Towards using soil water content observations for calibration of distributed urban drainage models

Vers l'utilisation des observations sur la teneur en eau du sol pour le calibrage de modèles distribués d'assainissement urbain

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RÉSUMÉ

Les modèles d'assainissement urbain entièrement distribués peuvent être utilisés pour analyser et prédire le comportement des infrastructures vertes d'assainissement urbain comme les noues, mais ils doivent être calibrés pour des sites d'étude spécifiques. Le fait de n'utiliser que les mesures des décharges issues de l'assainissement peut se révéler insuffisant pour y parvenir de manière optimale, d'où la nécessité d'envisager d'autres types de mesures. Cette étude identifie différentes approches pour inclure dans le processus de calibrage les observations sur la teneur en eau du sol (SWC) et examine comment elles affectent l'identifiabilité des paramètres et l'incertitude prédictive du modèle calibré. Pour cela, la méthode d'estimation généralisée de l'incertitude de probabilité est appliquée à un modèle d'une grande noue urbaine. Il s'est avéré que l'établissement de conditions initiales basées sur les mesures de la SWC améliorait la correspondance entre les SWC observées et simulées, mais réduisait également la précision du degré simulé d'infiltration. L'inclusion des observations de la SWC a permis d'identifier un paramètre (la teneur en humidité saturée du fond de la noue) qui n'était pas identifiable par les seules mesures des décharges. L'inclusion des observations de la SWC dans la dérivation des limites d'incertitude prédictives a rendu ces limites plus précises, mais lorsque la SWC avait été utilisée pour établir les conditions initiales, la limite d'incertitude n'a pas reflété ces observations. Il est conclu que les observations de la SWC peuvent fournir des informations utiles pour le calibrage des modèles distribués d'assainissement urbain.

ABSTRACT

Fully distributed urban drainage models can be used to analyse and predict the behaviour of green urban drainage infrastructure such as swales, but they need to be calibrated for specific study sites. Using only drainage outflow measurements may not provide enough information to do this in an optimal way, so additional types of measurements have to be considered. This study identifies different approaches to including soil water content (SWC) observations in the calibration process and investigates how they affect parameter identifiability and the predictive uncertainty of the calibrated model. This is done using the Generalized Likelihood Uncertainty Estimation methodology applied to a model of a large urban swale. It was found that setting initial conditions based on the SWC measurements improved the fit between observed and simulated SWC, but also reduced the accuracy of the simulated amount of infiltration. Including SWC observations allowed to identify one parameter (saturated moisture content of the swale bottom) that was not identifiable from outflow measurements alone. Including SWC observations in the derivation of predictive uncertainty bounds made those bounds narrower (more precise), but where SWC had been used to set initial conditions the uncertainty bound failed to capture the observations. It is concluded that SWC observations can provide useful information for the calibration of distributed urban drainage models.

KEYWORDS

calibration, distributed models, parameter identifiability, predictive uncertainty, soil water content

1 INTRODUCTION

Hydrologic models of urban drainage facilities such as swales may be used to analyse existing systems or to predict their future performance, but using them usually requires calibrating them for a specific site. Fully distributed (gridded) models can make use of high-resolution input data (e.g. elevation, land cover) and can assign different values to parameters in each element (grid cell) of their domain. This allows parameter values to represent actual physical properties in specific points, rather than averages over a larger area. This physicality can be beneficial in predicting the effect of changes in the system. However, it results in many parameters so that it may not be possible to calibrate them if only measurements of drainage outflow are used. Using more measurements inside the study area may increase the available information and ease the calibration process (Pokhrel and Gupta, 2011). One type of measurements that can be made throughout the area are volumetric soil water content (SWC) observations. Such observations have been used for calibrating natural catchment models (Christiaens and Feyen, 2002), but it is unknown if this is also applicable to high-resolution models of urban drainage systems. There are also different ways of using SWC observations in the calibration process. Therefore the goal of this paper is to compare different ways of using SWC observations in the calibration process and the effects that they may have on estimated parameter values and the uncertainty in the model predictions.

2 METHODS

2.1 Study site & hydrological model

The study site is a large swale that receives storm water runoff from an adjacent parking. Outflow from the swale was measured using a flume and a pressure transducer. SWC was measured in 6 points along the bottom of the swale and precipitation was measured with a tipping bucket rain gauge.

The hydrological model of the swale was made using the MIKE SHE (DHI, 2017) software package. The complex nature of this model meant that runtime was ca. 40 minutes (for one specific rainfall event), which is too long to be practical in calibration studies. Therefore the model was optimized for shorter runtimes by lowering the spatial resolution and only simulating flow over the asphalt parking area once and then using this as input for all further simulations. Additional improvements included removing local single-cell depressions in the topography which accounted for a large part of the simulation runtime. This reduced the runtime for the same event to ca. 10 seconds, making it suitable for systematic calibration. These optimizations provide a clear practical advantage, and could also to some extent be implemented automatically.

