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Numerical simulation of the coastal flooding in urban centres with underground spaces

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Abstract

Across coastal urban centres, underground spaces such as storage areas, transportation corridors, basement car parks, public facilities, retail & office and private spaces present a priority risk during flood events with respect to timely evacuation. However, these underground spaces are commonly not considered in urban flood prediction models, in many cases because the location and geometry of these underground spaces are often poorly known. In order to improve urban flood prediction models, various identified underground spaces have been included into the urban flood simulation presented in this paper. Here, the Software MIKE+ is adopted to simulate the coastal flood scenarios for the urban centre of the city of Belfast, Northern Ireland. In the simulation, unstructured triangular grids are used. Based on the numerical simulation, urban flood depth and flooding rates into the underground spaces can be obtained. Based on the comparison of simulated urban flood scenarios with and without underground spaces, the impact of underground spaces on street-level inundation and flood routing is evaluated. It can be observed that the inclusion of underground space has a significant impact on the flood routing process. Moreover, the underground spaces also present priority risk areas during flood events with respect to timely evacuation and to this end, underground spaces cannot be ignored in real urban flood prediction. The presented study can be used to increase communities' emergency preparedness and flood resilience.

Keywords: Coastal flooding; Numerical simulation; Urban centre with underground space; Flood routing process.

1. INTRODUCTION

The risk of coastal flooding is growing annually and is threatening people living in coastal areas. Previous studies have evaluated urban flood routing by numerical simulation (Henonin et al., 2015; Cui et al., 2019; Xing et al., 2019). However, underground spaces are not included in most of the previous research. In recent years, the importance of underground spaces has been increasingly recognized in urban flood modelling as they represent priority risk areas during flood events (Wu et al., 2013; Son et al., 2016; Kim et al., 2018; Shin et al., 2021). In the present study, coastal flood simulations are carried out for the city centre of Belfast, Northern Ireland. In particular, underground spaces are included in the models and their effects are discussed in detail.

2. SIMULATION SETUP

In the present study, the software MIKE+ Urban Flooding (DHI) is used to simulate the coastal flood routing in one part of city centre in Belfast. The simulated area is about 63,998 m² as shown in Fig. 1(a). The simulated area includes eight (8) Underground Spaces (US) and their locations as well as their respective volumes are provided in Fig. 1(b) and Table 1. For the computation, unstructured grids and 7053 nodes are used. The location, volume and ingress points for these underground spaces have been derived from mobile high-resolution LiDAR scanning of the urban streetscape (UrbanARK 2022). In order to represent the ingress points, manholes are introduced at these location in simulation. Moreover, the underground spaces are represented by basins at their respective locations and volumes. Besides, the time step for networks is 0.1s while the 2D overland time step is from 0.01s to 0.1s. In addition, the Max CFL is 0.8. In order to study the effect of underground spaces on flood routing and inundation, simulations with and without underground spaces are carried out and six cases are evaluated as shown in Table 2. The simulated durations of flood routing for all cases are four (4) hours. The other computational parameters are shown in Table 2. For the Cases 1 and 3, the inlet boundaries at northern and eastern sides are used respectively because the previous regional flood simulations indicate coastal flooding to originate along Belfast Harbour/ Lagan River which is in the Northeast of the model domain. Besides, the inlet discharge of 1m³/s is assumed.

