Flood Risk Assessment Implementing GIS hydrological Computation and 1D Hydraulic Model

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Abstract

A need occurred to determine service level capacity and flood risk assessment in Brøndby – Denmark, which was exposed to extensive floodings in recent years particularly during the monster rain event of July the 2nd 2011. This paper reviews a new method to combine GIS hydrological computation and 1-Dimensional (1D) hydraulic model to produce at 1D-1D hydraulic model that determines flood and hydraulic capacity of drainage systems. The case study is in Horsedammen in Brøndby. This new method has the ability to overcome the present hardware limitations regardless of size of the catchment and the resolution of the flood grid implemented in the model and still reaching accurate results. The new method has saved a great deal of modelling and simulation time. Simulations of status scenario of 5-year, 100-year and monster rain (1000-year) events have been carried out producing a 3D dynamic flood map for each scenario. The method is an effective tool for analysis, assessment, planning and design of drainage systems and can be used for river systems and other 1D modelled systems applied to rain events. The faster simulation of this method can be implemented in forecast modelling. Results can be presented on Google Earth and online GIS programmes.

Key words: Climate Change, flood modelling, GIS hydrological Computation, Horsedammen.

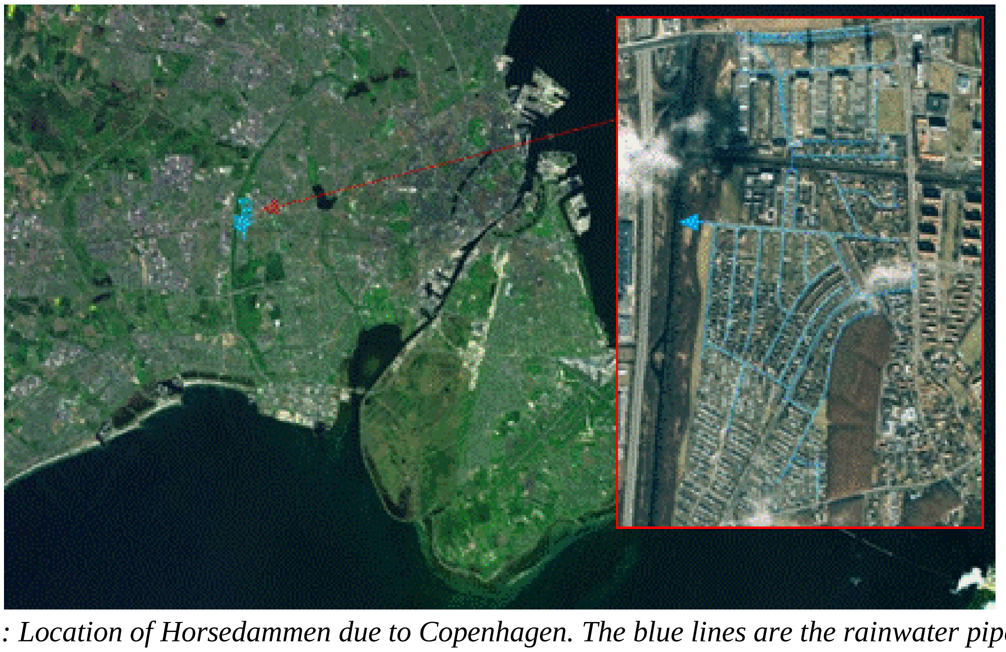

Figure 1: Location of Horsedammen due to Copenhagen. The blue lines are the rainwater pipe net of this study.

Introduction

The devastating flooding of the unanticipated 1000-year rain event in Copenhagen on the 2nd of July 2011 (Kbh, 2011) has caused damages assessed to approx. 6 milliard DKK (DNA, 2013-1). New regulations for climate change adaptation (DNA, 2013-2) since then are taking a place to avoid such an event in the future (CCA, 2012).

In Horsedammen (78 ha) located in Brøndby Municipality west of Copenhagen, damages urged to implement flood modelling to produce a flood risk map. The catchment includes mainly housing quarters that has been exposed to flood damages more than once.