2.2 Approaches for using SWC observations

Different ways are available for using SWC observations alongside swale outflow measurements to infer the values of model parameters. (It would also be possible to set the values of saturated and residual moisture content directly from the SWC observations, but this was not considered in this initial study as it would increase the number of model parameters used.) The alternatives considered in this paper are:

- Within the MIKE SHE model used for this study it is possible to specify the initial SWC based on the observations. The alternative to this is to let the model set the initial SWC based on an equilibrium pressure profile where water content declines gradually from saturation at the groundwater table with a minimum of either the field capacity or residual moisture content.
- The development of simulated SWC throughout the event can be compared with the observed time series for SWC, e.g. by using the Root Mean Squared Error (RMSE) summary statistic.
- The difference between the SWC at the end and at the beginning of the event (ΔSWC) can be determined for both observed and simulated values and can be seen as an indication of infiltration into the soil.

To compare these options, simulations were first made using two different initial conditions (from equilibrium and from observations). Then, the simulations were evaluated by comparing their time series output for SWC, their predicted change in SWC and swale outflow with the corresponding observations.

2.3 Simulation approach

The calibration process in this paper used an extended GLUE methodology (Vezzaro et al., 2013) where the model was run 11,550 times with randomly generated parameter sets (i.e. a Monte Carlo [MC] approach). From the results of these runs, the interaction between different model parameters and model performance (compared to field observations) was examined and predictions with uncertainty

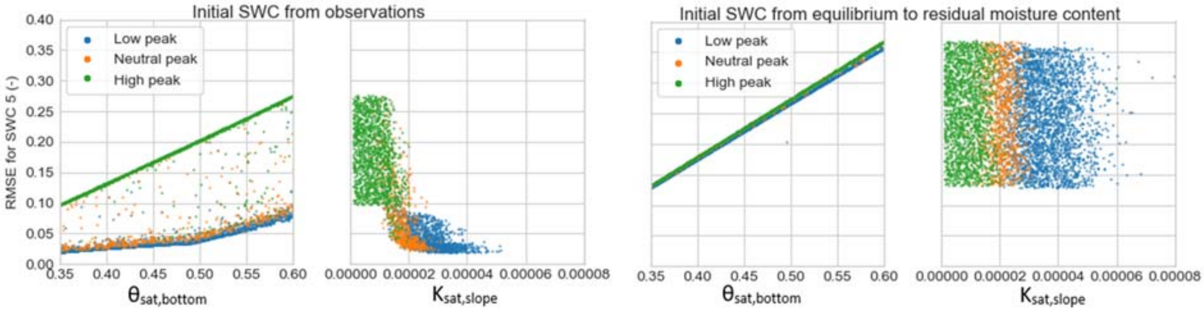

Figure 1: scatter plots showing the correlation between RMSE for SWC for sensor location 5 for a single rainfall event. 'Neutral peak' means that the simulated peak flow rate was within ±2 l/s of the observed peak, with 'high peak' and 'low peak' denoting simulated peaks more than 2 l/s higher respectively lower than observed. Note: parameter sets resulting in zero outflow from the swale are not included in the figure.

estimates were made for swale outflow and SWC. To limit the number of calibration parameters in this initial study, the model was divided into two zones: the bottom of the swale and the side slopes. Three parameters (saturated moisture content θ_{sat}, saturated hydraulic conductivity K_{sat} and Manning's M) were calibrated for both zones, while detention storage was calibrated only for the swale bottom. For this study, simulations were performed for individual rainfall-runoff events as a first step towards using long-term simulations in future work. Results shown below are for one event (selected because the low groundwater level meant groundwater exfiltration into the swale did not affect the surface runoff), but other events gave similar findings.

3 RESULTS

The general performance of the model is good, with the MC runs including parameter sets with Nash-Sutcliffe Efficiency (NSE) > 0.7 for the swale outflow for the events where groundwater exfiltration into the swale did not occur. Despite these good NSE values, visual comparison showed that (for the different events and calibration setups) the simulated hydrographs were generally too 'flashy', i.e. with relatively high, but narrow peaks compared to the observed data, which meant that flow volumes were underestimated unless peak flow rates were overestimated. Setting the initial moisture content from the observations lead to invalid starting conditions and failed model runs for 8% of the parameter sets sampled. Three of the seven parameters ($K_{sat,slope}$ and M_{slope} and M_{bottom}) showed a clear optimum value for achieving the best match (in terms of NSE) between simulated and observed swale outflow, while the other parameters were not identifiable from swale outflow alone.

