

Modelling Estuarine Morphodynamics on the South Coast of Ireland

K.M. Cronin^{†‡}, R.J.N. Devoy[†] and J.Gault[‡]

[†] Department of Geography
University College Cork
(UCC), Ireland.
Katherine.cronin@ucc.ie

[‡] Coastal and Marine Resources Centre
Environmental Research Institute
University College Cork (UCC),
Naval Base, Haulbowline,
Cobh, Co. Cork, Ireland



ABSTRACT

CRONIN, K.M.; DEVOY, R.J.N., AND GAULT, J., 2007. Modelling estuarine morphodynamics on the south coast of Ireland, *Journal of Coastal Research*, SI 50 (Proceedings of the 9th International Coastal Symposium), 474 – 479. Gold Coast, Australia, ISSN 0749.0208

Several important studies of coastal processes in Ireland exist, establishing the patterns of sea-level change, the impacts of storminess, erosion and sedimentation rates. Approximately half of Ireland's coastline is deemed sensitive to erosion under climate change. This paper presents work on the collection of field data and the setting up of a process-based model (Delft3D) to study morphological change in Courtmacsherry estuary on the south-coast of Ireland. Bathymetric and topographic surveys have been carried out and monitoring of the hydrodynamic and sediment transport regimes is being undertaken to validate and calibrate the models. Results from the hydrodynamic model simulations agree well with field measurements. The outputs from this modelling work shall be used to run an abstracted model (Asmita). Results from this study will be used to examine the drivers and processes responsible for changes occurring in Courtmacsherry and as example of estuarine-bay functioning in the region.

ADDITIONAL INDEX WORDS: *Sediment transport, process-based modelling, abstracted modelling*

INTRODUCTION

The morphodynamic changes that are occurring along coastlines worldwide are of great environmental interest and economic importance. These changes occur as a result of the erosion of sediments, subsequent sediment transport and deposition in a new location. The significance of sediment transport to marine environmental managers and coastal engineers has been widely recognised. The physical processes that occur in coastal regions are complex and establishing sediment transport patterns is one of the most difficult tasks in coastal studies. Increasing numbers of people are living adjacent to the coastline and with predictions of climate warming, the resulting sea-level rise and increased storminess, understanding of the processes that cause these changes to occur is vital. The estuarine and coastal environment is also subject to a wide variety of influences due to human activities. These include the management and development of the coastline due to shoreline retreat, the creation of hard structures such as, harbours, ports, jetties and their associated infrastructure, inputs of nutrients and contaminants, aquaculture and fishing activities, all of which damage the fragile coastal system.

Computer models can help in assessing whether land use or other changes occurring may upset the fine sedimentary balance in estuaries and coastal cells. Prediction of coastal evolution with numerical models is a powerful technique on which coastal management increasingly relies (VAN RIJN, 2001). It is true that modelling can be applied to investigate problems, but it is not straightforward, and can be subjective. It contains many risks, due to the many choices that have to be made and the fact that the problem is often complex. The choice of which type of model to use depends on the coastal management issues that need to be looked at, the resources available for model calibration, validation

and implementation, and the spatial and temporal scale and resolution of interest. Modelling approaches can be seen on a continuum from 'simulation' using all the relevant processes at the greatest detail possible to 'exploratory', which aims for a simple explanation of the poorly understood phenomena at a scale that corresponds to the feature of interest (WILCOCK and IVERSON, 2003).

This research deals with modelling the morphological change that occurs in an estuary on the south coast of Ireland using two modelling techniques, namely a process-based numerical model and an abstracted model (in which the underlying equations are simplified). This work enhances the knowledge gained from previous studies of sedimentation patterns and the effects of storminess in this region (SWIFT et al., 2004). The aim is to investigate the value of detailed and computationally expensive modelling and a more abstracted modelling approach for one particular estuary. The behaviour of the two models with respect to the each other and the estuary in question is examined.

In this paper a process-based model is being used to simulate the motion of the water, sediment transport and resulting morphological change. The outputs (together with field data) will be used to run an abstracted model in order to understand the behaviour of the system and the role different processes have in this behaviour.

Modelling estuarine systems

Models used for estuaries are commonly classified into empirical models, process-based models and abstracted models (SCHUTTELAARS et al., 2001, WANG et al., 1992; HANSON et al., 2003; VAN LEDDEN, 2004). The equations in empirical models are based on observations in nature and are purely experimental. They

assume that the data reflects adequately the essential properties of the process under study in space and time – otherwise model predictions will fail to capture the system behaviour (LARSON *et al.*, 2003). Dynamic or process-based models, on the other hand, are based on the mathematical description of water and sediment motion. WANG *et al.*, (1992) believe that dynamic models have a better theoretical basis than empirical models. These models don't rely on an equilibrium assumption, but on processes alone and this enhances their generic applicability.

