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Model development to identify the inflow and infiltration hydrograph in sanitary sewer systems

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Summary of key findings

Rainfall-derived Inflow and Infiltration (RDII) into sanitary sewer systems is the main cause of sanitary sewer overflows (SSOs), and can also cause serious operating problems of wastewater treatment facilities. The study presents a pollutant hydrograph methodology combining instantaneous unit hydrograph method to identify RDII. The discharge in the sewer system was divided into dry weather flow (DWF), rain-induced infiltration (RII) and rain-derived inflow (RDI) separately. The spectral analysis with fast Fourier transform was adopted to estimate the strength of different frequency components (the power spectrum) of the discharge and pollutant hydrography in dry weather. The least square method to optimize parameters in rainy weather. The parameter sensitivity and model uncertainty were also considered. The method was applied to estimate the contributions of RDI and RII to the wastewater flow in the sewer system in Wuxi city (China), the simulation result is credible.

Background and relevance

Rainfall-derived Infiltration and Inflow (RDII) into sanitary sewer systems has been recognized as a serious operating problem in sewerage systems (Lai et al., 2008). Traditional methods to assess infiltration and inflow (I/I) are based on volume balance by means of water consumption and wastewater production, e.g. Annual balance and daily balancing. Due to the day-night-rhythm the minimum foul water flow is very low and occurs at night, the I/I rate was assumed that is close to the total minimum night flow (Franz et al., 2007). Kracht and Gujer (2005) introduced a method determining the infiltration from a combined analysis of time series of COD concentrations and wastewater flow. Kracht et al. (2007) demonstrated the successful use of naturally occurring stable isotopes of water (18O/16O and D/H) to accurately quantify extraneous discharge of groundwater in a combined sewer network. Gustafsson et al. (1999) produced a MouseNAM model which takes into account both the fast runoff component from impervious areas and the slow runoff component caused by infiltration into the sewer system from the surrounding soil. Karpf and Krebs (2011) presented a methodology to identify I/I and estimate its quantity based on a multiple model approach. The EPA also proposed a RTK model to evaluate the Rainfall derived infiltration and inflow (Lai 2008). However, simulation of all these methods must require long time flow monitoring, especially after rainfall. Here we proposed a method to calculate the RDII based on a pollutant hydrograph methodology. The models simulation try to implement only based on the more economic monitoring equipment than the monitoring flow meters in sewer system.

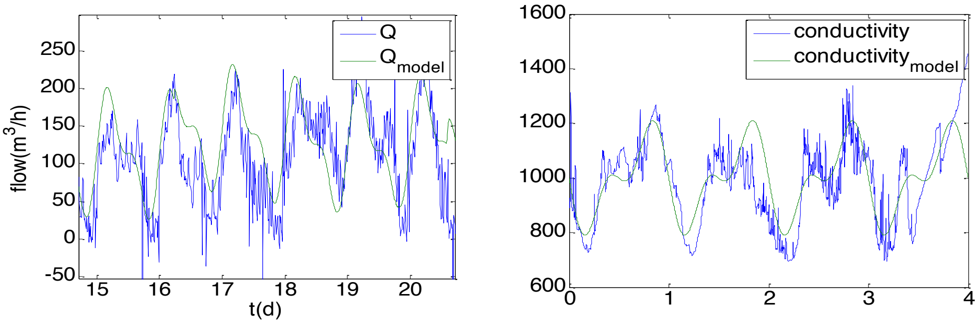
Methods and Materials

As many previous studies have pointed out that four major components of wet-weather wastewater flow into a sanitary system includes base wastewater flow (BWF), groundwater infiltration (GWI), rainfall derived inflow(RDI) and rainfall induced infiltration(RII) (Bennett et al., 1999; Vallabhaneni and Camp, 2007). GWI and BWF together comprise the dry-weather flow (DWF) that occurs in a sanitary sewer system. In the study a conceptual model to estimate the RDII was proposed based on the Nash Instantaneous Unit Hydrograph (was shown in following equation 1). The model is consist of hydrological process and substrate balance equation, where the hydrological model is used to describe the dynamic process of infiltration and inflow after rainfall, the substrate balance equation to combine all the three components of wet weather flow (DWF, RDI, RII) with their substrate concentration.

