Strategic Environmental Assessment, Severn Tidal Power

Call for Information

from

Hydro-environmental Research Centre,
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by

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Introduction

(i) General

The Hydro-environmental Research Centre at Cardiff University comprises: 4 academic staff, 3 research staff and typically 20 research students at any time, and specialises in the development, application and refinement of computer models of hydrodynamic, sediment transport, water quality and contaminant transport processes in coastal, estuarine and river basin systems. The Centre has links with similar organisations worldwide and over 50 UK and overseas companies and government departments have mounted the HRC’s models, with the models being used for over 100 environmental impact assessment studies worldwide. Staff within the Centre have published extensively in prestigious international journals and conference proceedings.

(ii) Severn Estuary Studies

The HRC has recently been funded to undertake a number of research studies on modelling flow, sediment transport and water quality processes in the Severn Estuary and Bristol Channel. The two main studies relevant to the information provided herein include: (i) Modelling the Fate and Transport of Particles in Water, for the Environment Agency, 2001-02, and (ii) Hydro-environmental Impact of Tidal Stream Renewable Energy Devices, for the Welsh Assembly Government, European Regional Development Fund, 2007-08. In the first of these studies, field and modelling investigations were undertaken to determine the interaction between the hydrodynamic processes and sediment and bacteria fluxes and interactions. In the second study further refinements were made to the HRC’s models to study the impact of tidal stream turbines and impoundments on the overall hydrodynamic, morphological and water quality characteristics of the Severn Estuary. The outcomes of the first of these studies are comprehensively described in four EA reports (Stapleton et al, 2007a,b,c,d), which can be obtained from the EA website: publications.environment-agency.gov.uk.

Computer and Laboratory Model Details

In the modelling studies undertaken to predict the hydrodynamic, sediment transport and water quality processes in the Bristol Channel and the Severn Estuary, the Centre’s DIVAST, FASTER and HEMAT models were used, and with the Centre’s three-dimensional (3-D) model also set up for this region from previous studies (Lin and Falconer, 2001). The models
were set up for the boundaries illustrated in Figure 1, i.e. from St Govan’s Point and Hartland Head along the western boundary to Gloucester at the eastern extremity (Harris et al, 2004).

The DIVAST (Depth Integrated Velocities And Solute Transport) and FASTER (Flow And Solute Transport in Estuaries and Rivers) models are based on finite difference implicit solutions of the Navier-Stokes and solute transport equations in 2-D and 1-D and for the hydrodynamic, and sediment transport and water quality process predictions respectively (Kashefipour et al, 2002). The hydrodynamic sub-model includes the effects of bed friction, the earth’s rotation, turbulence and wind action and the solute/sediment transport sub-model includes the effects of dispersion, diffusion, decay, erosion and deposition, and adsorption and desorption, and can also model risk assessment for bathing water compliance (Harris et al, 2002).

![Fig. 1 Schematic representation of the Severn Estuary and Bristol Channel, showing the extent of the computational domain used in the numerical models](image-url)

For the 2-D model the domain covered the Bristol Channel (14,636 km²) using a mesh of 726×504 grid squares, and with a fixed grid size of 200 m ×200 m. The upstream boundary, along the line of the M48 old Severn Bridge, was 2.8 km long and was specified as a tidal velocity boundary, whilst the downstream boundary was specified in the form of tidal elevations, obtained from the Proudman Oceanographic Laboratory (POL) Irish Sea model. The upstream boundary condition included the velocities as computed from the 1-D model. For the 1-D domain, at the upstream boundary of the River Severn, a flow rate varying from 60 m³/s to 106 m³/s was used for normal operating conditions. The inflows for the rivers Wye, Frome and Little Avon, located in the 1-D model domain, were treated as lateral inflows. The 1-D downstream boundary was close to the M4 new Severn Bridge, where water level data were used to drive the model, obtained from the 2-D model. To ensure stability in data transfer between the 2-D and 1-D models, and to ensure momentum conservation, the 1-D and 2-D models overlapped for a reach of over 4.5 km between the old and new Severn Bridge crossings (Yang et al, 2002). In addition to flow and water elevation data being included at the
open boundaries, discharges and water quality constituents were included for all of the main river and wastewater treatment works along the estuary and river, as shown in Figure 2. The riverine discharges and water quality indicator levels were obtained from the Environment Agency and the wastewater treatment loads were obtained from the water companies and from typical dry and wet weather flows, based on sewer model simulations.

