Storm Tide Inundation Modelling—Meeting the Challenge in London, Port Adelaide, and Cardwell

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Introduction

London, United Kingdom, and Port Adelaide, Australia, have large areas of reclaimed tidal marshes and flats. These areas lie below high tide levels and are at risk from storm tide inundation. The risk has largely been mitigated by the construction of sea walls and levees. However, risks of inundation and widespread damage remain from extreme events and from sea level rise. Cardwell Shire, while not as low, is at risk from severe tropical cyclones, as recently demonstrated by the Category 5 Cyclone Larry in March 2006. Three major investigations, the Thames Embayments Inundation Study, Port Adelaide Seawater Flooding Study, and Cardwell Inundation Study utilised two-dimensional (2D) models to identify the risks from storm tide inundation, and predict the storm surge from cyclonic events.

The Thames Embayments Inundation Study benchmarked four different software as options for a major emergency management system to predict the risks of storm tide inundation along the River Thames, London. The software trialled were ISIS (1D), LISFLOOD (2D raster routing), TELEMAC (2D finite element) and TUFLOW (2D finite difference). TUFLOW in conjunction with ISIS were selected and are currently being applied to cover the embayments along the River Thames. As part of the project, the ISIS and TUFLOW codes were merged and the ISIS 1D and TUFLOW 2D solutions dynamically linked. A long-term aim is to produce one model with the River Thames modeled using the existing ISIS model and the 23 embayments as 23 dynamically linked TUFLOW 2D domains to the ISIS domain.

The Port Adelaide investigations utilised a multiple 2D domain TUFLOW model developed to cover Barker Inlet, the Port River, various stormwater detention basins and artificial wetlands. Six different domains of different orientation and cell size were dynamically linked. The model was calibrated to the June 1999 storm surge and successfully reproduced the tidal

oscillations and amplification that was recorded in the Port River. Seawater flood inundation from storm tides and stormwater inundation from the local catchments were simulated for different design events. The modeling demonstrated the importance of the inertia terms in being able to reproduce tidal amplification and the ability to model a range of hydraulic features in 2D at different mesh resolutions.

The Cardwell Inundation Study is a major investigation defining the inundation risk from cyclonic storm surges and river flooding. The study is developing a multiple 2D domain TUFLOW model that covers the Coral Sea at a coarse resolution, down to fine resolution representation of the rivers and floodplains. The study is presently simulating and calibrating the model to Cyclone Larry, a Category 5 cyclone that struck the area shortly after the study was commissioned!

The projects' demonstrate the ability to simulate cyclones and storm-tide inundation via overtopping of major levees several metres in height and from breaching of flood defence walls and levees.

Tidal Thames Embayments Inundation Study

Over the course of history, development in and around London has encroached significantly into the River Thames floodplain. As a result, approximately 116 km^2 between Teddington Weir and Dartford Creek, covering 23 hydraulically discrete embayments, are at risk of storm tide flooding during an extreme event. The risk is predicted to increase in the future due to a combination of sea level rise and geological settlement of southeast England. There are also the risks associated with failure of flood defence walls and/or the Thames Barrier.

The UK Environment Agency requires a tool to improve its ability to plan for and manage a tidal flood event that breaches or overtops the defences. Halcrow, in conjunction with HR Wallingford were commissioned to carry out the Tidal Thames Embayments Inundation Study. WBM provided expert advice as a sub-consultant.

The first stage involved the benchmarking of different modeling approaches on a single representative embayment, and to make recommendations on the most suited modeling solution. The Greenwich embayment, located adjacent to the Thames Barrier, was selected as the trial area.

For modeling of floodplains, the main approaches used in the UK industry are

- Quasi-2D (1D network) models,
- 2D raster routing models,

- Fully 2D regular grid (typically finite difference) hydrodynamic models,
- Fully 2D irregular grid (typically finite element) hydrodynamic models, and
- Combinations of 1D hydrodynamic models with one of the above.

In order to provide recommendations on the most appropriate techniques to adopt, the following software were selected and applied to the Greenwich embayment to assess their accuracy and fitness for purpose.

- ISIS Flow (quasi-2D),
- LISFLOOD-FP (raster routing),
- TUFLOW (fully 2D, regular grid with 1D/2D dynamic linking), and
- TELEMAC 2D (fully 2D, irregular grid).