Results and Discussion

1. Variation of flow and conductivity in dry weather

A mathematic method characterizing the quantity and quality of the sewer system was proposed. The spectral analysis with fast Fourier transform was adopted to estimate the strength of different frequency components (the power spectrum) of a time-domain signal. Two major frequency was separated using Signal Processing Toolbox in MATLAB, for both flow and conductivity in the monitoring data of dry weather (shown in Figure 1). The frequency 1 represent period 1 day, which is obviously corresponding with residential living habit, and the frequency 2 represent period of 0.5 day, corresponding with morning and evening peaks. The amplitude is also a representation of the extent of variation. The amplitude of flow at frequency 1 is 67 m^3/h , indicating the difference between day time and night is 134 m^3/h. The amplitude at frequency 1 is larger than that at frequency 2, for both flow and conductivity, it indicate that the period one day is more notable than the period 0.5 day..



(a) (b)

Figure 1 The spectrum analysis of flow and conductivity.

2. Determination of parameters in the model

The results of the parameters listed in Table 1 (NS = 0.51). R1, R2 indicate the fraction of rainfall volume that enters the sewer system in the form of inflow and infiltration. In the first rainfall event, the rate of the rain derived inflow and infiltration is slight (R1=2%, R2=1%), because the rainfall is intensive and more beyond the capacity of the sewer system. In the other three rainfall events, the rates of the rain to derive inflow and infiltration are 20%and 10%, respectively. The value of R1 is larger than R2, this means the major part of rainfall derived inflow in the study sanitary sewer. The result indicated that the misconnection corresponding the inflow is the main problem, and the leakage and broken corresponding the infiltration is the minor problem. The physical significance of parameters K, N, Kg should be similar for each rainfall events for a given catchment since they depend on the geometry and sewer system layout.

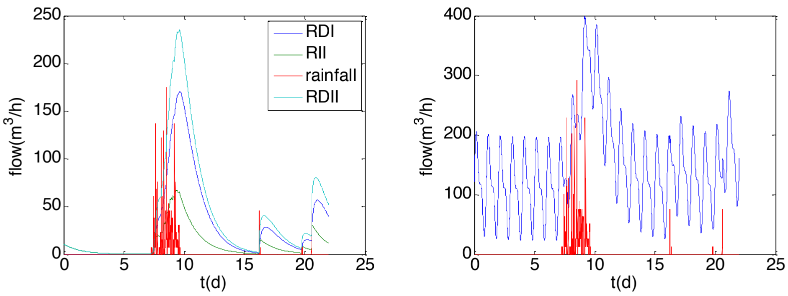
Table 1 The parameters of the model

R_1 (Rate of inflow)		R_2 (Rate of infiltration)		K (storage coefficient)	N (Number of reservoir)	Qg1 (Initial flow)	Kg (storage constant)
Event 1	Event 2,3	Event 1	Event 2,3				
2.2%	22%	0.8%	8%	1.1	1.5	11	34

1,2,3 indicate the number of rainfall events

3. The rainfall derived inflow and infiltration

According to the parameter determined, the RDII process for each rainfall event can be calculated and visualized in graph. The unit hydrographs of RDII hydrograph in response to rainfall was shown in Figure (2). The peak RDII flow can be as much as 230 m^3/h , whereas the mean DWF is 120 m^3/h , max DWF is 200 m^3/h. The peak total flow is 400 m^3/h , more than three times of the mean DWF, twice of the max DWF. The total RDII volume of first rainfall is about 44160 m^3, where the RDI is 30720 m^3, RII is 13440 m^3.



(a) (b)

Figure 2 (a) The RDII process for each rainfall event, and (b) The total flow in the sanitary sewer.

Conclusion

An pollutograph method developed by combining instantaneous unit hydrograph and mass balance model and illustrated the physical dynamic process of rain derived inflow and infiltration. According to the RDII calculated, the flow after rainfall in the sewer can be obtained. The result indicated that the peak RDII flow can be 230 m^3/h that is more than the max DWF. And the RDI is larger than RII, this indicated that the misconnection with the rainwater pipe network is the main problem in the study sanitary sewer system, and the leakage and broken is the minor problem compared with the misconnection.

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