Approaches to Modelling Large Floodplains and Wetlands

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Key Points

- Capabilities of hydraulic modelling software have increased significantly
- Improved computing power has allowed modelling of entire river reaches
- Appropriate application of models is as important as ever
- Lack of calibration data remains a key limitation in modelling exercises
- Opportunities exist for improved data capture during natural flood events

Abstract

The last decade has seen considerable advances in hydraulic modelling software and hardware capabilities, alongside which a number of different approaches to modelling large floodplains have developed. The modeller now has the choice of: 1D, 2D, 3D or linked model systems; single or mutli-domain grids or unstructured mesh topography; variable structure logic; and processing on either a graphics processing unit (GPU) or central processing unit (CPU), all available in a range of software packages with different underlying numerical schemes. With the increased accessibility of hydraulic modelling, the skill of the modeller in selecting an appropriate application and schematising the model correctly is more important than ever.

This paper presents an overview of the available approaches to modelling large river floodplains and wetlands, with emphasis on the advantages and disadvantages of each, and their appropriate application. Examples are presented based on project experience across Victoria.

Keywords

Environmental flows, hydraulic, model, MIKE, TUFLOW, floodplains, wetlands, regional

Introduction

The practical application of numerical models for floodplains and wetlands is relatively recent, with 2D models for floodplain investigations occurring only from the early to mid-1990s (Babister *et al*, 2012). The last decade, however, has seen rapid evolution of hydraulic modelling software and hardware capabilities.

Driven largely by user needs (and facilitated by improved hardware capabilities), hydraulic modelling software now provides options for complex control structure logic (within integrated 1D/2D models), improved linking between 1D and 2D components, and domains represented by regular grids, nested grids or flexible meshes.

Improved hardware capabilities mean that model schematisation is no longer limited in the same way by extent, spatial resolution, time step and computational complexity. For eco-hydraulics and stream management, this means environmental flow studies can go beyond looking at individual sites of importance and consider an entire river reach, as well as the connectivity between river, floodplain and wetlands to provide a better understanding of how to achieve desired watering outcomes. We are now also seeing the application of models outside their traditional use (e.g. to answer hydrological questions which would otherwise have been assumed).

With all these advancements, the modeller now has more choice than ever regarding model schematisation. There are, however, many potential technical challenges in developing hydraulic models over such large areas. The appropriateness of the approach selected, the subsequent schematisation and interpretation of results remains paramount.

For the new modeller, an excellent summary of common hydraulic model approaches, including their typical application, advantages and disadvantages is given in Babister *et al.* (2012). The focus of *this* paper is approaches to a number of aspects of modelling that are of particular importance to large floodplains and wetlands. Practical examples of the application of different approaches are provided based on project experience.

Computational Schemes

A key issue in numerical modelling is the computational speed. Two-dimensional numerical modelling software has typically utilised an implicit higher order computational scheme to solve the shallow water wave equations. That is, matrices are used to solve the equations, with information from the current and previous timestep being solved simultaneously. As a result of these numerical dependencies, parallelisation of the computation is not supported.

The alternative solution is to use an explicit computational scheme, which is forward solving, and removes the numerical dependencies, thereby allowing parallelisation across multiple computing cores. Explicit computational schemes, however, are severely disadvantaged by the smaller timestep required to maintain numerical stability.

Over recent years, the trend in gaming has seen rapid development of computer graphics cards. While the central processing unit (CPU) is usually limited to only a few cores, the graphics processing unit (GPU) has advanced to having *thousands* of smaller, more efficient cores. The increased processing power of a GPU now far outweighs the smaller timestep required for explicit computational schemes, and hence hydraulic modelling software is transitioning to explicit schemes. This has led to a reduction in model run times, in some cases up to 100 times faster than CPU models (Connell *et al.*, 2014 & MIKE by DHI, 2014a).

