Estimating risks from urban sewer flooding's -Combining quantitative microbial data with hydrological software to improve quantitative microbial risk assessment of urban sewer flooding's

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Quantitative microbial risk assessment of the impacts of flooded basements in urban areas by combining quantitative microbial data with hydrological software

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Abstract: During heavy rain events diluted wastewater often flood streets and basements or occur as overflow. As a consequence, exposure to the water during cleaning basements may lead to infection or severe illness. The purpose of this study was to generate a new quantitative microbial risk assessment (QMRA) of the impacts of urban flooding on human health with less uncertainty on the pathogenic concentrations and the dilution factor. This was accomplished by firstly validating a hydraulic model by use of quantitative data from dry weather flow and combined sewer overflow (CSO) from sub-catchments of the model. Secondly, opportunistic sampling of flooding and CSO events showed elevated levels of ammonia and *Enterococcus spp.* in flood water and CSO water when compared to stormwater and provided the basis for a risk assessment of flood water. By the approach of hydraulic modelling a risk of 4.9 x 10^-1 for single infections and 1.5 x 10^-2 for illness when exposed to *Campylobacter* in flooded basements (darkness) were estimated. By including the hydraulic model in the QMRA the uncertainty of the dilution factor for potential flood water was thereby reduced.

Keywords: combined sewer overflow, human health, hydraulic modelling, quantitative microbial risk assessment, stormwater, urban flooding.

Introduction

During heavy rain events streets and basements may be flooded by wastewater diluted by stormwater. Citizens may be exposed to this water when passing flooded areas or cleaning flooded basements. This exposure may lead to infection or severe illness (Ahern 2005) because the levels of faecal indicator bacteria and pathogens are raised in flood waters left in urban environments after flooding (Velthuis et al. 2010, Fewtrell et al. 2011). To assess the risk of such flood events, microbial risk assessment (QMRA) can be applied (Andersen et al. 2013, Fewtrell et al. 2011, Velthuis et al. 2010).

QMRA is a well-recognized tool to estimate the risk of disease. Unfortunately QMRA for human health related to flooding often relies on a range of assumptions, especially regarding water quality and hydrological conditions, due to lack of data on these parameters. To conduct a QMRA for flood water three essential parameters are required: the dose-response relationship, the pathogenic concentration and the dilution factor. Today dose-response relationships are well established for several pathogenic microorganisms, e.g. *Campylobacter jejuni* (Medema et al. 1996). In contrast, the pathogenic concentrations are challenging to quantify since the concentrations will vary with time and season, and are furthermore catchment specific. Consequently, many studies on human health impacts on flooding rely on insufficient water quality data.

Today, the water quality in flood water has to be assumed by use of literature values or previous measured concentrations. This is problematic because the water quality from flooding will vary because of the differences between the rain events, the
prehistory of rain events and sedimentation in the combined sewer system and the influence by the catchment variability’s. To overcome the uncertainty of the water quality hydraulic models can be applied to estimate the dilution factor of the system. But hydraulic models may not exist for the specific catchment of interest. The usefulness of hydraulic models was however shown in a study of bathing water contaminated with combined sewer overflow were the output of the risk assessment was compared to epidemiological data (Andersen et al. 2013).

To advance the quality of QMRA related to urban flooding this study used quantitative data on the microbial concentrations as input and for validation of a hydraulic model. The output of the simulation model should be applied in a dose-response relationship of Campylobacter to assess the human health risks associated with flooded basements.

**Material and Methods**

**Sampling and analysis**

Samples were collected under dry weather conditions (DWF) and during combined sewer overflow (CSO). Furthermore, samples were collected from flooded streets and basements. The indicator organisms *Escherichia coli* and *Enterococci spp.* were quantified by Colilert-18 and Enterolert detection kits in connection with the Quantitray 2000 system (IDEXX, Westbrook, Maine, USA) according to the manufacturer’s instructions. *Campylobacter spp.* was detected according to ISO TS 10272-3:2010, except direct plate spreading was applied instead of membrane filtration and were incubated under microaerophilic conditions (CampyGen, Oxoid, Denmark) for 48 ± 4 h at 37°C.

**Hydraulic modelling**

MIKE URBAN was the urban drainage model used in our study (Andersen et al. 2004). It is a 1-D fully hydrodynamic sewer model based on implicit definite difference scheme. The drainage model covered 47 km² and the wastewater was pumped to Damhusaaens wastewater treatment plant. To simulate water quality in the drainage system an advection-dispersion module was applied, including the water quality parameters ammonium (NH₃-N), *E. coli*, *Enterococci spp.* and *Campylobacter spp.* together with flow and water levels.

