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Analysis of the influence of rainfall variables on urban effluents concentrations and fluxes in wet weather

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SUMMARY

Urban rainfall runoff has been a topic of increasing importance over the past years, a result of both the increase in impervious land area arising from constant urban growth and the effects of climate change on urban drainage. The main goal of the present study is to assess and analyze the correlations between rainfall variables and common indicators of urban water quality, namely event mean concentrations (EMCs) and event fluxes (EFs), in order to identify and explain the impacts of each of the main rainfall variables on the generation process of urban pollutants during wet periods. To perform this analysis, runoff from eight summer rainfall events that resulted in combined sewer overflow (CSO) was sampled simultaneously from two distinct catchment areas in order to quantify discharges at the respective outfalls. Pearson statistical analysis of total suspended solids (TSS), chemical oxygen demand (COD), carbonaceous biochemical oxygen demand at 5 days ($CBOD_5$), total phosphorus (P_{tot}) and total kedjal nitrogen (N-TKN) showed significant correlations ($\rho = 0.05$) between dry antecedent time (DAT) and EMCs on one hand, and between total rainfall (TR) and the volume discharged (VD) during EFs, on the other. These results show that individual rainfall variables strongly affect either EMCs or EFs and are good predictors to consider when selecting variables for statistical modeling of urban runoff quality. The results also show that in a combined sewer network, there is a linear relationship between TSS event fluxes and COD, $CBOD_5$, P_{tot}, and N-TKN event fluxes; this explains 97% of the variability of these pollutants which adsorb onto TSS during wet weather, which therefore act as tracers. Consequently, the technological solution selected for TSS removal will also lead to a reduction of these pollutants. Given the huge volumes involved, urban runoffs contribute substantially to pollutant levels in receiving water bodies, a situation which, in a climate change context, may get much worse as a result of more frequent, shorter, but more intense rainfall events.

1. Introduction

Urban wet weather discharges (UWWD) refer to all rainfall in an urbanized catchment area that flows directly into a receiving environment without passing through a wastewater treatment system, including rain water, runoff water, discharges from separated storm water system outfalls, CSOs (Hemain, 1987). Urban rainfall runoff has become a topic of increasing importance in recent years, as a result of both the increase in impervious land area arising from constant urban growth and the effects of climate change on urban drainage (Denault et al., 2006; Langeveld et al., 2013; Mailhot et al., 2010; Semadeni-Davies et al., 2008; Willems, 2013). The results are an increase in the speed at which runoffs flow into receiving water bodies and changes in natural hydrological features in the latter. Until the mid-19th century, sanitary considerations in quantitative wastewater management in cities meant simply sending everything into the sewer system, which collected both rainwater and wastewater. Hemain (1979) argues that Weibel et al. (1964), American Public Works Association (1969), and Sartor and Boyd (1972) are three fundamental studies conducted in the United States that resulted in a general awareness of runoff water pollution in urban environments. This environmental awareness was expressed through several international conferences and summits. The early 1970s mark an increased interest in qualitative UWWD treatment. In

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the United States, the first federal act of its kind, the 1972 Clean Water Act (CWA), established the initial list of priority pollutants associated with water-quality criteria. Since then, several studies have been carried out to define the main pollution factors linked to urban runoff and to attempt to quantify UWWD impacts on receiving environments, including the United States Environmental Protection Agency's National Urban Runoff Program (US EPA NURP, 1978–1983), the French program (1980–1982), the Marais (1994–2000) experimental catchment, etc. In these and several other subsequent studies, the scope of physical and chemical analyses was limited and the studies were localized and focused on individual network types taken separately from other components of the wastewater system (Gromaire, 1998; Lessard and Lavallée, 1985; Zgheib, 2009). Publication of the European Union Water Framework Directive (Directive 2000/60/EC; WFD) contributed to studies looking simultaneously at different separate systems to track patterns of pollutants associated with human activity (Becouze, 2010; Dembélé, 2010). In order to differentiate the various risks posed by different levels of wastewater discharged into surface water bodies, the 2009 Canada-wide Strategy for the Management of Municipal Wastewater Effluent (SMMWE) drew up a list of substances of potential concern for the purpose of meeting environmental targets for discharges. This was aimed at reducing both bacteriological contamination from household wastewater and combined sewer system overflows in order to revitalize receiving environments. There are many sources of UWWD pollutants, including atmospheric pollution, wash-off of dry weather deposits and accumulated dry deposition in urbanized catchment areas, erosion of urban materials, inputs from wastewater systems by resuspension of particles deposited in times of dry weather (Parent-Raoult and Boisson, 2007). Previous work showed that several factors influence UWWD composition including the type of sewer system, water provenance, and catchment area and rainfall characteristics. This paper deals more specifically with rainfall characteristics as independent variables to explain urban pollutant fluxes and concentrations. Rainfall events play a crucial role both in scouring impervious surfaces and in eroding deposits accumulated in combined sewer systems, resulting in the remobilization of many pollutants. Several authors have concluded that pollution linked to CSOs and runoff water can substantially impact receiving environments (Burton and Pitt, 2002; Casadio et al., 2010; Chocat et al., 2007; Bi et al., 2014; Passerat et al., 2011). These impacts and the costs associated with collecting data on pollution caused by UWWDs have led to a growing interest in analyzing measured data in order to develops models for estimating fluxes and concentrations (Brezonik and Stadelmann, 2002; Dembélé, 2010; Mourad, 2005), including in catchment areas in which relevant data are not monitored. Published mass balance studies are generally carried out at the annual scale (Sabin et al., 2005; Wang et al., 2013) and, although studies at the event scale serve to highlight variations in inputs from different sources over time, such studies are relatively rare (Dembélé, 2010). Comprehensive studies are therefore needed prior to investing in treatment facilities and setting out land use guidelines aimed at reducing the potential impacts of human activities on the spatial and temporal evolution of UWWDs. Thus, Brezonik and Stadelmann (2002) argue that, in the absence of site-specific data, the actual impacts of potential new UWWD management practices are difficult to predict.

