<table>
<thead>
<tr>
<th>Title</th>
<th>Shallow Water Flow Based Simulation of Flash Floods in Small Catchments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author(s)</td>
<td>Tügel, Franziska; Özgen, Özgen; Hadidi, Ahmed; Tröger, Uwe; Hinkelmann, Reinhard</td>
</tr>
<tr>
<td>Citation</td>
<td>Proceedings of the Second International Symposium on Flash Floods in Wadi Systems: Disaster Risk Reduction and Water Harvesting in the Arab Region (2016): 34-41</td>
</tr>
<tr>
<td>Issue Date</td>
<td>2016-10</td>
</tr>
<tr>
<td>URL</td>
<td><a href="http://hdl.handle.net/2433/228080">http://hdl.handle.net/2433/228080</a></td>
</tr>
<tr>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Presentation</td>
</tr>
<tr>
<td>Textversion</td>
<td>author</td>
</tr>
</tbody>
</table>

Kyoto University
Shallow Water Flow Based Simulation of Flash Floods in Small Catchments
Franziska Tügel1*, Ilhan Özgen1, Ahmed Hadidi2, Uwe Tröger1, Reinhard Hinkelmann1

1Chair of Water Resources Management and Modeling of Hydrosystems, Technische Universität Berlin
2Chair for Hydrogeology, Technische Universität Berlin, 3TU-Berlin, Zentralinstitut El Gouna, Fraunhoferstr. 33-35, 10587 Berlin
*Corresponding author
Email: franziska.tuegel@wahyd.tu-berlin.de

Keywords: Shallow Water Equations, Urban Flooding, Natural Catchments, Infiltration

Flash floods as a result of heavy rainfalls often cause severe damages to settlements and the environment. In future, the occurrence and intensity of heavy rainfalls might increase due to climate change. The simulation of flash floods is an important tool to analyze flow processes during and after rainfall events and to develop methods to protect settlements and the environment against damages caused by flooding. Generally, rainfall-runoff simulation in catchments is carried out with hydrological models which only ‘roughly’ can take into account the topography, flooding areas and local details of flow processes. To overcome these drawbacks, shallow water based models have been further developed and applied in recent years. The Hydroinformatics Modelling System (HMS) can be used for different applications, as for example rainfall-runoff and flood modelling. HMS is a Java-based framework which is developed at the Chair of Water Resources Management and Modeling of Hydrosystems, Technische Universität Berlin. The two-dimensional depth-averaged shallow water equations are discretized with a cell-centered finite volume method and solved with an explicit MUSCL scheme. Precipitation and infiltration are considered as source/sink terms in the mass balance equation. Different applications of HMS will be presented: (1) the simulation of a dam-break through an idealized city (flooding), (2) rainfall-runoff simulation in a natural catchment and (3) rainfall-runoff simulation considering infiltration with the Green-Ampt model. One future objective is to set up a model of the El Gouna region in HMS. Preliminary studies contain the analysis of different scenarios concerning bottom friction, slope, rainfall, infiltration and additional inflow from upstream for an idealized catchment. By implementing a digital elevation model (DEM) the topography of the natural catchment will be taken into account to simulate the runoff in the region of El Gouna. During the flash flood event on 9 March 2014 data of rainfall and runoff were measured and are published in the doctoral thesis of Hadidi (2016). This event will be simulated with HMS and the numerical results will be compared with the measured data. Later on the model will be applied to investigate different scenarios of structural measures to protect the city of El Gouna against flooding.
Outline

- Motivation
- Modelling framework, physics and numerics
- Applications
- Conclusions and Outlook

Hydrological, hydraulic and environmental problems

- Flooded urban and rural areas
- Interactions
- Contaminant transport
- Sediment transport / morphology
- Urban runoff
- Infiltration

Numerical modeling of hydro- and environmental systems

- Processes
- Classical & new application fields
- High resolution data
- High performance computing
- Standard & robust numerical methods

Flash floods

Simulation of flash floods to:
- Analyze structural protection measures
- Develop early warning systems

2D shallow water models:
- Consider complex topographies, flooding areas and local flow processes
- Support high-resolution grids (~1m) to better resolve urban structures
- Include robust numerical methods which enable the modeling of propagating wet-dry fronts
- Deliver results of flow evolution in the whole simulated domain including water depths and flow velocities
Flash floods

product of extreme weather conditions

cause severe damages

storage and usage of fresh water

need of mitigation measures

El Gouna, 9th March 2014

flooded city of El Gouna

Hurghada 9th March 2014

flooded city of Hurghada

Berlin, 27th July 2016

parking cars transported by flood

Berlin, 27th July 2016

flooded city of Berlin

Outline

• Motivation

• Modelling framework, physics and numerics

• Applications

• Conclusions and Outlook

Highly random occurrence in arid/semi-arid regions as well as in regions with moderate climate
Hydroinformatics Modeling System

• hms is a Java-based object-oriented modeling framework which solves shallow water flow and associated processes using a cell-centered Finite-Volume Method (Simons et al. 2014).
• ‘Easy’ implementation of extensions, e.g. new conceptual approaches, coupling of processes
• ‘Easy’ handling of spatial data
• Developed at the Chair of Water Resources Management and Modeling of Hydrosystems

