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Model-based screening for critical wet-weather discharges related to micropollutants from urban areas

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ABSTRACT

Wet-weather discharges contribute to anthropogenic micropollutant loads entering the aquatic environment. Thousands of wet-weather discharges exist in Swiss sewer systems, and we do not have the capacity to monitor them all. We consequently propose a model-based approach designed to identify critical discharge points in order to support effective monitoring.

We applied a dynamic substance flow model to four substances representing different entry routes: indoor (Triclosan, Mecoprop, Copper) as well as rainfall-mobilized (Glyphosate, Mecoprop, Copper) inputs. The accumulation on different urban land-use surfaces in dry weather and subsequent substance-specific wash-off is taken into account. For evaluation, we use a conservative screening approach to detect critical discharge points. This approach considers only local dilution generated onsite from natural, unpolluted areas, i.e. excluding upstream dilution.

Despite our conservative assumptions, we find that the environmental quality standards for Glyphosate and Mecoprop are not exceeded during any 10-min time interval over a representative one-year simulation period for all 2500 Swiss municipalities. In contrast, the environmental quality standard is exceeded during at least 20% of the discharge time at 83% of all modelled discharge points for Copper and at 71% for Triclosan. For Copper, this corresponds to a total median duration of approximately 19 days per year. For Triclosan, discharged only via combined sewer overflows, this means a median duration of approximately 10 days per year. In general, stormwater outlets contribute more to the calculated effect than combined sewer overflows for rainfall-mobilized substances. We further evaluate the Urban Index ($A_{urban,impervious}/A_{natural}$) as a proxy for critical discharge points: catchments where Triclosan and Copper exceed the corresponding environmental quality standard often have an Urban Index >0.03.

A dynamic substance flow analysis allows us to identify the most critical discharge points to be prioritized for more detailed analyses and monitoring. This forms a basis for the efficient mitigation of pollution.

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1. Introduction

A variety of substances such as pharmaceuticals, personal care products and pesticides are used daily in urban areas. They are discharged into the environment via sewage treatment plants (STP), stormwater outlets (SWO) in separate stormwater systems and combined sewer overflows (CSO) in combined sewer systems. The occurrence of these anthropogenic substances was reported in concentration ranges of µg/l or ng/l – hence subsequently referred to as micropollutants – in rivers during or after rainfall events (e.g. Gasperi et al., 2014; Madoux-Humery et al., 2013; Musolff et al., 2010; Weyrauch et al., 2010). Urban sources of these micropollutants can be divided into two main groups: substances contained in dry-weather flow, subsequently referred to as *indoor* substances, and *rainfall-mobilized* substances from outdoor surfaces. Indoor substances are found in dry weather flows and are mainly discharged via STP (Phillips et al., 2012), whereas rainfall-mobilized substances are washed-off during rain events and can, therefore, make a greater contribution to wet-weather discharges (WWD, i.e. CSO and SWO).

Abbreviations: CSO, combined sewer overflow; dSFA, dynamic substance flow analysis; EQS, environmental quality standard; ha, hectare of impervious surface; STP, sewage treatment plant; SWO, stormwater outlet; TU, Toxic Unit.

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For example, concentrations of three pesticides (Diuron, Isoproturon and Glyphosate) were 5–20 times higher in CSO discharges compared to dry weather flows in the city of Paris (Gasperi et al., 2012a). Overall, wet-weather discharges can be important contributors to the micropollutant loads found in the aquatic environment (e.g. Brix et al., 2010; Gasperi et al., 2008, 2011; Meyer et al., 2011).

Pesticides (for plant protection purposes) and biocides (for non-plant protection use) (SR-813.12, 2005) may be particularly harmful to the aquatic environment. Some of these substances originate solely from urban areas, e.g. Terbutryn used as a biocide in building materials to prevent growth of unwanted organisms (Burkhardt et al., 2007; Coutu et al., 2012). Other substances such as Glyphosate occur in the runoff from agricultural fields as well as in urban gardening (Burkhardt et al., 2007; Hanke et al., 2010; Wittmer et al., 2010). Glyphosate was implicated as being ‘probably carcinogenic’ to humans (WHO, 2015), and a study by Hanke et al. (2010) showed that as much as 60% of the Glyphosate of a catchment can originate from urban systems. In addition, pesticide emission loads from urban areas were found to be in the same range as emissions from agriculture (Blanchoud et al., 2007; Wittmer, 2010).

