Urban Flood Modeling - Impact of Digital elevation model (DEM)

Modélisation des inondations urbaines - Impact du modèle numérique d'élévation (DEM)

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RÉSUMÉ

Dans le cadre de la gestion des risques d'inondation dans la ville de Rostock, les zones les plus exposées aux inondations en raison de la formation de flaques d'eau issues des égouts ont dû être recensées, en utilisant une combinaison semi distribuée entre la modélisation 1D et les modèles 2D des eaux usées. La surface du modèle d'inondation (bathymétrie) a été construite sous la forme d'une grille rectangulaire unique. La haute précision souhaitée du modèle doit être équilibrée avec l'effort de préparation du modèle, le temps de simulation et la stabilité numérique. L'impact du modèle numérique de terrain (MNT) comme élément déterminant du modèle a été pris en compte dans différentes résolutions (5 m et plus fines). Nos recherches ont montré que pour identifier les zones inondables, une résolution du MNT de 5 m est suffisante, ce qui permet de réduire considérablement la durée des simulations par rapport aux résolutions fines. Pour l'étude détaillée des zones vulnérables identifiées, la haute résolution nécessaire du MNT est limitée en raison des conditions numériques de propagation des vagues dans les eaux peu profondes. Ainsi, nous n'avons pas utilisé les données originales des drones (UAV) d'une résolution de 0,05 m mais les avons ajustées sur une grille de 0,5 m pour réaliser les simulations. Le couplage des modèles peut être amélioré en transposant les rues en données bathymétriques au niveau du sol de chaque nœud (mesure du niveau terrestre du regard d'égouts) en utilisant la fonctionnalité du SIG.

ABSTRACT

For flood risk management in the city of Rostock the flood prone areas due to sewer ponding had to be allocated, by using a semi-distributed model combination of 1D sewer modelling with 2D flood models. Flood model surface (bathymetry) was constructed as a rectangular single grid. The desired high model accuracy needs to be balanced with the effort of model preparation, simulation time and numeric stability. The Impact of DEM (Digital Elevation Model) as a decisive model input was considered in different resolutions (5m and finer). Our investigations resulted, that to identify the flooding hotspots a DEM resolution of 5m is sufficient, whereby duration of simulations could reduced significantly, compared with fine resolutions. For detailed investigation of identified hotspots the needed high resolution of DEM is limited due to numerical conditions of shallow water wave propagation, so we did not use available original Data from Unmanned Area Vehicles (UAV) in resolution of 0.05m, but resampled it to a grid of 0.5m for simulations. The coupling of models can be improved by impressing streets into bathymetry on the individual groundlevel of every node (terrestric measured manhole level) by using functionality of GIS.

KEYWORDS

DEM resolution, Flood propagation, Model coupling, Overland flood modelling, Urban drainage

1 INTRODUCTION

Flood risk management is an integrated task of urban drainage and whole community. This applies also for the city of Rostock, which developed in large research project inter alia an integrated model based flood risk assessment tool (Tränckner et al., 2019).

To allocate flood prone areas due to sewer ponding, the combination of 1D sewer modelling with 2D flood models became meanwhile state of the art. For a realistic 2D flood modelling, the flood model surface (bathymetry) is a decisive model input (Adeogun,et. al., 2015). The desired high model accuracy needs to be balanced with the effort of model preparation, simulation time and numeric stability. This paper describes comparative studies concerning the impact of resolution of bathymetry and DEM (Digital Elevation Model) on effort and accuracy of 2D models and suggest approaches for an effective improvement of model bathymetry.

2 METHODS

2.1 Data

The area of investigation is a small part (32 ha) of the city of Rostock, located in the North-German lowlands. Sewer network data were provided by the local operator. Landuse data are available in very high spatial resolution (Richter et al., 2017). DEMs from ALS (Airborne Laser Scanning) in different resolutions were considered: 5m x 5m, 2m x 2m, 1m x 1m. For small test area (Loop area), a DEM with extreme high resolution of 0.05m x 0.05m based on UAV (Unmanned Area Vehicles) has been created.

2.2 Models

To describe the processes of flooding, a semi-distributed model combination is used, consisting of modules for i) rainfall-runoff (kinematic wave approach, infiltration capacity by a modified Horton’s equation) ii) sewer transport (St. Venant equations, 1D) and iii) overland flow (shallow water equations, 2D). Models are coupled bidirectional by sewer nodes. Bathymetry is constructed as a rectangular single grid. Software from DHI © MIKE Urban and Mike 21 is used in Release 2016.

2.3 Approach

For first simulations identifying hotspots, hydrodynamic simulations of the whole investigation area were performed as more qualified alternative to GIS methods. These were run compared based on the available DEM with a resolution of 1m x 1m to 5m x 5m. For the loop area, we investigated in detail, how the accuracy of 2D flood modelling can be further increased, either by applying higher DEM resolution or by an intelligent combination of terrestric data with available DEM data.

