Supplemental Information

Using nodal infection risks to guide interventions following accidental intrusion due to sustained low pressure events in a drinking water distribution system

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1. Accidental intrusion modeling

Pressure values resulted from PDA are used to define the intrusion nodes and intrusion volumes. Tanyimboh and Templeman [1] equation is selected as the pressure-demand relationship. It is assumed that when nodal pressure head is more than 15 m the demand is completely satisfied and at nodes with pressure head less than the nodal elevation the demand cannot be supplied at all. For calculating the intrusion volume, the negative pressure values are calculated using the method presented in Hatam, *et al.* [2]. However, if one uses the recent version of WaterGEMS the issue described for the version used in our previous study regarding reporting negative pressure as zero is solved.

To simulate time-varying conditions, an extended period simulation is carried out for 336 hours. Normal hydraulic operating conditions are simulated for the first 240 hours to stabilize the water quality. Then, the unplanned shutdown of one WTP is simulated. The hydraulic and water quality time steps are 30 minutes and 30 seconds, respectively.

The orifice equation is applied to calculate the intrusion flow rate at each node using the nodal pressure value from PDA when the pressure head above the pipe is below 1 m. In this equation, for each node, the product of discharge coefficient and area of the orifice is calculated based on nodal leakage demand of the calibrated model under normal operation conditions. For each intrusion node, the contamination mass rate is calculated based on the intrusion flow rate at the node and the concentration of *Cryptosporidium* outside the pipe. More details on accidental intrusion modeling can be found in Hatam, *et al.* [3]. For the studied scenarios, after implementing the intrusion flow rates into the hydraulic model, the maximum nodal pressure variation was less than 0.006 m. Therefore, there is no need to recalculate the intrusion volumes based on the adjusted pressures.

In this paper, the intrusion duration concurs with the time of pressure loss and contaminant intrusion stops once the pressure is back.

2. Consumption time

Probability of consumption of contaminated water depends on the time of filling a bottle or glass from tap even if the water is not consumed immediately. In this paper, the terms of consumption time and filling time are used interchangeably. Figure S1 shows the modified kitchen tap use (in blue) that is set to zero at the time when there is no demand available under PDCs to account for demand satisfaction as computed by PDA.

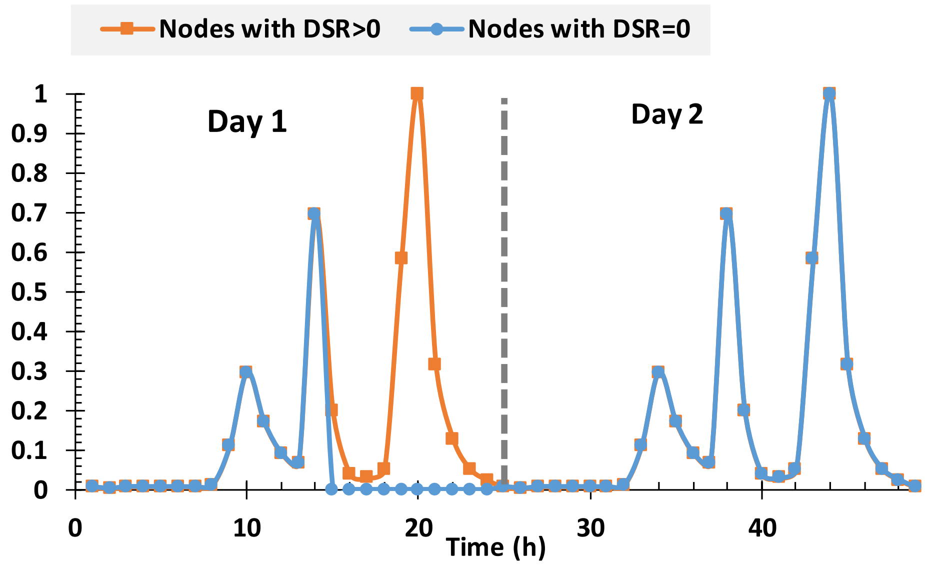
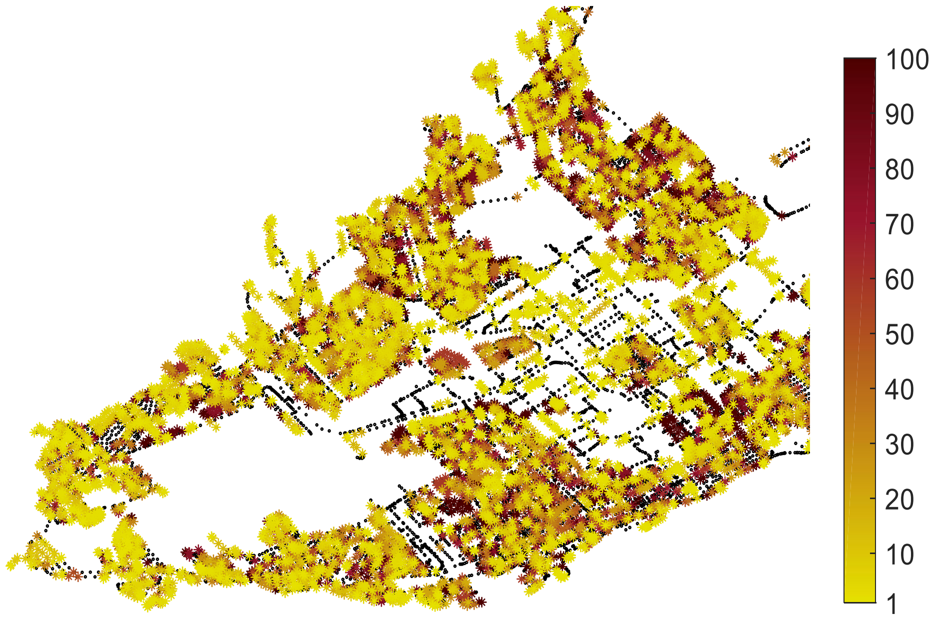