Experts in each of the modeling systems applied a consistent approach to development of the Greenwich models. Unfiltered (i.e., includes buildings) air-borne laser data was used to generate a 1m raster digital elevation model from which each model sampled its elevation data. The same distribution of five different bed roughness values was applied. Three scenarios were defined (an upstream breach, a downstream breach and an extreme overtopping event). Figure 1 shows the application of TUFLOW to a breach scenario in the Greenwich embayment. The results of the initial findings are presented in Wicks, et al. (2004) and Syme, et al. (2004). In summary, they are:

- The LISFLOOD-FP raster routing approach was ruled out due to poor accuracy, unreliable results and long run-times.
- The finite element TELEMAC 2D option was ruled out due to long run times and reliability issues.
- The ISIS and TUFLOW software were both selected as in combination they fulfilled the requirements for the study.

Being a one-dimensional (1D) solution, ISIS offered considerable benefits in terms of run times, plus the existing ISIS model of the tidal Thames is well calibrated and ready for use. TUFLOW was selected as the preferred platform for simulating overland inundation within the embayments due to its superior stability, and offered the opportunity to be dynamically linked to the ISIS solution through TUFLOW's well-established and proven 1D/2D linking capabilities (Syme, 1991).

During the next stage of the study, the ISIS and TUFLOW codes were successfully merged and dynamically linked. The entire study area could now be modeled as ISIS covering the tidal Thames and TUFLOW 2D domains representing the embayments as one overall model.

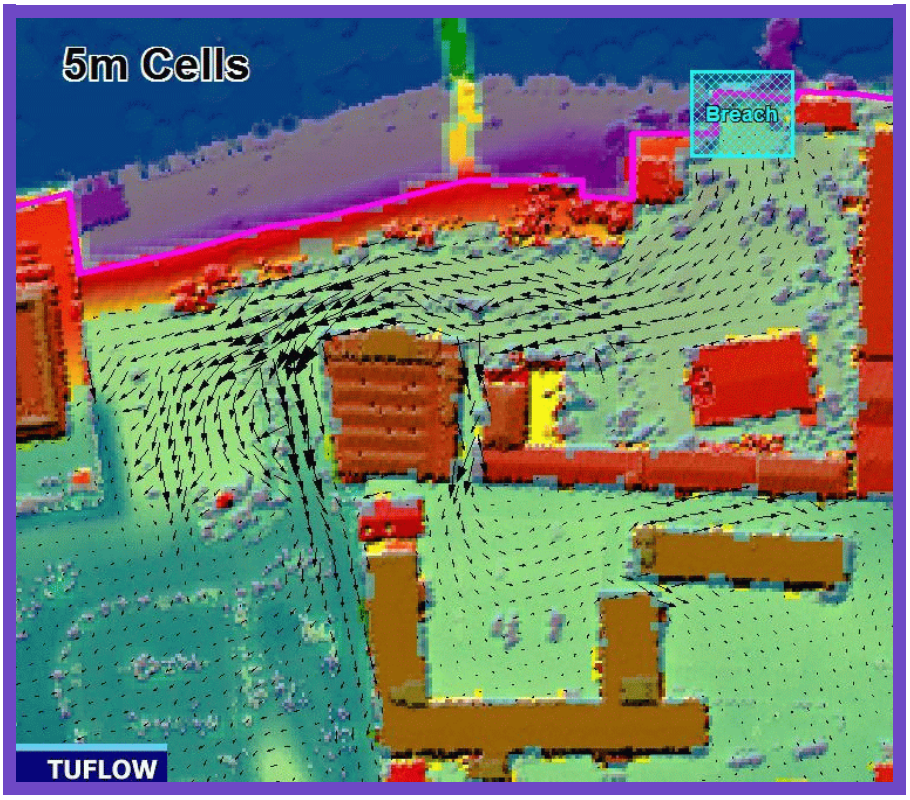

Figure 1. TUFLOW Modeling for the Greenwich Embayment

Port Adelaide Seawater Flooding Study

The Port Adelaide Enfield peninsular is located northwest of the city of Adelaide and lies adjacent to Gulf St. Vincent and the Port River. The study area covers approximately 10,300 hectares, with the majority of the area below the level of the highest astronomical tide.

The banks of the Port River extend about 50 kilometres and are protected in part by seawalls, embankments, and floodgates. Much of the land within the study area is reclaimed tidal flats and marshes, and therefore at high risk of being inundated. This land also experiences subsidence at over 2mm per annum. Under the Development Plan and State policy, all new development within the Port Adelaide Enfield region is currently required to be safe from 100 year storm floods and potential rises in sea level from climate change.

