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Climate change impact on infection risks during bathing downstream of sewage emissions from CSOs or WWTPs

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ABSTRACT

Climate change is expected to influence infection risks while bathing downstream of sewage emissions from combined sewage overflows (CSOs) or waste water treatment plants (WWTPs) due to changes in pathogen influx, rising temperatures and changing flow rates of the receiving waters. In this study, climate change impacts on the surface water concentrations of *Campylobacter*, *Cryptosporidium* and norovirus originating from sewage were modelled. Quantitative microbial risk assessment (QMRA) was used to assess changes in risks of infection. In general, infection risks downstream of WWTPs are higher than downstream CSOs. Even though model outputs show an increase in CSO influxes, in combination with changes in pathogen survival, dilution within the sewage system and bathing behaviour, the effects on the infection risks are limited. However, a decrease in dilution capacity of surface waters could have significant impact on the infection risks of relatively stable pathogens like *Cryptosporidium* and norovirus. Overall, average risks are found to be higher downstream WWTPs compared to CSOs. Especially with regard to decreased flow rates, adaptation measures on treatment at WWTPs may be more beneficial for human health than decreasing CSO events.

1. Introduction

Concentrations of human pathogens in surface waters are determined by a several processes. The pathogen input is important, but once released in the aquatic environment, pathogens are diluted, reduced by die-off and (temporarily) reduced by sedimentation.

Domestic wastewater is a major source of human pathogens to surface waters. Commonly, wastewater is treated by WWTPs before it is discharged into the surface waters. However, in the case of combined sewer systems, the capacity of the sewer systems and WWTPs may be exceeded during periods of high rainfall, and, untreated wastewater will be discharged directly into the surface waters. Since climate change predictions show an increase in intensive precipitation events (KNMI, 2014b), an increase in CSOs is expected in the Netherlands. Recent research on the effects of climate change on the frequency, duration and volume of CSOs supports this (Abdellatif et al., 2015; Bi et al., 2015; Nie et al., 2009; Semadeni-Davies et al., 2008). An increase in CSOs could result in increased influx of microbial pathogens and other pollutants into receiving waters.

Besides the changes in influx, climate change is also expected to influence river flow rates. In winter time, precipitation will increase river flow rates (Middelkoop et al., 2001). During dry summers, periods of low discharge will occur more often. This is mainly true for surface water-dominated rivers, such as the river Meuse (de Wit et al., 2007), as they cannot rely on a relatively stable groundwater fed base flow. Based on parameters, including general water quality variables, nutrients, heavy metals and metalloids, a case study on the impact of summer droughts on the water quality of the Meuse river (Van Vliet and Zwolsman, 2008) indicates a general degeneration of the water quality of the Meuse river during droughts. They concluded that the reduction of the dilution capacity of point source effluents was one of the reasons for the decline in water quality. The effects of changing flow rates may amplify or counteract the change in pathogen influx through CSOs.

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Most of the 715 official bathing water locations in the Netherlands are not in contact with wastewater from outlets of WWTPs or CSOs, as shown by completing bathing water profiles (EEA, 2015). An inventory of the accessible bathing water profiles (86%) shows that, of the bathing water locations in the Netherlands, only 11% and 10% could be influenced by wastewater discharges from WWTPs and CSOs respectively (Anonymous, 2016). At some of the locations with high wastewater discharge, additional wastewater treatment is applied to the emission or high emissions are monitored and communicated to the bathers.

About two-third of recreational activities in the Netherlands takes place at official bathing sites (Schets et al., 2011), so the implication is that people frequently bathe at unofficial sites as well. In Amsterdam, Greven and Jakobs (2015) found that 5%, of the people surveyed with regard to their swimming habits, occasionally swim in the canals. Another possibility is that people jump, fall or get pushed into the canal (Schets et al., 2008). Depending on the exact location of bathing, this section of the bathing population may experience increased exposure risks to surface water contaminated with pathogens from outlets of WWTPs and CSOs. Exposure to surface water contaminated with human pathogens, including viruses, bacteria or parasites, may lead to infection and subsequent illness, such as gastroenteritis or skin, ear and eye infections (Brunkard et al., 2011; Schets et al., 2010).

If climate change increases pathogen contributions of CSO events and affects flow rates, an increase in risk of infection is expected during recreation in close proximity of a WWTP or CSO. The main aim of this study is to quantify this change in risk for the Netherlands. Quantitative microbial risk assessment (QMRA) is used to determine the risk of gastroenteritis when exposed to surface water contaminated with norovirus, *Campylobacter* and *Cryptosporidium* originating from wastewater under current and future scenarios. This selection of pathogens was based on human disease burden, data availability and pathogen characteristics.

