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Assessing uncertainties in urban drainage models

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ABSTRACT

The current state of knowledge regarding uncertainties in urban drainage models is poor. This is in part due to the lack of clarity in the way model uncertainty analyses are conducted and how the results are presented and used. There is a need for a common terminology and a conceptual framework for describing and estimating uncertainties in urban drainage models. Practical tools for the assessment of model uncertainties for a range of urban drainage models are also required to be developed. This paper, produced by the International Working Group on Data and Models, which works under the IWA/IAHR Joint Committee on Urban Drainage, is a contribution to the development of a harmonised framework for defining and assessing uncertainties in the field of urban drainage modelling. The sources of uncertainties in urban drainage models and their links are initially mapped out. This is followed by an evaluation of each source, including a discussion of its definition and an evaluation of methods that could be used to assess its overall importance. Finally, an approach for a Global Assessment of Modelling Uncertainties (GAMU) is proposed, which presents a new framework for mapping and quantifying sources of uncertainty in urban drainage models.

1. Introduction

Uncertainty is intrinsic in any modelling process and originates from a wide range of sources, from model formulation to the collection of data to be used for calibration and verification. Uncertainties cannot be eliminated, but their amplitude should be estimated and, if possible, reduced. It is necessary to understand their sources and impact on model predictions. For example, the confidence level of a model's predictions should be included in every modelling application. Beven (2006) reported that there are many sources of uncertainty that interact non-linearly in the modelling process. However, not all uncertainty sources can be quantified with acceptable levels of accuracy, and the proportion of uncertainty sources being ignored may be high in environmental modelling investigations (Harremoës, 2003; Doherty and Welter, 2010).

In the literature, the following sources of uncertainties are listed (e.g. Butts et al., 2004): (i) model parameters, (ii) input data, (iii) calibration data, and (iv) model structure. The impacts of calibration methods and data availability are also recognised. Each of these sources is discussed below.

When dealing with complex urban drainage models, calibration may lead to several equally plausible parameters sets, reducing confidence in the model predictions (Kuczera and Parent, 1998). The concept that a unique optimal parameter set exists should therefore be replaced by the concept of "equifinality" (Beven, 2009) in which more than one parameter set may be able to provide an equally good fit between the model predictions and observations. Many published studies have dealt with the impact of uncertainties on model parameters, also known as sensitivity analysis (Kanso et al., 2003; Thorndahl et al., 2008; Dotto et al., 2009). Some studies used the results of a model sensitivity analysis to produce parameter probability distributions (PDs), which reflect how sensitive the model outputs are to each parameter (e.g. Marshall et al., 2004; Dotto et al., 2010a; McCarthy et al., 2010); while other studies used the sensitivity analysis to screen parameters for further analysis (e.g. Reichl et al., 2006; Haydon and Deletic, 2007). In most cases, model sensitivity results were also used to estimate confidence intervals around the model's outputs (e.g. Yang et al., 2008; Li et al., 2010).

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Impacts of input data uncertainties on urban drainage modelling are far less understood. Their importance, however, is widely studied in related areas (Kuczera et al., 2006). For example, the impact of systematic rainfall uncertainties on the performance of non-urban catchment models was recognised and assessed by Haydon and Deletic (2009). Work has also been completed on the propagation of input data uncertainties through urban drainage models (Rauch et al., 1998; Bertrand-Krajewski et al., 2003; Korving and Clemens, 2005). However, in these studies, the models were first calibrated assuming that measured inputs and outputs were true (no-error), and the impacts of input data uncertainties were then propagated through the models, while keeping the model parameters fixed. Recently, Kleidorfer et al. (2009a) and Freni et al. (2010) attempted to assess how input data uncertainties impact model parameters, investigating the interactions between these two sources of uncertainties. Freni and Mannina (2010) attempted to isolate the contribution of different sources of uncertainty in a complex integrated urban drainage model.

Research on the impact of calibration data on the accuracy of drainage models has focused on the effectiveness of the calibration and verification processes. Many studies have examined how to divide the available data into calibration and verification sets (McCarthy, 1976; Klemes, 1986; Vaze and Chiew, 2003; Wagener et al., 2004). A few recent papers (e.g. Mourad et al., 2005; Dotto et al., 2009) evaluated how the number of events used in calibration and verification of urban drainage models impacts on their predictive uncertainty. On the other hand, there is little work reporting on how uncertainties in measured calibration data impact on the model's predictive capacity. However, large uncertainties in measured urban discharges and water quality have often been reported (e.g. Bertrand-Krajewski, 2007; McCarthy et al., 2008), thus clearly demonstrating that calibration data sets may in themselves be a significant source of uncertainty in the model calibration process. In fact, McCarthy (2008) showed the influence of calibration data uncertainty on the calibration of a simple rainfall-runoff model.

