Progress of flood modelling in Newcastle

1 Aims and objectives

This work aims to estimate urban flooding due to extreme rainfall in different climate scenarios. The objectives include:

- To generate synthetic rainfall events with different return period in different climate scenarios.
- To calibrate and validate HiPIMS in urban area with infiltration and drainage capacity under consideration.
- To simulate floods with HiPIMS driven by synthetic rainfall events.

2 Study area and data

2.1 Domain map: Newcastle

The study area is in Newcastle city centre with its extent defined by the boundary of the postcode regions NE1, NE2, NE3, and NE4 (Figure 1).The flood model domain covers this region with a uniform grid on 2-m spatial resolution:

- Area: 34,879,468 m^2
- Grid: 4515×3057 grid with 8,719,867 computational cells with a 2-m resolution
- Location: Postcode region NE1-4, Newcastle upon Tyne, UK

In Newcastle upon Tyne, the average annual temperature is 8.5 °C. The rainfall here is around 655 mm per year. The average monthly rainfall in June and July here is around 55 and 60 mm, respectively.

2.2 Data source

The topography data of HiPIMS is generated based on the LiDAR Composite DSM downloaded from Digimap and rectified by removing bridges and overhead buildings that may block surface flows. Landcover data is used to estimate model parameters including friction, infiltration and drainage. The OS MasterMap Topography Layer contains features representing objects in the physical environment such as buildings, fields, road and tracks, fences, and letter boxes, which can provide urban landcover details in high resolution. Rainfall data for real events is acquired from UK Met Office C-band rainfall radar (NIMROD). Synthetic rainfall is estimated based on Flood Estimation Handbook (FEH). Observations of flood extent were collected from social media photos.