**QMRA**

In the QMRA, a known dose-response relationships for the pathogenic organism *C. jejuni* was used (Medema et al., 1996). The QMRA was conducted for a rain event (July 2nd 2011) with 58 mm of rain in 180 minutes, and with intensities up to 0.6 mm/min. The rain event caused flooding of basements of the investigated catchment. The origin of flood water was assumed to be rainwater run-off into the combined sewer system, where it was mixed with wastewater, and reached the ground surface when the sewer was overloaded (Figure 1). The risk was assessed (Figure 2) with the most conservative assumptions, and with a scenario of 1) accidental ingestion of contaminated water or 2) during the removal of water from flooded basements (darkness). The resulting concentrations of the microbial parameters were calculated by the hydraulic model based on DWF data.
The ingested volumes were based on the values used for people that have accidental contact, being 10 mL per incident for recreational use of people who engage in activities with minimal water contact, such as anglers, boater and individuals wading in the surface water (Donovan et al., 2008). This value is similar to the guideline value for individuals exposed to surface water during wading (USEPA, 2000). The ingested dose was the pathogen concentration in CSO water, representing potential flood water, multiplied by the ingested volume at a single exposure event. The decay rate of *Campylobacter spp.* in darkness was expected to be constant after 24 hours of retention time.

![Figure 1](image1.jpg)

**Figure 1** The way of a flooding event; overloaded sewers leads to flooding of e.g. toilets in basements wherefore cleaning by citizens are done in flood water of low water quality (3 water types shown).
**Results and Discussion**

**Validating the hydraulic model**

The output and validation of the hydraulic model was based on an average of the concentrations of diurnal fluctuations of ammonia and rain data from DMI (Danish Meteorological Institute). The results of the model were compared to the measured concentrations of ammonia during a CSO event (Figure 3), (preliminary results). The modelled ammonia concentrations were similar to the measured concentrations. Ammonia was used because it is a fully water soluble compound and therefore stable through the transport in the sewer system, and a very good water quality parameter. The model was then assumed to describe the overall transport and dilution processes in the sewer system. The preliminary results for the modelled *Campylobacter* spp. concentrations showed similar results (data not shown).
Figure 3 Ammonia (NH$_3$-N) concentration at dry weather flow (10 am to 10 am) and at the rain event (13.57 pm to 16:36 pm) leading to a CSO event. Note: Time is given as coordinated Universal Time (UTC).

Opportunistic sampling

Ideally, samples from flood water should be collected for verification of the output of the hydraulic model, but due to the infrequency of flood events this was not possible. Instead, sporadic samples of flood water from locations outside the model range were collected in the period 2011-2013 (Figure 4). Ammonia and Ortho-phosphate were generally detected in higher concentrations in flood water and CSO water than in stormwater. This was expected because the ammonia content primarily originates from the domestic use (Butler et al. 1995). The water temperature in flood water was on average 19.8°C, whereas for the CSO the water temperature were in average 16.4°C and for stormwater it was 16.8°C (Figure 4).

The $E.\ coli$ concentrations were in the range of 10$^4$-10$^7$ MPN/100mL in the flood water, 5 x 10$^2$ MPN/100mL in the CSO water and <1 to 2 x 10$^3$ MPN/100mL in the stormwater (Figure 4). The $Enterococci$ spp. concentrations were 10$^2$-10$^6$ MPN/100mL in flood water, 2 x 10$^3$ MPN/100mL in the CSO water, and 10$^1$-5 x 10$^4$ MPN/100mL in the stormwater. The indicator concentrations were comparable to the concentrations found in other studies of flood water (Fewtrell et al. 2011, Velthuis et al. 2010).

The $Enterococci$ spp. concentrations in the CSO water were higher than in the stormwater. It was therefore reasonable that the flood water and stormwater had similar concentrations of $Enterococci$ spp., because the flood water represents wastewater diluted by stormwater. On the other hand, the $E.\ coli$ concentrations were higher in the flood water than in the CSO and in the stormwater. Thus $E.\ coli$ may not be as good an indicator as $Enterococci$ spp. for distinguishing water sources. The measured concentrations of $E.\ coli$ and $Enterococci$ spp. concentrations in flood water were exceeding the guidelines from the EU directive 06/07/EC for good water quality for inland waters, except for two samples where $Enterococci$ spp. concentrations were complying with the guidelines (Figure 4).

$Campylobacter$ spp. were measured in both CSO and some of the stormwater samples being 3 x 10$^3$ to 5 x 10$^5$ CFU/100mL (Figure 4). Unfortunately, the flood water samples of this study were not analysed for $Campylobacter$. $Campylobacter$ was
however detected, but not quantified, in another study of flood water (Sterk et al. 2008). The concentrations of Campylobacter in the CSO water were comparable to the finding in other studies of CSO water, being in the range of $10^3$-$10^4$ CFU/L (Rechenburg & Kistemann 2009, Velthuis et al. 2010). In stormwater the concentrations of Campylobacter was near to the concentrations in the CSO water (Figure 4) but Campylobacter was also undetectable in some of the stormwater samples. This was an important finding because flood water from overflowed sewers contains mostly stormwater, e.g. the rain event the 2nd of July 2011 where the hydraulic model estimated 96.8% of stormwater in the flood water. The stormwater quality should therefore be known because it highly influences the water quality in flood water.

