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Opinion

Modelling and Forecasting Processes in Urban Environments: Particularly in the UK and China

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Abstract: The modelling and forecasting of the impact of extreme rainfall events in urban environments is becoming increasingly challenging as historical tools have been found to need refinement to acquire improved flood risk predictions for river and coastal basins. This article discusses some of the key challenges faced by flood modellers addressing the growing effects of climate change, with the key findings reported in this article being that (i) improved flood models are needed for accurately predicting extreme flood elevations and inundation extents through the inclusion of shock-capturing algorithms; (ii) improved flood hazard risk formulae are need to predict the stability and vulnerability of vehicles and people in extreme flood events; and (iii) assessing the impact of floods on water quality in river and coastal basins can only be delivered accurately when storm events are modelled holistically from the source to sea (S2S), with a systems-based approach to dynamically integrate surface and sub-surface flows etc.

Keywords: extreme floods; flood modelling; shock capturing; stability in floods; vehicles and people; water quality; source to sea; systems approach

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1. Introduction

Over the past half century, there have been growing international concerns about climate change and the impacts on increasing flood risk, water quality and ecological status, particularly regarding our understanding, prediction and management of the impacts of flooding and pollution in urban environments. Over the past 40 years, the writer has been involved in a great deal of related research and applied modelling studies in this field and some of the key lessons learnt and his views on future challenges based on his experience are given below.

2. Modelling Extreme Flood Events

One of the earliest experiences of lessons learnt was in the 2D modelling and prediction of flood elevation levels and inundation extent in river basins experiencing extreme rainfall events. In recent years, the UK, along with many other countries, has experienced more extreme rainfall events, which have led to severe flooding in river basins, particularly with steep catchments. Such an event occurred in the UK in 2004, in the small coastal town of Boscastle, southwest England. About 200 mm of rain fell in 5 h, with a 1 in 400 predicted return period. Extensive damage occurred to properties, bridges, etc., and it was one of the best recorded extreme flood events in the UK, with trans- and super-critical flows. When using a traditional and widely used 2D ADI (Alternating Direction Implicit) solver, severe oscillations occurred in the numerical solution and the only way in which a stable solution could be obtained was to increase the bed friction to an artificially high level. This then begged the question of how much of the friction was dissipating the numerical oscillations and how much of it was dissipating the energy of the flow. Through numerical experiments at the time, it was found that the only means of acquiring a stable numerical solution, without artificially increasing the bed friction, was to develop a shock-capturing algorithm, in this case based on the TVD (Total Variation Diminishing) method [1]. However, there are a number of alternative higher order schemes that have been used for similar studies in recent years to represent shock type flows, such as the Godunov scheme [2,3]. When this model was applied and tested, the predicted peak water levels in the river basin were 1–2 m above those predicted using the traditional ADI scheme, and when compared against over 30 peak wrack marks on buildings, etc., the TVD scheme was accurate to within over 90% [4]. These studies have therefore shown that for extreme rainfall events and where trans-critical river flows occur during floods, shock-capturing algorithms, or similar, are needed to predict the peak flood levels accurately.

3. Modelling the Stability of Vehicles and People in Floods

Another lesson learnt from the Boscastle study was that over 70 vehicles were picked up from a car park upstream of the village and floated downstream to the sea. However, one vehicle picked up became stuck in the small bridge and caused a rapid increase in the flood elevations upstream, thereby exacerbating the impacts of the floods. The question then arose "how do vehicles (and people) become unstable in floods and how do they move?" Research showed that there was little previous work undertaken in this field and a series of analytical, experimental and modelling studies were commenced at Cardiff University (UK) and Wuhan University (China), along with similar studies undertaken in many other countries, such as Milanesi et al. [5]. The on-going research between the two universities has led to a series of papers on the subject and new formulae have been developed, and included in flood models, to predict the incipient motion of vehicles and people in floods. Furthermore, new flood hazard risk formulae have been developed based on the hydrodynamic force on a body, i.e., related to the depth x velocity squared, rather than the depth x velocity, as used by many government and regional organisations for establishing hazard risk (including in the UK). The latest studies on the flood risk assessment of people and vehicles are given in Dong et al. [6] and more recently for studies in China [7], where the need for dynamic modelling between the urban surface and sewer system is shown to be essential for predicting accurate flood risk assessments. These studies have shown that (i) following the recent Valencia floods [8], where many cars moved and blocked flood pathways, further work is needed in developing refined formulae for the movement and interaction between vehicles and people safety in extreme flood events; (ii) urban surface and sewer process models need to be dynamically integrated for accurate flood level predictions; and (iii) flood hazard risk formulae and maps need to be based on the fluid flow per unit width x velocity and not just on the fluid flow per unit width (i.e., depth x velocity).

4. Modelling Water Quality

In recent years, there has been growing concern about increased storm water overflows in rivers and coastal waters, primarily assumed to be associated with sewage discharges from wastewater treatment works [9]. The main concerns have been potential health risks to bathers, as well as the ecological status of rivers. The increasing frequency of storm water overflows is associated with the historical design of urban drainage systems in many countries (e.g., the UK), where most sewer networks combine both urban surface runoff and domestic sewage. The cost of splitting the relatively clean urban runoff from the domestic sewage system is enormous for most countries, such as the UK, and only new developments tend to have partial separate systems. Historically, and even today, most—if not all—of the causes of river and coastal pollution are attributed by the public to be caused primarily by water companies. However, over a period of nearly two decades, the writer and colleagues have been involved in a series of studies to investigate the source of high faecal bacteria levels along the Ribble River Basin and the Fylde Coast in the UK [10]. As the models and field data acquisition were extended further up the river basin, and into the sub-catchments, it became increasingly evident that diffuse and point source agricultural inputs also had a significant impact on the river and coastal basin water quality and ecological status, particularly during and after extreme rainfall events. Furthermore, through the processes of adsorption and desorption, during and after a storm event, it was also established that sediment transport was an important vector of faecal bacteria through the water course, as well as the flow [11]. These studies have therefore shown that in modelling flood and water quality processes and predicting the impacts in river and coastal basins, it is necessary to (i) model and acquire data from the source to the sea (S2S) to establish the impact of different pollutant sources on the downstream receiving waters and (ii) include sediment transport and the processes of adsorption and desorption to determine the immediate and subsequent bacteria levels during and after a storm event.

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