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Editorial

Nigel Wright BSc, PhD, CEng, FASCE, FHEA, FICE
Honorary Editor and Chairman, Editorial Advisory Panel

1. Introduction

Welcome to the first of two themed issues on flood modelling, in which a range of state-of-the-art papers is presented. The previous themed issue on this topic (based on work in the Flood Risk Modelling Research Consortium (FRMRC) (EPSRC, 2012; Pender, 2006)) was in 2006 (Falconer, 2006) and the papers in that edition are among the most read and cited from the journal in the intervening period. This interest in the issues surrounding flood modelling is also reflected through the popularity of papers in the regular journal editions (Horritt *et al.*, 2010; Hunter *et al.*, 2008; Wang *et al.*, 2010). Clearly there is significant interest in flood modelling among both researchers and practitioners, so it is a prime topic as we continue our endeavours to produce a journal of interest to both audiences. The call for abstracts for this edition generated significant interest and the editorial advisory panel decided that it would be best to have two volumes rather than to reject a large number of interesting abstracts.

Flood modelling is widely used and is an integral part of engineering consultancy on flood risk management in the UK and across the globe. In many ways its use is mature compared with the early work of the 1970s and 1980s, but there is still a need to improve the usefulness of the results and to reduce the time and money taken to produce them. This need lies behind the papers in this themed issue. Before introducing these papers, I was asked to reflect more generally on the issues currently pertinent to flood modelling.

2. How reliable are our computer models?

In considering any modelling in the natural environment it is useful to consider the statement by George Box (Box and Draper, 1987), 'Essentially, all models are wrong… some are useful.' This statement can prompt strong reactions, but it conveys that any model implemented on a computer is only a representation of reality: it is not reality itself. First of all, in considering the physical situation, the mathematical description of it may neglect important physical phenomena. Second, when the mathematical equations are taken and made amenable to computation, further approximations may be introduced. However, despite these errors, models are useful in developing our understanding of reality and thereby assisting us and decision-makers. Professor Keith Beven has expressed this in a more complex, but clearly more rigorous, statement (Beven, 2002), 'a formal environmental model can only ever be an approximation to the perceptual model of the complex processes governing the response to some forcing'.

The acceptance of the fact that a model is just a model and not reality leads to the conclusion that the purpose of a model is not to represent reality exactly; in other words the model does not solve the real-world problem. The reason we use models is to increase our understanding of what is happening in reality, so the model is an important tool for the researcher or consultant, but it does not replace their skill and judgement. The outputs of the model require critical analysis and interpretation by the researcher or consultant and it is this analysis and interpretation that a client is paying for rather than just a set of print-outs from the model. This reminds me of the sketch in which a surly bank employee repeatedly responds to a customer query by bashing away at the keyboard only to give the response 'computer says "no"' with no attempt to interpret or explain the decision. Hopefully, consultants following this example would not last long.

This discussion leads to a cautionary note on calibration in models (Pappenberger *et al.*, 2007; Werner *et al.*, 2005). Owing to the approximations mentioned, there is a need to adjust parameters in a model to obtain the most appropriate values. However, this must be done with care in order to ensure that calibration of a friction parameter, for example, is not used to compensate for an effect that is not related to friction. This can lead to unphysical values of parameters that go beyond the range of validity.

3. A brief review

Much of the software used today can be traced back to computer programs developed in the 1970s and in some cases the fundamental algorithms have changed little. However, in the past two decades there has been a significant change in the sophistication of the user interface and the availability of high-quality data covering wide areas at high density. The user interface has been driven by advances in operating systems and by the development of geographical information systems. River modelling software no longer requires knowledge of the underlying operating system or a programming language. The simplicity that this has brought is sometimes outweighed by the large range of settings that come with increased sophistication and wide applicability.

