Integrated urban flash flood modelling in hillside catchments

Modélisation intégrée des crues éclair urbaines dans des bassins versants de collines

Stefan LEITNER*, Gerald KREBS, and Dirk MUSCHALLA

Institute of Urban Water Management, Graz University of Technology, Graz, Austria

*corresponding author; mail: stef.leitner@tugraz.at

RÉSUMÉ

L'Europe centrale connaît une augmentation des crues soudaines urbaines dues à de fortes tempêtes locales. L'urbanisation et le changement climatique mondial sont les principaux moteurs de cette tendance. Les modèles d'inondation sont un outil utile pour comprendre la dynamique des crues éclair en milieu urbain. Les modèles hydrodynamiques 1D-2D pour les crues pluviales (1D pour le modèle d'égout et 2D pour l'écoulement de surface en cas de surcharge) et les modèles hydrodynamiques 2D pour les crues fluviales définissent actuellement l'état des connaissances. Dans le contexte des crues soudaines en milieu urbain, le versant de la colline affecte considérablement la production d'eau de ruissellement en surface, en particulier en Autriche, en raison de la topographie montagneuse. C'est pourquoi il faut tenir compte des interactions entre i) le flanc de la colline - cours d'eau urbains et ii) le flanc de la colline - zone urbaine (y compris le réseau d'égouts) en ce qui concerne la production de ruissellement de surface. Ces relations nécessitent une approche de modélisation intégrée comprenant trois sous-systèmes (versant, cours d'eau urbains et zone urbaine) et leurs interactions ainsi que des modèles hydrologiques et hydrauliques unidirectionnels et bidirectionnels multiples. Le résultat est un modèle de surface intégré avec la possibilité de calculer la profondeur de l'eau de surface et la vitesse d'écoulement. De tels modèles constituent une bonne base pour une analyse plus approfondie, par exemple une évaluation des risques d'inondation éclair en milieu urbain.

ABSTRACT

Central Europe sees an increase in urban flash floods due to local heavy storm events. Urbanization and global climate change are key drivers for this trend. Flood models are a helpful tool to understand the dynamics of urban flash flood events. 1D-2D hydrodynamic models for pluvial floods (1D for the sewer model and 2D for surface flow in the case of surcharging) and 2D hydrodynamic stream models for fluvial floods currently define the state of the art. In the context of urban flash flood events, the hillside substantially affects the surface-runoff generation, especially in Austria, due to the mountainous topography. For this reason, the interactions between i) hillside - urban streams and ii) hillside - urban area (including the sewer system) must be taken into account with respect to surface-runoff generation. These relationships require an integrated modelling approach comprising three sub-systems (hillside, urban streams and urban area) and their interactions as well as hydrological and hydraulic models in a multiple unidirectional and bidirectional way. The result is an integrated surface model with the opportunity to calculate the surface water depth and flow velocity. Such models are a good basis for further analysis, for example an urban flash flood risk assessment.

KEYWORDS

urban flash floods, integrated modelling, hydrological modelling and calibration

1 INTRODUCTION

Urban flash floods are an interesting topic not only in the field of science but also in the practice field for planning engineers and stakeholders. Urbanization and global climate change increase the hazards of urban flash floods (Maniak, 2016), which can lead to high building or person damages.

A good example of one recent event in central Europe took place in Berlin in June 2017 (Davies, 2017). The total precipitation volume was measured between 150-247 mm within 24h in the greater Berlin area. One of the probable maximum precipitation in the history occurred on 16 July 1913 in Graz, where almost 600 mm were observed within 3h (Forchheimer, 1913) and (Dyck and Peschke, 1995).

Standard methods to assess and reduce the risk of urban flash floods are suggested by the EU Flood Directive (European-Community, 2007). Recent research or Interreg-Europe- Projects in the field focused on integrated heavy storm management including risk assessment (for example the current Europe-Interreg-Project RAINMAN). The contribution presents a novel modelling approach to improve the urban flash flood assessment, in particular the impact of hillside water in hillside regions and the interactions between the hillside, urban streams and urban area including the sewer system.

The approach provides a tool for integrated flash flood assessment in urban, hilly regions based on leading-edge modelling and Geographic-Information-Systems (GIS) technologies.

2 METHODS AND MATERIAL

The three main sub-systems that affect urban flash flood generation in urban-hilly catchments comprise: i) hillsides (HS), ii) urban streams (US) and iii) urban areas (UA) including the sewer system (Figure 1). The sub-system hydraulics interact either in uni or- bidirectional manner (Figure 1).