At the other end of the dynamic model scale are abstracted models. These models often focus on isolated processes so are useful tools to gain understanding of physical mechanisms (SCHUTTELAARS *et al.*, 2001). The processes driving the dynamics of the coastal system are described by a minimum number of variables and relationships (HUNTLEY *et al.*, 2004). Some argue that the main purpose of models should be to develop understanding (WILCOCK and IVERSON, 2003) and abstracted models can play a role in this. There is generally a lack of knowledge on how regular features, whether morphodynamic or hydrodynamic, develop from stochastic forcing in the coastal systems (HUNTLEY *et al.*, 2004). As multiple feedback mechanisms often complicate things (LAKHAN, 2004), processes may be abstracted so only the important assumptions, relationships, parameters and morphodynamic characteristics are included.

STUDY AREA

There have been several important studies of coastal processes in Ireland. A series of projects funded by the European Union since the early 1990s have facilitated the establishment of the patterns of long and short term changes in sea level and the impacts of storminess e.g. LOZANO *et al.*, (2004). Ireland has a long coastline of ~ 7800 km $\pm 5\%$ in length (DEVOY, 2000) which has been experiencing change since the last glaciation some 14,000 years ago. It lies in the main pathway of North Atlantic cyclones and the western coast is exposed to the full impacts of Atlantic swell wave and storm activity.

The site chosen for this study was Courtmacsherry Estuary on the south coast of Ireland (Figure 1). This mesotidal estuary is located in West Cork, about 12 km south of Bandon and immediately east of the village of Timoleague. The estuary consists of the drowned valley of the Argideen River, which is now filled with sediments resulting in an extensive mudflat. The seaward boundary of the estuary is between the headlands of Wood Point and Coolmain Point which opens out to Courtmacsherry Bay which in turn extends southwest to Leganagh point and southeast to the Old Head of Kinsale. The bay has mostly a rocky shoreline with sandy beaches in Broadstrand Bay and Blindstrand Bay on the west coast and Garretstown Strand and White Strand on the northeastern shores. The site contains a complex of coastal habitats including ten habitats listed on Annex I of the EU Habitats Directive.

This estuary may be considered typical of those found on the south coast of Ireland as previous work has shown that it experiences similar erosion and accretion rates. Lateral erosion rates of soft shorelines in the south coast region often exceed 1 m yr^{-1} and estuarine mudflats experience averaged sedimentation rates of 6.0 - 6.5 mm yr^{-1} (SWIFT *et al.*, 2004).

Not only is this site interesting from an academic point of view, the study also has practical implications. The estuary is progressively filling with coarser sediments creating navigational problems. As a result the main channel has had to be dredged in the past. This research will provide some insight into the patterns of sedimentation and the resulting morphological changes.

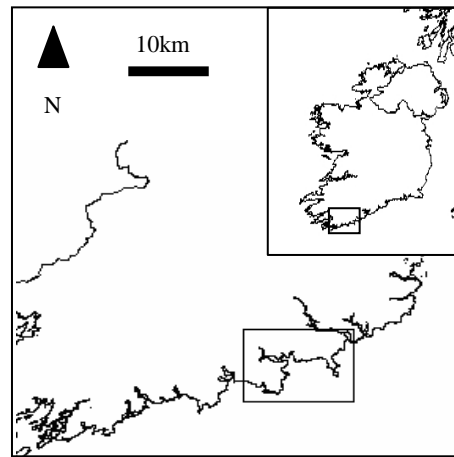


Figure 1. The study area

METHODOLOGY

The modelling system Delft3D, developed by WL | Delft Hydraulics is used for the process-based modelling. It performs 3D computations for coastal, river and estuarine areas and simulates flows, sediment transport, waves, water quality, morphological developments and ecology.

Most of the work done to date has been the collection of field data and the setting up of the hydrodynamic module (Delft3D-FLOW) of Delft3D. This involved defining the model extent, the grid size, the number of layers, generation of the land-boundary outline and the curvilinear grid.

