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MODEL VALIDATION USING CROWD-SOURCED DATA FROM A LARGE PLUVIAL FLOOD

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On 28 June 2012, Newcastle upon Tyne, UK, was hit by a large convective storm delivering 45 mm of rain in less than two hours. Although not large on a world scale, the event had a big local impact. Widespread areas of the city were inundated and traffic was blocked in and around the city for about 6 hours. The following morning there was very small amount of visible evidence that the event happened. To gather data about the event through crowd sourcing Newcastle University organised and publicised a web page inviting public to upload their flood photographs, pin them on the map and optionally write a comment. In a more classical manner Newcastle City Council sent questionnaires to all the residents in the streets from which they received any reports about the flood and asked them to describe the flood in and around their properties. Data gathered from these sources were used to validate and calibrate the model of this event simulated using the hydrodynamic modelling software CityCAT developed at Newcastle University. CityCAT combines very accurate numerical methods with advanced software architecture providing both ease of use and accuracy in performance. Combination of those two main properties enables modelling of complex flow situations such as propagation of shocks and flows over initially dry areas, commonly in urban flash floods. Agreement between the gathered data and modelling results was satisfying at a majority of places when reduced rainfall input accounting for the drainage network was used. Crowd-sourced data, photographs and questionnaires, have proven to be effective tools in model calibration/validation.

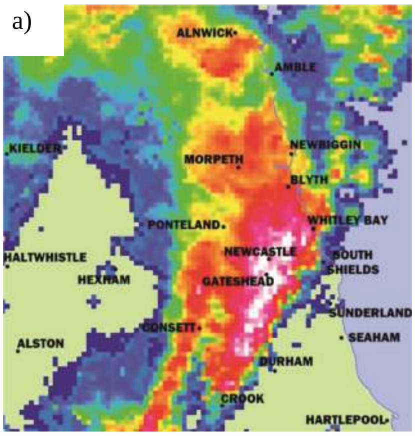
INTRODUCTION

The validation of a hydrodynamic model is a challenging task since water level measurements outside a river channel are not available. Moreover the spatial and temporal extent of a flood event in combination with a diverse and complex surface in urban areas demands both high quantitative and qualitative reference points. Nonetheless the validation of the model is crucial in order to increase confidence in modelling results and model predictive capabilities.

Recent technological developments enabled access to a range of new data sources for the validation and calibration of hydrodynamic models and the input data applied. Di Baldasssarre et al. (2009) compared model results against delineated flood inundation maps from satellite images. Terms such as *volunteered geographic information* (VGI) (Goodchild 2007) and crowed-sourcing (Goodchild & Glennon 2010) emerged through new hardware devices such as GPS in mobile phones and social media including facebook, twitter and youtube. In recent years studies using crowed-sourced data to investigate flood events can be found (Poser et al. 2009; McDougall 2011; McDougall, K., Temple-Watts 2012).

The purpose of this work is to compare crowd-sourced data against the results achieved by the newly developed hydrodynamic model CityCAT (Glenis et al, 2013). The event investigated is the pluvial flood that occurred on 28 June 2012 in Newcastle upon Tyne. At the rain gauging stations of Jesmond Dene and Whitley Bay the event exceeded the intensity of a 100 year return period event (Environment Agency, 2012b). The Disdrometer rain gauging station, owned by Newcastle University and situated on campus, recorded a maximum rainfall accumulation of 18.8 mm/15 min. The high intensity of the storm event can also be observed on the radar image in Figure 1a. The drainage network in the city of Newcastle could not cope with the rainfall amount resulting in many instances of surcharging such as the dramatic 'fountain' on Grey Street (Figure 1b).

a)



b)

Figure 1. (a) UKPP Hyrad radar image at 15:15, 28th June 2012 showing 15 min accumulation: white: 16 mm, pink: 8 mm, red: 4 mm (Environment Agency 2012b) and (b) surcharging manhole during the event

METHODS

The use of crowd-sourced data for the validation of calculated inundation depths required a number of data preparation steps. From the large number of pictures and comments received by Newcastle City Council and through the website launched by Newcastle University a selection of the most valuable images for the purpose of the validation was made. Referring to photographs, one of the main criteria was the quality of the picture (i.e. resolution) in order to deduce the water depth at the represented location. Furthermore, images including the exact time of their creation were preferable. For photographs without a known time of creation, it was estimated by comments available and the picture itself. Herein the visibility of rainfall within the photograph was used when deciding if it was taken during the rainfall event or afterwards.