In hilly regions, the boundaries of urban catchments are often HS, which can often generate a high surface runoff rate (hillside-water) during heavy storm events (Kirkby,1988). Hillside-water is directly connected to the stream runoff and the urban area. The overloaded US can cause fluvial flooding in urban areas. Interactions between HS and UA present sources for pluvial floods. Additionally, overloaded sewer systems or flooded areas from surface runoff due to heavy storm events cause pluvial floods. The hillside water, fluvial and pluvial floods as well as hydraulic interaction of the described sub-systems further increase the hazards of urban floods. For the assessment of flooding in urban catchments, all three sub-systems have to be considered, thus resulting in an integrated hydrological-hydraulic modelling approach including all important hydrological and hydraulic processes and connections (Figure 1).

This paper represents an innovative integrated modelling approach, which includes hydrological and surfaces hydraulic sub-models for each considered sub-system. The HS and the UA are conceptualized by a grid-based two-layer concept. The hydrological model determines the effective-precipitation (P_{eff}) for the corresponding sub-system as input for the hydraulic model. The US is modelled including the geometry of their riverbanks. The UA includes all important manholes and pipes.

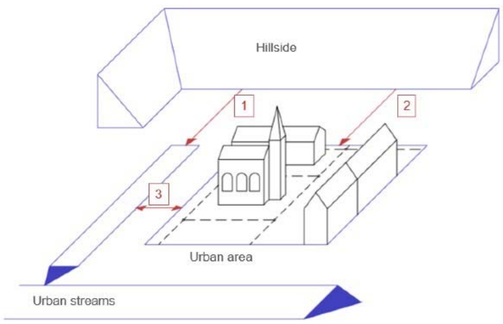

Figure 1: Main sub-systems and interactions (of the type bidirectional and unidirectional) of an integrated flood model approach

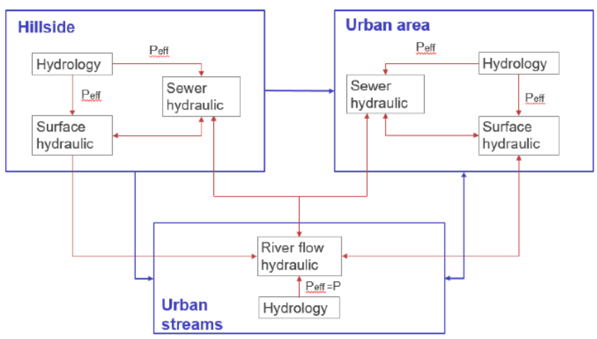

Figure 2: Integrated model approach (red lines: interactions between the different model, blue lines: interactions between the different sub-systems)

The dominant hydrological and hydraulic processes of the corresponding sub-system are implemented in each defined model (hydrological and hydraulic). For the hydrology model, a 2D raster model and a spatially detailed model based on the hydrological-response-units approach (HRU) are used for each sub-system. This model includes runoff generation in rural and urban areas. For the infiltration, the approximate theory-based Green-Ampt approach was used (Rawls et al,1992). The interactions between the hydrological and the hydraulic model in the surface hydraulic model or the sewer model are in each sub-system of the type unidirectional. Several hydraulic model approaches exist to calculate the surface runoff in conveyance systems (in this study sewers and urban streams). 2D hydrodynamic models represent the most important processes for the sub-system US and are considered state of the art. For the runoff concentration and transportation in the sub-systems HS and UA many model approaches are available – from lumped approaches using Nash-Cascades to highly-detailed approaches using the 2D-Shallow water equations. Only the last model approach (full 2D-flood models or quasi-2D flood models) can provide the state variable - water depth and flow velocity - in sufficient quality.

Thus, to obtain both - the surcharge volume and the water levels - in the sewer system, a detailed sewer model based on the Saint-Venant-Equation is required. The sewer model interacts with the surface-runoff model of type bidirectionally and with the hydrological model unidirectionally. Between the applied hydraulic surface model exist unidirectional and bidirectional interactions: The interaction is unidirectional both – between HS and UA; between HS and UA. The surface hydraulic model has two interactions: i) with US and ii) with the sewer model (UA), both times in a bidirectional manner. Combined Sewer Overflows (CSO) represent a bidirectional interaction between the hydraulic stream model and the sewer model if no flap gates are installed. The presented integrated 1D-2D hydrological and hydraulic model approach (Figure 2) contains all relevant sub-systems, models and interactions.

3 RESULTS

The presented integrated 1D/2D modelling approach was tested for a pilot area in the city Graz, Austria. The pilot area catchment includes all three sub-systems – HS, US and UA (including the sewer system). The average hillside slope is about 15 percent and 25 percent from the 132 hectare catchment area is impervious. Using the integrated model approach, a 1D/2D hydrological-hydraulic model was developed to simulate a heavy storm event observed in the year 2009. The result of this model scenario is the flooding areas, indicated by the maximum water depths occurring during the simulation (Figure 3).