The curvilinear grid was generated in the program Delft3D-RGFGRID using Cartesian coordinates. Curvilinear grids are used in finite difference modelling to provide a high grid resolution in the area of interest and a low resolution elsewhere. The grid lines were curved to follow the land boundary and channel thus creating a smoother and more natural domain. Bathymetric and height data were then interpolated over the grid by grid-cell averaging or triangular interpolation. In areas where there were more depth points than grid cells, grid-cell averaging method was used and in areas where there were more grid cells than depth points triangular interpolation was used.

Input and Validation Data

One of the first major requirements was the collection and processing of up-to-date bathymetric data in order to generate an accurate model bathymetry. The last set of bathymetric surveys done in this estuary was in the early 1990's and then only the main navigation channel was surveyed. The Admiralty Chart for the area dates back to 1977.

Hydrodata Ltd. were contracted to do the bathymetric survey (Figure 2) and used a vessel which was fitted with an in-hull transducer. Positioning was made by a Trimble NT300D DGPS and depth data was acquired using a precision survey echosounder, namely a Knudsen 320M dual frequency system (210 kHz, 33 kHz). The speed of sound profile in the water column was measured using an Odom Hydrographics Digibar and tide levels were measured using a Microtide self-recording tide gauge.

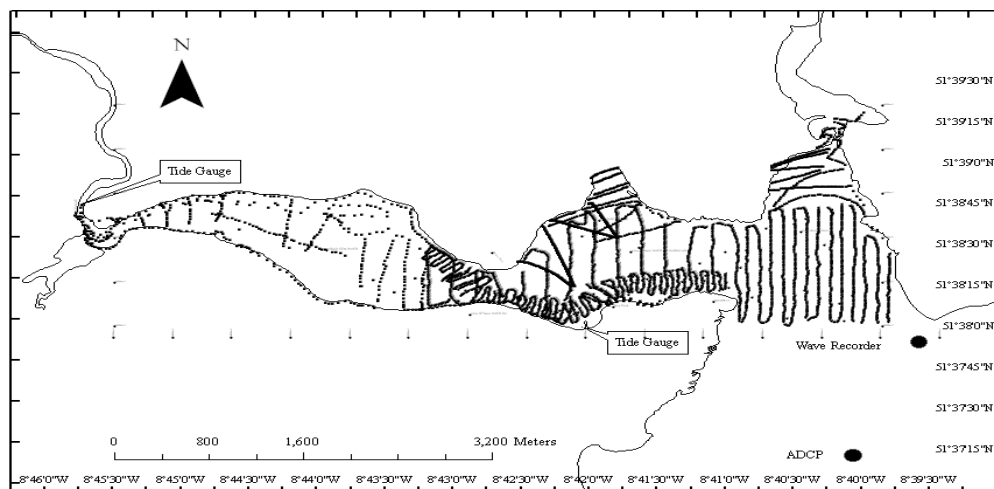


Figure 2. Bathymetric, GPS survey and instrument locations

A Trimble GIS Data Capture System, namely a GPS Pathfinder® ProXR/S receiver, was used to complete the survey of areas not reachable by boat (Figure 2), such as the mudflats and intertidal areas. This system provides real-time submetre accuracy with built-in SBAS, OmniSTAR and beacon capabilities. Post-processing was done with the software GPS Pathfinder Office. The data was vertically corrected to Ordnance Datum Malin and with RINEX GPS data (from permanent GPS stations) downloaded daily from the Ordnance Survey Ireland website.

Two Valeport (Model 740) tide gauges were installed in July 2006. One tidegauge was placed off the pier in Courtmacsherry Harbour and the other off a bridge at Timoleague (see Figure 2). Using this data, tidal analysis was performed using the Delft3D-TIDE module to extract the major tidal constituents (SA, MS0, 2Q1, Q1, O1, M1, S1, 3MS2, MNS2, MU2, N2, M2, LABDA2 and S2) which were then used as boundary conditions for the hydrodynamic simulations.

A wave recorder and an ADCP (acoustic doppler current profiler) were deployed in Courtmacsherry Bay on the 26th July 2006 for a period of one month (Figure 2). The wave recorder and ADCP provided continuous data for the period from 26th July to 26th August 2006 on tidal heights, currents and waves. The Valeport directional wave recorder (Model 730D) was installed at a depth of 10 m at IW 54265 42336 (N51 37.934 W8 39.674). It is a directional wave recorder and provides tidal elevations, a variety of wave statistics, the energy spectrum and directional spectrum. Data from this recorder was also used as boundary conditions for the hydrodynamic simulations. A Workhorse Sentinel ADCP (300 kHz) with a waves array (Teledyne RD Instruments) was also deployed at a depth of 12.8 m at IW 53761 40959 (N51 37.189 W8 40.100). This instrument uses pressure sensor and surface tracking (from beams) derived parameters to ensure high quality results when calculating for example, the significant wave height, max and mean wave height, wave period and direction. Further deployments of these instruments are planned.

