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Microbial health risks associated with exposure to stormwater in a water plaza

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ABSTRACT

Climate change scenarios predict an increase of intense rainfall events in summer in Western Europe. Current urban drainage systems cannot cope with such intense precipitation events. Cities are constructing stormwater storage facilities to prevent pluvial flooding. Combining storage with other functions, such as recreation, may lead to exposure to contaminants. This study assessed the microbial quality of rainwater collected in a water plaza and the health risks associated with recreational exposure. The water plaza collects street run-off, diverges first flush to the sewer system and stores the rest of the run-off in the plaza as open water. *Campylobacter*, *Cryptosporidium* and *Legionella pneumophila* were the pathogens investigated. Microbial source tracking tools were used to determine the origin (human, animal) of the intestinal pathogens. *Cryptosporidium* was not found in any sample. *Campylobacter* was found in all samples, with higher concentrations in samples containing human *Bacteroides* than in samples with zoonotic contamination (15 vs 3.7 gc (genomic copies)/100 mL). In both cases, the estimated disease risk associated with *Campylobacter* and recreational exposure was higher than the Dutch national incidence. This indicates that the health risk associated with recreational exposure to the water plaza is significant. *L. pneumophila* was found only in two out of ten pond samples. Legionnaire's disease risks were lower than the Dutch national incidence. Presence of human *Bacteroides* indicates possible cross-connections with the CSS that should be identified and removed.

1. Introduction

Climate change will produce an increase in frequency and intensity of storm events. Consequently, urban sewage systems will be overwhelmed more often, and street flooding will occur more frequently (Ashley et al., 2005). New urban water features are emerging in cities to deal with this problem. These features serve as temporary storage of rainwater, reducing pluvial flooding during intense rainstorms, and making rainwater available for other purposes, such as landscape irrigation or recreation. Water plazas are an example of these temporary storages of rainwater where the water is used for urban recreation.

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Rainwater is, in principle, of good microbiological quality, but gets contaminated through roof and soil input (e.g. surface runoff) (Marsalek and Rochfort, 2004). Therefore, exposure of humans to urban rainwater may lead to health risks (Fewtrell and Kay, 2008). Microbial hazards may be present in water bodies that collect rainwater due to input of faecal material such as sewage discharge containing human enteric pathogens (*Campylobacter*, *Cryptosporidium*, norovirus, rotavirus, etc.) or animal faecal input (from waterfowl, dogs, and other animals) containing zoonotic pathogens (Arnone and Walling, 2007; Hofstra, 2011). *Legionella pneumophila* has been found in rainwater on roads (Sakamoto et al., 2009), roof rainwater harvesting systems (Ahmed et al., 2010; Schets et al., 2010), and pluvial floods (Schalk et al., 2012). Microbial risks are also influenced by climate change. A higher frequency and strength of storms and draughts affects the concentration of pathogens present in (storm) water (Hofstra, 2011; Hunter, 2003).

The microbial quality and/or health risks in rainwater have been assessed in various features such as pluvial flooding and runoff (de Man et al., 2014c; Sidhu et al., 2012; ten Veldhuis et al., 2010), splash parks that use rainwater (de Man et al., 2014a), or rainwater roof harvesting (RRH) containers (Ahmed et al., 2012a, 2008, 2010). Water plazas that collect roof and street run-off from a larger urban area are relatively new engineering concepts that combine stormwater storage with water recreation and their water quality and microbial risks have not been studied previously.

Identifying the probable sources of faecal contamination may be important in estimating human health risks (Soller et al., 2010). Faecal source tracking (FST) tools consist of identification of host-specific gut bacteria, host-specific viruses, detection of chemicals associated with human waste (sterols, caffeine, etc.), or mitochondrial DNA from gut cells that are shed through the faeces (Hagedorn et al., 2011). FST has been used to identify faecal sources in RRH (Ahmed et al., 2012b) and sewage impacted stormwater drains (Sauer et al., 2011; Van De Werfhorst et al., 2014), and in Quantitative Microbial Risk Assessment (QMRA) studies in bathing beaches (Colford et al., 2007; Schoen and Ashbolt, 2010; Soller et al., 2010) and other recreational waters (Staley et al., 2012).

