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Simplified Approach for Calibrating Groundwater Flow in SWMM

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Abstract

Storm Water Management Model (SWMM) is a widely used software for designing and analysing the performance of urban drainage systems. The software simulates the reaction of drainage systems to precipitation. When the stormwater network includes open channels and ditches, the groundwater level may significantly affect the water levels and flow within these systems. However, as the availability of information on groundwater is scarce and the direct measurement challenging, calibration of it is a demanding task. Herein a method that utilizes SWMM's Unit Hydrograph feature is suggested for distinguishing groundwater flow from the rest of the runoff. This approach allows to significantly decrease the time needed for calibration.

Keywords: storm water management model, groundwater, calibration, unit hydrograph, urban drainage systems, open channel flow.

1 Introduction

Calibrating hydrological models, such as the Storm Water Management Model (SWMM) [1], is crucial for ensuring the accuracy and reliability of predictions regarding urban drainage system performance. The calibration process involves adjusting the model's parameters to ensure its outputs align with observed real-world data [2]. The SWMM model is composed of three modules: hydrological, hydraulic, and water quality. The hydrological module determines the pathway of rainwater, whether it ends up in the conveyance system, is intercepted, or infiltrated [1].

Despite the availability of numerous methodologies for calibration, the task remains challenging for urban drainage system models [2]. This is partly because, in addition to pipes and culverts, these systems often include ditches, channels, ponds, and other runoff structures not completely isolated from groundwater aquifers [3]. This results in a bi-directional flow between the groundwater aquifer and the urban drainage system, significantly impacting system performance during extreme weather events. Some cities, especially those close to coastal areas, are more prone to groundwater inundation due to the minimal elevation difference between the groundwater table and seawater level [4, 5]. Groundwater impacts can be significant and occur further inland than surface water effects, consequently resulting in flood volumes that are equal or greater than those caused by surface flooding [6, 7]. This aspect is often overlooked in modelling efforts and these parameters often remain uncalibrated due to the uncertainty of data related to groundwater aquifers [8].

The challenge is compounded by the difficulty in measuring the parameters related to groundwater and aquifers directly, leading to reliance on literature values. Consequently, studies focusing on the implementation of various Low Impact Development (LID) strategies [8, 9] often fail to fully account for flow patterns between the urban drainage system and catchments. Siegrist et al. [10] highlighted that including ditches in the UDS without accounting for this could lead to significant modelling errors, resulting in poorly planned mitigation measures and fewer post-construction improvements. Dent et al. [11] suggested additional parameters related to elevation and flow coefficients, that influence the interaction between channels and aquifers, should be included in the calibration in the case of high groundwater influence and inflows to the system.

The number of parameters for the calibration of groundwater can be quite large (for example 20 according to Vassiljev et al. [12]), making the calibration very time-consuming if the entire system is calculated. The herein presented approach proceeds from the supposition that flow can be divided into parts: a) those that do not depend on groundwater (e.g., flow from impervious areas) and b) those that form groundwater. The flow from part a) depends on precipitation (assuming other factors like air conditions are relatively stable). This allows for the use of the unit hydrograph for the calculation of part a), thereby reducing the time needed for calculation.

The usefulness of this method arises from the fact that urban areas usually contain many impervious areas that produce flow during small rainfall events, while the pervious areas do not induce flow. This allows for the estimation of flow rates, total water volume, and the overall shape of the hydrograph from the catchment area, where during small rainfall events, mainly impervious areas contribute to the shape of the unit hydrograph. This approach makes it possible to split the hydrograph into two parts during high rainfall events. As a result, it is possible to transform the whole system into a simpler model that contains flow from groundwater and flow from impervious areas represented by the unit hydrograph. In this case, calculations time is in the order of few seconds for the tested area.

2 Methods

In this study, we propose an alternative method for analysing the reaction of stormwater sewer systems with high groundwater influence to precipitation events, aiming to significantly reduce computational time without compromising accuracy.

Implementing the Unit Hydrograph approach, it is possible to calculate groundwater flow as the difference between the measured and the calculated flows. After which, the flow, including the groundwater contribution, may be simulated by using a sub-catchment containing an aquifer. Figure 1 shows the simplified scheme, which contains a single junction contributing the flow estimated by the unit hydrograph and a groundwater aquifer representing all groundwaters flows.

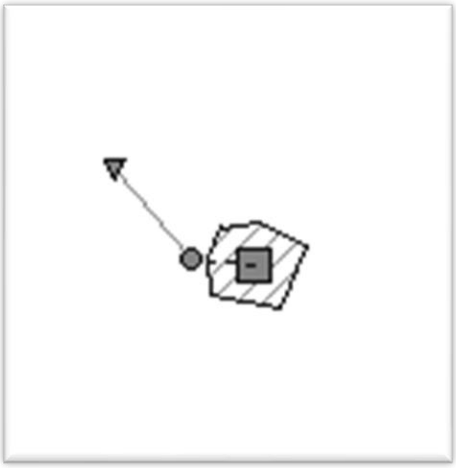

Figure 1: Simplified scheme for modelling.

