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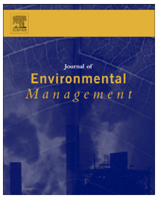

Research article

Field data analysis of active chlorine-containing stormwater samples

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ABSTRACT

Many municipalities in Canada and all over the world use chloramination for drinking water secondary disinfection to avoid DBPs formation from conventional chlorination. However, the long-lasting monochloramine (NH_2Cl) disinfectant can pose a significant risk to aquatic life through its introduction into municipal storm sewer systems and thus fresh water sources by residential, commercial, and industrial water uses. To establish general total active chlorine (TAC) concentrations in discharges from storm sewers, the TAC concentration was measured in stormwater samples in Edmonton, Alberta, Canada, during the summers of 2015 and 2016 under both dry and wet weather conditions. The field-sampling results showed TAC concentration variations from 0.02 to 0.77 mg/L in summer 2015, which exceeds the discharge effluent limit of 0.02 mg/L. As compared to 2015, the TAC concentrations were significantly lower during the summer 2016 (0–0.24 mg/L), for which it is believed that the higher precipitation during summer 2016 reduced outdoor tap water uses. Since many other cities also use chloramines as disinfectants for drinking water disinfection, the TAC analysis from Edmonton may prove useful for other regions as well. Other physicochemical and biological characteristics of stormwater and storm sewer biofilm samples were also analyzed, and no significant difference was found during these two years. Higher density of AOB and NOB detected in the storm sewer biofilm of residential areas – as compared with other areas – generally correlated to high concentrations of ammonium and nitrite in this region in both of the two years, and they may have contributed to the TAC decay in the storm sewers. The NH_2Cl decay laboratory experiments illustrate that dissolved organic carbon (DOC) concentration is the dominant factor in determining the NH_2Cl decay rate in stormwater samples. The high DOC concentrations detected from a downstream industrial sampling location may contribute to a high stormwater NH_2Cl decay rate in this area.

1. Introduction

Chlorine products have been used from the early 20th century to disinfect drinking water; however, this widely-used treatment has disadvantages, including the reactivity of chlorine with organic compounds in the water, which causes it to dissipate rapidly in distribution systems. This reactivity also results in the production of disinfection by-products (DBPs) (Hrudey, 2009). To limit the formation of chlorinated DBPs, an alternative water disinfection method, chloramination, has been developed and applied to drinking water systems throughout North America (Wahman and Speitel, 2012). After chlorination, ammonia is added to convert the residual chlorine to chloramines, of which monochloramine (NH_2Cl) is the dominant disinfection species. NH_2Cl has proven useful for water distribution systems, where it is desirable to have a longer-lasting residual and its corresponding disinfection effect (Brodtmann and Russo, 1979; Mitcham et al., 1983; Norman et al., 1980); however, it can also lead to detrimental environmental effects, as described below.

Drinking water chloramination may introduce chloramines into surface waters through various means, including distribution system leaks and breaks, lawn and garden watering, car and driveway washing, street cleaning, firefighting, and industrial or commercial wash-down and construction activities. Although residential

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outdoor water use is typically a relatively small percentage (6% in the United States, on average) of the total annual residential water use (Coomes et al., 2010), it may be considerable in summer months (Nouri et al., 2013): for example, 40–60% of residential water consumption in Texas (White et al., 2004) and almost 30% in California (Mays, 2002) were associated with lawn irrigation activities. In contrast, commercial car washing is responsible for only about 1% of municipal water use and its subsequent discharge to stormwater sewers can be negligible, since these companies typically remove some pollutants on-site (Sablayrolles et al., 2010; Zaneti et al., 2012) and discharge dirty wash water almost exclusively to sanitary sewer systems (Brown, 2000, 2002). However, the situation is less clear for car dealerships and car rental locations, where cars may be washed outdoors. Finally, the production of large-volume industrial pressure-vessels – boilers and large storage tanks that have a minimum inner diameter of 60 cm (PricewaterhouseCoopers LLP, 2008), but that may be as large as 10.7 m in diameter, 76 m in length, and 680 tonnes in mass (Cessco Fabrication and Engineering Ltd, 2014) – require the use of municipal water for ‘hydro-testing’ of vessel integrity. After completion of the hydro-testing procedures, testing water is occasionally discharged to the stormwater system without dechloramination. These water uses are thought to be the major active chlorine sources in storm sewers under dry weather conditions, and consequently introduce chloramine-containing water into stormwater drainage systems.