There are many studies on the effectiveness of calibration algorithms. For example, Gaume et al. (1998) showed that different calibration methods can lead to different parameter sets, which demonstrate a similarly good fit between measured and simulated data. This can occur as a result of difficulties in finding a global minima, especially for systems where the objective/criteria function surface is nonlinear. It is evident that these problems become more important as model complexity increases (Silberstein, 2006), or where models are ill-posed (Dotto et al., 2009). Therefore it is not surprising that some calibration algorithms simply cannot find the global minima in rather complex urban drainage models (Kanso et al., 2003).

Given the wide range of communities and applications in which uncertainty is studied, there is no general consensus in the literature with regard to the terminology used. For example, the terms "sensitivity" and "uncertainties" are often used interchangeably and yet have distinctly different meanings. A further example is that some input variables that could be measured, but are also refined through calibration processes (such as, effective imperviousness in rainfall-runoff modelling), are sometimes regarded as fixed inputs and at other times as model parameters. These terminology problems need to be addressed so as to improve the communication between research groups, thus the coherence and applicability of future studies.

Despite previous work attempting to unify definitions and approaches of uncertainty evaluation (e.g. Walker et al., 2003), no universal framework and methodology for categorising and assessing modelling uncertainties has been accepted. Indeed, Montanari (2007) stated that uncertainty assessment in hydrology suffers from a lack of a coherent terminology and hence a systematic approach.

This paper is a contribution in the debate to develop common terminology and a conceptual framework for accounting for uncertainties in urban drainage modelling. It outlines a Global Assessment of Modelling Uncertainties (GAMU), which presents a new framework for mapping and quantifying sources of uncertainty in urban drainage models.

2. Methods

The International Working Group on Data and Models, which works under the IWA/IAHR Joint Committee on Urban Drainage (JCUD), conducted several workshops focused on uncertainties in monitoring and modelling of urban drainage systems:

(1) 'Integrated Urban Water Management Modelling: Challenges and Developments', Melbourne, Australia, 2006, in conjunction with the 7th Urban Drainage Modelling and 4th Water Sensitive Urban Design conferences (7UDM & 4WSUD);
(2) 'Uncertainties in data and models', Lyon, France, 2007, as part of the 6th Novatech conference; and,
(3) 'Challenges in monitoring and modelling of stormwater treatment systems', Edinburgh, UK, 2008 as part of the 11th International Conference on Urban Drainage (11ICUD).

This paper represents the outcome of these workshops. The literature, guidelines and standards on uncertainties in measurements (Bich et al., 2006; ISO, 2008, 2009a,b) were also consulted, as well as recent relevant work on uncertainties. This paper thus presents a review of the state of the art, and an attempt to harmonise concepts, definitions and protocols.

3. Proposed framework for a Global Assessment of Modelling Uncertainties (GAMU)

The first step in the proposed uncertainty framework is to map the sources of uncertainty and their links; their contribution and significance are then evaluated. Finally, the propagation of all sources simultaneously provides an analysis of their effect on the model sensitivity and consequently on the uncertainty of the model predictions.

3.1. Mapping uncertainties

The majority of urban drainage models require calibrating prior to use. This calibration process is referred to as the 'inverse problem' (Gallagher and Doherty, 2007), whereby parameter values are determined from measured calibration input data, calibration output data and the model structure by applying an objective function. When using models for prediction outside of calibration, or when models are simply used with estimated parameter values (from expert knowledge, literature or defaults), the process is known as the 'forward problem'.

A generic modelling framework was therefore adopted, for which the following information is needed (Fig. 1): model structure MS (i.e. relationships, linkages and numerical methods), input data ID (e.g. rainfall or potential evapotranspiration time series) and model parameters *P* (e.g. effective impervious area, linear reservoir lag-time parameters in rainfall-runoff conceptual models). For the inverse problem, the following information is also needed: calibration input data (e.g. rainfall intensity time series), measured calibration output data (e.g. flow time series), calibration algorithms CA and objective functions OF selected by the modeller according to the model requirements (e.g. sum of the squared errors).