The HEMAT (Hydro-Environmental Modelling and Analysis Tool) model is a two-dimensional unstructured grid finite volume model, with a user friendly interface driving the hydrodynamic and water quality modules. The model is based on the solution of the same equations as for the DIVAST model and employs a second-order accurate oscillation free numerical scheme for both hydrodynamic and solute transport equations. HEMAT can simulate and predict the fate and decay of faecal indicator organisms etc. in integrated river catchment, estuarine and coastal basin systems and without the need for any linking. The model of the Bristol Channel and Severn Estuary consists of 44,407 unstructured grid cells, with the smallest grid spacing being about 40 m around the barrage site, and with the grid being about 2 km near the open seaward boundary. Details of the HEMAT grid over the domain and in the region of the barrage are shown in Figures 3 and 4 respectively.

Fig. 2 River and wastewater treatment works locations and load inputs
Fig. 3 Computational mesh used over the domain in the HEMAT model

Fig. 4 Grid refinement around the Barrage site
More recently a physical hydraulic model has been constructed in the Hyder Hydraulics Laboratory, with the School of Engineering at Cardiff University, and this model consists of a glass reinforced plastic model, constructed to a 1:25,000 horizontal scale and with a 1:125 vertical scale. The model is located within the tidal basin in the laboratory, which enables tides to be generated of any form and through the vertical movement of an overflow weir. Water is pumped into the model upstream of the weir and measurements of water elevations and velocities are taken using water level recorders and Acoustic Doppler Velocity (ADV) meters respectively, with 3-D velocity fields being measured using a sampling frequency of 25 Hz. The physical model is shown in Figure 5, together with an ADV recorder in place in Figure 6.

Fig. 5 View of the physical model of the Severn Estuary and Bristol Channel
The physical hydraulic model studies have only recently commenced and a typical set of preliminary results are shown in Figure 7 for illustrative purposes only. It is intended that the physical hydraulic model will be primarily used for computational model calibration and verification and for studies relating to acquiring a better understanding of the water quality processes and fluxes associated with diffuse source pollution.

**Computer Model Verification**

Before any computational model can be used with any degree of confidence it is desirable that the model should be calibrated and verified against field measured data. For the Severn Estuary and Bristol Channel the availability of detailed field data for model validation is limited compared to the availability of similar data for other key U.K. estuaries, such as the Humber,
Mersey and the Thames. However, a number of data sources have been used for model calibration and validation and a typical set of comparisons between predicted and measured water elevations are shown in Figure 8, for Amroth and Mumbles respectively. For comparisons between the measured and predicted velocities, obtained using the computational model, data were acquired at two sites from the Admiralty Charts and the corresponding results are illustrated in Figure 9.

![Figure 8](image_url)

Fig. 8 Typical comparison of measured and predicted tidal elevations at Amroth and Mumbles
Fig. 9 Typical comparison of tidal current speeds at two Admiralty Chart sites

**Computer Model Results**

The models outlined above were then used to undertake simulations of the velocity, sediment transport and water quality processes to predict conditions in the estuary, both without and with the Cardiff-Weston Barrage. Only this particular barrage configuration has been considered in these preliminary studies, with other barrage locations planned for consideration in future studies.

The first simulations shown below in Figure 10 illustrate the typical velocity distributions through the sluice gates and the turbines, at mean water level, for the flood and ebb tides respectively. The results show the strong currents through the sluice gates and turbines, as well
as the regions of particularly high currents in the strong wakes generated downstream of the sluice gates and turbines respectively.

Following on from these model predictions the model was then used to predict power generating curves for ebb tide generation only, with the corresponding results being shown in Figure 11. Although the model has only been used to-date for this mode of barrage operation, it is intended that future simulations might consider a range of different operating conditions, including two-way (or flood and ebb tide) generation, with pumping, and with such operating conditions offering an opportunity to explore the scope for reducing the predicted loss of intertidal habitats upstream of the barrage. These results show the limitations of operating a barrage to generate during ebb tide only, in that the peak predicted power output is 6 GW for the tidal conditions considered and with power being generated only for between 4 and 5 hr of the tidal cycle.
The models were then run for a series of different boundary conditions, including tidal heights, riverine flows, sediment and solute level inputs and various model parameters, such as bed roughness etc. For all of these simulations a series of comparisons were undertaken for various conditions, both without and with the barrage, and with the main comparisons being shown in Figures 12 to 18.

