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# 15 Hydrodynamic modelling of the Mersey Estuary for a tidal power barrage

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**SUMMARY**

Details are presented of the development and application of numerical hydrodynamic models for a proposed Mersey Tidal Power Barrage which have been used to support parallel energy yield, shipping, accommodation works and environmental studies. The output from these models has proved invaluable in comparing alternative Barrage layouts and in refining the design of the shipping facilities. This modelling was successfully undertaken in-house using the DIVAST basic model mounted on personal computers.

## 1 Introduction

The use of modelling techniques to study the hydrodynamics of an estuary is not new and this is particularly true of the Mersey Estuary in North West England. In 1885 Osbourne Reynolds constructed in his laboratory at Manchester University a physical model of the River Mersey which was based on scientific principles (Reference 1). It was used to study the influence of eddies on the formation of water channels and movement of sediment using a mobile bed. Following completion of the Manchester Ship Canal in 1893 another physical model, constructed by Professor Gibson also of Manchester University, was used to examine proposed improvements of the navigable approach to the Mersey and Port of Liverpool by extending the training walls in Liverpool Bay. Such walls were subsequently built resulting in an approach channel that has remained stable to this day. The use of the physical model to predict increased scour of sediment in the shipping channel was borne out.

More recently, since 1983 a series of studies has been carried out on a proposed barrage to extract tidal energy from the estuary of the River Mersey.

Stage III of these studies commenced late in 1990 and has been extended for completion by the end of this year. It is envisaged the next phase of studies, Stage IV, will carry the proposal to a final decision on approval and capital funding. This paper, therefore, reports upon hydraulic modelling which is substantially complete but has not yet been drawn to a final conclusion. These studies are being progressed by the Mersey Barrage Company ("MBC") which, in addition to subscriptions from its own shareholders, receives funding assistance from the Department of Trade and Industry (formerly Department of Energy).

The Mersey is a particularly suitable natural site for such a project having a large tidal range, 8.4 m on Mean Springs, and having a large surface area of 70 $km^2$ discharging through a Narrows of less than 2 km width.

At the outset of these studies the importance of sedimentation and hence hydrodynamic modelling was recognised since large parts of the Estuary have a sandy or silty bed. The resulting hydraulic modelling for sedimentation studies has been reported elsewhere (Reference 4). However, as the studies progressed, hydrodynamic modelling has also been required for energy yield predictions, shipping studies and environmental studies generally. This paper describes the development and results so far obtained from the latter hydrodynamic modelling.

## 2 The Mersey Barrage

The Mersey Barrage will harness the energy of the tides by retaining the tidal prism of an incoming flood tide in the basin behind a permeable controllable barrier. A potential head is created by delaying the release of water from the basin. This provides a head during the ebb tide to drive turbines within the Barrage. The net energy yield may be increased by utilising the turbines in reverse briefly after high water, pumping a volume of sea-water into the basin. This volume is later released at a greater head difference so creating more electricity than is consumed. During the flood period, flow into the basin is provided by channel sluices and the idling turbines. Channel sluices were chosen in preference to hydraulically more efficient submerged venturi sluices because of poor ground conditions.

The selected Barrage location is designated Line 3F and shown in Figure 1 between Dingle and New Ferry.