Forty bed sediment samples were also taken at various locations throughout the bay and estuary using a Van Veen grab sampler. Particle size analysis was performed in order to provide detailed information on the nature of the bed for sediment transport modelling.

Further validation data is provided by repeated boat surveys. Measurements are taken of surface and bottom suspended

sediment concentration, surface and bottom current velocity, salinity and temperature at a series of stations through the estuary and into the bay. In addition, experiments using a fluorescent sediment tracer are currently underway to test the use of such tracers in providing significant validation data for simulated sediment transport patterns. Results to date suggest a very dynamic environment.

Surface elevation changes are being measured on two beaches in Courtmacsherry Bay, namely Broadstrand and Blindstrand by conducting repeated topographic surveys using a *Sokkia* SET 4010 EDM. The purpose of these surveys is to see whether these beaches may be a source of some of the sandy sediments that are entering the harbour and estuary.

RESULTS

Most of the work done to date has been the gathering of field data to run the models. The deployment of the wave gauge gave information on significant wave height (H_s), mean, significant and peak period (T_1 , $T_{1/3}$ and T_p respectively), maximum wave height (H_{max}), total energy (E) and wave direction. It can be seen from Figure 3 that even in July and August the area experiences quite a varying degree of wave heights and wave energy, due to passing storms. Wave height and energy increased significantly over the winter months. The propagation of these high energy waves into

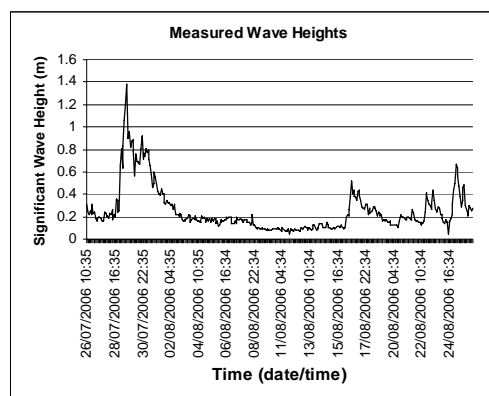


Figure 3. Wave height from wave gauge

the narrow estuarine channel at Courtmacsherry and over the sand and mud flats will have a significant impact on sediment transport patterns.

Work has been started on calibrating the hydrodynamics of the process-based model. The hydrodynamic module, Delft3D-FLOW, simulates depth-averaged (2D) or 3D unsteady flow and transport phenomena resulting from tidal and/or meteorological forcing, including the effect of density differences due to a non-uniform temperature and salinity distribution by solving the unsteady shallow water equations

In this module sediment transport is computed in the same way as any of the other conservative constituents, such as salinity and temperature but a number of important differences are also included (WL | DELFT HYDRAULICS, 2005). So far runs have not included the simulation of sediment transport and have just concentrated on the hydrodynamic flow. Preliminary results show a good agreement with measured water levels although work is continuing to achieve the best concurrence possible. Figure 4a

shows a comparison between simulated water depth for one station in the main channel and water depth measured by a tide gauge in the channel. The tidal cycle is reproduced accurately. Figure 4b shows the simulated water depth for the same station over a longer period of time, demonstrating the continued stability in computed water depths.

Areas that are drying out in reality are also drying out in the simulations. Figure 5a shows the area at low water and Figure 5b shows the corresponding inactive model grid cells at low water. Fluctuating water levels are also simulated well. Figures 6a and 6b show simulated water levels for observation stations at an intertidal area and at the entrance to the harbour respectively.

Figures 7a and 7b show the variation in simulated current magnitude throughout July in different locations. Current magnitude is much larger in the estuarine channel than at its mouth. The variation in current strength with time will affect the stress exerted on bed sediments and the rate at which suspended sediment is transported and kept in suspension.