The water depth at each study site was estimated by relating it to objects shown in the pictures such as car tiers, walls, traffic signs or other significant landmarks. Figure 2 shows the images used to estimate the inundation depth at observation points H and J. This work was supported by Newcastle University students working on their final projects (Gamble 2013; Stijne 2013). The locations of the objects were further used to delineate the coordinates of the observation points used in the simulations to obtain time-depth series. Finally twelve images representing twelve different locations within the Newcastle City Council area were selected (Figure 3).

An important step was the improvement of the DEM. This included the deletion of bridges, the opening of road underpasses and the editing of buildings which span over roads. Furthermore roads were incised by 0.125 m to represent curbs. These alterations were done on the 0.5x0.5 m DEM. Consequently the edited DEM was re-sampled to a 2x2 m and 4x4 m DEM.

The hydrodynamic simulations of the storm event were obtained using City Catchment Analysis Tool – CityCAT which is a 2D surface flow model based on the finite volume solution of the shallow water equations which enables accurate solution of flow over initially dry and complex urban topography. In addition, the Green-Ampt method, implemented within CityCAT allows the simulation of infiltration in green areas (Glenis et al. 2013).

The buildings and green areas were extracted from the OS MasterMap®, Tiles: NZ16, NZ17, NZ26, NZ27, updated June 2012, Ordnance Survey GB. Using Edina Digimap Service, http://edina.ac.uk/digimap, downloaded: June 2013. All simulations in this paper were performed using Manning coefficient of 0.02 for hard surfaces and 0.06 for green areas.

The disdrometer recorded rainfall at Newcastle University was applied uniformly over the whole study area as rainfall input. For each modelled domain four different simulations were run: the recorded and a reduced rainfall time series were applied to two different cell size resolutions (4x4 m and 2x2 m). Use of the reduced rainfall input accounts for the loss of water through the drainage network and it is the standard practice for models without drainage network. The reduced rainfall input was calculated by subtracting 12 mm/h from the recorded rainfall time series as recommended by (Environment Agency 2012a).

a) b)

Figure 2. Images of observation points H (a) and J (b) used for estimation of inundation depths

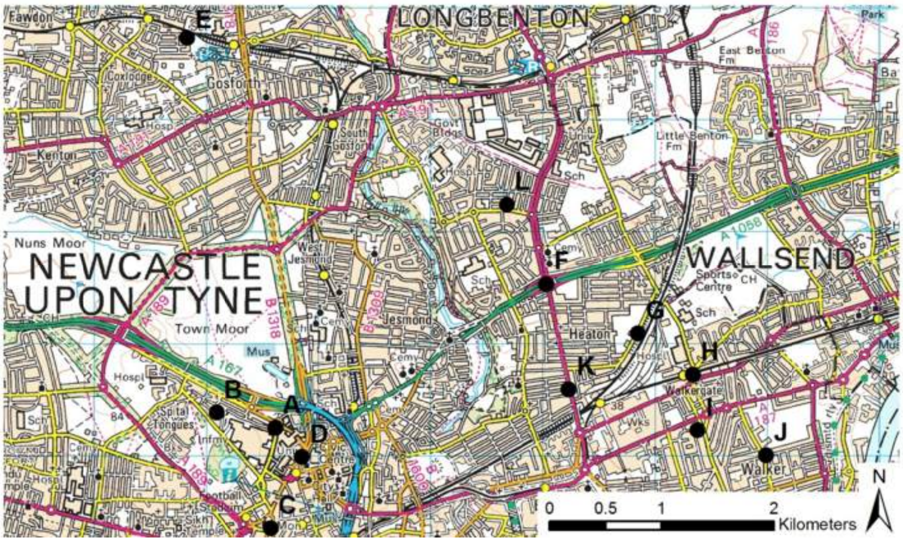


Figure 3. Location of the observation points within the Newcastle City Council area (Thematic 1:50,000 Ordnance Survey).