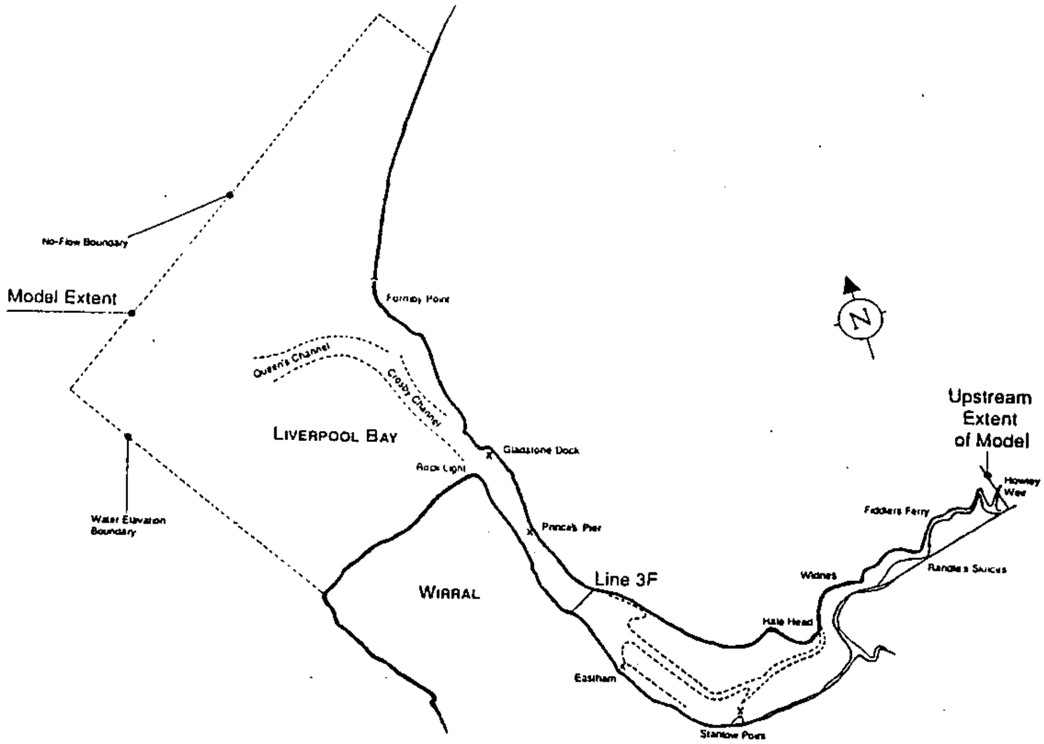


FIGURE 1 <u>Barrage location</u>

Some leading parameters of the presently preferred layout of the Barrage which has been developed through three stages of feasibility studies are given in Table 1. A general plan of this layout is shown in Figure 2 which slightly differs from that previously proposed with the smaller lock at the Liverpool shore (Reference 4).

**TABLE 1** **<u>Mersey Barrage : Leading Parameters</u>**

| | |
|---|---|
| Length between river banks | 1,900 m |
| Turbines | 28 No each 8 m diameter |
| Channel Sluices | 46 No each 17 m wide |
| Installed Capacity | 700 MW |
| Net Energy Yield | 1.4 TWh/annum |
| Peak ebb (generating) flow | 14,000 $m^3$/sec (approx) |
| Peak flood (sluicing) flow | 28,000 $m^3$/sec (approx) |
| Locks:- | 1 No 270 m x 36 m |
| | 1 No 215 m x 23 m |

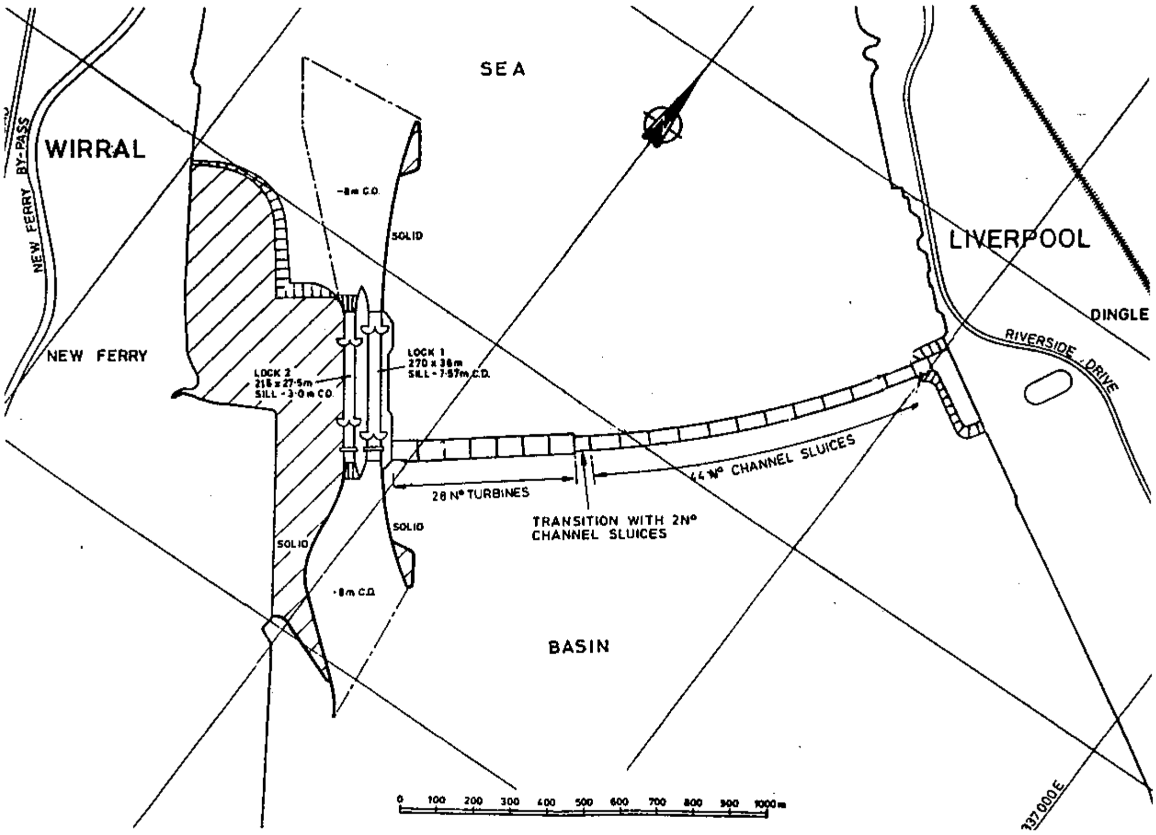


FIGURE 2 Barrage plan

## 3 Model development

### 3.1 Selection

MBC recognised the need to be a technically competent and informed Client because of the many interactions between the disciplines involved in assessing the potential impacts. The focus of these interactions is the change in tidal propagation which in turn effects energy yield, shipping and the general Estuary environment.