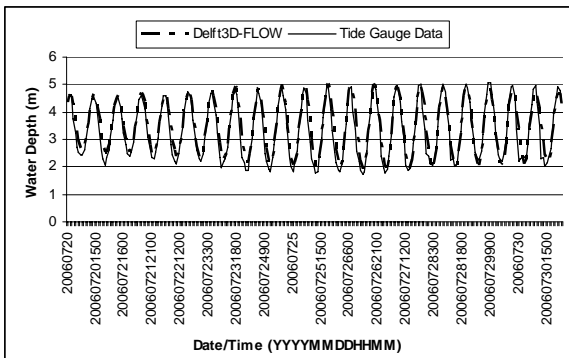


Figure 4a. Simulated Vs real water depth

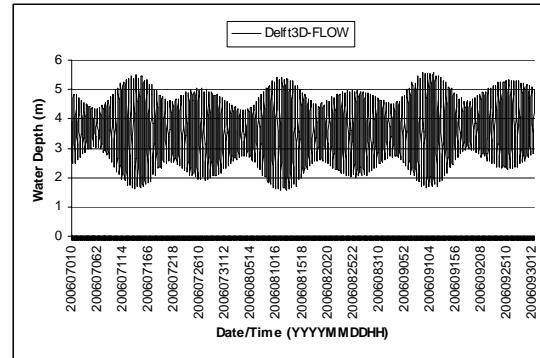


Figure 4b. Simulated water depth over longer period

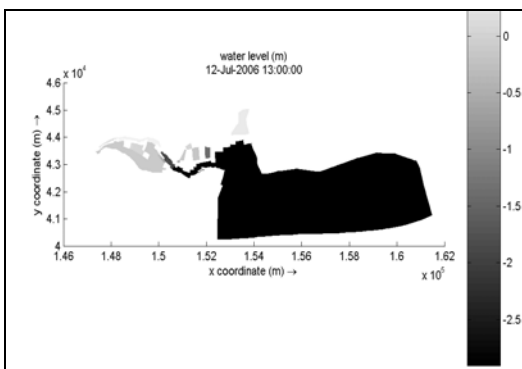


Figure 5a. The area at simulated low water

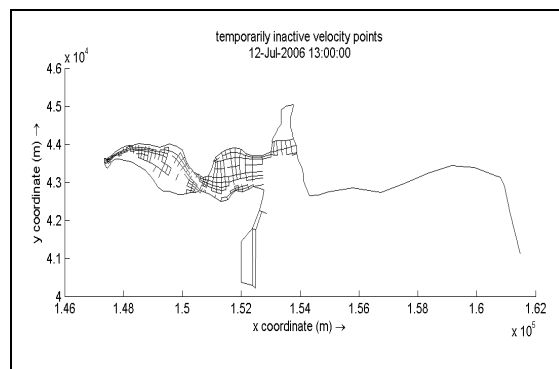


Figure 5b. Inactive grid cells at low water

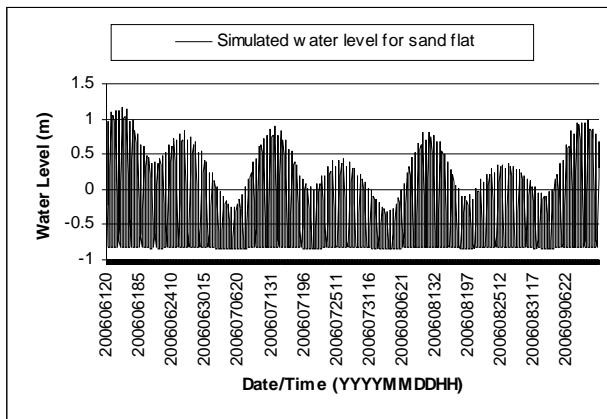


Figure 6a. Simulated water levels at an intertidal station

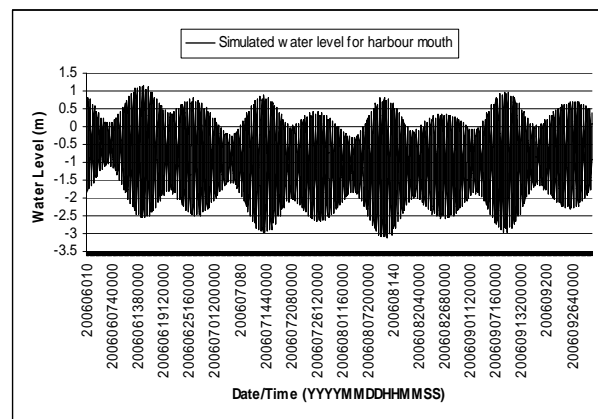


Figure 6b. Simulation water levels at the harbour mouth

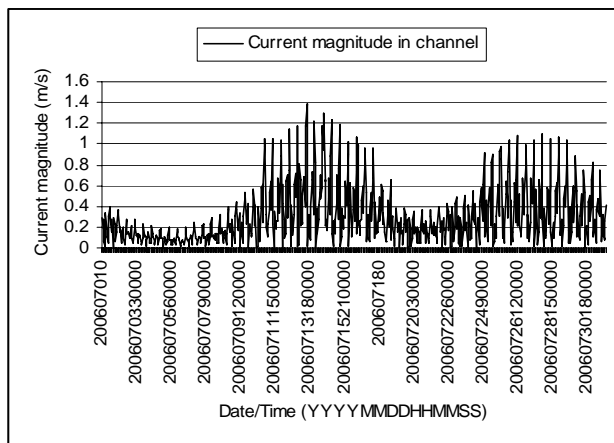


Figure 7a. Simulated current magnitude in the channel

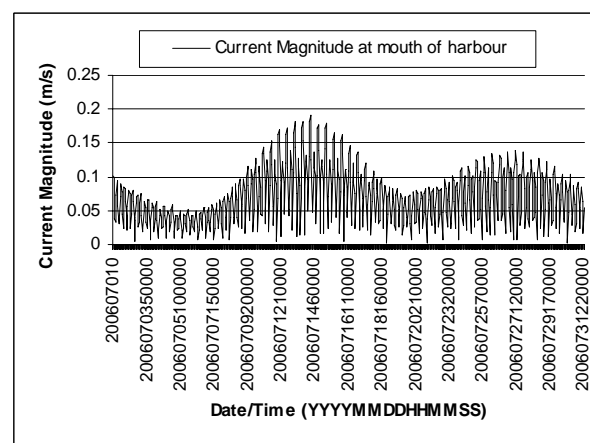


Figure 7b. Simulated current magnitude at the harbour mouth

DISCUSSION

Currently, even with advanced computing techniques, estuaries are still difficult to model correctly due to the complexity of the processes occurring within them and the wide range of space and timescales involved. Knowledge is still limited on the movement of sediment particles in oscillating and turbulent flows over different bed types. Models require clearly defined boundaries but in nature this is not the case. For example, the main sediment transport may occur so close to the bed that the boundary between what is bed load and suspended load is unclear.

3D models may provide detailed descriptions of the physical processes but increased computational time may not be appropriate for use by environmental managers, where speed and ease of application is important (GLEIZON et al., 2003). Any model used is likely to represent a range of processes and important questions to ask are: does this model simulate the key processes, to what accuracy must these processes be parameterised and what are the critical levels of accuracy beyond which this parameterisation becomes meaningless (GLEIZON et al., 2003)? The large uncertainty expected when predicting sediment transport is also important when calibrating a model. Adjustments of many experiment coefficients may make a model fit well but this may be of limited use in reality. The fitted model could be so uncertain that it shouldn't be applied to predictive studies so as EIDSVIK,