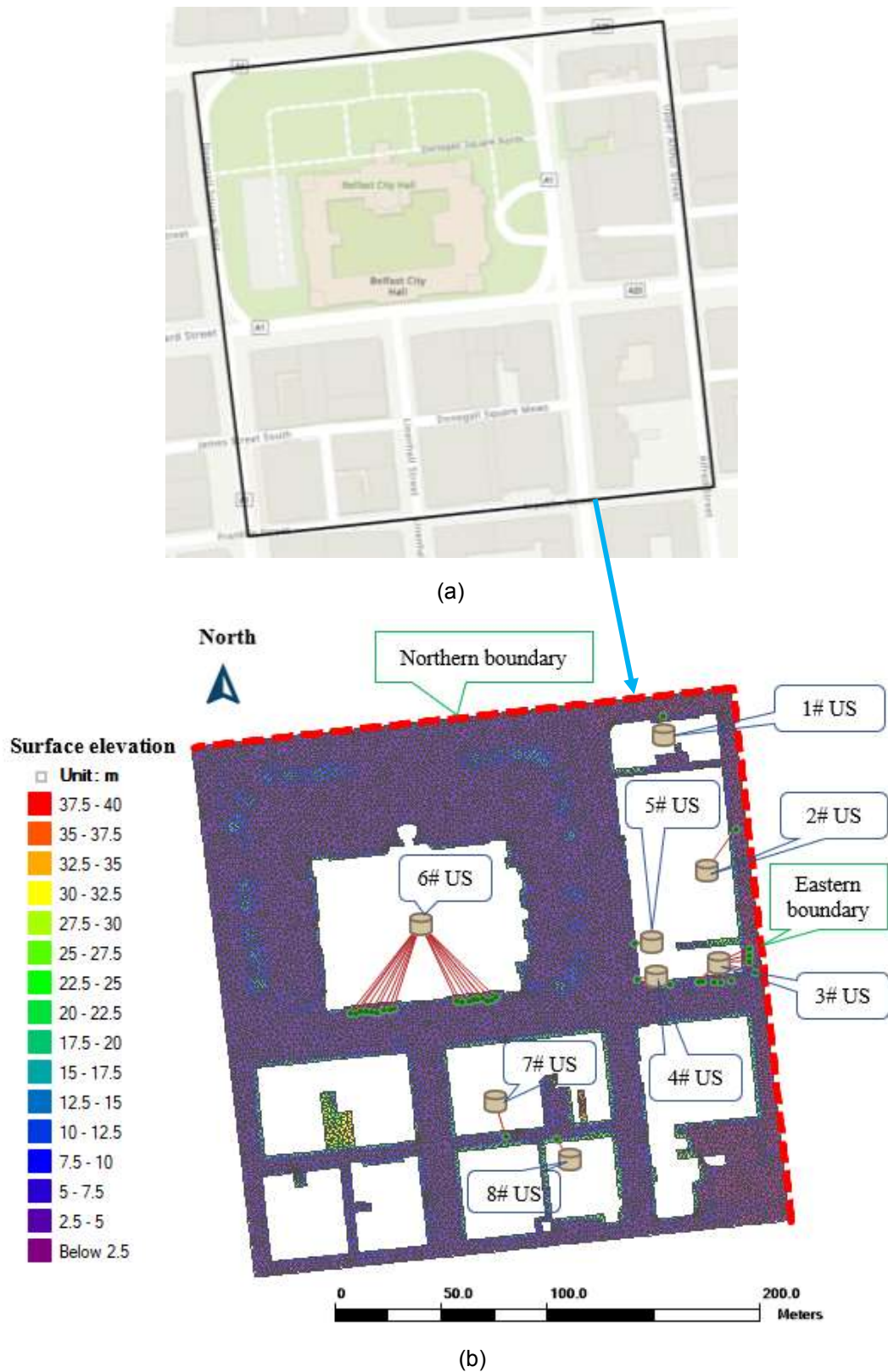


Figure 1. The simulated area of Belfast City Centre (a) and the respective simulated model layout (b).

Table 1. The volumes of Underground Spaces (US) and inflow discharges inside US in simulations.

Underground Space No	Total Volume (m ³)	Inflow discharge in Case 2 (m ³)	Inflow discharge in Case 4 (m ³)	Inflow discharge in Case 6 (m ³)
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1	602.3	70.6	0	602.3
2	4716.2	4716.2	4716.2	4716.2
3	1177.3	0	113.1	193.9
4	651.5	0	0	0
5	326.0	0	0	0
6	12371.9	0	0	0
7	2818.4	0	0	0
8	2709.3	0	0	0

Table 2. Computational parameters used.

Case No	Inlet boundary type and specified discharge	Other boundaries	Including the underground space
1	1 m ³ /s for northern inlet	Closed	No
2	1 m ³ /s for northern inlet	Closed	Yes
3	1 m ³ /s for eastern inlet	Closed	No
4	1 m ³ /s for eastern inlet	Closed	Yes
5	1 m ³ /s for northern and eastern inlets respectively	Closed	No
6	1 m ³ /s for northern and eastern inlets respectively	Closed	Yes

3. DISCUSSION

The simulated water depths for Cases 1-6 are displayed in Figs. 2-4. It can be seen that the differences between the results with and without underground spaces are obvious. For example, the flood waters only occupy small parts for the model domain for cases that include the underground spaces (cases 2,4 and 6) while it arrives at most parts of the computational area for the cases without the underground spaces (cases 1,3 and 5). The reason is that the water flows into the underground spaces for Cases 2, 4 and 6. The inflow discharges into individual underground spaces are shown in Table 1. It is clear that water flows into the underground spaces of US1-3#. Moreover, the underground space of 2# is full of water for Cases 2, 4 and 6. On the other hand, the underground spaces of 4-8# remain empty because the water has not yet reached these locations in simulated period. Overall, it changes evidently the simulated results by including the underground spaces. Therefore, the underground spaces can not be ignored in urban flooding simulation.