Tonkin Consulting commissioned WBM to undertake seawater modeling of the Port Adelaide Enfield region to better understand the risks associated with seawater flood inundation within the Port Adelaide Enfield Council region. A TUFLOW hydraulic model of the region was developed to provide a base case against which planning controls could be established and management measures can be hydraulically assessed.

Interesting aspects and challenges of the study (Tonkin, 2005) carried out by WBM were

- The detailed statistical analysis of 60 years of tidal data at the Inner and Outer Harbours to derive design storm tide heights and duration. This analysis derived design storm tide heights by a long-term statistical analysis of the tidal anomaly (difference between the recorded and predicted tide). Of particular interest was extending the analysis to include duration by analysing not just exceedance of peak water levels, but exceedance of water level versus duration. To process the more than half a million data points, special software was developed. The end result is the reliable synthesis of not just a peak storm tide level for a given probability of occurrence, but also the shape/duration of the storm tide.
- Calibration of the TUFLOW model to the June 1999 storm event, and demonstration that the model reproduces the tidal amplification that occurs in the Port River (Figure 2). The Inner Harbour gauge located near the town centre experiences a higher tidal range due to amplification of the tidal wave up the Port River. This amplification is more pronounced during storm tides. Inclusion and appropriate solution of the inertia terms in the governing equations is required to reproduce these effects.
- Extension of the TUFLOW model to six interlinked 2D domains of different resolution and orientation to better simulate the hydraulic processes by varying the computational cell size from 10m in the surrounding artificial wetlands to 30m in the harbour and Port River.

Cardwell Inundation Study

The North Queensland coast of Australia is at risk from storm surges and flooding associated with tropical cyclones. This was experienced recently with Cyclone Larry, a Category 5 cyclone that caused widespread destruction within Cardwell and neighbouring shires in March 2006. A month prior, WBM Pty Ltd was awarded a major study to establish the storm surge and flooding risks for Cardwell Shire, one of the areas devastated by Cyclone

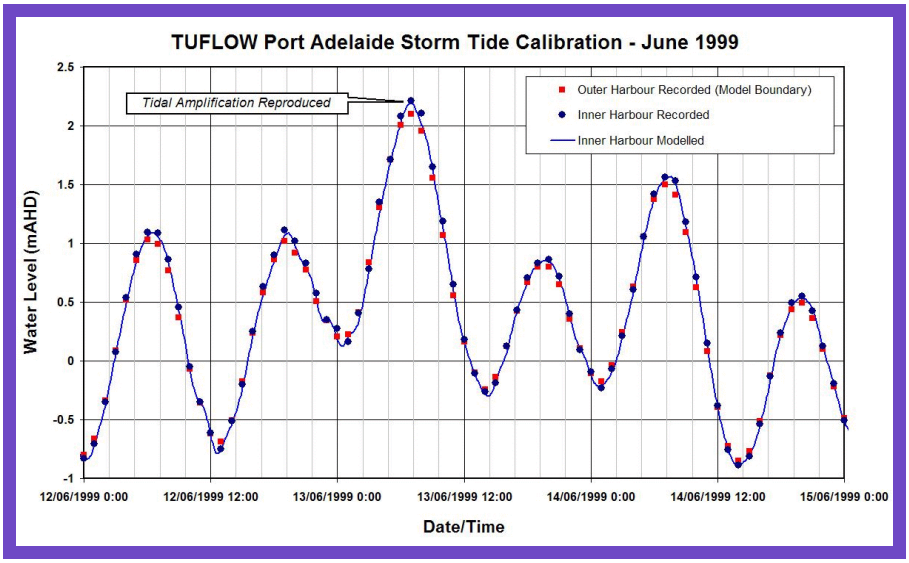

Figure 2. Calibration to the Port Adelaide June 1999 Storm

Larry. Not surprisingly, WBM engineers have been on-site and collected invaluable model calibration data!

One of the key features of the study will be the simulation of numerous, hypothetical, cyclones in a TUFLOW model as part of a Monte Carlo analysis. This exercise is utilising a new feature of TUFLOW that includes the addition of atmospheric pressure differential terms, wind fields, and wind stresses on the water column. The synthetic generation of cyclone pressure and wind fields is based on Appendix C of QG (2001).

Figure 3 illustrates the variation in water surface elevation due to wind and pressure of a hypothetical cyclone striking the Queensland coast (note that the water surface is greatly exaggerated in the vertical scale). Videos of this hypothetical cyclone can be viewed on the animations page of http://www.tuflow.com.