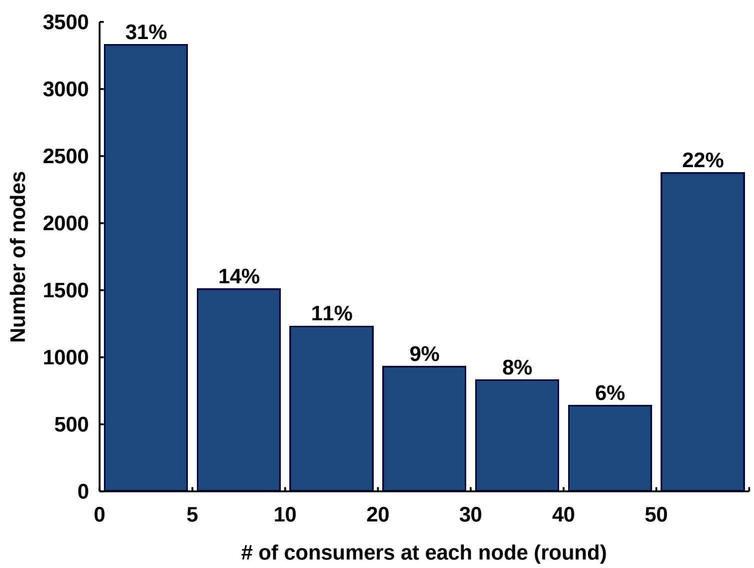
Figure S1. Probability of filling a glass or bottle for consumption over the 2 days. Consumption at kitchen tap use [4] (orange, square); modified kitchen tap use for this study for the residential nodes with no available demand for consumption based on PDA results at days 1 and 2 for the 10 hours scenario (blue, circle); days 3 and 4 are the same as day 2.

3. Nodal Population

Population spatial distribution of 400,000 population supplied by the three WTPs in the studied network is demonstrated in Figure S2. The minimum person at a node is one and the maximum is 1352. The number of people on a node is determined only based on residential demand as other demand types are usually used for other purposes such as processing, cooling or cleaning. Also, for example for school it happens that children bring bottles of water from home. Therefore, in this study only the residential exposure from tap water is investigated. To obtain the number of people at each node, the daily residential demand of that node is divided by the daily average demand per people. The daily average demand is estimated by dividing the total residential demand of the studied network by total population (400,000). For population calculation, the nodal demand under normal operating condition is used and the daily pattern is considered.



(a)



(b)

Figure S2. (a) Geographical distribution of population, and (b) histogram of number of people at each node; Exclude nodes with zero population.

