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Coupled 1D-2D hydrodynamic inundation model for sewer overflow: Influence of modeling parameters

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Abstract

This paper presents outcome of our investigation on the influence of modeling parameters on 1D-2D hydrodynamic inundation model for sewer overflow, developed through coupling of an existing 1D sewer network model (SWMM) and 2D inundation model (BREZO). The 1D-2D hydrodynamic model was developed for the purpose of examining flood incidence due to surcharged water on overland surface. The investigation was carried out by performing sensitivity analysis on the developed model. For the sensitivity analysis, modeling parameters, such as mesh resolution Digital Elevation Model (DEM) resolution and roughness were considered. The outcome of the study shows the model is sensitive to changes in these parameters. The performance of the model is significantly influenced, by the Manning's friction value, the DEM resolution and the area of the triangular mesh. Also, changes in the aforementioned modeling parameters influence the Flood characteristics, such as the inundation extent, the flow depth and the velocity across the model domain.

Keywords: Inundation; DEM; Sensitivity analysis; Model coupling; Flooding

1. Introduction

Small-scale urban flooding in most cities around the world, where underground sewers are employed to transport both storm and wastewater, is usually caused by sewer overflow due to inadequate carrying capacity of sewers. Most of the existing inundation models that could be explored to predict small-scale urban flooding are designed for prediction of flooding in large flood events, such as river floods. Therefore, some changes to these models are essential before they could be efficiently adopted as candidates for 1D-2D coupling for small-scale urban flood modeling. The quest for

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effective models to predict small-scale urban flooding, resulted in the development of a new 1D-2D model, obtained from coupling together an existing 1D Storm Water Management Model.

(SWMM, http://www.epa.gov/ednnrmrl/models/swmm/index.htm#Description,2008), 2D inundation model, BREZO (Begnudelli et al., 2008; Begnudelli and Sander, 2006; Brett, 2008). The process involved in the development of new 1D-2D model, its subsequent application for optimization have been reported elsewhere (Adeogun et al., 2012; Delelegn et al., 2011). However, during simulation with 1D-2D models, large number of parameters (calibration values), input data are required. In such a situation, it is expected that the simulation model would be sensitive to the quality of the data employed in simulation, model development. In view of the aforementioned statement, conduct of a sensitivity analysis on a simulation model might be instrumental to identifying specific area of concentration during model development, calibration. Also sensitivity analysis might provide useful information on the influence of quality of data employed during model simulation on the accuracy, validity of the model, thus paving the way for model improvement.

Sensitivity Analysis (SA) is basically an extension of an uncertainty analysis, aiming to determine the contribution of uncertainty in individual input parameters on the output (Crosetto et al., 2000; Moel et al., 2012). SA is usually performed as a series of tests in which an input parameter into a model is changed during model simulation and response to the changes in model performance due to the change in the input is then observed. Thus, SA has been regarded as a useful tool in model building as well as in model evaluation (Crosetto et al., 2000). The conduct of sensitivity analysis on a model during simulation enables to identify parameters that have significant influence on model performance. Identifying the dominant factors influencing model performance could pave the way for reduction of the influence of these factors on the model performance, in terms of uncertainties introduced by the factors (Moel et al., 2012). For instance, Hunter et al. (2008) has reported the influence of calibration procedures on model performance of some selected 2-D hydrodynamic models by employing different pairs of roughness coefficients chosen from a wide but plausible range (Hunter et al., 2008). In the same vein, Bates and De Roo (2000) studied the effect of friction parameter and grid size on model performance of a 2-D hydrodynamic model and the authors concluded that bed friction, a parameter during model simulation, significantly influenced performance of the model (Bates and De Roo, 2000).

Against this background, sensitivity analysis has been performed on our recently developed 1D-2D inundation hydrodynamic model to provide insight into influence of input parameters on the model performance. Input parameters, such as mesh resolution, DEM resolution and roughness were considered in the study.

2. Sensitivity analysis and case study area

Local and global approaches are the two approaches to SA usually employed in practice (Pappenberger et al., 2008). In the local approach, input parameters are varied one at a time while keeping the other input parameters constant (Saltelli, 1999). This is achieved by varying input parameters manually one at a time to evaluate the model performance to the change in the input and random sampling and regression analysis are common techniques used in this approach (Turanyi, 1990). However, only the sample space around the baseline situation is explored and interaction between input parameters is not considered (Moel et al., 2012). On the other hand, the global approach of SA considers the entire sample space, and the total variation around the output is apportioned to the different input parameters while accounting for the interaction between these parameters (Ratto et al., 2001).

Furthermore, uncertainty analysis normally employed to study variation of model parameters in simulation models can be categorized into pre-calibration and post-calibration sensitivity analysis (Tsegaye, 2008). The pre-calibration SA is done prior to calibration of the model to identify the sensitive and insensitive model parameters, without prior knowledge of their values. This makes it possible to put more effort into calibration of sensitive parameters during the calibration phase of model development. Monte Carlo Simulation (MCS) is commonly used in pre-calibration uncertainty/sensitivity analysis. MCS is a global method which considers many possible values within the entire input parameter distribution to estimate the sensitivity of the model performance to a change in input parameters. In contrary, post-calibration uncertainty/sensitivity analysis, is used to investigate the effect of changes in optimized model input parameters on model performance. This analysis provides an indication of risk associated with decision-making using predictions of flood models due to inaccuracies of model input parameters.

The local SA is the simplest method to quantify the effect of individual parameters on model performance. In this approach, the input parameters are perturbed by a given percentage away from the correct (or optimized) value, while