RESULTS

Figure 4 shows an example of a CityCAT simulation result after 192 min for the 2x2 m DEM using the recorded rainfall time series. The area in the top-right section of the figure represents the Newcastle University Campus area where points A, B, C and D are situated.

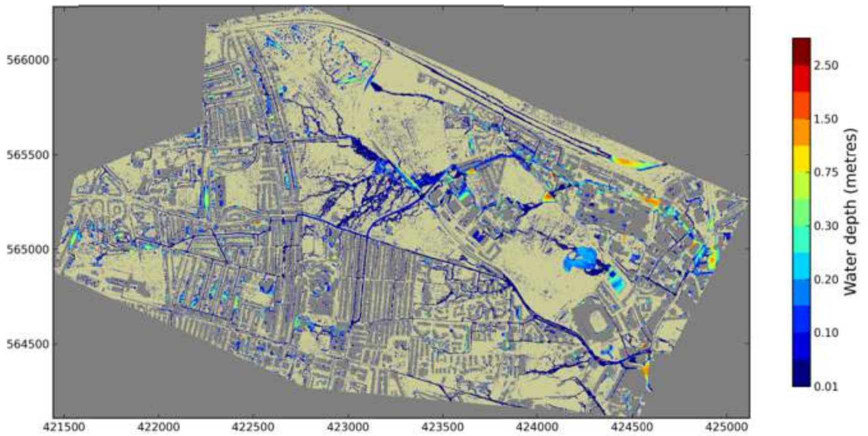


Figure 4. Simulation on 2 m DEM applying 100% rainfall: CityCAT result after a run time of 192 minutes including the Newcastle University Campus area (top-right)

Table 1 summarises the simulation results for the five observation points for which the exact time of observation was available. Simulation using the 4x4 m DEM and the recorded rainfall time series shows relatively large gap between simulated and observed inundation depths at points A and B. This was also the case for the 2x2 m DEM. Applying the reduced rainfall time series however delivered better results in terms of matching the observed flood depths for all points. Interestingly the improvements where greater for the simulations on the 4x4 m DEM compared to the 2x2 m DEM.

Table 1. Comparison of simulated and observed water depths at point with exact recording time – inundation depths in m

		4x4 m DEM		2x2 m DEM		difference	
Point	Observed depth	recorded rain	reduced rain	recorded rain	reduced rain	4x4 m	2x2 m
A	0.8	1.61 (+0.81)	0.68 (-0.12)	1.9 (+1.10)	1.11 (+0.31)	0.93	0.79
B	0.7	3.04 (+2.34)	2.76 (+2.06)	2.87 (+2.17)	2.68 (+1.98)	0.28	0.19
D	0.2	0.37 (+0.17)	0.15 (-0.05)	0.54 (+0.34)	0.48 (+0.28)	0.22	0.06
K	0.3	0.54 (+0.24)	0.43 (+0.13)	0.51 (+0.21)	0.48 (+0.18)	0.11	0.03
L	0.3	0.28 (-0.02)	0.25 (-0.05)	0.44 (+0.14)	0.38 (+0.08)	0.03	0.06

The graphs in Figure 5 and Figure 6 show the comparison between the observed and simulated inundation depths for the observation points G and I respectively. For none of these points the exact observation time was available. Based on the photographs however the conclusion was made that the image at point G was taken during the rainfall event whereas the image at point I after it.