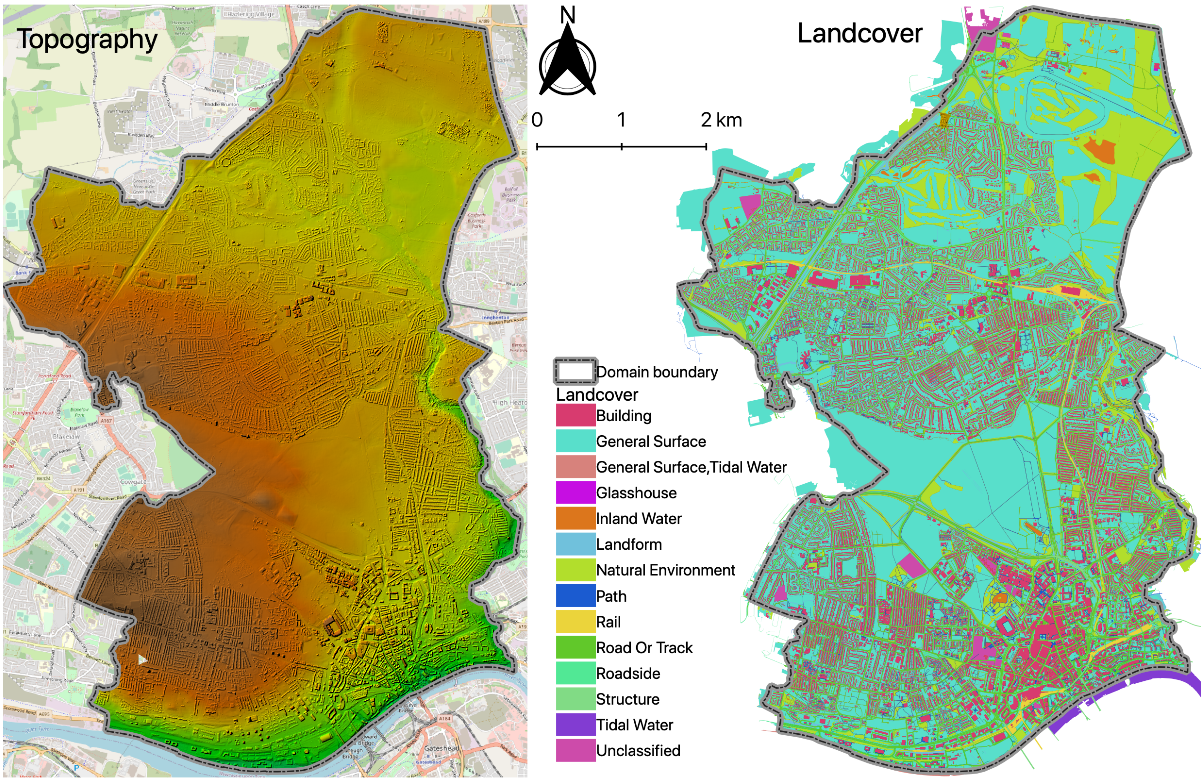


Figure 1: Domain map: Newcastle city centre postcode region NE1-4

3 HiPIMS Setup

3.1 An event to validate HiPIMS

HiPIMS is validated against a summer flash rainfall event happened on June 28, 2012, which caused amplified impact as it overlaid with the evening peak commute (see Figure 2). The major rainfall lasted around three hours from 14:00 to 17:00. Heavy rainfall can be observed in the south of the domain, which is the city centre of Newcastle, according to the NIMROD radar rainfall data (Figure 3).

3.2 Parameter estimation

There are three types of parameters needed to be estimated, i.e. Manning's coefficient for friction, infiltration rate, and drainage capacity. These parameters should be estimated based on the attributes and status of different landcover types. For Manning's coefficient, typical values used were 0.02 for tarmac roads or pavement, 0.03 for grassland areas, and 0.1 for heavy woodland and vegetation according to the suggestions from the Environment Agency [1]. It also suggested "national averaged" values for infiltration (30% loss of rainfall) and drainage parameters (12 mm/hr loss rate to all cells) in urban area. However, as high quality of landcover data is available in this study area, it is feasible to estimate the drainage parameter and the infiltration parameters more specifically according to different landcover types as summarised in Table 1. The drainage parameter is set based on an assumption that drainage networks are distributed underneath roads and tracks. The assumption for setting infiltration parameters is that infiltration on the landcover type of Land is significantly higher than it on the other types that the latter can be