The correlation between model parameters and goodness-of-fit for SWC depended on the initial conditions used. Setting the initial SWC from the observations resulted in clear correlations (see figure 1 for an example) between RMSE of the SWC and the two model parameters $K_{sat,slope}$ (which was also identifiable by swale outflow) and $\theta_{sat,bottom}$ (not identifiable from swale outflow). For $\theta_{sat,bottom}$ two distinct groups of parameter sets were visible where the sets predicting a too high peak outflow rate also gave larger errors in SWC. Setting the initial SWC to an equilibrium condition showed no clear correlation between SWC and $K_{sat,slope}$ and did not show the two distinct groups in the scatter plot between SWC

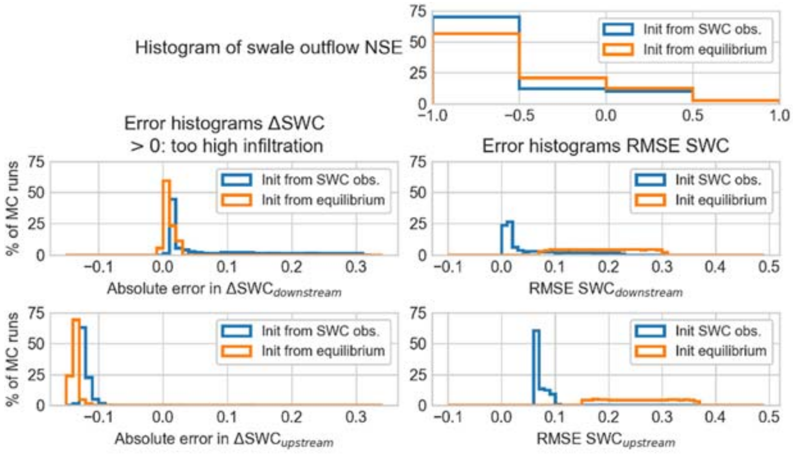

Figure 2: histograms showing error statistics for all Monte Carlo runs using two different initial conditions for soil moisture (different colour lines). SWC errors are shown for sensors furthest downstream and upstream.

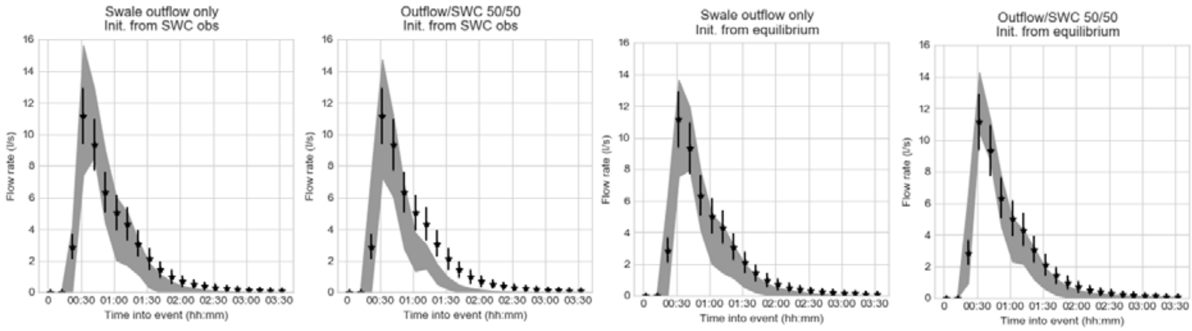

Figure 3: predictive uncertainty bounds (gray) along with observations and their estimated uncertainty (black) for the swale outflow (l/s), using different initial conditions (columns) and ways of evaluating parameter sets (rows).

(lower RMSE) between observed and simulated SWC (as expected), but the errors in ΔSWC were larger for three of the six SWC sensors (see figure 2), indicating larger errors in the amount of infiltration.

Concerning the predictive uncertainty, uncertainty bounds derived according to Vezzaro et al. (2013) (considering only NSE of swale outflow) covered the observations well for both sets of initial conditions (see top row in figure 3), although the uncertainty band was slightly narrower around the peak when initial conditions were set to an equilibrium in the model. ΔSWC (calculated over the average SWC of all six sensors) was included in the evaluation by weighing it equally to NSE of swale outflow after rescaling both metrics so that they ranged from 0 to 1. For the case with fixed initial conditions the ΔSWC inclusion made the uncertainty bound narrower, but less accurate, while for the equilibrium initial conditions it made the uncertainty bound slightly narrower, but without losing accuracy.

4 CONCLUSIONS AND FUTURE WORK

For a high-resolution model of a swale, calibrations were performed for two different initial conditions and two different ways of comparing simulated and observed soil water content (SWC). Fixing the initial SWC based on the measurements gave better performance (than the model's default initial SWC equilibrium) when considering SWC observations as a time series, but weakened the identifiability between SWC error and model parameters K_{sat} and θ_{sat}. It also resulted in larger errors in the change of SWC (i.e. infiltration) during the event at three of the six sensor locations. The fixed initial conditions resulted in a slightly more uncertain prediction for the peak flow. When including the change in SWC in the evaluation of parameter sets to estimate predictive uncertainty, the fixed initial condition performed clearly worse than the equilibrium initial condition.

The initial results presented here show that including SWC observations in the calibration procedure can affect the inference of values for some parameters and that different ways of including SWC observations have different effects on parameter identifiability and model predictive uncertainty. More work is however needed to test these findings for longer term simulations.

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