4. CONCLUSIONS

In this paper, coastal flood routing and inundation in one part of Belfast city centre was simulated using MIKE+ Urban Flooding. Six (6) cases with and without including underground spaces were simulated. The flood routing duration was four (4) hours. Based on the simulation, the flood routing process and the discharge flowing into the underground spaces were obtained. It is found that including the underground spaces in simulation clearly changes the flood routing process. Underground Space of 2# is consistently flooded across all simulated cases, while underground spaces of 4-8# remain unflooded because the flood has not yet reached these locations. It is anticipated that that future simulations over longer simulation periods will show even stronger differences between modelled cases with and without including underground spaces. Overall, the results indicate that including the location, volumes and ingress points to urban underground spaces may provide insights into predicting accurately urban flood routing processes and valuable information for emergency planners with regard to the timeliness of evacuation measures for individual underground spaces and the accessibility of above ground emergency routes.

5. ACKNOWLEDGEMENTS

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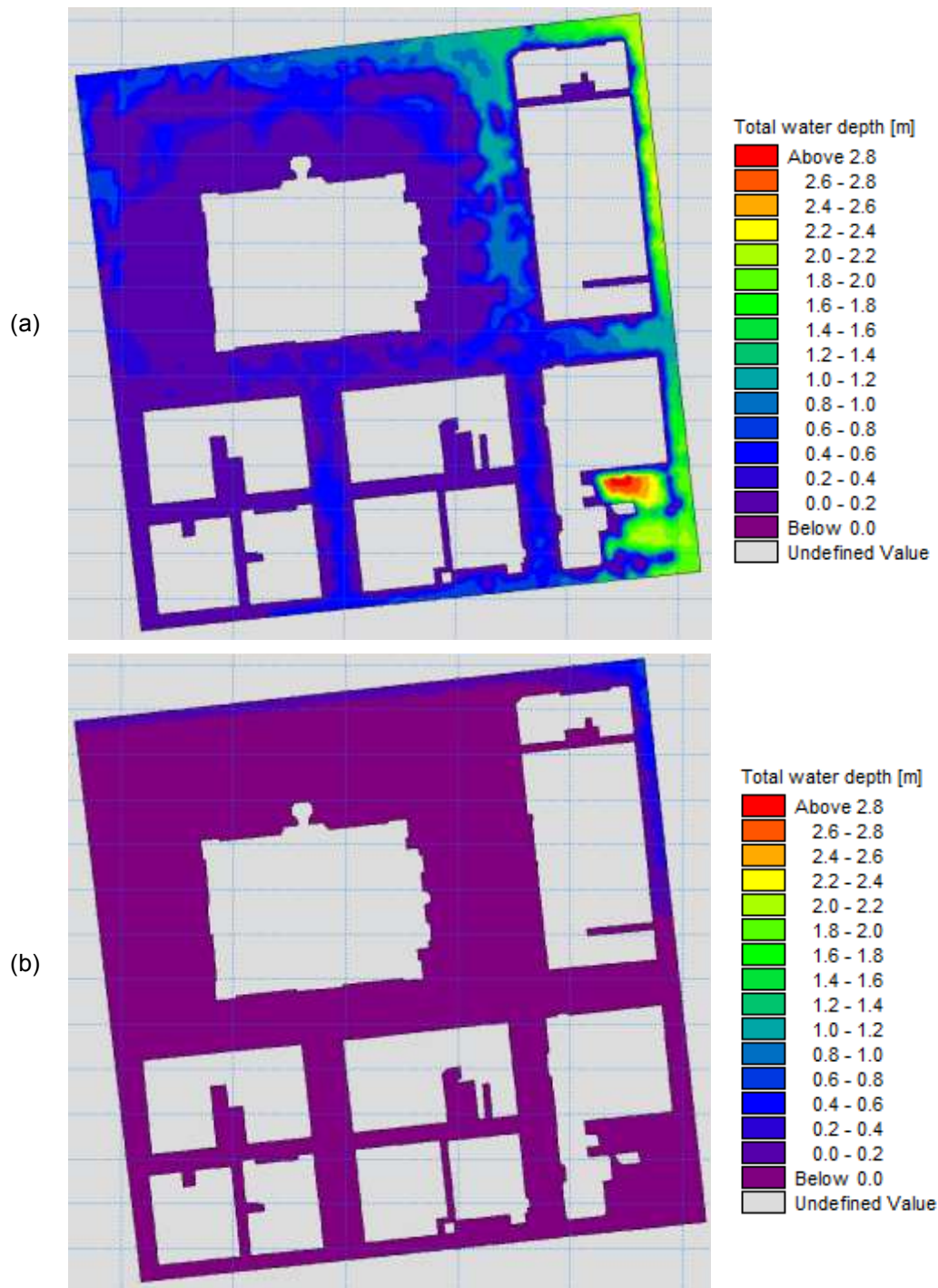