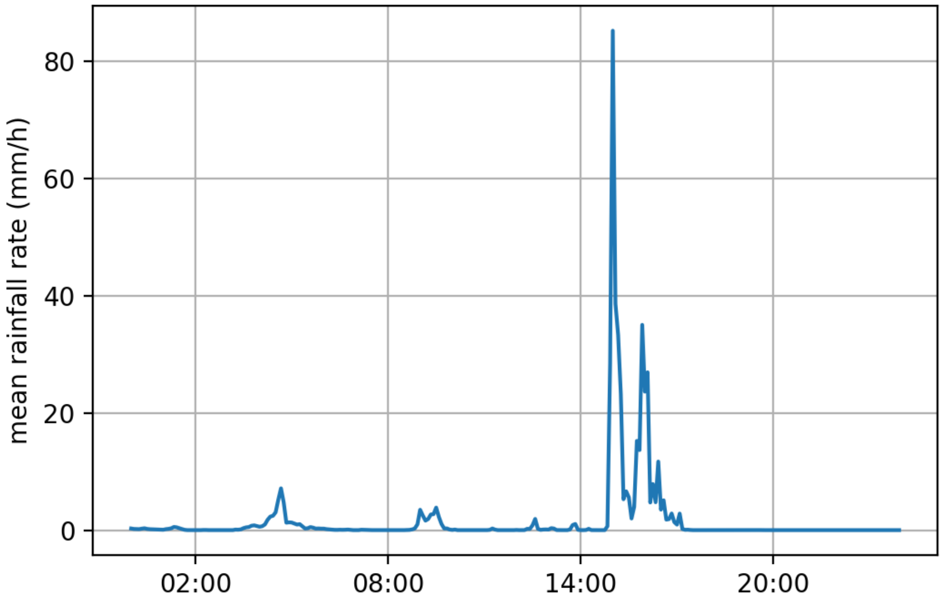
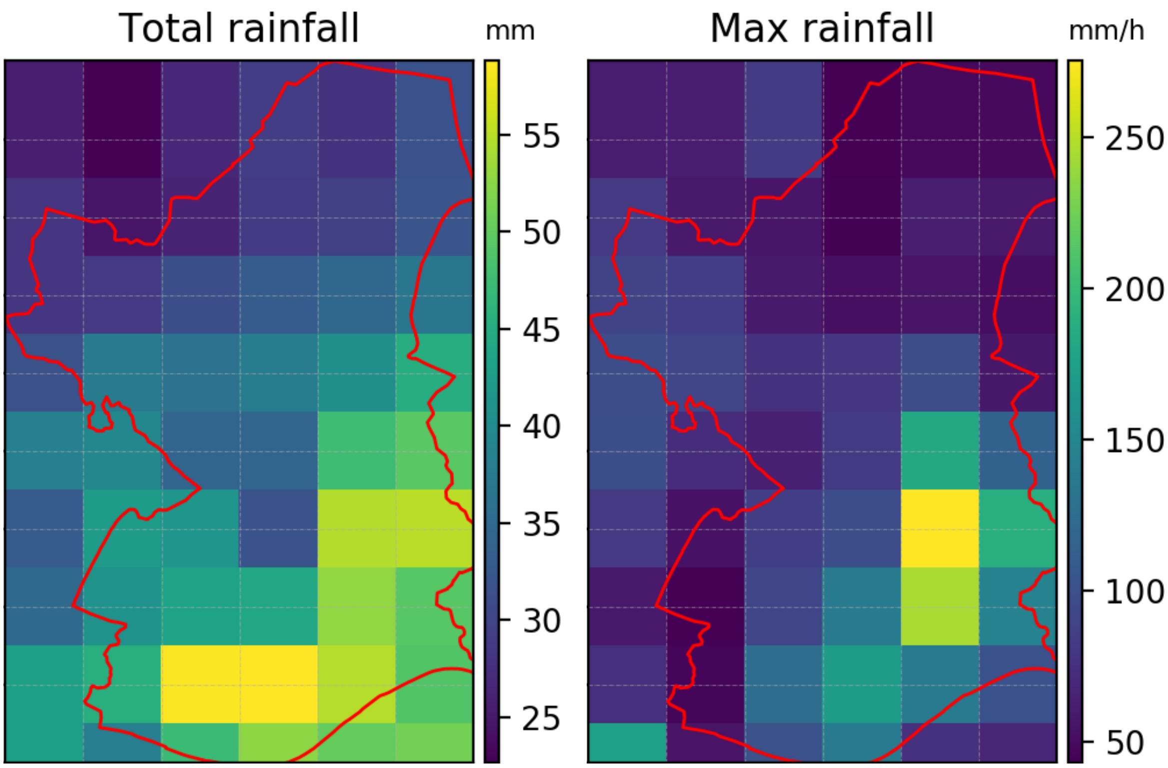


Figure 2: Average rainfall rate of cells within the model domain on Jun 28, 2012.



(a) Rainfall totals

(b) Maximum rainfall rate

Figure 3: One day accumulated and maximum rainfall on June 28, 2012.

treated as non-permeable.

In summary, the model parameterization strategy for flood simulation in Newcastle is as below:

• Friction is estimated based on two sets, one for Land (43.604%) and the other for other landcover types (56.396%)

• Infiltration is estimated based on two sets, permeable for Land 43.604%) and non-permeable for other landcover types (56.396%)

• The drainage parameter is set on cells of Road and track (8.073%).

Initial condition for this simulation is a dry DEM. The boundary is set as a transient open boundary along the domain outline.

Codes	Theme	Descriptions
10021, 10062	Buildings	Building, Glasshouse
10203	Land, Water	General Surface, Tidal Water, Foreshore
10167	Rail	Rail
10172	Road or Track	Road or Track
10183	Roadside	Roadside
10123, 10119	Path	Path, Path Step
10185, 10193, 10187	Structures	General, Pylon, Upper level of communication
10056, 10111, 10053, 10054, 10096, 10099, 10217	Land	General surface, natural environment, multi surface, step, landform slope, landform cliff, unclassified

Table 1: Landcover type and code.

3.3 Model validation against observations

According to previous sensitivity test, manning's coefficient has minimal impact on flood simulations for HiPIMS [2]. Therefore, manning's coefficient is set as 0.03 for Land and 0.02 for other types of landcover. Infiltration were estimated based on a sensitivity test result in Swale catchment, Yorkshire, which suggest a set of values for four parameters of infiltration according to the Green-Ampt Equation over permeable land. For drainage capacity, no sewer or a very high sewer parameter (over 50 mm/hr) will result in an either overestimated or underestimated inundation, according to our sensitivity test ranging from 0 to 100 mm/hr. It suggests that the simulation results are sensitive to the sewer parameter and the best estimation of drainage capacity is 30 mm/hr for this case. The inundation map is show in Figure 4. The places with photo-confirmed flooding are found flooded in the simulated inundation map, although we don't have enough photos to confirm all of the flooded locations.

