM) present in water (Rook, 1974). Trihalomethanes (THMs) and haloacetic acids (HAAs) are the most prevalent DBPs in drinking water. Their formation is relatively well understood and their levels are regulated in various countries (in particular THMs) (Singer, 2002; Richardson, 2011). THMs are volatile organic compounds and the most commonly observed are chloroform (TCM), bromo-dichloromethane (BDCM), dibromo-chloromethane (DBCM) and bromoform (TBM). HAAs are organic compounds among which the most prevalent in drinking water are monochloroacetic acid (MCAA), monobromoacetic acid (MBAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA) and dibromoacetic acid (DBAA). But the DBP family is quite large: more than 600 DBPs have been detected and most DBPs are not regulated. Recently, there has been increased

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interest in investigating the presence of non-regulated DBPs: some DBPs, such as nitrogenated DBPs (haloacetonitriles (HANs) and halonitromethanes (HNMs)) and brominated DBPs, may have higher toxicological effects than THMs and HAAs, especially in terms of their cytotoxicity and genotoxicity (Krasner et al., 2006; Bove et al., 2007; Muellner et al., 2007; Richardson, 2011). Our study focuses on HANs and HNMs and the main HNM found in drinking water in particular, trichloronitromethane, also known as chloropicrin (CPK) (Richardson, 2011). Likewise, haloketones (HKs) are also among the non-regulated DBPs presenting the highest levels in drinking water reported in several studies (Krasner et al., 2006; Wei et al., 2010).

Typically, in North America, each small community or rural jurisdiction must cover its own capital and operating costs related to drinking water supply (Dore et al., 2013). Because of financial constraints, small water systems (i.e., serving 5000 or fewer people) may experience some difficulty implementing adequate treatment technologies to remove DBP precursors and hiring qualified operators to manage operational conditions (Edwards et al., 2012; Dore et al., 2013). As a result of these conditions, small systems using surface waters may be more vulnerable to DBPs due to a higher chlorine demand. In fact, a previous study showed that average measured concentrations of some DBPs in small Canadian systems using surface waters can be more than 10 times higher than those reported in the literature for medium and large systems (Guilherme and Rodriguez, 2014). This latter study was conducted by the authors in 25 small systems where monthly samples were collected between October 2010 and October 2011.

Understanding the variability of DBPs is challenging because various factors influence their speciation and evolution in water distribution systems. Factors include: the nature and the amounts of NOM and ions present in raw water (Uyak and Toroz, 2007; Karanfil et al., 2008), disinfectant concentration and contact time (Singer, 1994; Liang and Singer, 2003; Rodriguez et al., 2004; Speight and Singer, 2005; Bull et al., 2009) and type of disinfectant (Adams et al., 2005; Crittenden and MWH Inc., 2005; Bull et al., 2009; Bougeard et al., 2010). Moreover, pH and temperature influence DBP speciation and formation kinetics (Croue and Reckhow, 1989; Yang et al., 2007; Fang et al., 2010). Consequently, important temporal and spatial variations are commonly observed in the measured concentrations of DBPs in drinking water. With the exception of our recent study consisting of a one-year monthly sampling campaign in 25 small systems (Guilherme and Rodriguez, 2014), only a few studies are available on small systems and they mainly investigate the occurrence of regulated DBPs (Charrois et al., 2004; Tung and Xie, 2009). Most studies have focused on the temporal and spatial variations of DBP occurrence in large systems and placed the emphasis on regulated DBPs such as THMs and HAAs (Lebel et al., 1997; Summerhayes et al., 2011; Mercier-Shanks et al., 2013). Moreover, only long-term variability (annual, monthly or seasonal) is evaluated in these studies. Furthermore, in most studies only a few locations are sampled along the distribution system. In the short term, information on the variability patterns of regulated and non-regulated DBPs could help utility managers improve their routine operations in order to reduce the levels of DBPs (through treatment adjustments) and identify representative sampling moments and locations for monitoring purposes (i.e., regulatory compliance).

Thus, the aim of this study was to investigate the short-term temporal and spatial variability of DBP occurrence in small systems. The study focused on both regulated and non-regulated DBPs. Unlike our previous study that dealt with seasonal DBP changes through monthly samples (Guilherme and Rodriguez, 2014), the present study was based on daily sampling campaigns carried out within a short time period during the summer in various locations along the DS. In this research and according to our knowledge, this is the first time that the short-term variability of regulated and non-regulated DBP occurrence in small municipal systems has been studied. The study describes the short term variability of DBPs and, in an exploratory manner, associates such variability with the variability of common water quality parameters, such as residual disinfectant.

2. Methodology

2.1. Case studies

An intensive sampling program was carried out during the summer of 2012 in six small water systems (SWSs) of two provinces of Canada, Newfoundland and Labrador (NL) and Quebec (QC). The study focused on the summer, since various studies have shown that during this season, levels of most DBPs are generally at their highest. In fact environmental conditions, such as higher water temperature, favor the reaction of NOM and the formation of DBPs (Lebel et al., 1997; Rodriguez et al., 2007; Guilherme and Rodriguez, 2014).

All the systems were supplied by surface water sources. Five of the six systems used chlorine (in the form of sodium hypochlorite or chlorine gas) as their main disinfectant for primary and secondary disinfection. One system used UV as a primary disinfectant and chlorine as a secondary disinfectant. The three systems in NL (NL1, NL2 and NL3) served a population varying from 320 to 1020 inhabitants. In QC, the three systems (QC1, QC2 and QC3) served a population varying from 1500 to 3800 inhabitants. All the systems in NL and one in Quebec (QC3) did not present any prior treatment to chlorination, whereas in QC, QC1 and QC2 used conventional treatment processes prior to disinfection (coagulation, flocculation, sedimentation and filtration). In fact, in QC, there are regulations that mandate water utilities supplied by surface waters to remove turbidity and NOM, mainly through filtration, before the water is subjected to chlorination. Also, QC2 was the only SWS characterized by a rechlorination process in its distribution system (located just before DS2). Table 1 presents information on the populations served and treatments used in the six SWSs studied.

2.2. Sampling and analysis

In each system, water was sampled within the water treatment plant (WTP) just before disinfection. Various points were selected along the DS in order to collect samples at different residence times of the water (Table 2). Water was sampled at six locations along the DS from the beginning (DS1) to the end of the DS (DS6). Sampling campaigns were conducted daily (from Monday to Friday) for one month in July 2012 for QC and August 2012 for NL. On Mondays, Wednesdays and Fridays, each system was sampled in WTP and all along the DS (from DS1 to DS6) in order to study the spatial evolution of water quality. But on Tuesdays and Thursdays, water was sampled only in WTP and DS3 to maintain a follow-up of the temporal variability of water quality during the month. All samplings were conducted at the same time every day. Samples were taken in faucets, after letting water flow for 5 min in order to sample representative water from the distribution

Table 1
General characteristics of SWS under study.

SWS	Type of treatment	Population
NL1	Chlorination	321
NL2	Chlorination	1020
NL3	Chlorination	450
QC1	Activated carbon Coag.–Floc.–Sed.–Filt. UV Chlorination	3220
QC2	Coag.–Floc.–Sed.–Filt. Chlorination Rechlorination in the DS (between DS1 and DS2)	1528
QC3	Chlorination	3826

Coag.–Floc.–Sed.–Filt.: coagulation, flocculation, sedimentation, filtration.