A new flood modelling method has been developed during this task. The new method depends on a combination of 1-Dimensional (1D) pipe net model, terrain model and GIS-hydrological computation to produce a 1D-1D flood model.

Description of catchment and pipe net

The catchment includes high buildings in the north and detached house-quarters in the middle and south. A school is located at the mid-west side. See Figure 1.

A trunk sewer of 1,1 m diameter concrete pipe is the major pipe line that flows from east to west beneath Horsedammen street and mouths a discharge to the channel along the west side of the catchment. The Horsedammen pipeline collects rainwater from the rest of the catchment from north and south through several pipelines as it is presented in Figure 1.

Method review

Traditional 2D-1D flood models are constructed upon coupling a 1D underground model of pipe net, channels and rivers to a 2D surface model on the terrain to produce a flood map. The 2D model computes flow from cell to cell in either a rectangular grid or a flexbile mesh, which applies pressure on hardware capacity during the long and/or unstable simulation for large catchments. In order to overcome this, compensation with accuracy is imposed on model building and simulation by enlarging cell size, reducing coupling points, greater simulation time steps, etc.

The method reviewed in this paper relies on a 1D model for pipe net, rivers and channels beneath terrain coupled with another 1D model for terrain depressions and flow paths between them. The resulted 1D-1D flood model can simulate accurate results in much less time and hardware capacity. A method review is presented below.

Preparation of terrain model

A surface model is produced by integrating different feature class layers as buildings, streets, etc. on the terrain model raster as presented in Figure 2, which can be used for GIS-computation.

Flood potential map

Also called a blue spot map. It is computed due to filling the surface model depressions and computing volume, depths and area of fillings. See Figure 3-left.

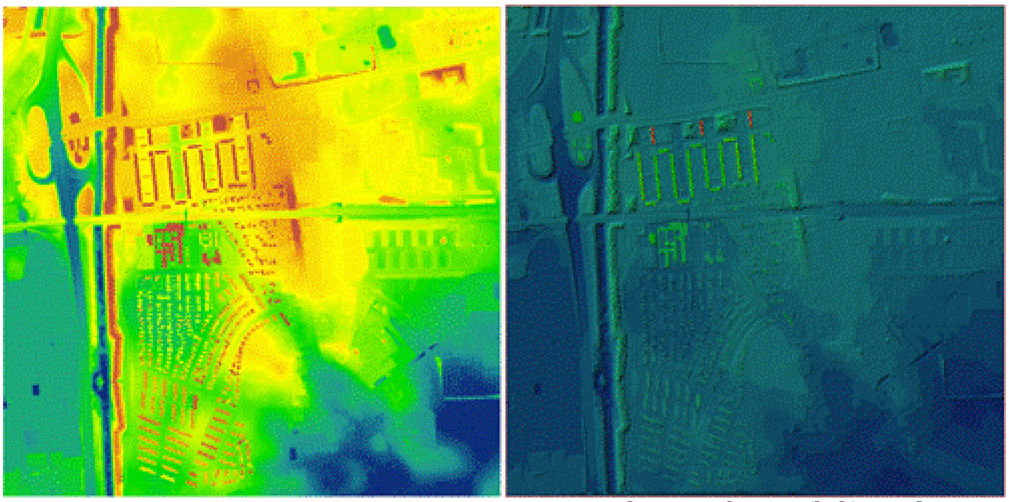

Figure 2: Integrating terrain raster with building, streets, etc. feature classes (left) producing a surface model ready for GIS-computation (Right).

Flow accumulation paths on top of the fillings can be computed in terms of form, size and flow capacity to the required detailed level. The catchments (River basins) of flow accumulation paths can also be determined in terms of area, form and location. Figure 3-right shows the computed flow accumulation paths and their catchments.