With such a simplified scheme the calculation only takes a few seconds. Using these calculated results, it is possible to calibrate the groundwater related parameters. The list of these parameters is quite long as aquifers, sub-catchments and groundwater flows are controlled by more than 20 parameters.

3 Results

The Unit Hydrograph based approach was tested using the data available on the drainage system that is in Viimsi, Estonia. This system (Figure 2) contains more than 1800 sub-catchments and multiple hundreds of links and nodes.

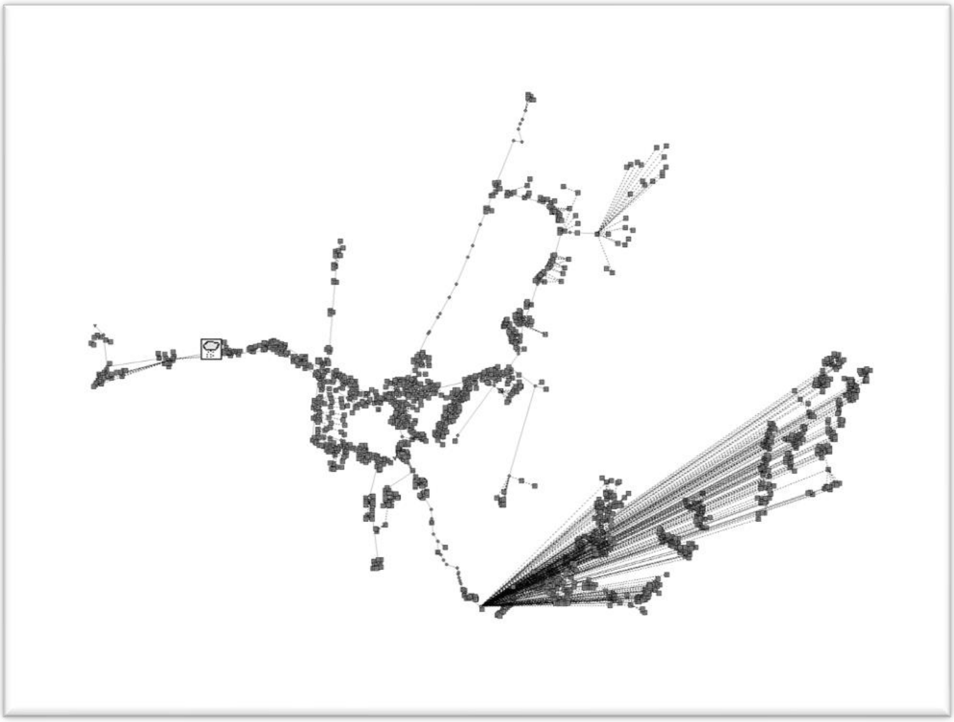

Figure 2: Viimsi drainage system.

This large number of elements within this drainage system leads to long calculation and calibration times. For instance, while using the SWMM model, which includes links, nodes, sub-catchments, and all relevant elements, calculating the entire system for one iteration takes several minutes (in our case, 6 minutes). Conducting 10 simulations for calibration of only 1 parameter will take approximately 1 hour.

To reduce the time spent on calibration, a simplified version of the stormwater system representing the nodes where measurements were conducted on the physical system was set up (Figure 1) to calibrate groundwater related parameters. In this model the infiltration related parameters may be calibrated based on the approach presented in [12]. The initial values to start the calibration may be estimated by comparing the catchment reactions to various precipitation events. For example, the smaller rainfall events do not cause a change in the nearly constant g wflow at the measurement node (Figure 3).