The benefit of utilising GPU over CPU models has been clearly proven in Inglis *et al.* (2016) where 9 traditional CPU models, each representing a segment of the Goulburn River from Eildon to the Murray River were combined to two GPU models split at Nagambie. The two whole of reach models had both faster run times *and* a finer resolution grid. The smaller grid size allowed improved connectivity across anabranches and wetlands. In addition, consistency from one model to the next across the previously overlapping area was no longer an issue. Model results showed a significant increase in quality through the transition to a GPU model. This led to an improved understanding of the impact of flooding, both for environmental benefit and the impact of public and private land and infrastructure.

The transition of models to GPU has also allowed the extension of model application, beyond their traditional use. Small scale, rapid-run hydraulic models are being developed to help solve hydrological questions, for input to hydrological models and/or larger hydraulic models. This is discussed further in the Hydrology Section below.

Spatial Representation

While the improvement of computing power has facilitated the ability to model whole reaches of large floodplains and/or wetlands, there remains a trade-off between run-time and model size/resolution. Traditional two-dimensional modelling has utilised a rectilinear grid, whereby the domain is uniformly represented by squares. In order to accurately represent a waterway, the grid resolution needs to be sufficiently small such that there are at least three to five grid cells across the width of the waterway. Where the waterway and large areas of floodplain are to be modelled, this makes for a substantial number of grid cells, with correspondingly large file sizes and run times.

Many hydraulic models now have a flexible mesh option, which allows for variable resolution across the model domain. This allows the many waterways and linear features such as levees, roads and channel embankments to be represented in detail in the mesh, with larger elements in the flatter floodplain. This allows the models to maintain a fine resolution in the topography across areas of specific interest with reasonable run times.

Figure 1 provides example model domains with a regular (rectilinear) grid and a flexible mesh schematisation.

