Integrating real-time control functions of local and meso scale drainage measures in hydrological modelling

Intégration de fonctions de gestion en temps réel à l'échelle locale et moyenne dans la modélisation hydrologique

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RÉSUMÉ

Pour intégrer le calcul des fonctions de contrôle des mesures de drainage à l'échelle locale et méso dans des modèles de captage hydrologiques en méso-échelle, de nouvelles méthodes sont nécessaires. Ces méthodes permettent la modélisation d'un grand nombre de mesures de drainage distribuées dans l'espace. La nécessité de modéliser ces mesures émerge du besoin de s'adapter aux impacts du changement climatique et de la croissance urbaine dans la gestion des inondations urbaines. À cette fin, des mesures de drainage qui sont mises en œuvre de manière flexible, sont nécessaires. Ces dernières permettent d'atténuer l'ampleur des inondations et fournissent des solutions durables. Une combinaison de systèmes de drainage à l'échelle locale et de rétention d'eau dans des zones multifonctionnelles comprenant des fonctions de contrôle en temps réel fournit une stratégie appropriée pour faire face aux pressions actuelles et futures sur les infrastructures de drainage urbain. Cet article présente une méthodologie et les résultats d'application permettant de modéliser des mesures de drainage à l'échelle locale pour un bassin urbain situé à Hambourg, en Allemagne. Les résultats démontrent le potentiel de ces mesures pour atténuer la durée des inondations. Ce travail fait partie du projet de recherche allemand StucK ("Gestion de drainage à long terme en milieu urbain sous influence des marées, en prenant en considération les changements climatiques").

ABSTRACT

To integrate the computation of control functions of local and meso scale drainage measures in hydrological meso scale catchment models, new methods are required which enable the modelling of a large number of spatially distributed drainage measures. The demand to model these measures emerges by the need to adapt to the impacts of climate change and urban growth in urban flood management. For this purpose, drainage measures are required, which are implemented in a flexible way, mitigate the extent of flooding and provide sustainable solutions. A combination of local scale drainage systems and water retention in multifunctional areas which comprise real-time control functions provide an appropriate strategy to cope with present and future pressures on the urban drainage infrastructure. This article presents a methodology and application results to model local scale drainage measures for an urban catchment in Hamburg, Germany. The results demonstrate the potential of these measures to mitigate the extents of flooding. This work is part of the German research project StucK ("Long term drainage management of tide-influenced coastal urban areas with consideration of climate change").

KEYWORDS

Hydrological modelling, local scale drainage measures, real-time control, rainwater harvesting, spatial mapping.

1 INTRODUCTION

Predicted impacts by climate change and urbanisation poses increasing challenges for adaptation in many cities worldwide. More than 54 % of the world's population already lives in urban areas as reported by UN DESA (2014). The range of predicted impacts by climate change on the intensity of heavy precipitation in Central and Eastern Europe varies between 15 % to 35 % till 2100 (Jacob et al. 2014). To address this margin of uncertainty in impacts by urbanisation and climate change, flexible as well as sustainable solutions are required. Thereby, retrofitting central stormwater drainage systems with Local Scale Drainage Measures (LSDMs) is an ongoing present trend in many countries world-wide (see Maksimović et al. (2015)). LSDMs manage storm- and rainwater close to its source by imitating the natural processes of infiltration, evaporation and retention. To analyse the performance of LSDMs in concerning for example the mitigation of flooding numerical modelling is required. The demand in quantifying the performance of LSDMs on catchment scale with hydrological models is increasing, but still rarely realised (see Li et al. 2017). Some of the shortcomings in modelling LSDMs and real-time control functions with currently available hydrological catchment models are tackled in this work.

2 METHODOLOGY

In hydrological catchment models the processes are computed on specified scales. The currently supported scales need to be extended to integrate computation routines for LSDM modelling. The development of methods comprises a GIS based local data mapping, a dynamic time step computation, an explicit network generation and enabling small computation times as well as a parsimonious data structure for the application of the model. The theoretical approach of spatial and temporal scales used in this work are described in more detail in (Hellmers und Fröhle 2017).