4. One-hour event with daily demand patterns

The cumulative probability distribution of the number of infected people for 200 random consumption behaviors and the spatial distribution of risky areas are shown in Figure S3 for one-hour event with daily demand patterns in the hydraulic model.

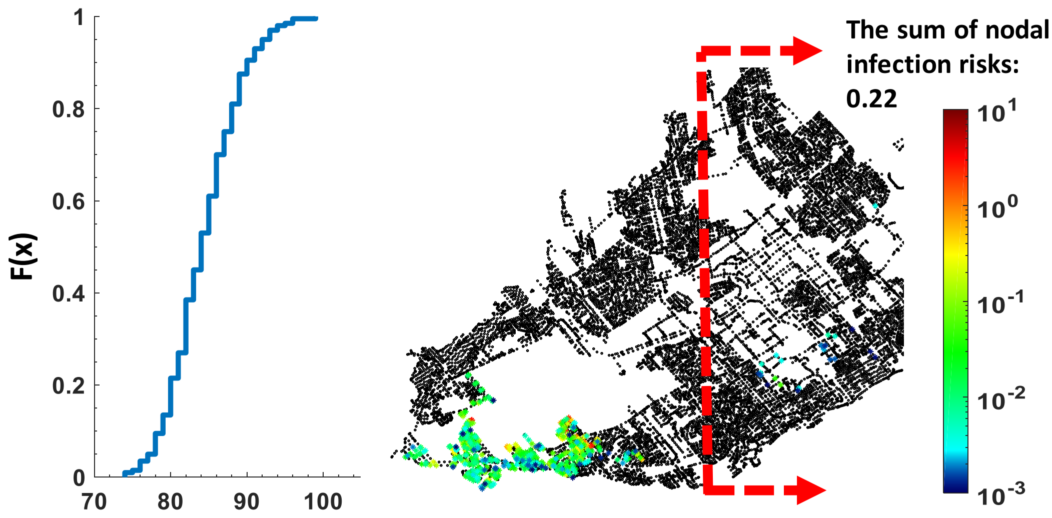


Figure S3. The probability distribution of the number of infected people during 4 days of simulation; 200 Monte Carlo simulations; 1 hour intrusion (a). The spatial distribution of the nodal risk corresponding to consumption event with F(x) =1 (b). Daily pattern in the hydraulic model.

5. Pressure distribution under PDCs

Geographical distribution of nodal pressure is demonstrated in Figure S4. Nodes with pressure values less than 1 m are the nodes prone to intrusion in this study.

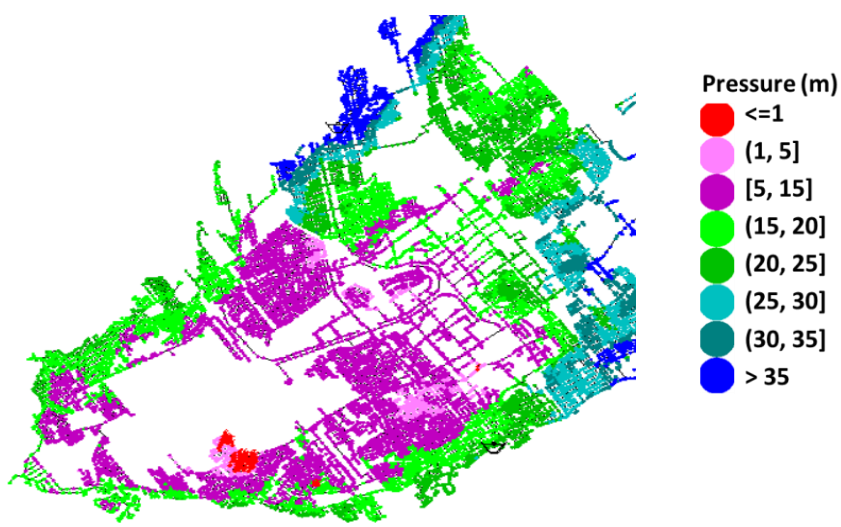


Figure S4. Spatial distribution of pressure using PDA under low/negative pressure event, at 7:00 PM.

References

1. Tanyimboh, T.T.; Templeman, A.B. Seamless pressure-deficient water distribution system model. *Proceedings of the ICE - Water Management* **2010**, *163*, 389-396, doi:10.1680/wama.900013.
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