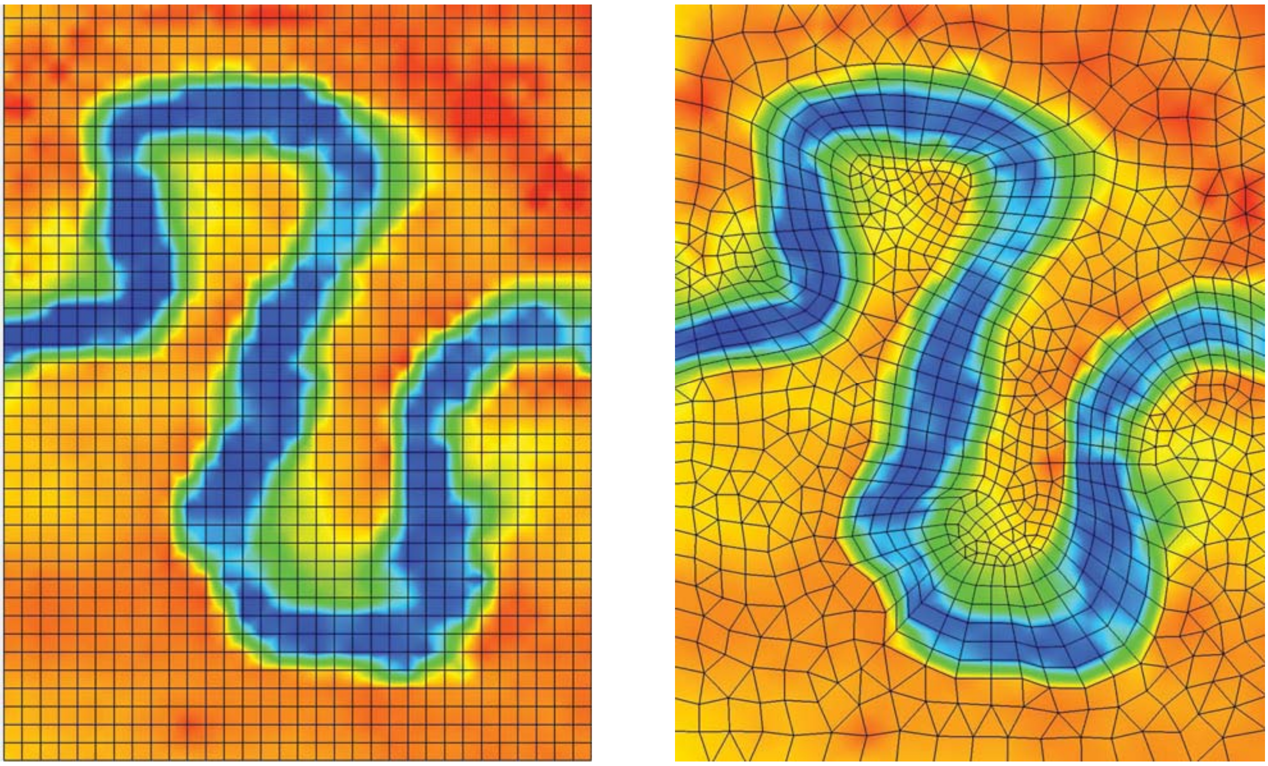

Figure 1. (a) Regular grid; (b) Flexible mesh

An accurate mesh requires considerable thought and planning so that physical features are described accurately and in the most computationally efficient manner. Consideration of the important features of the floodplain / wetland, areas of interest and potential hydraulic controls aids in creating a realistic representation. Waterways are generally represented with a finer resolution, and preferably as a patched (i.e. quadrilateral) mesh so that the elements align with the direction of flow. As elevations are assigned to the edges of elements, consideration of the element size and subsequently how that impinges on the interpretation of the channel banks and waterway capacity is important, particularly where in-bank flows are to be investigated.

Similarly, it is preferable to have the mesh align with key hydraulic controls such as roads, bridges and levees. These can be represented as dikes and/or weirs that are applied to the mesh, however there is potential for a loss (or increase) in floodplain storage as a result of their application.

Flexible mesh models usually utilise the GPU and are useful in that they allow modelling of large areas in short timeframes. A good example is the Loddon River catchment, which covers an area of over 10,000 km^2, and has a floodplain which can be greater than 40 km wide. The entire area is currently being modelled utilising MikeFM software run on GPU as part of a regional flood mapping project for DELWP. Model run times, for large flood events where the majority of the model domain is activated, are in the order of 4.4 hours simulation per hour real time.

Flexible mesh models have only recently integrated complex 1D structures.

Hydrology

Many existing hydrological models (e.g. REALM, eWater Source, Big-MOD, RORB, etc.) require the user to manually describe flow distributions through tabular relationships or simplistic equations. It requires the user to have detailed information regarding floodplain behaviour, or to make large assumptions that can impact on model performance. Streamflow gauges are often used without questioning the flows, and flow distribution relationships between anabranches are often guessed. Hydraulic models can be applied to develop more certainty around these hydrological assumptions.

Whilst it is commonly understood that a flow gauge with a long period of record is the best source of information, the accuracy of the rating curve is often overlooked. It is not uncommon for a rating curve to overestimate or underestimate flows by up to 40% in the extrapolated zone of a rating curve (Tate *et al.*, 2014).

Small scale, fine resolution hydraulic models can be developed across the area of interest, with steady state stepped-inflows as input. The resulting water levels and flows can be extracted to develop the rating curve in the extrapolated section. This process has been applied successfully by the authors in a number of flood studies, where high flows in the extrapolated section are of interest. It could also be applied to locations where rating curves don’t exist, but could be of benefit (e.g. for flood runners which connect wetland ecosystems to the Murray River).

Hydraulic models can also be developed to investigate flow distribution relationships, for input into hydrological models. Similar in the approach to developing rating curves, a steady-state stepped inflow can be applied upstream of the distribution split, with levels and discharges extracted across each distributary. These relationships can then be used in hydrological models to accurately describe flow splits where previously the user would have just guessed.