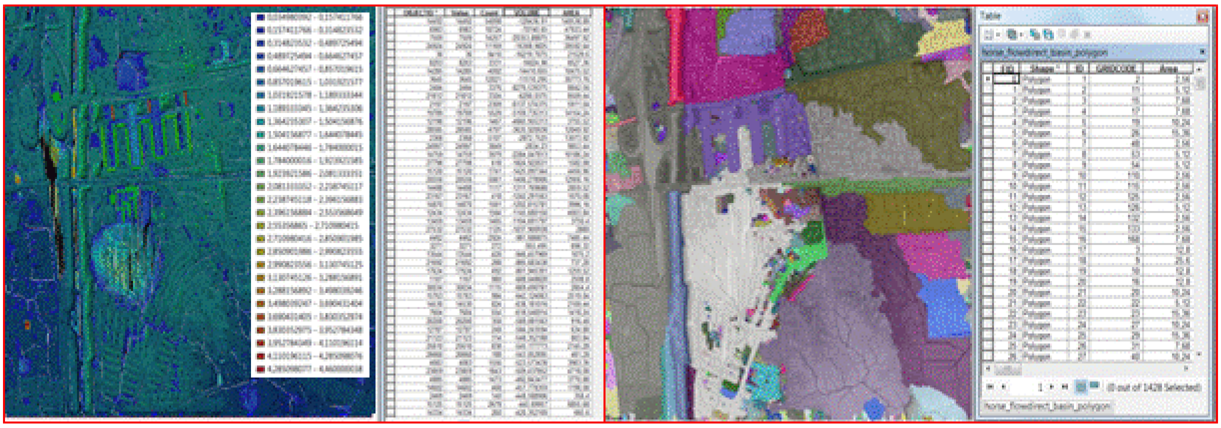

Figure 3: Identifying potential floods with computing area, volume, depth and flow accumulation paths (left). Flow accumulation path catchments (Right).

Flood model

Volumes, areas, depths, form and location of terrain depressions from the blue spot map will be described in a 1-D model. Overflow between blue spots on the terrain will be described in the 1-D model by weirs, orifices and open channels of the flow accumulation paths as it is described on the terrain. All of this formulates the 1-D model on the surface. The 1-D model on the surface is connected to the 1-D model beneath surface. Due to this step, building up the aimed integrated flood model has been accomplished. Figure 4-left illustrates the flood model.

Figure 4: Flood model where Basins, weirs, orifices and flow accumulation paths formulate the 1D model on the surface is connected to the 1-D model beneath surface of pipe net, rivers and channels (Left). A 5-year event flood map in Horsedammen compared to node flood map (Middle). And a 3D dynamic flood map of a 5-year event (Right).

Model simulation

Basins in the flood model get filled with certain water volumes on a time step basis due to simulation of a certain rain event. Results of volumes, depths and velocities can be transferred to the GIS platform to fill depressions and produce a dynamic flood map based on a time step basis. Figure 4-right shows maximum flood level for a CDS5 event.

In this case study rain events of CDS5, CDS100 and CDS1000 have so far been simulated. CDS5 is the design rain event in Denmark for separated rainwater drainage systems (SVK27, 2005). CDS100 is the climate rain event (No climate change factors added) (SVK29, 2008). CDS1000 is the rain event that hit Copenhagen in July 2011.The new regulations aimed to handle such an event (DNA, 2013).