In summarising the results from these model predictions, the key findings are as follows:

- The high tide - relative to Barry - water elevations are shown in Figure 12, with the high tide levels upstream of the barrage being approximately 1 m lower than without a barrage and with the high tide levels reduced typically of the order of 20 cm for a region up to about 15 km seawards of the barrage.

- The maximum tidal currents, for each grid cell, are shown in Figure 13, with the peak currents exceeding 2 m/s over much of the main channel from a transect just seawards of Minehead to Aberthaw (i.e. the line of the ‘Outer Barrage’), to a transect upstream of the old Severn Bridge. Figure 13(b) shows that if the barrage were to be built, then the region identified within the red domain would no longer be suitable for tidal stream turbines and with this region (just offshore of Barry and Nash point) being one of the few sites deemed to be suitable for tidal stream devices within the Estuary.

- Figure 14 shows a Google Earth plot of the Severn Estuary, which identifies clearly the region of high turbidity and suspended sediment concentrations, stretching from Barry to Minehead on the seaward side to upstream of the old Severn Bridge. These high levels of turbidity and suspended sediment concentrations (i.e. in excess of 1200 mg/l) are caused by the high tidal currents in the region. If a barrage were to be built from Cardiff to Weston, then the currents in the region would be reduced, except in the immediate locality of the sluice gates and the turbines, and the corresponding suspended sediment concentra-
tions would be reduced significantly as shown in Figure 15. The much reduced high suspended sediment levels would lead to a corresponding increase in the light penetration through the water column, and particularly in the region bounded by the red line shown in Figure 14.

- The studies reported in the introduction and undertaken for the Environment Agency have shown that a strong interaction exists between the adsorption and desorption of enteric bacteria with the bed sediments and particularly those sediments known to be high in organic content. A new conceptual model has been developed by the HRC for sediment bacteria interactions and the simulations shown in Figure 16 indicate that, not only will a barrage reduce the overall suspended sediment levels within the region marked in red in Figure 14, but it will also lead to reduced bacterial levels in the water column across most of this region.

- Figure 17 illustrates the sites upstream of the barrage that are at risk from estuarine flooding under current conditions. Figure 18 shows the predicted maximum water levels for all grid cells for a spring tide and the results show that the barrage will reduce the peak levels, both upstream and downstream of the barrage; i.e. from a transect from Barry to Minehead all the way up to Gloucester. Towards the tidal limit near Gloucester the model predicts reductions in the peak tidal elevation of up to 1.5 m and immediately downstream of the barrage the corresponding peak elevation will be reduced by up to about 0.5 m.

Conclusions

The HRC at Cardiff University have recently extended their past computational modelling studies, on the hydrodynamic, sediment, water quality and contaminant transport processes in the Severn Estuary and Bristol Channel, to predict the impacts of a tidal energy provision barrage across the estuary and located from Cardiff to Weston.

Whilst there is no doubt that such a barrage will have some adverse impact on a range of environmental and ecological aspects, and particularly upstream of the barrage, the recent model studies undertaken by the HRC also confirm that there will be some positive hydro-environmental aspects associated with a barrage. In particular, there will be a general reduction in the magnitude of the tidal currents, leading to a significant reduction in the suspended sediment concentrations and turbidity levels which, in turn, will result in a corresponding increase in the light penetration levels and reduced bacterial levels in the water column. The reduced bacterial levels occur as a result of reduced inputs from the bacteria adsorbed on the sediments.

The model predictions also show that there will be reduced peak water elevations, both upstream and downstream of a barrage, with the level upstream reducing almost linearly by up to a maximum of 1.5 m near Gloucester. Hence, the results show that a barrage would reduce the flood risk to property, both upstream and - to a lesser extent - downstream of a barrage.
(a) Without barrage

(b) With barrage

Fig. 12 Predicted tidal elevations at high water spring tide
(a) Without barrage

(b) With barrage

Fig. 13 Predicted maximum tidal currents across domain
Fig. 14 Evidence of high suspended sediment levels in the estuary
Fig. 15 Predicted suspended sediment levels at mean water level, for flood spring tide
Fig. 16 Predicted bacteria levels at mean water level, for ebb spring tide
Fig. 17 Areas at risk from flooding
Fig. 18 Predicted maximum water levels at all grid cells for spring tide
References


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