The roundabout on the north end of Queen Victoria Road is a critical junction of two busy roads connecting the north university campus to outlets of the city centre. Serval photos were posted on Twitter showing flood inundation in this area. One photo is compared with the simulated inundation map overlaid by the Google Earth 3D view (see Figure 5). The simulated flooded extent in Figure 5(b) looks similar to the flooding observed from Figure 5(a).

Another position also with photo confirmed flooding is shown in Figure 6, which is on an artery road (A167(M) Central Motorway) of Newcastle city centre. The simulated

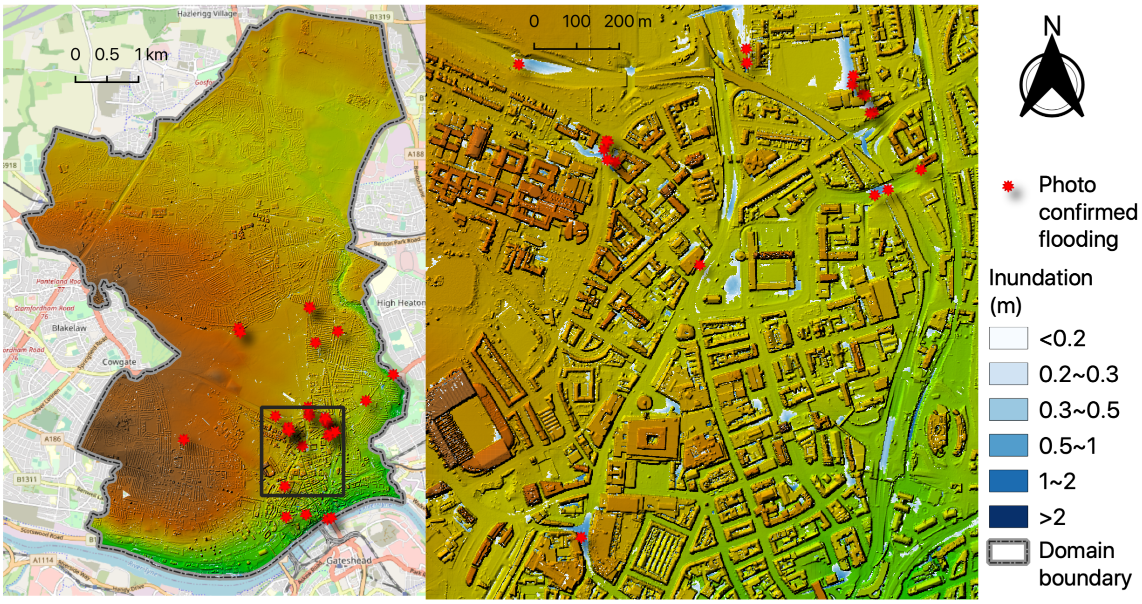
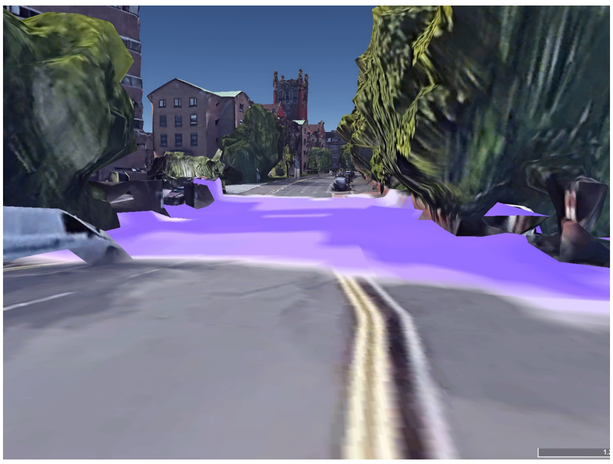


Figure 4: Simulated inundation map for the event on June 28, 2012.

flood inundation can also agree reasonably well with photo observations in the same hour. It can be observed that the road lanes towards both directions are completely flooded at an evening peak hour, which resulted in serious traffic congestion (long queue of vehicles in Figure 6(a)).