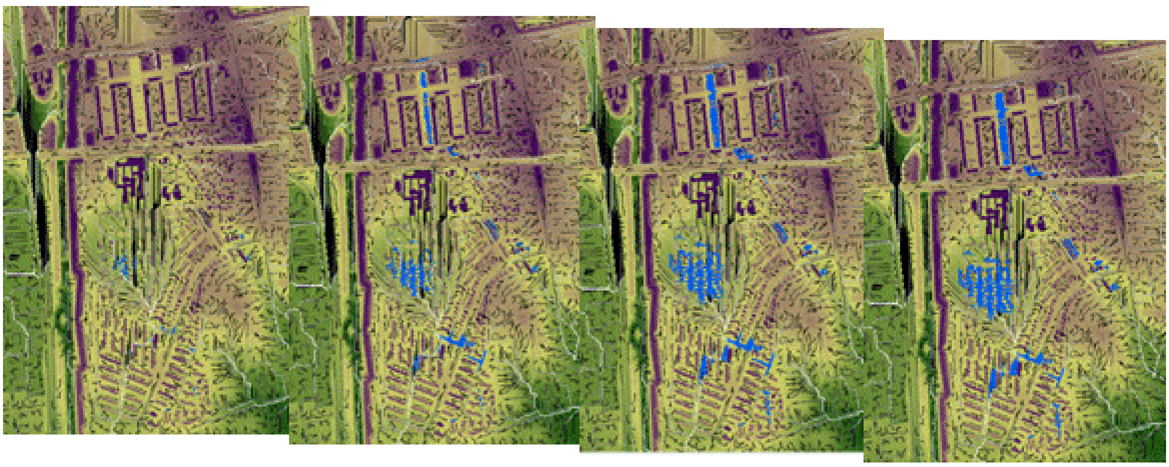

Figure 5: Presentation of flood results in Horsedammen for a 240 minutes CDS100 event. From left to right: Flood at minutes 111, 120, 130 and the peak on 150-160.

Result presentation

Results can be presented in 2D and 3D flood maps as time step dynamic video. Water level, flood depths, flood areas, velocities, volumes and water balance can be extracted from the model.
Figure 5 shows a presentation of dynamic flood map events of 100-year.

Results can be presented in in videos as 3D dynamic sequence on a basis of a time step. See Figure 6.

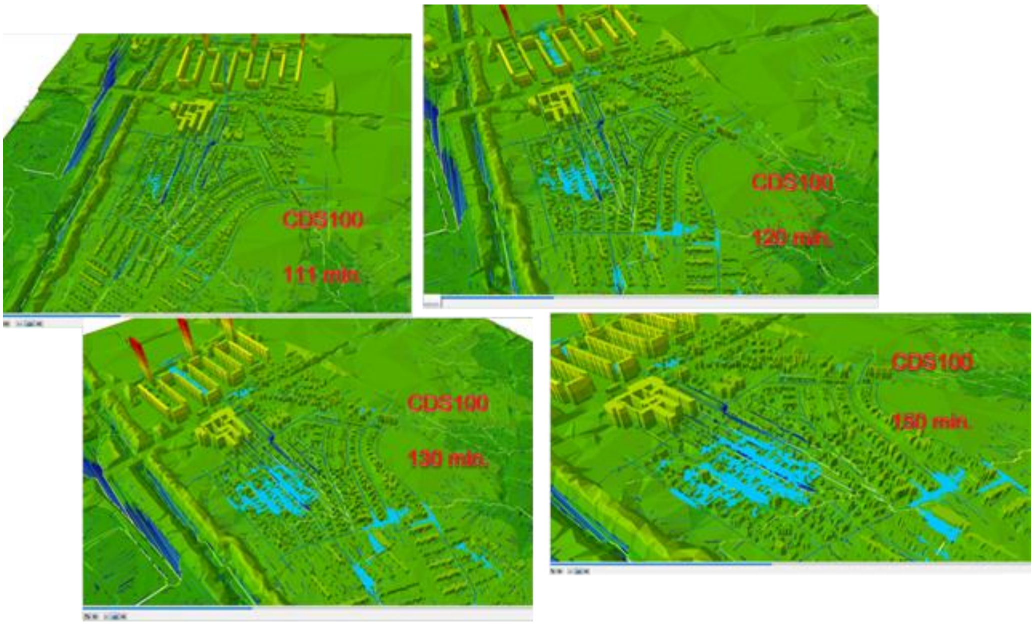

Figure 6: Dynamic presentation of result in 3D videos of the event CDS100.

Result publishing

Results can be published online on Google Earth or similar services, which give an immediate public access to the results.

Figure 7: Online publishing of results on Google Earth or similar services: A probability of different events

Figure 7 illustrates an example of publishing 3D dynamic events showing the maximum impact of 5-year event (Dark blue), 100-year event (Blue) and 1000-year event (Light blue).