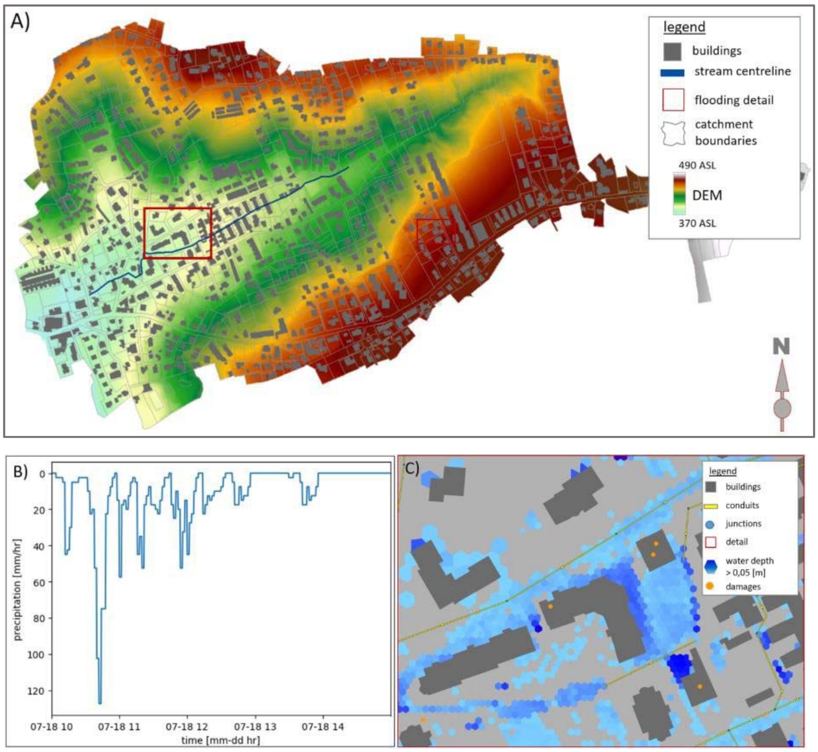

Figure 3: A) Overview map of the pilot area including the DEM (370 - 490 ASL) B) The precipitation time series from the heavy storm event on 18.07.2009 as input data for the simulation. C) flooding areas represent as maximum water depth > 0,05 meter and the knowing operation locations from the fire department for the plausibility check.

The calibration of surface runoff models for flooding conditions is challenging due to the lack of appropriate data. Therefore, no calibration and validation could be performed for this model, due to missing data for water depth, flow or flow velocity. But a plausibility check was conducted by comparing the simulation results with documented damages of the respective flooding event (damage data from the fire department). Additionally, videos and photos from social media or damage data from insurance companies could provide a suitable source to verify these kinds of models, but was not used in this case study (Table 1).

Table 1: Opportunities for a plausibility check and model verification methods for urban flash flood models

methods	source	reference value	type
social media	Facebook, YouTube, Twitter	videos and photos	qualitative
damage data	insurance companies	locations of damages	qualitative
operation protocols	fire department	location of operation	qualitative

4 CONCLUSION

The integrated 1D/2D hydrological and hydraulic model approach including the three sub-systems HS, US and UA (including the sewer system) provides a sound foundation for an integrated urban flash flood management to identify hazard areas within a catchment. The approach considers all relevant interactions between the three sub-subsystems and between the hydrological and hydraulic models.

The locations of the maximum water depth obtained from the simulation were compared with the operating protocols of the fire department for one heavy storm events (2009). A calibration based on measurement data could not be performed due to missing data. In the context of urban flash flood modelling, this gap must be closed with future innovative calibrations/validation methods. One possibility would be to use quantitative data (water depth or flow velocity) to calibrate/validate the model with statistical methods.

LIST OF REFERENCES

Davies, Richard. 2017. „Germany – Berlin Streets Under Water After 150mm of Rain in 24 Hours“. Http://Www.Floodlist.Com. 30. Juni 2017. http://floodlist.com/europe/germany-berlin-flood-june-2017.

Dyck, Siegfried, und Gerd Peschke. 1995. *Grundlagen der Hydrologie. 3*. Berlin: Verlag für Bauwesen.

European-Community. 2007. „Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks“. *Official Journal of the European Union*, Nr. L288: 27–34.

Forchheimer, Ph. 1913. „Der Wolkenbruch im Grazer Hügelland vom 16. Juli 1913“. *Sitzungsbericht der Akademie der Wissenschaften*, 2099–2109.

Kirkby, Mike. 1988. „Hillslope Runoff Processes and Models“. *Journal of Hydrology*, Januar.

Maniak, Ulrich. 2016. *Hydrologie und Wasserwirtschaft: eine Einführung für Ingenieure*. 7., neu Bearbeitete Auflage. Lehrbuch. Berlin: Springer Vieweg.

Rawls, W. J., L. R. Ahuja, D. L. Brakensiek, und A. Shirmohammadi. 1992. „Infiltration and Soil Water Movement“. In *Handbook of Hydrology*, herausgegeben von D. R. Maidment, 5.1-5.51. New York, USA: McGraw-Hill.