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A stochastic sewer model to quantify health risks to residents from sewer flooding with quantitative microbial risk assessment

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Abstract. This work presents a stochastic sewer model (SIMDEUM-WW) to predict dry weather sewer flows and pollutant loading within a sewer network; by generating probabilistic household demand patterns based on information about inhabitants and appliance usage. The stochastic outputs were fed into MIKE URBAN (DHI) for hydrodynamic and water quality simulations under several weather conditions. The MIKE URBAN model includes a 2D overland flow model and a 1D sewer network model that flows are exchanged via manholes. The model was validated against field measurement data and the results show that the SIMDEUM-WW can adequately calculate wastewater and pollutant loading. A quantitative microbial risk assessment model was developed to assess the infection risk due to *E. coli* contamination from combined sewer overflow. It was predicted that that the probability of infection from *E. coli* was high.

Keywords. Flood model, human health, QMRA, stochastic modelling, urban drainage

1. Introduction

The prevalence and intensity of heavy rainfall events over the last decade have become more frequent due to climate change (1–3). Increased urbanisation and changes in land use has further complicated this problem, as the natural hydrological cycle is disrupted by non-permeable surfaces. This leads to increased run off, and an upsurge in flood risk. Consequently, there is an emerging need to develop strategies to reduce urban flood risk and improve water management (4). Exposure to flood waters poses many health risks to human populations. Previous literature has shown a variety of diverse health effects from urban flooding, which can affect both physical and mental wellbeing (5). The health implications are convoluted and include drownings, injuries, and microbiological illnesses and diseases (6). Further consensus from medical literature reveals the impact flooding has on mental health (7). Yet, there is a lack of understanding in past research on the effects pathogens, such as *E. coli* can have on humans from sewer exceedance. When this has been researched very few have quantified the outcome. Similarly, adding rainfall to SIMDEUM-WW has not been adopted previously.

2. Methods and Materials

The present paper aims at modelling 1D probabilistic wastewater flows with 2D surface flows in a U.K urban catchment. Field measurement data (sewer discharge, *E. coli* concentrations and water quality parameters), recorded at a combined sewer overflow (CSO) provided model validation. Under different weather conditions sewer exceedance was simulated and a quantitative microbial risk assessment (QMRA) model was established to measure the risk of infection to residents from a surcharging manhole after two storm events.

2.1 Study location and data

The location used for the modelling is situated in Sandford, the Poole Harbour region of the U.K. A small section of Sandford Town was chosen for the analysis, which included 500 households. Data were provided by the water utility company Wessex Water. Data included a sewer map and CSO monitoring data that was collected from two different storm events at Wareham CSO outflow. The data contained spill volumes and durations, and pollutant loads of E. *coli* **(Figure 1.)**, N, P and SS. Rainfall data was obtained from the Medical & Environmental Data Mash-up Infrastructure database (MEDMI).

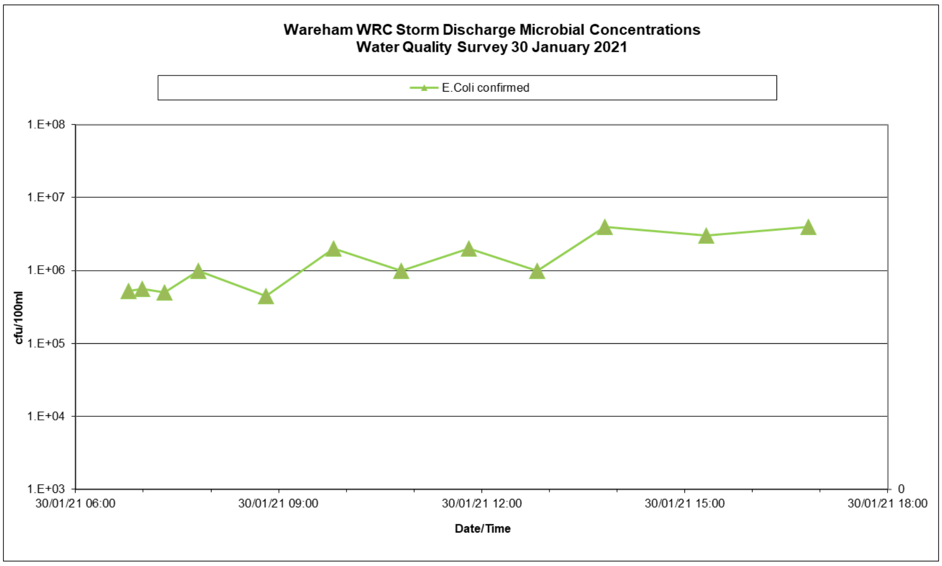

Figure 1. Confirmed E. *coli* concentrations sampled at Wareham from the first storm event.