The main goal of the present study is to assess and analyze the correlations between rainfall variables and mean fluxes and concentrations at the rainfall event scale in order to identify and explain the influence of each of the major rainfall variables on the generation process of urban pollutants in times of wet weather. This experiment was carried out simultaneously on two distinct catchment areas in the Longueuil, Québec, Canada urban agglomeration for summer rainfall events recorded at both sites. To this end, only discharges observed at the outfalls of a separated storm water system and a combined sewer overflow are examined.

2. Materials and methods

2.1. Experimental framework: study sites, sampling procedure, monitored parameters and rainfall events

The study was carried out on two experimental catchment areas (Fig. 1) within the Longueuil urban agglomeration, a near suburb located south of the City of Montreal, Québec, Canada. Characteristic features of the catchment areas are presented in Table 1.

The first catchment area is a 1240-hectare (ha) unitary catchment area serving a medium-density residential area (population 47,000) in downtown Longueuil, mainly comprising multi-family housing (80%) units, commercial and institutional facilities (10%), industrial (5%) and a regional park (5%). The catchment area is drained by the Rolland–Therrien combined sewer system collector equipped with two Innovex-type regulators for limiting flow (to 1.25 m^3/s) to the one treatment station downstream during wet weather. Excess discharge goes directly to the receiving environment via a valve-type storm water overflow. The impacts of this structure are deemed major because future land development will have a direct influence on it. This unitary catchment area is therefore the main focus of the study.

The second area is a 465-ha separated storm catchment area located in the neighboring town of Boucherville in the Longueuil agglomeration. The catchment serves an area (population roughly 9000) essentially comprising single family units (78%) located along a highway (100,000 vehicles/day), and a large industrial area (20%). Storm waters in the catchment area are collected in a separated storm collector and discharged untreated into the receiving environment. Because its characteristics are similar to those of the Longueuil combined sewer system catchment area, inclusion of the Boucherville catchment area in the study was inescapable. The St. Lawrence River is the common receiving environment for effluents from both catchments located 5 km from one another. The study covers a period from May to October, corresponding to the low-water period for receiving water bodies in the region.

Table 1 shows catchment area characteristics, including total and active surface areas, percentage of impervious surfaces, runoff coefficient, and type of land use. These data were provided by the Longueil agglomeration engineering branch. Table 2 shows the parameters of interest monitored as part of the study and their respective analytical limits of detection (LOD). All chemical analyses were carried out on whole samples in accordance with standard methods listed in Table 2.

Given the random nature of precipitation, sampling was carried out with an Isco 6700 autosampler with Teflon tubes, in accordance with the Ministère de l'Environnement du Québec's Centre d'expertise en analyse environnementale (CEAEQ-MDDEFP) requirements. An Isco 4150 height-velocity flow logger probe was placed on a metal plate fixed to the pipe invert. The flow logger first measures flow height using a pressure transducer, then flow velocity based on the Doppler Effect principle. Flow is calculated using values of height, velocity and actual pipe cross-sectional area. The device is placed in a control chamber downstream from the overflow point for the combined collector in Longueuil and in the last downstream inspection chamber before the outfall into the receiving environment for the Boucherville storm sewer. All devices were fitted with a data logging system set to record at 5 min intervals.

The autosampler sampling program starts when the capacity of regulators is out and when a water level is detected by a float switch connected to it on the downstream side of the overflow