In general, although quantitative observations of flood depth and extent are not available for this event, we can conclude that HiPIMS is able to reproduce pluvial flood events in Newcastle city centre with the selected spatial resolution and parameters.

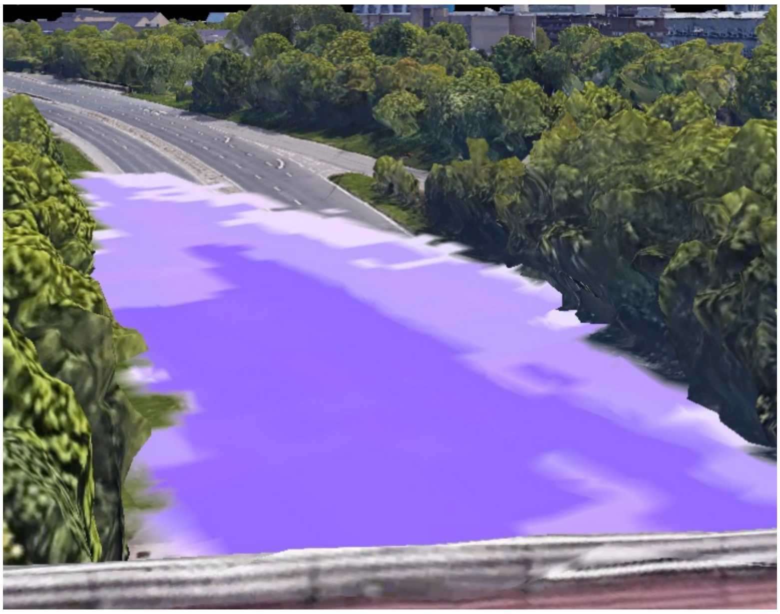
(a) Photo taken on 28-Jun-2012 16:27



(b) Simulated flood on 28-Jun-2012 16:30

Figure 5: Compare observed and simulated flood inundation on Queen Victoria Road next to RVI.

(a) Photo taken on a bridge over A167 Road at 17:36



(b) Simulated flood from the same view of (a) at 17:15

(c) Simulated flood around the north of Newcastle University campus at 17:15

Figure 6: Compare observed and simulated flood inundation on A167.

4 Simulations with synthetic rainfall events

Several rainfall events are designed based on Flood Estimation Handbook at different return periods (2, 10, and 30 years) and two climate scenarios (current and the 70-year future projection). The one day and one hour rainfall rate is shown in Figure 7. One-hour events have higher peak rainfall rates compared with one-day events at the same return period and climate scenario.