For modelling LSDMs a method is developed to define a parametrisation which include the geographical location and drainage attributes. To map the large number of heterogeneous local scale data structures per meso scale subcatchment GIS-based data import and data processing functions are applied. For example, the distribution of green roofs depends on the availability of building contours, whereas the distribution of retention spaces and infiltration measures depends on the availability of free spaces. This demands for a modelling approach which can handle a large number of spatially distributed measures and a sufficiently detailed land use map matching the spatial detail of the distribution of LSDMs within meso scale subcatchments. For this purpose, a mapping with "overlying" data structures is created. Because of the fact, that LSDM data structures are situated within contours of meso scale subcatchments, relevant preset parameters of meso scale attributes are adopted for local scale data structures. These meso scale parameters are defined in shapes to describe the prevailing pedology, geology, landuse and watershed parametrisation. These shapes are intersected to create data structures on the basis of Hydrological Response Units (HRUs) which are made up of different layers. For detailed flood routing computation among structures on the local scale, the geographical location per LSDM is calculated to provide information about distance and gradient between source and sink LSDM structures. Interlinked flood routing among LSDMs is computed with the parametrisation defined per source and sink data structure. The net of local scale interlinked streams is generated on-the-fly during the execution of the simulation run.

In state-of-the-art hydrological models the network represents the interlinked order among three main types of net elements: (1) stream segments (namely river segments, reservoirs, pipes, ditches, open rills); (2) junction nodes and (3) spatial structures (subcatchments). Stream segments are computed with flood routing methods. Each stream segment is connected with an inflow and outflow junction node. The junction nodes function as joint connections to set rules of flow redistribution in the network interconnections. Nodes can be directly connected with stream segments or other junction nodes to distribute the flow according to control functions. A subcatchment compile the spatial and temporal parameters of drained areal compartments in the network structure on the meso scale. LSDM data structures are connected with these meso scale subcatchment, but are computed separately. The direct network connections are depicted in the example in Fig. 1. By these connections an explicit network is defined according to drainage attributes of LSDMs. This approach is enhanced by additional run-on (water uptake) and runoff (redistribution) functions. Local control systems are modelled for green roofs, cisterns and multifunctional areas which include a pre-emptying function of the water storages. The control segments (systems) on the meso scale can be reservoirs, gates or weirs.

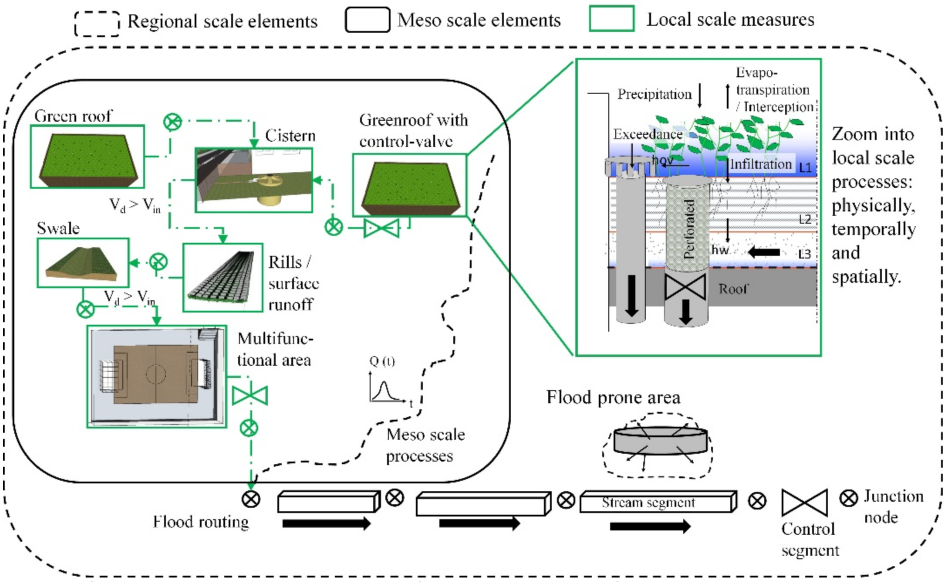

Fig. 1 Scheme of a created network including LSDMs with control functions to pre-empty storages based on forecasted rainfall intensities.

In control systems on the local scale, the water volume utilized for rainwater harvesting depends on seasons and weekdays for gardening as well as for domestic or industrial water demands. Therefore, rainwater harvesting volumes need to be defined at least on a daily resolution. Different criteria are required for modelling the control devices in LSDMs. The developed methodology in this work enables to model a control function per time step on the basis of control criteria by precipitation intensities, water level and discharge. According to that criteria, a comparison of the variable being controlled with a critical setpoint is performed. If the setpoint is reached a control function is activated. The input time series for the control function are explicit or implicit. The explicit time series are imported as observed precipitation or gauge data series. The implicit control functions depend on interim computed values within the system. The scheme of a control system is illustrated in Fig. 2. It is required to couple different models and to enable fast data transfer. Ensemble data of rainfall forecast system show promising results to be used in future (see Jasper-Tönnies et al. 2018). The computation time of the rainfall forecast as well as the hydrological model has to be reasonable small (< 5 minutes) to enable a fast data transfer. These control functions are developed for local scale structures, but are applicable as well on meso scale.

