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Microbial risks associated with exposure to pathogens in contaminated urban flood water

J.A.E. ten Veldhuis [a,*], F.H.L.R. Clemens [a], G. Sterk [a,1], B.R. Berends [b]

[a] Water Management Department, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft. PO Box 5048 2600 GA Delft, The Netherlands

[b] Interfaculty Institute for Risk Assessment Sciences, IRAS, Utrecht University. PO Box 80178, 3508 TD Utrecht, The Netherlands

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ABSTRACT

Urban flood incidents induced by heavy rainfall in many cases entail flooding of combined sewer systems. These flood waters are likely to be contaminated and may pose potential health risks to citizens exposed to pathogens in these waters. The purpose of this study was to evaluate the microbial risk associated with sewer flooding incidents. Concentrations of *Escherichia coli*, intestinal enterococci and *Campylobacter* were measured in samples from 3 sewer flooding incidents. The results indicate faecal contamination: faecal indicator organism concentrations were similar to those found in crude sewage under high-flow conditions and *Campylobacter* was detected in all samples. Due to infrequent occurrence of such incidents only a small number of samples could be collected; additional data were collected from controlled flooding experiments and analyses of samples from combined sewers. The results were used for a screening-level quantitative microbial risk assessment (QMRA). Calculated annual risks values vary from 5×10^{-6} for *Cryptosporidium* assuming a low exposure scenario to 0.03 for *Giardia* assuming a high exposure scenario. The results of this screening-level risk assessment justify further research and data collection to allow more reliable quantitative assessment of health risks related to contaminated urban flood waters.

1. Introduction

The frequency of flooding and the damage caused by urban flood events have increased over the past decades, mainly due to accelerated urbanisation (Ashley et al., 2005). When urban flooding occurs in areas with combined sewer systems, flood water is likely to be faecally contaminated and may pose health risks to citizens exposed to pathogens in these waters. Faecal contamination of urban flood waters was investigated after severe flooding in New Orleans following Hurricanes Katrina and Rita (Sinigalliano et al., 2007) and after the Elbe floods in Germany in 2002 (Abraham and Wenderoth, 2005). Elevated levels of faecal indicator bacteria and microbial pathogens were found in flood waters and in sediments left in the urban environment after the flood. Faecal contamination of flood waters and subsequent contamination of drinking water sources have been found for severe flood events in Bangladesh and Indonesia (Sirajul Islam et al., 2007; Phanuwan et al., 2006). Physical and mental health effects associated with severe floods have been studied by several authors (Fewtrell and Kay, 2008; Ohl and Tapsell, 2000; Tapsell and Tunstall, 2003 and Tunstall et al., 2006) based on

* *Corresponding author*. Tel.: +31152784734; fax: +31152784918.
E-mail addresses: j.a.e.tenVeldhuis@tudelft.nl (J.A.E. ten Veldhuis), f.h.l.r.Clemens@tudelft.nl (F.H.L.R. Clemens), B.R.Berends@uu.nl (B.R. Berends).
[1] Present address: KU Leuven, Hydraulics Laboratory, Kasteelpark Arenberg 40 – 3001 Heverlee, Belgium.
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interviews with people affected by floods. Lulani et al. (2008) quantified combined health effects of flooding in terms of disability-adjusted life years based on a list of assumptions.

Microbial health risks associated with faecally contaminated flood waters are not only induced by severe, extensive flood events. Especially in lowland areas flooding of combined sewers occurs almost yearly. For instance in the Netherlands, a commonly applied design criterion for combined sewer systems is a maximum flood frequency of once per year or per two years (RIONED, 2004). The reason why higher flood frequencies are accepted in lowland areas is that expected damage of sewer flooding in flat areas is less than in sloping areas: flood waters spread over larger areas, resulting in smaller flood depths compared to sloping areas where flood waters concentrate in local depressions. This implies that exposure of citizens to faecally contaminated flood waters may occur on a regular basis. The spatial extent of these flood incidents is usually small, flood waters covering a part of a street up to several streets (Veldhuis ten and Clemens, 2009).