2.2 Hydraulic discharge

SIMDEUM was originally developed in the Netherlands as a water demand tool (8), though has since been developed and calibrated to simulate wastewater discharge based on household and appliance usage data, using Monte Carlo Simulations (9,10). Calibration took place in a Dutch case study (Prinseneiland). Input variables (household occupancy, home–presence, individual details of household water consumption and average household occupancy) were adjusted in the calibration procedure. Validation included reviewing model performance over an average week using the Nash–Sutcliffe efficiency (NSE), the root mean squared error (RMSE) and correlation coefficient (R^2). Dry weather flow data was chosen at several points of the year (2 weeks from each season) to produce mean water use patterns of the catchment.

2.3 Wastewater

SIMDEUM-WW links water quality from the stochastic flow patterns. A variety of pollutants and water quality indicators can be modelled, including E. *coli*, biological oxygen demand (BOD), chemical oxygen demand (COD), nitrogen (N), phosphorous (P) and suspended solids (SS). Appropriate inputs for nutrient values in SIMDEUM-WW were conducted in previous research (10).

2.4 Coupled 1D-2D model

MIKE URBAN (DHI) is a coupled 1D sewer and 2D overland flow model. The sewer model is used to analyse the water movement within sewer systems that flow is confined by the drainage network and can only move along the pipes such that it is regarded as a 1D modelling practice. On the other hand, the surface runoff may propagate in any horizontal directions such that it is considered as a 2D modelling approach. The flow interactions between 1D and 2D models are exchanged via manholes. In this study, outputs from SIMDEUM hydraulic discharge are integrated into the 1D MIKE model. The storm event period was set for simulation period.

2.5 Water quality model

MIKE ECO Lab is an integrated module in the DHI software. The module is coupled to the Advection-Dispersion Modules of the hydrodynamic flow model, so that transport mechanisms based on advection-dispersion can be integrated in the MIKE ECO Lab simulation. E. *coli*, N, P and SS were simulated over the storm duration period.

2.6 QMRA

QMRA measures the probability of infection and disease from human exposure to pathogens and microorganisms. It is based on an identification and the content of the pathogen, what the level of exposure is, and the dose- response based on concentrations. In this research the risk levels per storm event will be estimated using the Beta Poisson dose response model. There are four main steps necessary for a QMRA.

Table 1. Steps and procedure of QMRA

QMRA Steps	Procedure taken in this project
1. Hazard identification	*E. coli*
2. Exposure assessment	Ingestion volumes from the literature (11)
3. Dose-response	Beta- Poisson
4. Risk characterization	Probability of infection from 2 storm events

3. Results and discussion

As this is ongoing work preliminary results will be discussed. It is predicted that the stochastic sewer model can properly calculate wastewater flows and pollutant loading. However, small errors exist due to SIMDEUM-WW being calibrated on households in the Netherlands. The water consumption patterns in the UK household are not the same as the Netherlands households, though water demands in both countries are similar. As drainage systems are complicated other errors may include flow and pollutant loading at the pipe outflow. Combined sewer systems are very complicated, so flows and pollutants from other parts of the system is likely. It is also predicted that the probability of infection to residents is high, due to the E. *coli* concentrations. **Table 2** shows that inland waters should have concentrations of 1000 cfu/100 ml^{-1} to be of a good standard. Concentrations recorded at Wareham CSO are far larger than EU guidelines.

Table 2. Bathing water classification values for inland waters (12).

Parameter	Excellent quality[b] (cfu[a]/100 ml^{-1})	Good quality[b] (cfu/100 ml^{-1})	Sufficient quality[c] (cfu/100 ml^{-1})
E. coli	500	1000	900

[a] cfu: colony forming units; [b] based on 95^{th} percentile; [c] based on 90^{th} percentile

4. Conclusion

It was predicted that the numerical model was able to replicate accurate hydraulic and wastewater discharges, validated against CSO monitoring data collected from two different storm events. Though small error was present due to the complexity of dual drainage systems and the fact SIMDEUM was calibrated in The Netherlands. It was also predicted that the QMRA showed that the probability of infection was high to residents from sewer exceedance.

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