Software design

• Accessible through generalized interfaces.
• Independent of represented information
  → Physically-based model
  → Geospatial database
  → External data sources
  → …

hms layer concept

Software design

hms core
Shallow water equations

- Two-dimensional shallow water equations:
  \[ q = \begin{bmatrix} h \\ \mathbf{v} \end{bmatrix}, \quad f = \begin{bmatrix} \varrho \mathbf{v} h + \frac{1}{2} \varrho g h^2 - \nu_v \nabla (\varrho h) \\ \varrho \mathbf{v} h + \frac{1}{2} \varrho g h^2 - \nu_v \nabla (\varrho h) \end{bmatrix}, \quad s = \begin{bmatrix} -\nu_f \frac{\partial h}{\partial x} - \varrho g h \frac{\partial h}{\partial x} - \frac{1}{\varrho} \mathbf{v} \cdot \mathbf{n} \\ -\nu_f \frac{\partial h}{\partial y} - \varrho g h \frac{\partial h}{\partial y} - \frac{1}{\varrho} \mathbf{v} \cdot \mathbf{n} \end{bmatrix} \]

- Mass sink/source term (e.g., rainfall, infiltration)
- Turbulent viscosity
- Bottom shear stress
- External forces (e.g., wind, Coriolis)
- Density

- Constant turbulent viscosity or algebraic turbulence model
- Hydrostatic reconstruction for well-balanced results
- Point-implicit solution of friction term

General Finite-Volume solver

- General form of 2D conservation law:
  \[ \frac{\partial q}{\partial t} + \nabla \cdot f = s \]

- General cell-centered Finite-Volume method:
  \[ q^{n+1} = q^n - \frac{\Delta t}{A} \sum_k f_k^e \cdot \mathbf{n}_k + \Delta t s^n \]

- Independent of mesh type
- Explicit time discretization

“General” Godunov-type solver

- Using a Riemann solver for flux computation: exact solver, HLL, HLLC, Roe’s
- Efficient solution of SWE and any number of other processes which are not influencing the Riemann solution directly
- Second order accuracy in space; avoiding spurious oscillations through TVD methods

Runoff generation / infiltration

- Effective rainfall \( \rightarrow \) runoff generation model
  - Infiltration
  - Evapotranspiration (planned)
- Conservation law for the soil water content:
  \[ q = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \quad f = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \quad s = \begin{bmatrix} \mathbf{r} \\ \mathbf{s} \end{bmatrix} \]

- Infiltration in the unsaturated zone
  - Green-Ampt or Philip’s model
- Coupling with Richard’s or two-phase flow model

Outline

- Motivation
- Modelling framework, physics and numerics
- Applications
- Conclusions and Outlook

Previous studies
The Second International Symposium on Flash Floods in Wadi Systems

**Flash flood in an simplified urban district**

**Numerical results of rainfall runoff simulation**

**Parameter studies on idealized catchment**

**Parameter studies**

**Heumöser slope**

**Present study: Flash flood in region of El Gouna**
The Second International Symposium on Flash Floods in Wadi Systems

Parameter studies
Runoff at catchment outlet
3) Infiltration
- Infiltration (Reference Case)
- Infiltration sandy soil (10 l/s)
- Infiltration loamy soil (6 l/s)

4) Additional inflow
- Infiltration (Reference Case)
- Infiltration sandy soil (10 l/s)
- Infiltration loamy soil (6 l/s)

Parameter studies
Runoff at catchment outlet
5) Infiltration
- Infiltration (Reference Case)
- Infiltration sandy soil (10 l/s)
- Infiltration loamy soil (6 l/s)

6) Infiltration and additional inflow
- Infiltration (Reference Case)
- Infiltration sandy soil (10 l/s)
- Infiltration loamy soil (6 l/s)

Preliminary studies
7) 3x3 idealized buildings, inflow 500 L/s, rain intensity 50 mm/h

Model of El Gouna
- Model area: 11 km x 6 km
- 70400 cells
- Resolution: 30 m x 30 m
- 20 m/s inflow at outlet of wadi based on Hadidi (2016)

First results of the model of El Gouna
Flow velocity magnitude (m/s)
Water depth (m)

First results of the model of El Gouna
Water depth at N-E edge of Campus El Gouna (not exact) (m)
Outline

- Motivation
- Modelling framework, physics and numerics
- Applications
- Conclusions and Outlook

Conclusions and Outlook

- Idealized Catchment:
  - Most important parameter: Inflow

- Model of El Gouna:
  - Water "reaches" the location of TUB Campus after ~ 4.4 hours
  - Infiltration was not considered
  - Constant inflow ≠ natural

- Next steps:
  - Implementation of measured hydrograph as boundary condition
  - Considering infiltration and comparing results
  - Grid refinement in the city area, resolving buildings and infrastructures
  - Implementation of structural protection measures:
    - Dams, canals, basins, local measures for buildings

References