The aim of this study was to investigate the microbial hazards and health risks associated with a newly built rainwater plaza in an urban environment in Rotterdam (The Netherlands). For this purpose, the water in the plaza was monitored for reference pathogens during a stormwater runoff simulation experiment. FST was used to determine the origin of faecal contamination and relate faecal markers to pathogens presence and concentration.

2. Materials and methods

2.1. Site description

The water plaza Bellamyplein, located in the city of Rotterdam (The Netherlands), has a surface of 5000 m^2 and is designed to collect streets and roofs rainwater from an area of 2 ha, although in the current situation, this area is only 0.8 ha. It can store up to 864 m^3, corresponding to 108 mm of rain, in the current situation, and 43.2 mm, in the future. The square has four platforms at different levels. When it rains, the water flows towards the plaza and into an underground drain. When this has filled up (60 m^3) the water flows on to the lowest terrace (at −2.10 m NAP or Amsterdam Ordenance Datum), and from there it flows up till the highest terrace is filled (at −1.40 m NAP), when it continues raining (Fig. 1). 10.6 mm of rain will fill up the lowest terrace (4.3 mm in the future) where children can already play. The plaza is equipped with a first flush pump (FFP) that discharges the first 60 m^3 of collected water into the combined sewer system (CSS).

2.2. Microorganisms of interest

Escherichia coli (EC) was chosen as indicator of faecal contamination since the European Bathing Water directive relies on this indicator for classifying the water quality (Anonymous, 2006). Three host-specific indicators were chosen: Human *Bacteroides* (HB), Avian *Helicobacter* (AH), and canine mitochondrial DNA (CD) as indicators of human, avian, and canine faecal contamination, respectively.

Campylobacter and *Cryptosporidium* were the gastrointestinal pathogens selected because their presence is expected in locations where bird and dog droppings are present (Baker et al., 1999; Waldenstrom et al., 2002). *L. pneumophila* was selected because it has been shown to multiply in engineered water systems (Diederen, 2008), cases of legionnaire's diseases (LD) have been related to increased rain conditions, and it has been found in pluvial floods (Sakamoto et al., 2009; Schalk et al., 2012) and RRH containers (Ahmed et al., 2010). Viruses were not targeted because human faecal material was not expected in street run-off (de Man et al., 2014c).

2.3. Simulation experiment and sampling

A simulation experiment was conducted to study the functionality of the system. The square was cleaned with pressured drinking water the day before the event, providing the unique opportunity to study the impact of fresh street deposits (without contribution of run-off from roofs) on microbial water quality. On the day of the experiment, two fire hydrants, located in two streets surrounding Bellamyplein, were opened and ran for 3 h at 60 m^3/h. The water flowed over the street pavement into the street gutters, leading the water into the

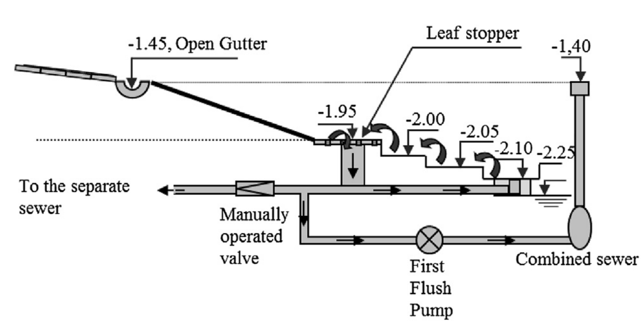

Fig. 1 – Description of the water flow in the water plaza. Numbers indicate the NAP level (modified from Rodenburg and Doelder (2013)).