(2004) suggests, "it may be that simple models would be preferred".

With so many potential errors involved it leads one to wonder about the value of a more abstracted approach? The two approaches shall be examined with respect to Courtmacsherry Estuary. The ASMITA (Aggregated Scale Morphological Interaction between a Tidal inlet and the Adjacent coast) model developed by STIVE et al., (1998) will be used in the abstracted modelling approach. It is a behaviour-oriented model, which describes the evolution of a tidal inlet towards a new equilibrium, forced by external conditions or geometric interventions (KRAGTWIJK et al., 2004). The model describes the evolution of the tidal inlet system towards equilibrium as a function of the surplus or deficit of sediment, the capacity for exchange between the component parts and the potential for sediment to be imported or exported across the model boundary.

There is no doubt that process-based numerical models are essential for the accurate prediction of sediment transport over shorter time-scales. Results to date show good reproduction by the Delft3D model of the hydrodynamic fluctuations in Courtmacsherry Estuary, but the use of abstracted models may be valuable in assessing the processes shaping the estuary over longer time scales. Abstracted models may be useful tools to help understand the stochastic behaviour of the system and the

processes that drive the morphodynamic changes. This sort of tool may indeed be more useful for environmental managers than merely the prediction of morphodynamic change.

ACKNOWLEDGEMENTS

Many thanks to those who have assisted with work in the field. In particular Mary Murphy and Roisin Murphy from the Department of Geography (UCC) and Dr Max Kozachenko from the Coastal and Marine Resources Centre (CMRC). Also many thanks to the Marine Institute who allowed the use of their ADCP for the project and similarly to the Hydraulics and Maritime Research Centre (UCC) for their wave recorder. The bathymetric survey was funded by Cork County Council and is gratefully acknowledged.

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