3 RESULTS AND DISCUSSION

3.1 Flooding hotspots

A comparison of simulations with bathymetries in different resolutions of DEMs shows (Fig. 1), that a resolution of 5m is sufficient to identify the main flooding hotspots, at least in plain areas. The flooding hotspots in result of this different simulations match to each other (intersection of different flooding areas by functionality of GIS yields sufficient overlapping area) and were successfully validated to passed real flooding events. Covered flooding area is increasing by decreasing resolution, due to propagation of the water volume on larger cells. Since flooding maps have immanent uncertainties, even those that base on a DEM with high resolution (Brandt 2016), a high resolution is not necessary to identify hotspots.

The duration of simulations can reduced significantly by decreasing the resolution of the bathymetry, from 4 h (0,5 m resolution) to 4 min (5 m resolution) in this case, on same computer.

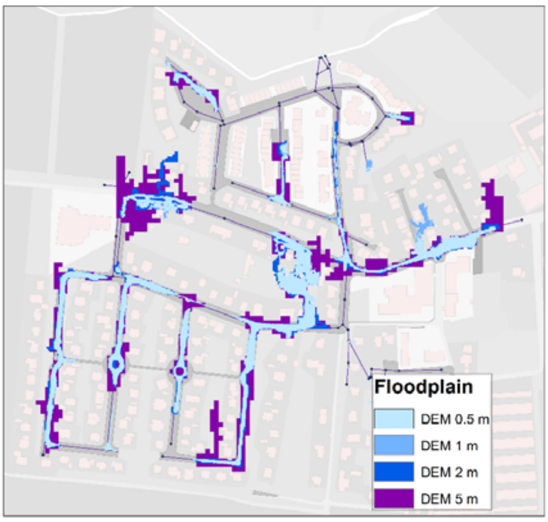

Figure 1: Comparing simulations with different resolution of DEM and bathymetry respectively

3.2 Loupe models

3.2.1 Bathymetry resolution

For detailed investigation of identified hotspots single loupe models had to build up. The resolution of DEM in this case seems to be selected as high as possible. However, there are limitations due to numerical conditions of shallow water wave propagation. If the bathymetry is a single grid, the equations are solved semi-implicit. The stability of simulation depends on Courant condition (DHI Materials 2011):

Courant number $C_R = \frac{\Delta t}{\Delta x}\sqrt{gh} \leq 1$ Δt - time step, h - water depth, Δx - grid spacing, g - gravity

For ensuring this condition, a small size of grid cell requires a corresponding small time step. Assumed a water depth of 0.2 m (is not an extraordinary flooding depth) simulations with UAV-data in resolution of 0.05m so would require a suitable time step of 0.035s. Even if this would be practicable under limitations of software, there is another obstacle relevant for stability concerning water depth in grid cells (DHI Materials 2011):

Abbott number $\frac{h}{\Delta x} \leq 1$

When the water depth exceeds the grid size significantly, this can lead to simulation break (Toombes, L. et al. 2011). That means, using a grid size of 0.05m already a water depth h ≥ 0.05m will overrun this ratio.

It must be established, that even though a fine resolved DEM from UAV data may lead to better simulation results, in practice this is limited by numeric. UAV data in very fine resolutions like 0.05m are not directly usable under this conditions (Shallow water equations, single grid). Possibly simulations will be realized better by other numerical models and solutions respectively (Thrysøe et.al. 2016), (Bates et. al. 2010). For this reasons finally we did not use original UAV-Data, but resampled it to a grid of 0.5m, successfully simulating with time step of 0.5s.

3.2.2 Bathymetry structure

Concerning the coupling of two models (sewer network 1D, overland flow 2D) the consistency of parameters at the coupling elements in both models is very important for a stable numeric and tolerable volume errors. That means the difference between groundlevel of nodes (manhole level) and corresponding value of DEM grid cell should become minimal. In practice this is often not the case, because of deviation errors between the DEM and terrestic measured data. The classic way to eliminate these differences is to adjust the groundlevel of every node to corresponding DEM values, so that the DEM stays consistent. However, manipulating the groundlevel of nodes in relation to original values will cause more or less relevant changes of the flooding situation at nodes.