Statens Serum Institute (Denmark) reported about 4000 yearly incidents of Campylobacter. Campylobacter was thereby the most commonly reported cause of bacterial gastroenteritis in Denmark. This was also found in the United Kingdom where an estimated incidence rate of 8.7/1000 populations was found for Campylobacter (Adak et al. 2002). Campylobacter was therefore chosen as reference pathogen for the QMRA.

Figure 4 Ammonia (NH$_3$-N), Ortho-phosphate, Temperature, E. coli, Enterococci spp. and Campylobacter spp. concentrations from sampling of flood water, CSO and stormwater. For E. coli and Enterococci spp. the water quality guidelines for good bathing water quality from the EU Directive 06/07/EC was shown. For Campylobacter spp. the flood water were not analysed, for stormwater the missing columns represents samples where Campylobacter were below the detection in 100µl sample.

QPMRA

The data from the sporadic sampling and the output from the hydraulic model provided the basis for making a QMRA for the single exposure risk of Campylobacter from the rain event the 2nd of July 2011. The scenario was cleaning of flooded basements after 24 hours of retention time. The used values for the risk assessment calculations were shown in Table 1. When the dilution factor found by the hydraulic
model was used the single exposure infection risk were $4.9 \times 10^{-1}$ for *Campylobacter*. When adjusted by the incidence of illness (30% reduction) the single risk of illness was $1.5 \times 10^{-2}$ (Table 1). This resulted in 49% infection risk or 15% illness risk for citizens exposed to flood water when cleaning up their basement. The risk was in the upper limit to what have been found in other studies of flood water (Velthuis et al. 2010, Fewtrell et al. 2011, Sterk et al. 2008). However this study did not include assumptions on the contribution by stormwater runoff directly to the recipient, because the scenario was for overflowing sewers in basements. The concentration of *Campylobacter* in the recipient was $8 \times 10^{3}$ CFU/100mL. The concentration was similar to the measured concentrations of *Campylobacter* in the stormwater and the CSO water (Figure 4). Thus when comparing the measured concentrations of *Campylobacter* with the estimated concentration found by the hydraulic model the dilution factor seemed reasonable.

For an assumed dilution factor, being 10 times lower than the modelled, the single risk infection were 3.1% lower than for the modelled dilution factor being $5.2 \times 10^{3}$ (infection) $1.6 \times 10^{-2}$ (illness). This resulted in 52% infection risk or 16% illness risk for citizens were infected when exposed to flood water. Thus assumptions of the dilution factor rather than using hydraulic models to estimate the dilution factor will change the outcome of the QMRA.

By use of the hydraulic model an improved QMRA of flooding incidents by sewer overflow were thereby implemented for *Campylobacter*.

### Table 1 Single exposure infections risks and summary of values used in risk assessment calculations for Campylobacter.

<table>
<thead>
<tr>
<th></th>
<th>Mean concentration <em>Campylobacter</em> mL$^{-1}$</th>
<th>Ingestion mL</th>
<th>Dilution factor org. mL$^{-1}$</th>
<th>Dose</th>
<th>Single infection risk</th>
<th>Single illness risk$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic model</td>
<td>2500</td>
<td>10</td>
<td>30</td>
<td>800</td>
<td>$4.9 \times 10^{-1}$</td>
<td>$1.5 \times 10^{-2}$</td>
</tr>
<tr>
<td>Assumed dilution factor</td>
<td>2500</td>
<td>10</td>
<td>20</td>
<td>1250</td>
<td>$5.2 \times 10^{-1}$</td>
<td>$1.6 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

a) Assumed retention time of 24 hours
b) Adjusted according to incidence of illness for Campylobacteriosis, being 30% (WHO, 2004).

### Conclusions

The health risk was estimated for citizens exposed to flood water when cleaning up basements. The opportunistic sampling of *E. coli* and *Enterococci spp.* showed concentration that exceeded the guidelines from the EU directive 06/07/EC of good water quality for inland waters. Further there was a clear difference in the water quality of flood water, CSO water and stormwater with the lowest concentrations in the stormwater.

By use of the hydraulic model, CSO data, and opportunistic sampling of flood water a new generation of QMRA was conducted for *Campylobacter*. This included knowledge of the dilution factor in the sewer system by use of a hydraulic model that used rain data instead of assumptions from literature values or previous measurements of the microorganisms of interest.

The QMRA for *Campylobacter* and the concentrations of indicator bacteria from sewer flooding incidents showed a potential health risk to citizens exposed to flood water by cleaning up basements. Contact with flood water should therefore be avoided.
Acknowledgements
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