Application of databank-based assimilation for development of real-time urban inundation prediction system

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Highlights

- Seamlessly integrated river, inundation, and sewer network models is applied
- A new data assimilation methodology of databank-based assimilation method is applied
- Real-time sensing via manhole IoT device shall be integrated in the near future.

Introduction

Water related hazards due to heavy rainfall have been increasing in Japan and they are becoming serious issues by affecting human life and property in particular in urbanized areas. There have been several researches related to numerical simulation of such urban flooding by realization of observed flood events or addressing potential risk of possible urban flooding through scenario analysis, which output to be used for urban planning or disaster mitigation management. Due to the increasing frequency of urban flooding, the demand of real-time prediction of the urban flooding is increasing, e.g. in the field of early warning system or evacuation management. Nevertheless, owing to the complexity of the hydrological and hydraulic process in the urbanized area, real-time predication of urban inundation relying on physics-based numerical models is challenging. Sanuki et al. (2016) developed an integrated flood forecast model, so-called seamless model that is able to predict the water levels along rivers, within a sewerage network system and the overland inundation depth. However, due to uncertainties of precipitation pattern and detailed flow characteristics on the ground and sewerage pipelines, the accuracy of the model is not satisfactory especially in the urbanized city areas (Sanuki et al. 2017). In this context, Wu et al developed the databank-based data assimilation technique, which updates the water level condition in the sewer network from the pre-calculated water level databank with numerous rainfall patterns.
This study highlights advancement of the combined methodology of the seamless model and databank-based assimilation techniques, with introducing future application of the real-time sensing information of water levels in the sewer networks through manhole-integrated Internet of Things (IoT) device.

Study area

Urbanized areas in the lower Tsurumi river basin

The Tsurumi river is located between Tokyo and Yokohama cities (Figure 1). The river is known for its rapid urbanization in the 1960s, resulting in flood vulnerable city. In order to cope with urban flooding, various structural countermeasures, such as runoff reduction ponds, multi-purpose retarding basin, and storm water storage have been built as a comprehensive flood control program.

Water level monitoring in sewer network

Water level loggers have been installed in downstream section of sewer network system to monitor the behaviour of water level at the time of storm rainfall (Figure 2). Water loggers are installed in vicinity of pumping station. Storm water are pumped out to the river by the pumping operation. When the incoming flow becomes bigger, the water level exceeds weir height and the excess water is diverted to the Nippa-Suehiro water storage pipe (thick black line shown in Figure 1), which is built ca 60m subsurface.

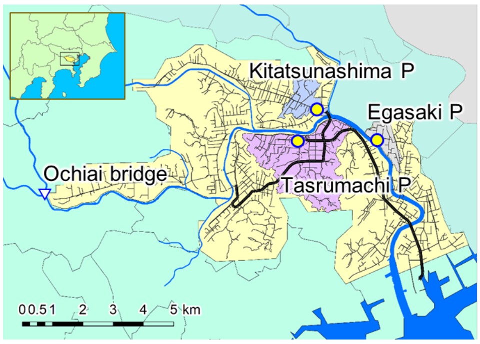

Figure 1. Location of the study area, the Tsurumi river basin

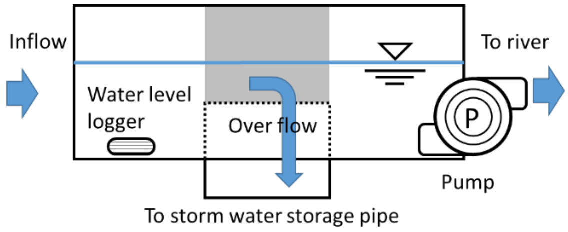

Figure 2. Schematic view of the water logger installation.

Methodology

Inundation Prediction

The seamless model (Figure 3) consists of a one-dimensional river flow model, a two-dimensional non-linear shallow water model for computation of tide, tsunami, storm-surge, a two-dimensional overland flow model, a one-dimensional sewer network model including 8820 manholes and 8787 pipes. Distributed hydrological model WEB-DHM (Wang et al. 2009) is used to provide upstream runoff for the 1D river flow model. The 2D non-linear shallow water model is used for estimating the water level at the river mouth and possible overflow to the land surface. The river flow model and the sewer network model are solved by the 1D Saint-Venant equations. The 2D overland flow model is solved by the non-linear shallow water equations which are not listed here. The 1D river flow model, 1D sewer network model and 2D overland flow model are coupled with each other by water exchange through manholes, outfalls, pumping stations and overflow. The Seamless model can simulate possible urban inundation due to various causes. More details of the model can be found in Sanuki et al. (2016). Computation cost of the model is relatively low and Sanuki et al. (2017) demonstrated the applicability to the real-time forecast of urban inundation.