Concentration measurements are the most important information for assessing the effects of wet-weather discharges on receiving waters. However, in the absence of flow (load) and specific land-use data, the transferability of concentrations to other sites is low. In view of the high land-use diversity on small scales, it is challenging, if not impossible, to identify and describe a single typical, representative discharge. Furthermore, as for example in Switzerland, there is often a vast number of uncounted wet-weather discharge points, with very limited or no systematically collected information available on location and operation characteristics. In addition, it is resource and time-consuming to measure wet-weather discharges accurately, since emission concentrations vary temporally with rainfall intensity and spatially with land use (e.g. Gasperi et al., 2014; Madoux-Humery et al., 2013). A model-based screening tool designed to facilitate the comparison of different sewer systems, catchments and pollutants of wet-weather discharge points is consequently crucial for decision-makers.

A substance flow analysis (SFA) based on the concept of mass balances within defined system boundaries is an effective method to calculate loads entering the water cycle (Bader and Scheidegger, 2012). An SFA was applied in Lausanne to determine Copper and pharmaceutical loads discharged into a lake (Chèvre et al. 2011, 2013). We apply the SFA concept to all Swiss municipalities and additionally consider the dynamic accumulation and wash-off behaviour of the rainfall-mobilized substances, as was done for micropollutants from facades, for example (Coutu et al., 2012; Wittmer et al., 2011). This dynamic substance flow analysis (dSFA) allows us to calculate discharge concentrations at high temporal resolution. In this study, we aim to answer the following three questions:

i. How can we screen for potentially critical wet-weather discharge points?
ii. How do SWO and CSO compare with regard to discharged micropollutants?
iii. Can we find a proxy – available area-wide on a national/regional scale – to highlight critical wet-weather discharges?

2. Methods

2.1. System description and boundaries

The dSFA was carried out for entire Switzerland (41,285km^2) at municipal level, i.e. 2500 administrative regions (median area 748ha, 95%-interquantile 138–5,889ha; median number of inhabitants 1,170, 95%-interquantile 106–15,950 inhabitants). Wet-weather discharge points were aggregated to one location per municipality (for CSO and SWO individually). Municipalities were selected as catchment boundaries in order to have a realistic data set representing the variability of urban areas and their sewer systems. Aggregation at municipal level was found to be suitable because most urban sewer systems, corresponding STPs and wet-weather discharges are autonomous within a municipality. Ten-minute intervals were chosen as a temporal resolution for modelling, corresponding to the potentially short duration of wet-weather discharges. In order to quantify the effect of wet-weather discharges in a conservative way, the following two conditions were set:

i. The maximum tolerable discharge load is limited to the environmental quality standard (EQS) at the corresponding flow in the receiving water during wet-weather discharges. This requirement is in line with the Clean Water Act (EPA, 1972) of the United States as well as the relevant Swiss regulations (WPO, 1998).
ii. Unused “capacity” from upstream must not be filled up. Thus, unpolluted runoff from lightly populated areas upstream should not compensate local emission hotspots further downstream.

In order to meet these two conditions, each municipality is considered to be “self-sustaining”. This means that the clean runoff from natural areas (A_{nat}), generated locally within each municipality, must be sufficient so that urban wet-weather discharges do not lead to the EQS being exceeded (Fig. 1). As long as this condition is fulfilled locally, wet-weather discharges are not anticipated to cause any detrimental effects in all water bodies. Subsequently, the ratio of locally generated clean runoff (q_{nat}) and wet-weather discharge flow (q_{WWD}) is referred to as the *local dilution potential*, and the effect assessment (exceeding the EQS) as the *local effect potential*. The implications of considering only the local dilution potential for the effect assessment are further discussed in Section 3.7.

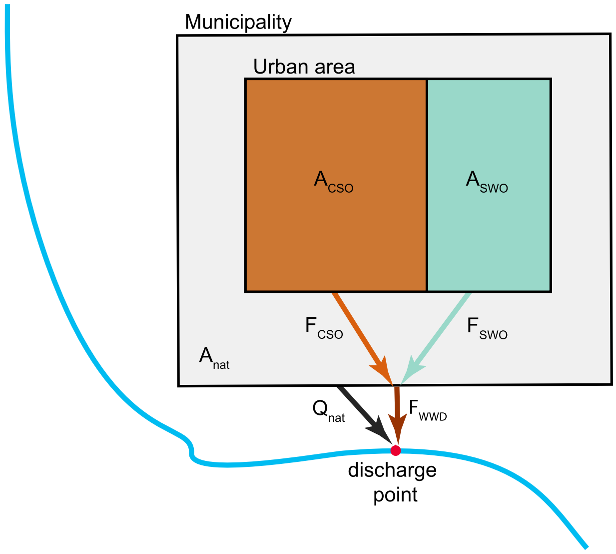

Fig. 1. Schematic representation of the mass fluxes in one municipality. The wet-weather discharge from the municipality $F_{WWD}(t)$ ($= F_{CSO}(t) + F_{SWO}(t)$) is diluted by the locally generated, natural flow Q_{nat} ($= q_{nat} \cdot A_{nat}$). The flow in the receiving water is not taken into account in order to not rely on upstream capacity (local dilution potential).

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