Remotely sensed data have transformed the modelling of inundation over rural and urban floodplains (Bates, 2012), which is now a long way from the 1990s when cross-sections were still taken from a paper map using a ruler and pencil. In a useful and timely review, Bates (2012) characterises this as moving from a 'data-poor' to a 'data-rich' science. Techniques such as airborne laser altimetry (Lidar) (Bates *et al.*, 2003; French, 2003; Gomes-

Pereira and Wicherson, 1999; Marks and Bates, 2000) were able to capture data at a resolution of 2–5 m and, while the vertical accuracy of 10–15 cm was not as good as ground survey, the data were less time consuming to collect and the density less sparse. With improvements in technology and reduced costs, Lidar now offers horizontal resolution down to 0·25 m and vertical accuracy of ~5 cm. In urban areas it is often necessary to combine raster-based data, such as Lidar, with vector-based data, such as that for roads and buildings contained in the OS MasterMap data. This further increases our ability to represent the complex flow paths that characterise the urban landscape. In an urban context we are fast approaching a limit where greater horizontal resolution will be of little use unless we have detailed data on kerb alignment, road drainage location, state of maintenance and so on. Remotely sensed data can also be used in model validation, but again the data need careful interpretation and manipulation (Mason *et al.*, 2007).

Increasing computer power means models now run much faster and, as well as saving time, this has allowed for the study of more ‘what if’ scenarios, larger river networks or urban areas and has allowed for the increased use of models in two dimensions. As well as hardware improvements there has been work on the implementation of parallel processing (Neal *et al.*, 2010; Villanueva and Wright, 2006a) and the use of graphics card technology through graphics processing unit (GPU) implementations (Brodtkorb *et al.*, 2012; Lamb *et al.*, 2009). The latter have proved particularly powerful given the conceptually straightforward mapping of the two-dimensional (2D) domain onto the pixel-based GPU representation; of course, as I am sure the developers of GPU codes would agree, the devil is in the detail. These developments hold up the possibility of even faster or larger computations in the future.

Early work on modelling for flood prediction focused on one-dimensional (1D) equations (Price and Samuels, 1980), which are sufficient when the river flow has one dominant direction, but on floodplains this is not always the case and the solution of the 2D equations becomes necessary. The initial work on solving flooding in two dimensions (Bates *et al.*, 1992; Gee *et al.*, 1990; King and Roig, 1988) demonstrated the potential of the technique, but it was not yet a tool for routine use. The need to use unstructured, triangular meshes to accommodate natural geometries meant that this early work used the finite-element method, or later the conservative finite-volume method (Anastasiou and Chan, 1997; Sleigh *et al.*, 1998). Two-dimensional simulations became far more commonplace with the availability of remotely sensed data and the development of algorithms that linked 1D and 2D solutions (Dhondia and Stelling, 2002; Lin *et al.*, 2006; Villanueva and Wright, 2006b). The latter have proved particularly popular in the UK where they have ensured that the existing investment by the Environment Agency and its consultants in 1D models can continue to be used alongside 2D models. The use of remotely sensed data for 2D simulations has led to a move back to regular, Cartesian grids and away from unstructured grids.

Uncertainty has been a focus for much research and formed a key part of the FRMRC. Uncertainty is an inevitable part in any modelling, particularly that involving the natural environment. As discussed above, there are several sources for this: neglect of physical process representation (Neal *et al.*, 2012; Willis *et al.*, 2012); inaccuracy in the estimation of parameters (Beven and Freer, 2001); errors in the discretisation of the equations used (MacDonald *et al.*, 1997; Skeels and Samuels, 1989). Naturally much research is aimed at reducing all sources of errors within modelling, but it is not realistic to imagine that uncertainty will be completely removed. Therefore, we must acknowledge the uncertainties that exist and develop the means to represent them in a way that makes decision-makers and stakeholders aware of them, while maintaining an appreciation of the need for modelling. We must convince them that, despite the uncertainties, decisions made based on modelling are more robust than those made without modelling. For more detail on the concepts behind uncertainty and practical ways in which to incorporate uncertainty estimation in modelling studies and outputs, the FRMRC outputs in this area are a good start (Leedal *et al.*, 2010; Pappenberger *et al.*, 2006).