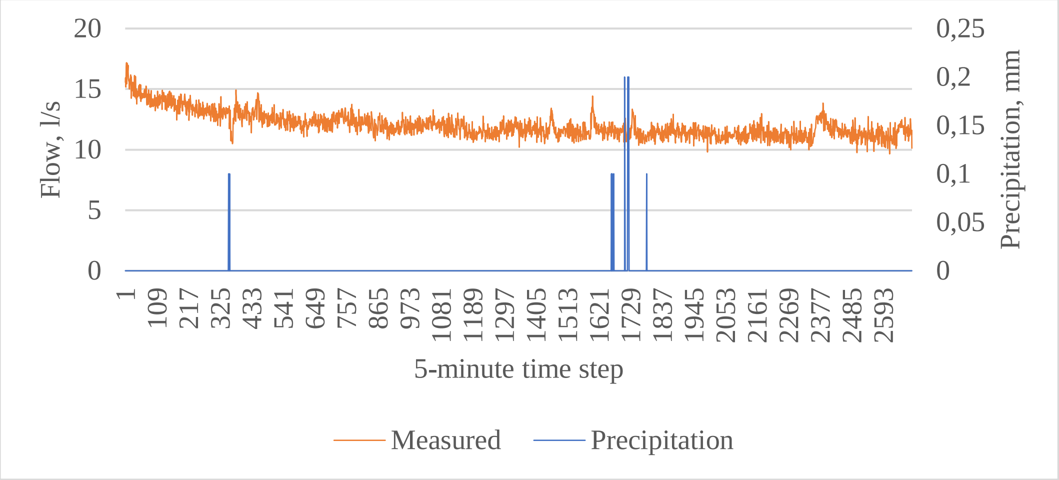

Figure 3: Reaction of measured flow to small precipitation events

It gives possibility to estimate the shape of the unit hydrograph. The unit hydrograph approach requires the sewershed area, the fraction of rainfall that enters the sewer system (parameter R), the time from the onset of rainfall to the peak of the unit hydrograph (parameter T), and the ratio of time to recession of the unit hydrograph to the time to peak (parameter K). These can be estimated based on measurements.

Figure 4 illustrates the measured flow dynamics in response to quite a small precipitation event (less than 1mm). The measured values show that parameter T equals 9 units and parameter K equals to 22/9=2.44 and the results given by the Unit Hydrograph show small increase at the beginning caused by very small precipitation. Increase 45minut or 9 units 41-50 decrease 22 units*5 50-72. One can see that groundwater flow is stable in this case. Figure presents for example unit hydrograph in case for saving time as there are fewer parameters to match during calibration and when fixing groundwater-related parameters.

Figure 4: Measured flow dynamics and the results given by the Unit Hydrograph in case of small precipitation.

Figure 5 exemplifies that accurate knowledge of the catchment area size has a significant impact on the accuracy of the modelled flows.

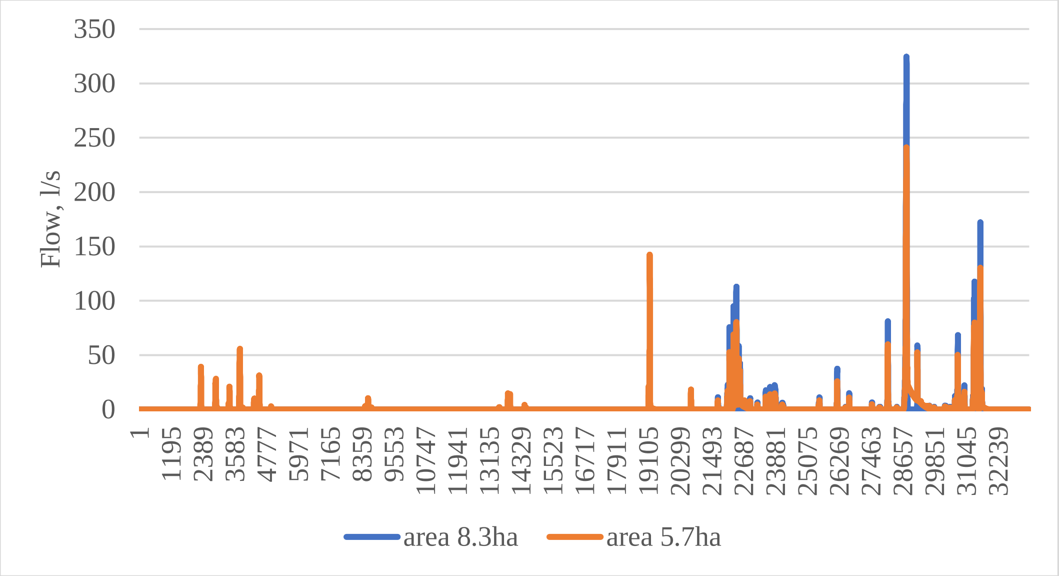

Figure 5: Effect of catchment area size on the flow dynamics applying the unit hydrograph

