

## **A COMPARISON OF ONE- AND TWO-DIMENSIONAL MODEL SIMULATION OF THE CLYDE ESTUARY HYDRODYNAMICS**

Damir Bekic<sup>1</sup>, David Alan Ervine<sup>2</sup> and Pascal Lardet<sup>3</sup>

This paper gives an evaluation of application of one- and two-dimensional numerical models in the simulation of estuary hydrodynamics. The evaluation is based on identification of the relative strength and limitations of two commercial numerical models. Being part of river and coastal area, and influenced by meteorological conditions, water levels and currents in estuary are driven by various internal and external forcings. According to available recordings, the influence of tides, river inflow, precipitation, wind shear and air pressure on estuary hydrodynamics was analysed. Recordings were available for several historical events. Calibration of numerical models and the influence of each affecting parameter were made through comparison of observed water levels and those predicted by a model on several positions along estuary reach. Terrain model was build from a recent survey data (2004) and it was assumed that the estuary morphology was unchanged. To gain an appropriate evaluation and comparison of numerical models, the estuary dynamic was analysed on meso-scale domain and over a few tidal periods. On such spatial and temporal scale, the water body is under dominant influence of tidal waves and land runoff, but also affected by wind shear and atmospheric pressure.

The subject of the study was the River Clyde estuary in Scotland (UK), which has meso-tidal range of 3 m and long term average river inflow of 110 m<sup>3</sup>/s. Above the city of Glasgow the estuary is fluvio dominant, but tidally dominant in and below the city. During 300 years natural river valley was artificially deepened and narrowed, and today in Glasgow it is 10 m deep and 200 m wide rectangularly-shaped construction, with protected river banks. Upstream and downstream of the Glasgow river sustained its natural regime. Upstream reach has meandering shape in plan with hydraulic depth of 4 m and width of 50 m. Downstream reach has a funnel shape of increasing width from 230 m to 3000 m and of constant depth of 11 m. Along the 56 km long corridor a detailed one-dimensional (1D) hydrodynamic model was set-up using the ISIS Flow software. It comprised river channel and floodplains of the fluvial and tidal reaches of the estuary. A two-dimensional (2D) hydrodynamic model was configured using the MIKE21 HD model comprising area of 28×5.5 km in the tidal reach. Model was built on 20 m grid and was numerically stable for the Courant number below 2.7. Numerical simulations were conducted for several historical events during period 1991-2005, for which observations of water levels, wind speed and direction, and air pressure were available. Predictions of water levels by numerical models were inter-compared and compared also to recorded values on several water gauging stations. After calibration and verification of models, a sensitivity analysis on the various tidal shapes, fresh water inflows, wind shear and air pressure were conducted. Finally, the effect of internal meteorological forcings on water levels was predicted using a 2D model.

---

<sup>1</sup> Research Assistant, Water Research Department, Faculty of Civil Engineering, Zagreb, Croatia (dbekic@grad.hr)

<sup>2</sup> Professor, Department of Civil Engineering, University of Glasgow, Glasgow, G12 8LT, UK (ervine@civil.gla.ac.uk)

<sup>3</sup> Senior hydrologist, Halcrow Group Ltd, Edinburgh, EH3 6LB, UK (LardetP@halcrow.com)

Based on the comparison of water levels between 1-d and 2-d model predictions and observations, two conclusions may be derived. Firstly, exclusion of wind effect showed that both models predicted similar water levels, but lower than observed. Even though the estuary is hyper-synchronous and the funnelling amplification effect is bigger than frictional damping, there was no difference in predictions between 1-d and 2-d models. Furthermore, even though the estuary downstream is more like a compound channel, the effect of lateral momentum transfer is too small to show-up in a 2-d model. Secondly, inclusion of wind effect showed smaller differences between predicted and observed water levels by both models, but the difference in MIKE21 model was smaller than in ISIS Wind model. Based on the comparison of water level predictions in 2-d model for simulations with and without meteorological conditions, the following conclusions may be derived. As the 10 hPa lower air pressure gives 10 cm water level increase, it follows that the influence of air pressure is significant in predictions of estuary flood levels. Inclusion of observed meteorological conditions has showed that the combined effect of wind and air pressure increased flood levels by 80 cm. Finally, for the flood level predictions in macro tidal estuaries both 1-d and 2-d models can be recommended. However, as 1-d models still do not include air pressure effect and as they (ISIS Wind) give poorer predictions than 2-d models (MIKE21) of wind shear effect, the utilisation of 2-d models is recommended for flood level predictions in estuaries with strong wind and air pressure influence.

## REFERENCES

- Bekic D. (2005), Numerical Modelling of Estuary Hydrodynamics, Master's project, University of Zagreb, Faculty of Civil Engineering.
- Burns G. and Burns J. (1999), Firth of Clyde Costal Flood Warning Service, Scottish Environmental Protection Agency-West Region, Regional Board Meeting, 19 November 1999.
- Cameron W.M. and Pritchard D.W. (1963) Estuaries, In M. N. Hill (editor): The Sea vol. 2, John Wiley and Sons, New York, 306 - 324.
- DHI Software (2003), MIKE21 Coastal Hydraulics and Oceanography - Users Guide.
- Ervine D.A., et al. (2000), Two-dimensional Solution for Straight and Meandering Overbank Flows, Journal of Hydraulic Engineering, ASCE, Vol. 126, no. 9, September, pp 653-669.
- Heatlie F. (2004), 1-D modelling of Tides and Storm Surges in the Clyde Estuary, Master's Project, Department of Civil Engineering, University of Glasgow, UK.
- Nielsen C., Apelt C. (2003), The application of wave induced forces to a two-dimensional finite element long wave hydrodynamic model, Ocean Engineering, Volume 30, Issue 10, pp. 1233-1251.
- RCFMS study (2004), River Clyde Flood Management Strategy - Hydrodynamic Modelling Report, Glasgow City Council, Glasgow, UK.
- Stoschek O. and Matheja A. (2000), Sensitivity Analysis of Numerical Solving Techniques for Modeling Sediment Transport under Tidal Conditions, 4th Int. Conf. on Hydroinformatics, Iowa City, USA.
- Thain R.H., Priestley A.D., Davidson M.A. (2004), The formation of a tidal intrusion front at the mouth of a macrotidal, partially mixed estuary: a field study of the Dart estuary, Estuarine, Coastal and Shelf Science, Volume 61, Issue 1, pp. 161-172.
- Tomczak M. and Godfrey J.S. (1994): Regional Oceanography: an Introduction, Pergamon, Oxford. Also available at <http://www.es.flinders.edu.au/~mattom/>
- Wright A. and Norton P. (2000), Inter-comparison between one, two, and three-dimensional numerical models, MAFF Project FD1401, Modelling Estuary Morphology and Processes - Final Report, EMPHASYS Consortium.