Data-bank based assimilation method

Measured water depth by the water loggers were used to improve the prediction skills of the seamless model through application of the proposing data assimilation model. In contrast to the previous numerical experiment, in which spatial variation of the water level was specified for data assimilation, the number of measured data in the actual field is limited and thus a certain method is required to specify the spatial distribution of the “measured” water level for the data assimilation. The present study applies the databank-based approach by Wu et al (2019) (Figure 4), in which the databank of water level distribution are simulated by giving numerous scenarios with different precipitation patterns. In each scenario, the time-varying flow field was computed by the seamless model and the simulated water depths at each of manholes and pipelines were recorded. In the real-time predication, the water depths measured at three locations were compared with the ones of each scenario of the data bank and the scenario which yields the minimum root-mean-square deviation of the water depths at the four locations was selected for resetting initial conditions in the real-time prediction at each of the assimilation intervals.

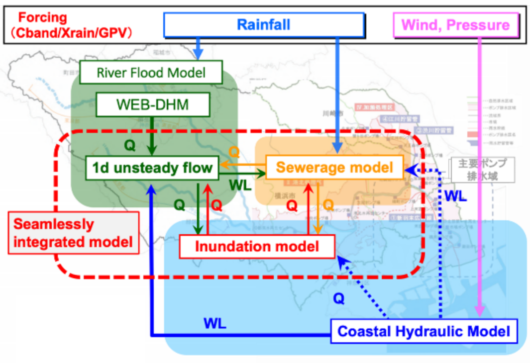

Figure 3. Schematic image of the seamlessly integrated model

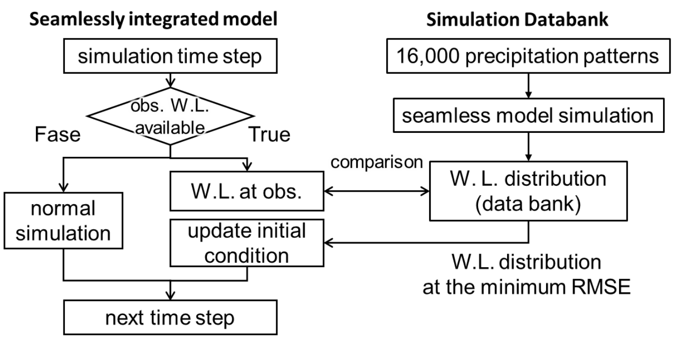

Figure 4. Data-bank based assimilation calculation flow

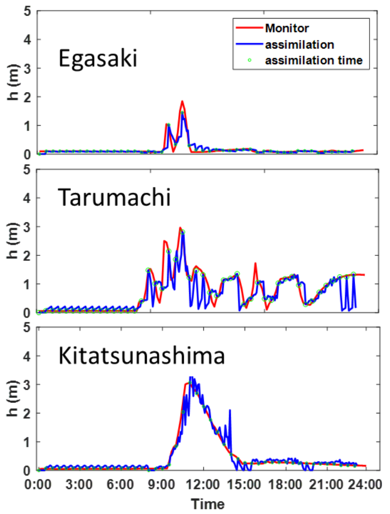

Figure 5. Comparison of observed and simulated water level at three locations in the sewer networks.

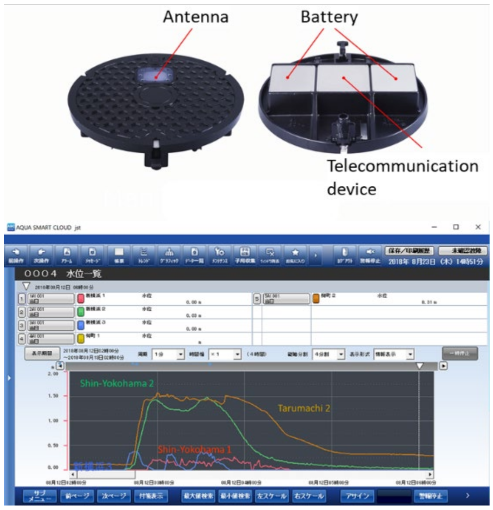

Figure 6. Smart Manhole cover (upper figure) for real-time sensing of water level in sewer networks to be seen over the internet cloud system (lower figure)

Results and discussion

Figure 5 shows time evolution of the observed and simulated water levels at three observation stations with data assimilation carried out every 30 min. The results suggest that the simulated water levels agree well with the observation. The general tendency and most of the peaks of the hydrographs were reasonably represented by the seamless model with data assimilation. However, there were still some discrepancies between the results. For example, fluctuations of water level can be seen, which is considered due to the operation of the nearby pump stations.

Overall, the results show improvement of the simulated results by application of databank-based assimilation method, which is based on information from water level loggers, i.e. offline information, and that can be replaced by the real-time sensing data from Smart Manhole cover, which transmits water level information every 1 min. to the internet cloud (Figure 6).

Conclusions and future work

In this study, a databank-based assimilation method - derivation of data assimilation, was applied. The method makes use of the real-time measurement of water level at pipes to search the most similar scenario in a previously generated database and water level distribution in the scenario is then used to optimize the numerical result. While the proposed method is based on a simple concept, it is demonstrated that the methodology was able to improve the accuracy of the Seamless model for real-time prediction of urban inundation.

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