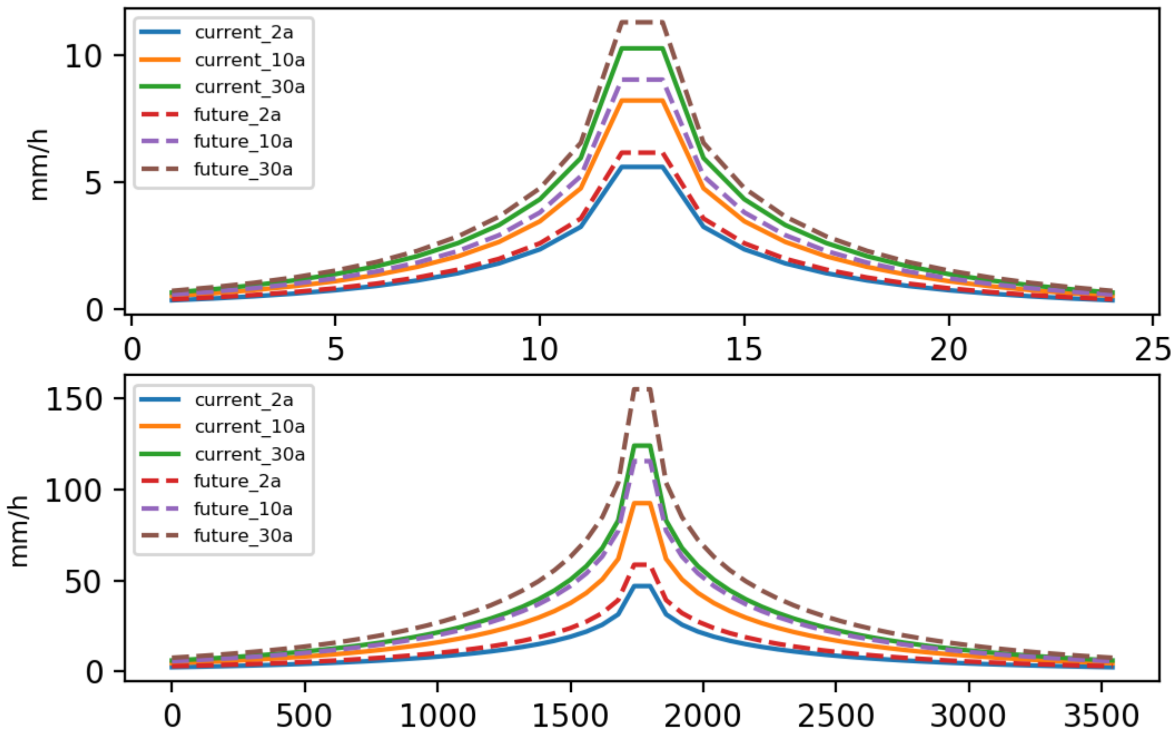


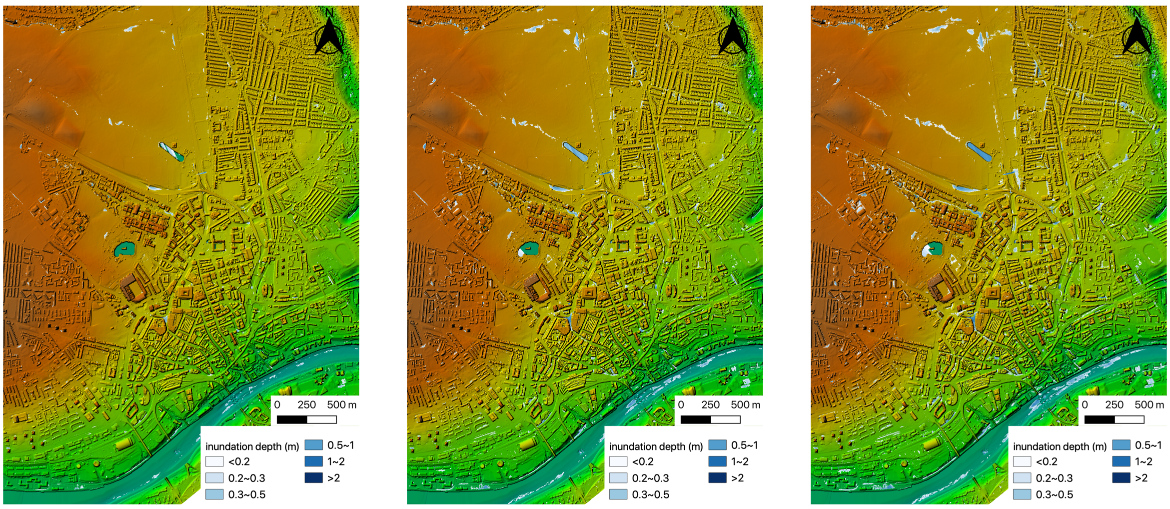
Figure 7: Designed rainfall events. The upper panel shows one-day events with the x-axis indicating hours. The bottom panel shows one-hour events with the x-axis indicating seconds

Using the model parameters estimated in Section 3, twelve simulations have been done with HiPIMS driven by the designed rainfall events. Some of the results of one-hour events are shown in Figure 8.

References

[1] Environment Agency (2019). What is the updated Flood Map for SurfaceWater?. Technical report, version 2.0. Environment Agency, Bristol, UK.

[2] Smith, L. S. (2018). Computational methods for and applications of high-performance computing in flood simulation. Newcastle University. Retrieved from http://theses.ncl.ac.uk:8080/jspui/handle/10443/4277.



(a) 2-year RP, current (b) 10-year RP, current (c) 30-year RP, current

Figure 8: Compare observed and simulated flood inundation on A167.