Figure 2. Flood routing and water depth for Case 1 (a) and Case 2 (b).

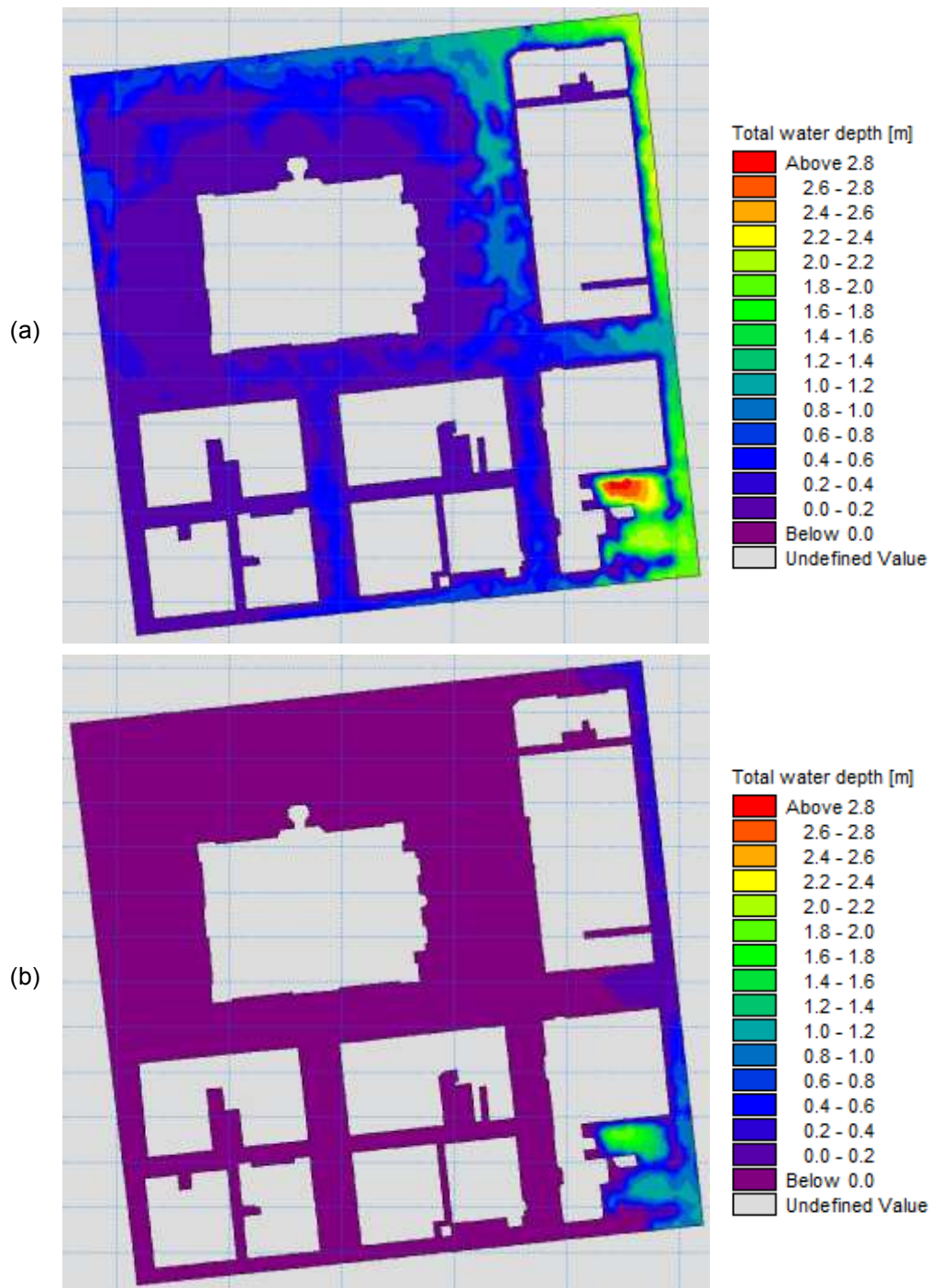


Figure 3. Flood routing and water depth for Case 3 (a) and Case 4 (b).