Occurrence of urban flood incidents is expected to increase in the future, as climate change will induce more intense rainfall (e.g. Lenderink and van Meijgaard, 2008) and ongoing urbanisation continues to increase inflow to urban drainage systems. In addition, flooding caused by infrastructure failures like pipe blockages is expected to occur more frequently in the future as systems are ageing (Veldhuis ten et al., 2009). Increased flood frequencies and growing population densities will increase health risks associated with exposure to contaminated urban flood waters.

Health risks associated with combined sewer overflows (CSOs), which occur at a higher frequency than flood incidents, have been investigated by Donovan et al. (2008) who find a probability of contracting gastrointestinal illness from incidental ingestion of water near CSOs ranging from 0.14 to nearly 0.70 over the course of a year for visitors and recreators (e.g. swimmers), respectively, associated with the presence of faecal pathogens indicated by the presence of faecal *Streptococcus* and *Enterococcus*. Schets et al. (2008) investigated microbial quality of surface water in canals and recreational lakes in Amsterdam that receive polluted water from CSOs, raw sewage from houseboats and dog and bird faeces. The estimated risk of infection with *Cryptosporidium* and *Giardia* per exposure event ranged from 0.00002% to 0.007% and 0.03% to 0.2%, respectively, for occupational divers professionally exposed to canal water. The effect of CSOs on surface water quality has been investigated by Kay et al. (2008). They quantified faecal indicator concentrations and export coefficients for catchments with different land use and under specific climatic regimes. Urban areas are identified as one of the key sources of faecal indicator organisms, with significantly higher values occurring for high-flow conditions, during or after rainfall. Curriero et al. (2001) analysed the more general relationship between precipitation and waterborne disease outbreaks for 548 reported outbreaks in the USA from 1948 through 1994. They found a statistically significant association between weather events and disease; overflows from combined sewer systems are mentioned as one of the potential sources of contamination.

The purpose of this study was to conduct a screening-level quantitative microbial risk assessment (QMRA) to evaluate the risk associated with exposure of citizens to pathogens in flood waters resulting from combined sewer flooding. Samples were collected and analysed for 3 sewer flooding incidents and controlled flooding experiments were conducted to test survival of pathogens in flood water. The results were used to conduct a screening-level quantitative microbial risk assessment.

2. Materials and methods

2.1. *Experiments*

Flooding incidents occur infrequently and often unpredictably in terms of time and location; this makes sampling from flooding incidents a difficult task. During the measurement campaign in the summer of 2007, several heavy rainfall events occurred; one of those caused flooding at locations that were known to flood regularly. During and shortly after a heavy rainfall event on 16 July 2007 water and sediments were sampled from 3 flooding incidents in the Hague, the Netherlands. Rainfall lasted for more than 7 h; the total rainfall volume amounted to 25 mm. All 3 locations were served by combined sewers; streets were partially flooded over a length of several hundred meters (Fig. 1). Water samples were taken in duplicate during the flooding incidents; duplicate sediment samples were taken at one location after flood waters had withdrawn. The samples were cooled and analysed within 18 h after sampling.

In addition, controlled urban flooding experiments were conducted to test survival of microbial organisms in flood water. A metal ring (Ø 0.5 m) was cemented to the street surface on a parking lot and the ring was filled with wastewater from a nearby combined sewer. The wastewater was diluted with non-chlorinated tap water to simulate dilution of wastewater with rainwater during sewer flooding incidents. The dilution factor was chosen based on values of *E.coli* and intestinal enterococci found in samples from the flood incidents and values found in wastewater samples from the combined sewer system. The controlled flooding experiments

Fig. 1 – Flooding on 16 July 2007 at sampling site Scheveningen Boulevard II, the Hague.