Developments in two dimensions have adopted different approaches to physical representation. In particular, various researchers have adopted a ‘reduced complexity’ (McMillan and Brasington, 2007) approach that neglects momentum transfer and solves a form of the diffusion wave equation (Bates and de Roo, 2000; Bradbrook, 2006; Estrela and Quintas, 1994). This method was suited to the use of remotely sensed data and on coarse grids was faster than the solution of the full shallow water equations. However, the timesteps required at finer meshes were not feasible (Hunter *et al.*, 2008). The most popular implementation, Lis-Flood-FP (Bates and de Roo, 2000) has been further developed (Bates *et al.*, 2010; Hunter *et al.*, 2005) and this method is now generally faster, but the differences are not as great as once envisaged. In engineering practice, use has been made of methods that represent a far greater level of approximation in order to achieve very fast simulations (i.e. HR Wallingford’s rapid flood spreading method (Gouldby *et al.*, 2008) and Halcrow’s Isis Fast), while a number of consultants have adopted the full shallow water equations (Innovyze (Lhomme *et al.*, 2010) and JBA Consulting (Crossley and Lamb, 2010)). More recently, research has been conducted on using sub-grid scale representations (Yu and Lane, 2006a, 2006b) to increase accuracy while maintaining feasible computing time. The approaches to reduced complexity are evaluated by McMillan and Brasington (2007).

4. Future needs and developments

Predictions of future directions are always prone to appear naive when revisited with the benefit of hindsight, but with that caveat the following are put forward.

- Improved methods for modelling urban areas are needed.
  This need arises from the increased risk from pluvial flooding and the need to use inundation modelling for a resilience

approach to flood risk management. This will require further integration of surface and sub-surface models to cover surface water, drainage networks, groundwater and so on. It may well require the use of both structured and unstructured grids together, as is routinely done in three-dimensional Navier–Stokes software. Further developments on the use of sub-grid models to increase accuracy on coarser grids will be needed.

- There is a need for more quantitative ways of comparing different physical representations and advising users which is most appropriate for a particular situation (Neal *et al.*, 2012; Willis *et al.*, 2012).
- It is necessary to continue to reflect uncertainty in modelling. This is a technical issue in terms of developing methods that quantify uncertainties and include uncertainty over future drivers (urbanisation, demographic change and climate variability); it is also a socio-technical issue in the development of users' and stakeholders' confidence in handling uncertainty.
- The interaction between stakeholders and decision-makers on one hand and modellers on the other has already become an integral part of modelling studies and this trend will continue. This is driven by the need for democratic accountability and the increasing requirement from government for private contributions to flood risk management schemes. People and organisations will not contribute to schemes that they are not convinced by and they must trust the models used to design these schemes. Furthermore, the involvement of stakeholders in developing the model for each scheme from an early stage can improve the model results by learning from local knowledge of what happens during flood events (Odoni and Lane, 2010).
- With the increased need to demonstrate a positive cost–benefit analysis, it is important to look at the wider economic and social impact of flooding. Damage to infrastructure and homes can have impacts far beyond the area where the flooding occurs, particularly now that the global economy is increasingly interconnected. This effect was seen in the increase in hard disk prices following the combined effect of the Japanese tsunami and floods in Bangkok in 2011 (Fuller, 2011).

The papers in this themed issue address a number of these topics. Huang *et al.* (2012) examine how to reduce uncertainties in representing morphological change in rapid movement of water and sediment from a landslide breach. Three papers address issues in modelling urban areas: Stelling (2012) examines improved ways of gridding in urban areas; Snell *et al.* (2012) look at the complex system of the London Underground and Ellis *et al.* (2012) address how remotely sensed data can be used in pluvial flood modelling. Jamieson *et al.* (2012) report on an improved approach to large-scale flood modelling that improves on the work mentioned above on the rapid flood spreading model (RFSM) (Gouldby *et al.*, 2008). Darch and Jones (2012) put forward a means of amending design flows to account for climate change, which is a key contributor to future uncertainty, but also an area where it is difficult to obtain clear advice; this paper helps in that regard by presenting a means of altering the parameters in the UK *Flood Estimation Handbook* (CEH, 1999).

I hope you find these papers interesting and useful. Do look out for the second themed issue in the New Year.

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