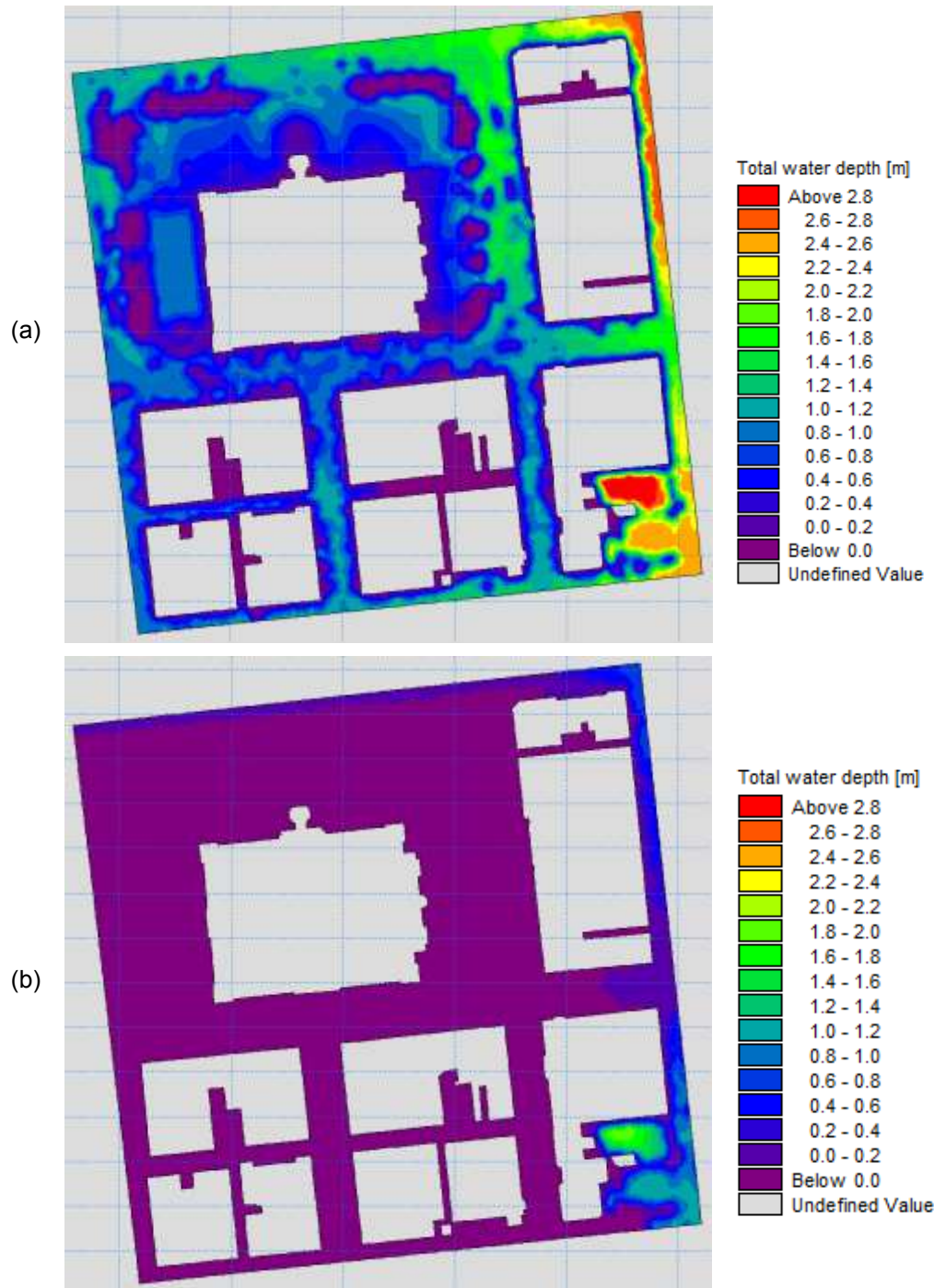


Figure 4. Flood routing and water depth in Case 5 (a) and Case 6 (b).

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