At near-neutral pH, chloramines can release free chlorine through auto-decomposition processes (Vikesland et al., 2001). The chloramines and the free chlorine species released from chloramines are measured together as the total active chlorine (TAC) in stormwater. In 1973, Brungs's study showed that the TAC concentration of effluent discharge should not exceed 0.002–0.2 mg/L depending on the discharging period for the protection of aquatic organisms. Further, Brooks and Bartos reported that the active chlorine has a 1% lethal concentration of 0.08 mg/L to some fishes with an exposure duration of 120 min (Brooks and Bartos, 1984). In 1985, EPA proposed that the concentration causing 50% mortality can be as low as 0.0053 mg/L to some invertebrate species (United States Environmental Protection Agency, 1985). Elevated TAC in fresh water can be acutely lethal to fish, crayfish, snails and some fish-food organisms over exposures of 6 min–48 h. Also, long-lasting chloramine species can be toxic for fish growth with a much lower concentration, thus leading to a chronic environmental risk (Brungs, 1973). Moreover, the Canadian Council of Ministers of the Environment (CCME, 1999) guidelines for the protection of aquatic life list a maximum TAC concentration in surface waters of only 0.5 μg/L, and their recent Canada-wide strategy (CCME, 2009) reduced the permissible TAC concentration in discharged effluent from 0.2 to 0.02 mg/L. To adhere to these guidelines, it is clearly important to determine the TAC concentrations of sources that contribute to surface water flows, which include municipal stormwater discharges.

The objectives of the current study are to evaluate the TAC concentration and other water qualities in Edmonton storm sewers under dry and wet weather conditions in various neighborhoods during summer months, and to study the possible relevance of some stormwater characteristics to TAC dissipation rates. The TAC concentration as well as other physicochemical properties of stormwater, and the biological characteristics of storm sewer biofilm were analyzed in this research. Wet weather stormwater characteristics have been analyzed in a variety of studies (Makepeace et al., 1995; Pitt et al., 2004; Liu et al., 2013), but studies of dry weather stormwater qualities are relatively rare. Since many other cities also use chloramination for their drinking water disinfection, the TAC analysis results from this fieldwork in Edmonton can also be used as a reference case for other cities. This is believed to be the first research for TAC concentration analysis in storm sewers, and the results of this study should attract more attention to the issue of stormwater TAC contamination and its potentially harmful impacts on the aquatic environment.

2. Material and methods

2.1. Location selection

To study the impact of different outdoor water use types on the TAC concentration in stormwater, field samples were collected from storm sewers in four Edmonton neighborhoods selected to represent four major land-use types: (a) residential, as a reference for other land-uses, (b) parks and recreation, for their extensive green areas and correspondingly more uniform irrigation and fertilizer use than residential areas, (c) commercial, with a focus on automobile dealerships and rental business areas and (d) industrial, with a focus on areas with pressure vessel fabricators. Each neighborhood lies within one of two stormwater catchments, Kennedale in north Edmonton and 30th Avenue in south Edmonton. The Kennedale and 30th Avenue catchment maps are shown in Fig. 1 and the storm sewer network maps of the sampling locations are shown in Fig. 2.

Within these two catchments, the four neighborhoods were then selected according to the following criteria. Stormwater drainage system characteristics played a key role, particularly the location of the neighborhood within the pipe network, the presence of stormwater ponds upstream and availability of access points for water sampling. In terms of location within the network, sampling near the sewer network's upstream-end would ensure that stormwater flows originated in the catchment under consideration, while sampling farther downstream would make it difficult to attribute pollutants to probable sources. In addition, the selection of long, uninterrupted sections of pipe would permit attribution of changes in water quality to chemical and biological interactions occurring within the pipe section, and give more time for such interactions to occur. Potential locations with mixed land-uses within or upstream of the neighborhood were excluded. Finally, several potential neighborhoods were eliminated because of logistical hurdles, such as traffic conditions, site accessibility and sampling difficulty.

In selecting the residential location, low-density neighborhoods with higher property values were prioritized for their relatively large lawn and garden areas (cf. the Albuquerque, New Mexico, study conducted by Al-Kofahi et al., 2012). Application of the above criteria resulted in selection of the high property-value Blue Quill Estates neighborhood, shown in Fig. 2(a). The M. E. Lazerte Park in the Kennedale catchment was selected among the irrigated parks of the two catchments, based on data available for determining irrigation volumes, the type of water used for irrigation (potable), and the park location within the neighborhood and sewer pipe network. Its location is shown in Fig. 2(b). In the 30th Avenue basin, commercial car washes, dealerships and car rental agencies clustered in one location near 34th Avenue and 99th Street NW, which contained approximately two dozen automobile-related service providers. The location selected – at 93rd Street near 34th Avenue (see Fig. 2(c)) – had the largest number of automotive services businesses and met the pipe-network based criteria described above. For industrial sites, the pressure vessel industry is potentially a large point-source contributor of chloramine pollution. The production of large pressure vessels requires the use of municipal water for vessel-integrity testing; this testing water is occasionally discharged to stormwater rather than sanitary systems. Many pressure-vessel manufacturers were near the intersection of 97th