Considering point G, the simulation using the 4x4 m DEM and the recorded rainfall input revealed a difference of approximately +0.3 m between the observed and the peak of the simulated inundation depth. Using the 2x2 m DEM and the recorded rainfall provided a slight improvement. A much greater correspondence can be observed when the reduced rainfall input time series was applied. These findings however are based on the comparison of the inundation depths towards the end of the rainfall event. Therefore they have to be considered carefully as the observed inundation depths could represent any point in time throughout the event.

Regarding point I, the simulated flood depths for the time after the event lies within a range of approximately ±0.15 m of the observed one. An underrepresantation of the observed flood depth was identfied for the simulation on the 4x4 m DEM and the reduced rainfall time series input only. Furthermore, the difference between the recorded and reduced rainfall time series applied is much greater for the 4x4 m DEM compared to the 2x2 m one. In comparison to point I, both runs on the 4x4m DEM are over-representing the observed depth at point J by approximately 0.2 m and 0.35 m respectively (graph not shown). The results from the 2x2 m DEM at this point are within ±0.1 m of the observed time-depth period (after the event).

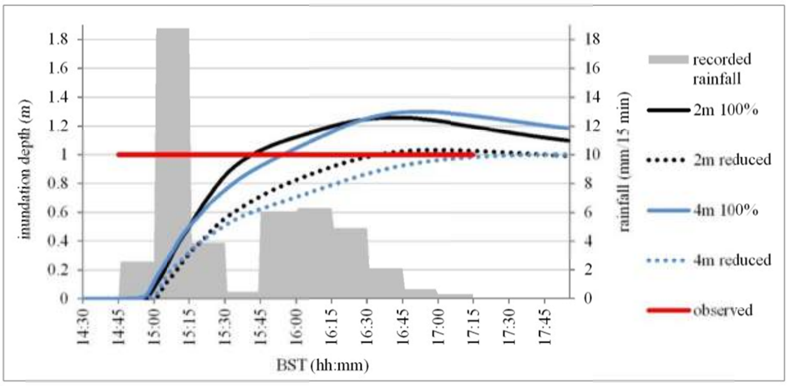


Figure 5. Comparison of simulated and observed inundation depths at point G

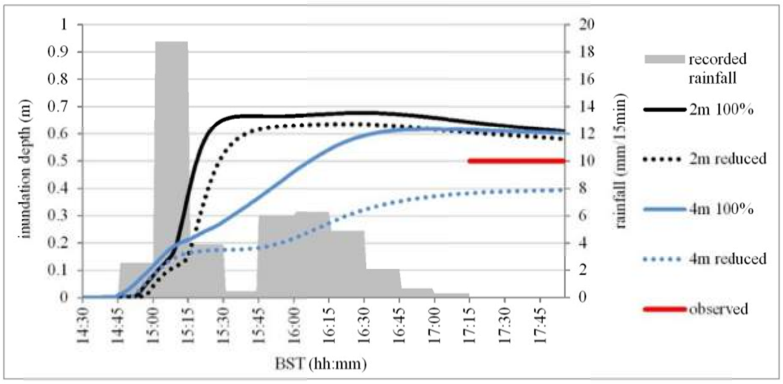


Figure 6. Comparison of simulated and observed inundation depths at point I

For observation points C, E, F and H no exact time of observation are available. However, it was assumed that all photographs at these points were taken after the rainfall event. The simulated water depths at these points revealed relatively large differences, compared to the observed ones (>1 m). Especially the application of the recorded rainfall time series resulted in an over-representation of the event simulated. Nonetheless the use of the reduced rainfall provided a closer match between the observed and simulated inundation depths. At point H for example, the difference range between -0.1 m and -0.5 m on the 4x4 m DEM and 0.55 and 0.44 on the 2x2 m DEM respectively.