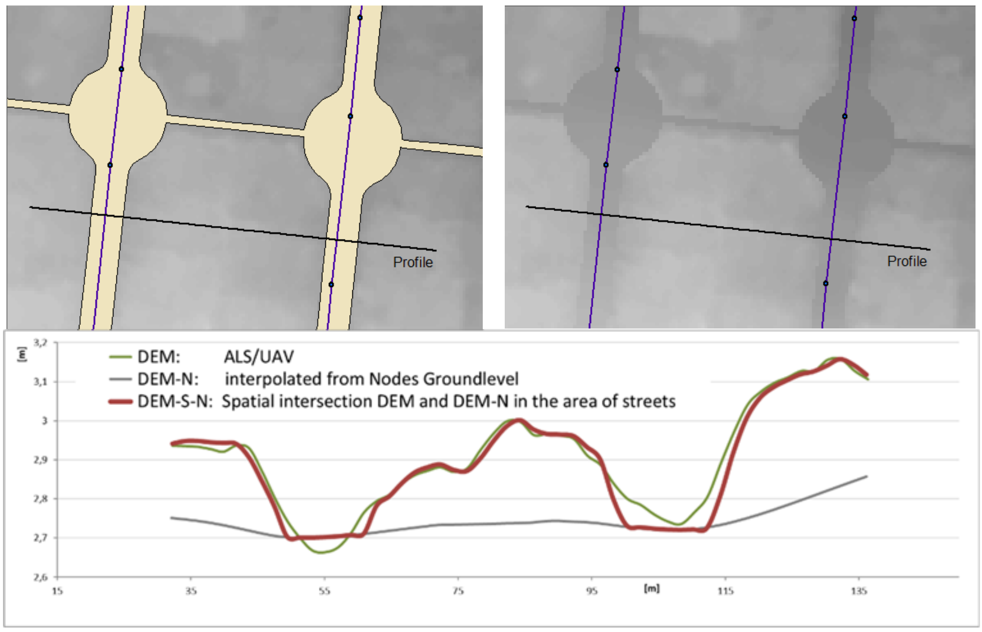

Figure 2: Intersection of DEMs for impressing streets with individual groundlevels of nodes

To solve this, we recommend in opposite the adaption of DEM to groundlevel at nodes. To do this in an automatic way, first an artificial DEM (DEM-N) has to be created by interpolation on all sewer node groundlevel values. This DEM-N will adapt exactly to individual groundlevel of all nodes. The intersection of this DEM-N with DEM in the area of streets by GIS-Tools results a new DEM (DEM-S-N) with the same resolution but individually impressed street areas, without any differences at coupling elements (Fig. 2). The street area was given by polygons from landuse map, which is created on base of Orthophotos. Curbsides are mapped by grid cells, due to Bathymetry is constructed as a single grid.

This way, differences between node groundlevel and DEM level are prevented simulation volume error are minimised, by keeping the original flooding situation. A side effect, the possible propagation of flooded water in street space is included (Fig. 3). Assuming the flood from manholes always will propagate on the whole street area this scenario seems to be more realistic. A constraint is, that realistic values of curbstone high in the resulted DEM-S-N are not ensured, due to automatism and deviation errors of DEM.

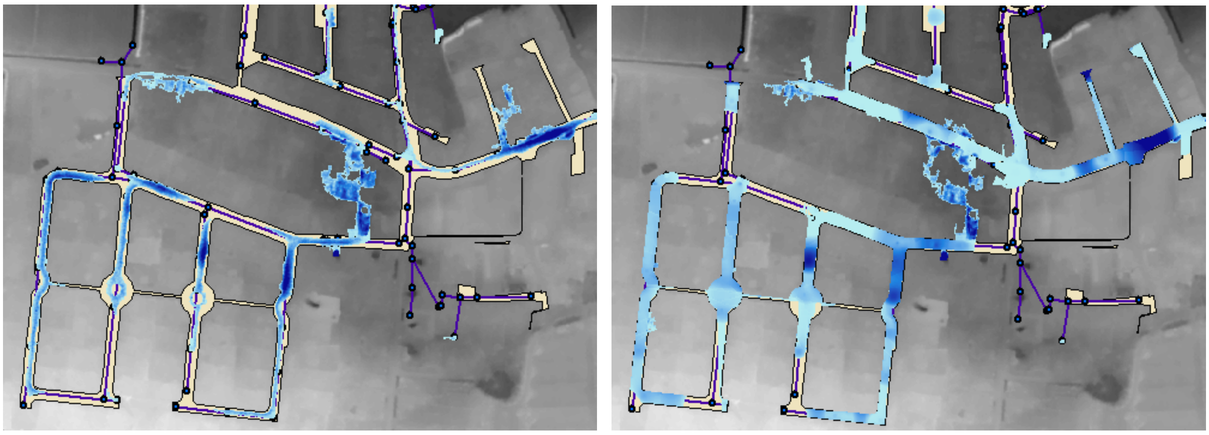

Figure 3: Flooding area without (left) and with (right) impressed streets

4 CONCLUSIONS

- DEM resolution of 5m is sufficient to identify the flooding hotspots, at least in plain areas.
- In loupe areas very fine resolved bathymetry (e.g. UAV 0.05m) is not usable for Simulations with single grid, due to numeric of shallow water equation.
- The coupling of models can be improved by impressing streets in bathymetry on individual groundlevels of nodes (terrestric measured manhole level).

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