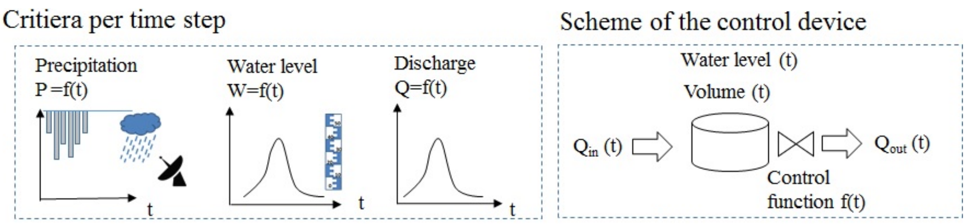

Fig. 2 Scheme of control systems with criteria for local and meso scale structures.

3 MODEL VERIFICATION AND APPLICATION

The developed model is applied in the German research project StucK ("Long term drainage management of tide-influenced coastal urban areas with consideration of climate change"). Verification tests are performed by comparing the computation output of the numerical model with observed drainage fluxes of local scale laboratory physical green roof models (see Hellmers und Fröhle 2017) and an application of the model to compute the performance of LSDMs for an urban catchment in Hamburg, Germany. The urban district area "Moorfleet" is located at the downstream section of the tidal influenced catchment Dove-Elbe, in Hamburg.

The area has a size of about 8.4 km². A storm event in August 2002 serves as basis to analyse the impacts of LSDMs in three scenarios. The first scenario (1) considers an increased rainfall intensity (climate change CC scenario). The second scenario (2) analysis the installation of LSDMs in the upstream low lying lands of the urban catchment “Moorfleet” in Hamburg. In the third scenario (3) the installation of LSDMs in an industrial area downstream of the catchment is analysed with respect to mitigate the impacts of an increased rainfall intensity. The green roofs are defined with an operational valve system to pre-empty the retention layer in advance to forecasted storm events. The pre-emptying function is activated automatically 12 hours before a forecasted event with an intensity above 4.5 mm/min. The location of the installed LSDMs are illustrated on a map in figure Fig. 3. In the study area “Moorfleet” the peak discharge is reduced by 50 % (from a maximum of 8 m³/s to 4 m³/s) by the implementation of green roofs with a total area of 274.840 m² which are coupled to cisterns (total area of 5,376 m²) and multifunctional areas (total area of 47,814 m²).

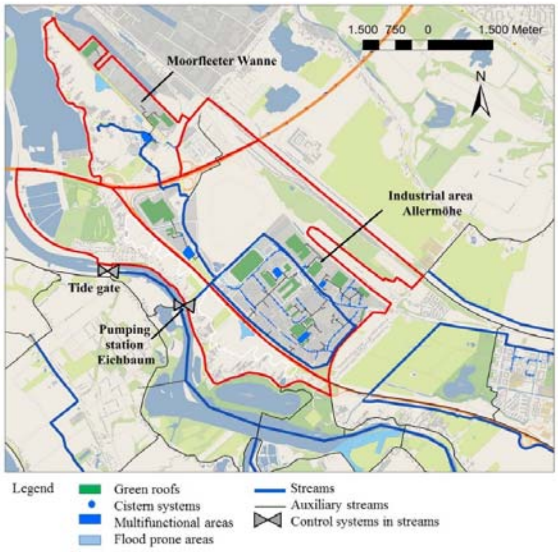

Fig. 3 Location of the modelled LSDMs in the application study area Moorfleet in Hamburg.

4 RESULTS AND CONCLUSION

The strength of the developed methodology is the definition of parameters and computation procedures on different spatial and temporal scales. The method enables to zoom into the processes (physically, spatially and temporally) where detailed physical based computation is required and to zoom out where lumped conceptualized approaches are applied. It enables the simulation of several different designs of local scale drainage measures of the same type per subcatchment. For example, different structures of green roofs or different kinds of cisterns with rainwater harvesting or pre-emptying functions are defined per subcatchment. The results in modelling LSDMs with control functions of rainwater harvesting and pre-emptying demonstrate the potential to mitigate the extents of flooding in an application study in Hamburg.

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