DISCUSSION

The comparison between the observed and simulated inundation depths at the twelve investigated points revealed interesting results. At some points, the difference is relatively small compared to others. One major impact herein is thought to be caused by the location of the points as some represent road-underpasses whereas others are located on open streets. In case of latter ones the simulated water depths can be considered more accurate (A, D, G, I, J, K, L) since flow at these points allows a conveyance of the water throughout the simulations. Considering points at road underpasses however (F, H) water is accumulating over the whole period until the area is filled with water. Similar observations could be identified for points B and C which are located at local terrain depressions. At point E the exclusion of buildings through the building-hole (BH) method is causing an artificial dam effect leading to an over-representation of the calculated inundation depth.

The reduced rainfall input accounting for the drainage network delivered generally more reasonable results compared with the recorded rainfall time series. This together with the accumulation only effect at road-underpasses and local terrain depressions and sewer flooding from manholes, underlines the importance of accounting for the drainage network when modelling floods in urban areas.

Considering the two simulated DEM resolutions of 2x2 m and 4x4 m it could be identified that the reduced rainfall had a greater impact on the 4x4 m DEM. In terms of matching the observed inundation depths, the simulation results did not allow to identify a clear pattern whether to prefer the 2x2 m or 4x4 m DEM. However this does not imply that both DEM resolutions provided the same results or the same accuracy as interpolation from a finer DEM carries an associated loss of information (Fewtrell et al. 2011). At some points it might seem that coarser resolution provides better results due to interpolation. However, that might be circumstantial and in general use of finer resolution is preferable if feasible. Considering the results in Table 1, some of the simulated inundation depths on the 4x4 m DEM tend towards and under-representation of the observed depth. The effect of interpolation and the associated loss of terrain height needs to be taken into consideration herein. Associated with the different DEM resolution is the location of the observation points and their introduction in the model. Since the observation points in the model are implemented by coordinates located within a single cell, they represent 4 m² on a 2x2 m DEM and 16 m² on a 4x4 m DEM respectively.

Regarding the delineation of water depth from pictures and their application in a validation process, the exact time of the image taken proved to be vital. Not only does this provide a reference for the water depth, it also helps to identify processes that happened at the time the image was taken. An example of that is point A. The picture at this location shows a spilling sewer increasing the inundation depth at this point. The application of crowed-sourced data for the validation of flood inundation depths leads to the general discussion of quality assurance when dealing with such data (Heipke 2010; Goodchild & Li 2012).

Referring to the difference between the observed and simulated inundation depths the question to what extent the results of an urban flood modelling study can be considered as accurate can be raised (Apel et al. 2008). The complex urban environment of buildings, roads and drainage network can only be implemented in a 2D hydrodynamic model in a simplified way. In the course of this study the drainage network was introduced through a reduced rainfall input. Furthermore the previously discussed effect of DEM resolution and the location of the observation points contribute to this question. Nonetheless the comparison of simulated and observed inundation depths delivered satisfying results at certain locations. Further work needs to be done to improve the results on a broader scale. This includes the implementation of the drainage network within a future version of CityCAT. Moreover a spatially non-uniform rainfall and different surface roughness coefficients should be tested. The application of different building extraction algorithms and finer DEM resolution are additional options for improvement.

CONCLUSIONS

Crowed-sourced information of a pluvial flood on 28th June 2012 in Newcastle upon Tyne was applied for the validation process of the event simulated by the 2D hydrodynamic model CityCAT. Of twelve investigated locations some points showed a relatively good match between the observed and simulated inundation depths with differences of up to ±0.3 m. In contrast differences of >1 m could be identified for locations at road-underpasses, local terrain depressions and where the BH method causes an artificial dam effect. An improvement of the results could be observed through the application of the reduced rainfall (-12 mm/h) accounting for the drainage network at all locations. This highlights the necessity of introducing the drainage network within urban flood modelling studies. Considering the application of photographs and the inundation depth delineated the exact location and the time of the picture taken proofed to be vital for the validation process.

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