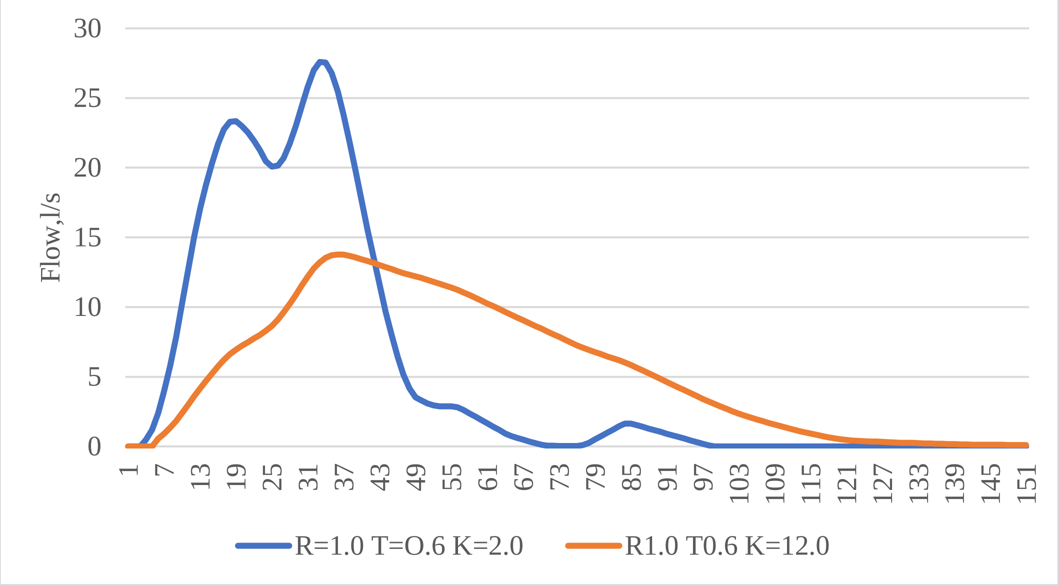

Figure 6: Unit hydrograph at different K values

If there is significant precipitation, then there exists also some influence on the groundwater flow (Figure 7).

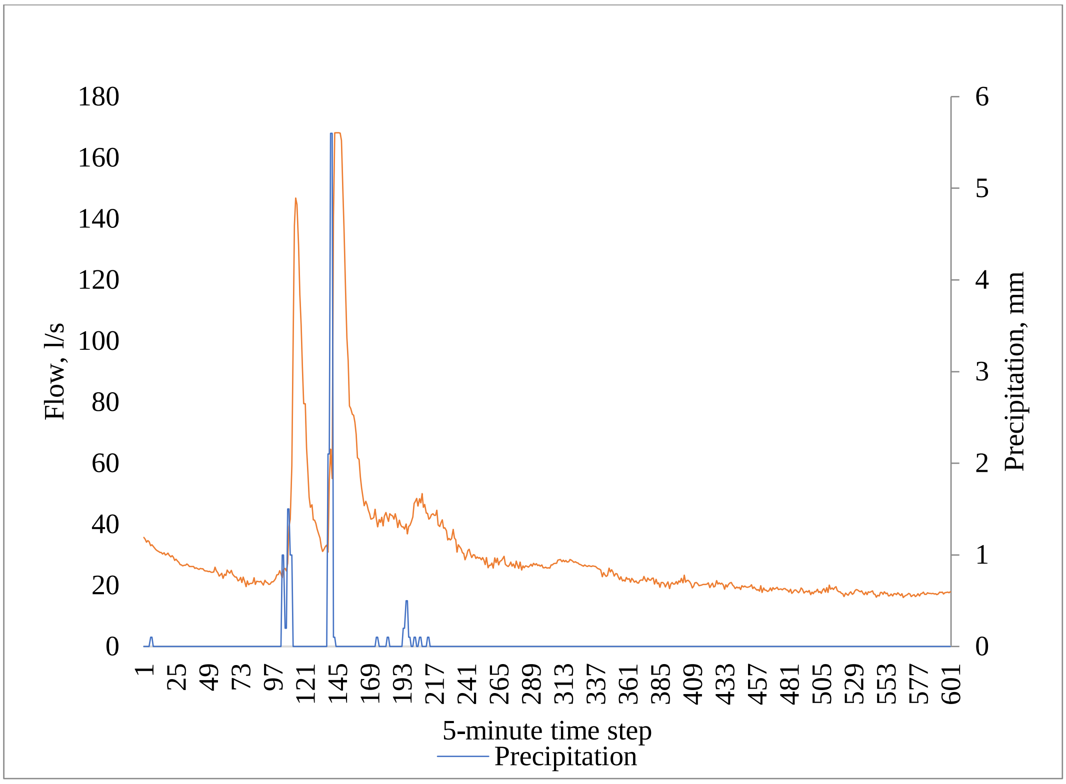

Figure 7: Reaction of measured flow to large precipitation events

4 Conclusions and Contributions

In this article an option for estimating the parameter values and increasing the speed of calibration for areas influenced by high groundwater level was proposed. The calibration results may be used for the whole system, but correction based on on-site measurements could be needed to validate the results.

Acknowledgements

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