In previous QMRA studies (Sterk et al., 2015, 2016), the assumption was that people swim randomly over the summer. However, as discussed in these papers, better estimates of probabilities of human exposure to surface waters could improve predictions of the infection risks. One improvement would be to weigh the chance that people will be swimming based on the conditions of a certain day. Intuitively, one could say that higher temperatures result in more water recreation. However, besides water temperature, factors like air temperatures, precipitation, sunshine and economic factors like amount of leisure time will largely determine whether or not people will be bathing. For example, data from Statistics Netherlands shows that recreation takes place more often during the weekends than on a weekday (Centraal Bureau voor de Statistiek 2009). In this study, change in risks of infection are not only based on changes in dose, but also on bathing behaviour.

2. Methods

2.1. Sewer system model

Calculations of rainwater fluxes into the sewer system were based on a standard rainfall-runoff model used for sanitary works in the Netherlands. The sewer system itself was modelled using a simple reservoir model (RIONED, 2004; van de Herik and van Luytelaar, 1989). Fig. 1 shows a schematic overview of the model.

Part of the precipitation (P) is temporarily stored at the surface in depressions and puddles (S_0). The maximum amount of depression storage (S_0Max) is determined by surface type and its inclination. For a summary of model variables see Table 1. A distinction is made between four different surface types, namely impervious paved surface (like bitumen), pervious paved surface (like paving bricks), roofs and unpaved surface. Distinction in inclination is made into sloped surfaces (>4%), flat surfaces, and flat and wide surfaces (flow length to reach sewer system >100 m).

The depression storage (S_0) on the impervious areas can be emptied (during dry weather conditions) due to evaporation. The potential evaporation (ET_{pot}) depends on temperature and radiation (Hiemstra, 2011), but the actual evaporation (ET_{act}) is limited by the volume of water available in the storage:

$$ET_{act} = \begin{cases} ET_{pot} & S_0 > ET_{pot} \\ S_0 & S_0 \le ET_{pot} \end{cases} \tag{1}$$

For the pervious areas, the storage volume can also be emptied by infiltration.

Infiltration capacity, $f_c(t)$, was calculated using the infiltration model of Horton (Horton, 1941). In this model, infiltration capacity decreases exponentially while water is present on the surface. During dry periods, the infiltration capacity is restored to its initial value. At the start of the rain event f_c equals the maximum infiltration capacity (f_b [L T^{-1}]). The change in infiltration capacity is determined by:

$$\frac{df_c(t)}{dt} = \begin{cases} k_a(f_c(t) - f_e) & P + S_0 > 0 \\ k_h(f_c(t) - f_b) & P + S_0 = 0 \end{cases} \tag{2}$$

where f_e is the minimum infiltration capacity [L T^{-1}], and k_a [T^{-1}] and k_h [T^{-1}] are constants determining the exponential decrease and increase respectively. As for evaporation, actual infiltration f(t) is limited by the volume of water available.

Since not all excess water (Xs) reaches the sewer system immediately, the volume of excess precipitation stored dynamically at the surface is modelled as an additional compartment. Change in dynamic storage (h [L]) is determined by:

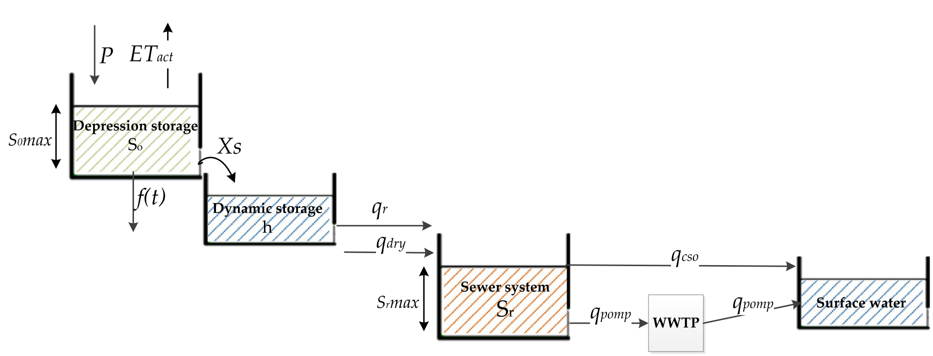

Fig. 1. Schematic overview of rainfall-runoff model combined with the reservoir model. P is precipitation; ET_{act} is evapotranspiration; f{t} is infiltration rate; X_s is excess precipitation water; q_r is the water flux entering the sewer system; q_{dry} is dry weather flow, q_{cso} and q_{pomp} are discharges from a CSO event and to the WWTP respectively.