The TUFLOW model being developed consists of several nested 2D domains. The outer 2D domain covers the Coral Sea beyond the Great Barrier Reef. A finer resolution domain covers the reef and inner coastal waters, and even finer domains will cover the coastal bays off Cardwell Shire, as well as the coastal rivers, creeks, and floodplains. Of particular interest will be the calibration of the TUFLOW nested grid model to data collected from Cyclone Larry and the floods that followed.

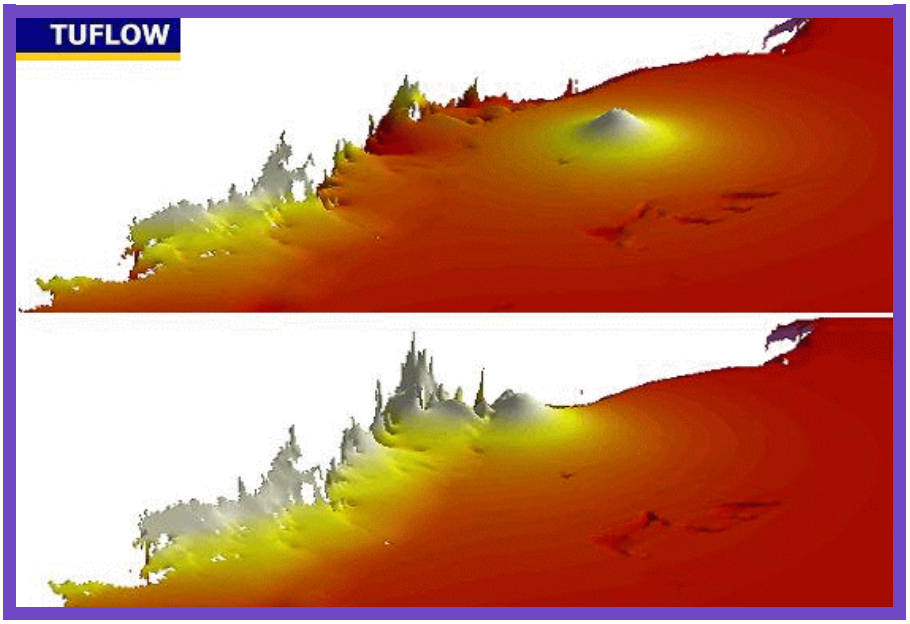

Figure 3. Cyclone Modelling for North Queensland Coast

Conclusion

Three major storm tide inundation studies of London, Port Adelaide and Cardwell have utilised 2D modelling to define the flood risk, and assess mitigation measures to reduce the risk. Each study has an element of research and development, a risk in itself, that has resulted in new approaches and methods for enhancing storm tide risk assessment.

The Thames Embayments Study benchmarked different types of hydraulic solutions and software, and has helped pioneer the ISIS/TUFLOW dynamic link. The Port Adelaide Study used an innovative approach to statistically analyse long-term tidal records to derive storm tide heights in combination with duration exceedance. The study was also one of the first multiple 2D domain models to dynamically nest grids of different resolution and orientation. The Cardwell Inundation Study is the first major investigation to simulate cyclones using the TUFLOW software.

These studies are successfully meeting their challenges, by taking on, researching and embracing new technology.

References

Queensland Government. 2001. “Queensland Climate Change and Community Vulnerability to Tropical Cyclones—Ocean Hazards Assessment—Stage 1.” Queensland Government.

Syme, W.J. 1991. “Dynamically Linked Two-Dimensional/One-Dimensional Hydrodynamic Modelling Program for Rivers, Estuaries & Coastal Waters.” M.Eng.Sc (100% Research) Thesis, Dept of Civil Engineering, The University of Queensland.

Syme W.J., M.G. Pinnell, and J.M. Wicks. 2004. “Modelling Flood Inundation of Urban Areas in the United Kingdom using 2D/1D Hydraulic Models.” Presented to the 8th National Conference on Hydraulics in Water Engineering, Gold Coast, July 2004.

Tonkin Consulting. 2005. “Port Adelaide Seawater Stormwater Flooding Study.”

Wicks J.M., W.J. Syme, M.A.A.M. Hassan, B. Lin, and O. Tarrant. 2004. “2D Modelling of Floodplains—Is it worth the Effort.” Presented to the DEFRA Conference, United Kingdom.