Comparison with a traditional flood modelling

Figure 8 shows a comparison of a CDS100 event simulation result between a traditional flood model (2D-1D model coupling) (HOFOR, 2013-1) and flood model described in this paper (1D-1D model coupling). The flood map is almost the same although there is less flooding in the 2D-1D around the upstream pipelines and greater in the downstream pipelines. This can be explained by the following:

- No precipitation water enters directly to the 2D model without flowing first into the 1D model. In 2D-1D models precipitation and runoff flows into the 1D model and then due to lack of capacity in the 1D model, overflows water to the 2D model coupled on top of the 1D model. When there is capacity again in the 1D model, water flows back to the 1D model through the coupling nodes.

- The two models in the 1D-1D model are integrated into one flood model connected in all nodes to the catchments that receive precipitation input. The 1D-1D model in the method suggested by this paper, the precipitation and then runoff flows directly in the flood model in both the underground 1D model and the on top surface 1D model.

Figure 8: Comparison between a CDS100 in the traditional flood modelling (Left) and in the method suggested in this paper (Right).

- In this particular 2D-1D model (Figure 8-left) a great area of Brøndby Municipality was modelled and to overcome lack of hardware capacity, the model has been simplified. Pipes less than 400 mm diameter has been removed (HOFOR, 2013-2). See Figure 8-left. This resulted into less coupling nodes between 2D and 1D models. This has reduced water transfer from the 1D model to the 2D model and has forced water to flow downstream to pop up in the 2D model through other nodes. This gives a reduced flooding upstream and exaggerated one downstream.

- Terrain models has to be handled before modelling due to hydrological obstacles that can crash down any simulation attempt and in other cases lead to wrong results. Tunnels have to be opened, bridges have to be removed, piped streams have to be included in the model or terrain to be modified and terrain model has to be smoothed hydrologically (Several methods) in order to allow water to flow from cell to cell without having a hydrological jump between cells. There is a small tunnel in Figure 8, which has not been opened in the terrain model of the 2D-1D model in Figure 8-left. This could give a bit of different results.

Future perspective

Risk map

Mobile properties like cars, immobile properties like buildings, cultural sights, natural sights, etc. are the society assets that a flood event can damage. A risk assessment can help to determine a new design service level of drainage systems locally for every catchment. It can also help emergency civil forces to be prepared in case of flood impact.

Flood risk is a function of damage cost and probability of damage event.

Risk = D x P ------------- (eq1)

Where ***D*** is flood damage cost or relative damage, ***P*** is probability ***= 1/T*** and **T** is return period of flood event.

D depends on velocity of flooding water, depth, volume, Area and duration of flooding as factors that can affect significantly the degree of damage. It is necessary to create a relative damage value map of each factor.

By creating a map of properties value, a Risk map of damage cost or relative damage of each event can be created. This map and associated data will be the basis of climate change adaptation plans and actions.

Forecast

Fast flood simulations are necessary to provide flood data that a tactical emergency plan can rapidly be made to reduce losses. The 1D-1D flood modelling method suggested by this paper is much faster and can provide the needed speed for forecast modelling.

Variable runoff coefficient

It has been noticed that the runoff coefficient for surfaces of less than 1.0 increases due to longer rainfall duration and higher intensity. Taking this relationship into consideration can improve flood modelling results.

Conclusions

- Flood modelling method suggested by this paper is much faster, more detailed, can be more accurate than traditional 2D-1D flood modelling method and much less demanding on current hardware capacity. The greater the catchment area the more observable these advantages are.

- Water exchange between underground 1D model and the surface flood model in the method suggested by this paper is more efficient than the 2D-1D flood modelling method.

- Flood risk assessment can be reliable implementing flood modelling. Nodes/Manholes flood of just an underground 1D model or/and blue spot map is not sufficient to establish credible flood risk assessment.

- A flooding map cannot be credible without flood modelling by including the 1D model beneath surface in addition to the 1D or 2D model on surface.

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