The use of hydraulic models for developing rating curves and distribution relationships, however, is limited by the available topographic data. Consideration must be given to both the vertical and horizontal accuracy of the data set, as well as the resolution, and datum.

A direct rainfall (also known as ‘rain-on-grid’) method can be applied to situations where catchment topography does not lend itself to simple catchment and tributary delineation, such as in distributary systems and very flat catchments. Rain is applied directly to the model domain, allowing the topography to generate runoff patterns after losses are accounted for. This can be used to great effect in defining overland flow paths and providing rapid flood mapping. There are a number of model schematisation assumptions that can have a large impact on the performance of this type of modelling, in particular: grid size and roughness in rural areas, and the incorporation of pipes and pits in urban areas.

Hydraulic Controls

Hydraulic structures such as culverts, weirs and bridges play an important role in water resource management. The incorporation of these controls as 1D structures linked to a 2D domain is not a new concept, however, representation has typically been simplified (e.g. by a single stage-discharge relationship or binary unidirectional flow).

Water management investigations often seek to determine the optimal operation of hydraulic control structures, based on variations and dynamic operation. The incorporation of control logic to structures now allows representation of movable gates and pumps, which can vary in response to water levels, discharges, velocities, volumes, time and head difference at any point within the model (DHI, 2014b). This allows varying logical operating rules to be embedded in the model.

Modellers can be enticed to utilise control structure logic because it is presumed that as they are more advanced it will provide better/more accurate results. The authors, however, have found that in many circumstances, there are simpler methods that are more functional and less susceptible to errors. If not applied appropriately, control structures can become a source of mass error and create instabilities in the model, reducing confidence in the results.

Data Capture

Opportunities to calibrate models of large floodplains and wetlands are often limited, largely because the data does not exist. Efforts to capture data are repeatedly focused on major flood events, which are often less critical in environmental flow studies, where an understanding of model performance in low level floodplain inundation associated with watering events is the aim of the exercise.

The generally accepted standard for calibration is to match discharges and levels to gauge data, and inundation extents to aerial photography. However, model accuracy may be improved by considering any available data, a lot of which can be captured freely and easily by local operators.

It is beneficial for water managers to collect as much information as possible when the opportunities arise around natural and managed inundation events. Water level and flow gaugings at strategic locations can be supplemented with time-stamped photos, aerial and satellite imagery, and documented notes to provide a means to verify and improve modelled estimates of inundation extents and timing of inundation through the floodplain wetlands. In particular, the recent availability of satellite data, free online to download, offers great opportunities for large scale environmental monitoring of wetlands.

For projects with large scale investments in infrastructure based around modelled information, making a relatively minor investment in collecting information to improve modelled estimates is a wise investment.

Calibration data can improve model accuracy, or at least, aid in understanding the limitations of models – thereby preventing inappropriate reliance on model results.

Summary

Table 1 below provides a summary of the typical applications, advantages and disadvantages of each of the approaches discussed within this paper.

Table 1 Summary of modelling approaches

Approach	Advantages/Applications	Disadvantages/Limitations
CPU model (implicit scheme)	• Larger timestep required for stability	• Doesn't support parallelisation
GPU model (explicit scheme)	• Allows parallelisation • Allows more detail and/or larger areas for similar run time	• Smaller timestep for stability • Complex coupling with 1D is only recent
Rectilinear grid	• Quick to establish • Useful for scenario comparisons because the grid is rigid and remains the same	• Trade-off between resolution and run time • Limited to a single resolution across a domain
Flexible Mesh	• Targeted detail • Fast run times	• Time consuming to produce • Recent introduction of complex coupling with 1D
Hydrological Applications	• Reduced assumptions • Input to 1D hydrological models	• Accuracy limited by available topographic data
Control Structure Logic	• Optimising operating procedures • Allows changes to structure control based on a number of variables	• Can be a source of mass error or instability • Often 'over-engineered'

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