Therefore, it was decided to establish an in-house hydraulic modelling capability as an essential management tool allowing rapid evaluation of alternatives and providing consistent hydraulic data as required by the various specialist studies.

To meet the technical needs of flexibility and accuracy, a two dimensional ("2-D") depth averaged numerical model was required. To meet the operational needs of simple operation, ease of development and study team centralisation, a personal computer based model was preferred. DIVAST, a 2-D alternating direction implicit finite difference model developed at Bradford University (see for example References 2 and 3), was found to be suitable.

For hydraulic modelling to support sedimentation studies only, it was recognised that the two require specialist expertise in their coordination and application. HR Wallingford was retained for this work.

A DIVAST Mersey Barrage model was initially created using a 150 m square mesh size by Rendel Parkman on behalf of MBC in 1989. However, during Stage III the increasing demands of accuracy and versatility made necessary extensive further development which was undertaken directly by MBC.

## 3.2 Bathymetry

In Stage II bathymetric data was taken from a 1977 survey by the Mersey Docks and Harbour Company. A partial bathymetric survey had been completed in 1984 as part of a study by Cheshire County Council and a satellite image of the Estuary became available in 1989. These showed clear differences from the 1977 data.

Therefore, a full bathymetry survey was commissioned in 1990 by MBC and at the same time field water level and velocity data was collected. The 1990 bathymetry now modelled shows that although extensive movement of the low water channels has taken place the total Estuary volume has within a few percent remained steady at approximately 700 x $10^6$ $m^3$ over the last 40 years.

## 3.3 Boundary conditions

The model uses a rectilinear grid, which has been orientated to align with the centre line of the Barrage. To eliminate any significant effect of the Barrage operations upon the assumed boundary conditions the model boundaries in Liverpool Bay were extended seawards. In addition, the mesh size has been reduced to 75 m so that the model now contains a total of 83,000 wetted cells. Water levels are defined along the western and eastern boundaries in Liverpool Bay with no flow across the northern boundary (Figure 1). This assumption is regarded as being justified as flow data from Liverpool Bay has been shown to be mainly tangential to this northern line. (Reference 5.)

A flow rate at the tidal limit, Howley Weir, is nominally set at 50 $m^3/s$ which is the modal flow of the Mersey, outfalls and the primary tributaries in the Upper Estuary combined.

The Barrage itself is simulated by an internal flow boundary at the Barrage location. The Barrage flows are calculated by reference to the head difference across the Barrage in accordance with the predetermined operating regime and using turbine and pump performance characteristics obtained from scale model testing. In addition, the hydraulic performance of the high level channel sluices was determined by flume model tests.

The choice of internal boundary definition has meant that the flows through the Barrage are calculated explicitly within an implicit model. This can lead to instability at low head differences across the Barrage and as a consequence it was found necessary to damp the response of flow rate to change in head difference.

### 3.4 Local model

In order to provide more accurate flow patterns in the vicinity of the Barrage locks a local model with 37½ m mesh has also been developed. This model extends some 15 km from the mouth of the Narrows to a line between Eastham and Garston, approximately 5 km upstream of the Barrage. The upstream and downstream limits are level boundaries driven by output from the main model with the downstream boundary additionally having the flow orientation, though not magnitude, specified.

### 3.5 Validation

Validation was carried out against water levels and velocities measured during the 1990 survey at sites from Liverpool Bay to Runcorn Bridge. The model provides an acceptable representation of the water levels and current velocities across a range of tides. Figure 3 and Figure 4 show a comparison of predicted and measured water levels and velocities.

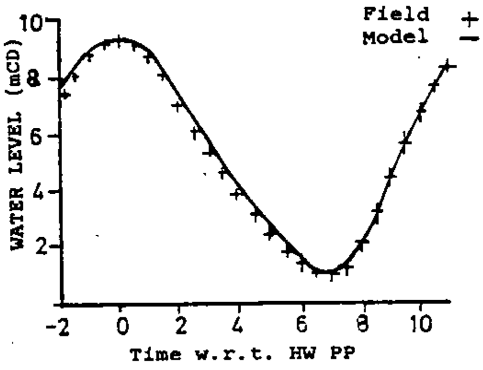


FIGURE 3 Water levels at Liverpool

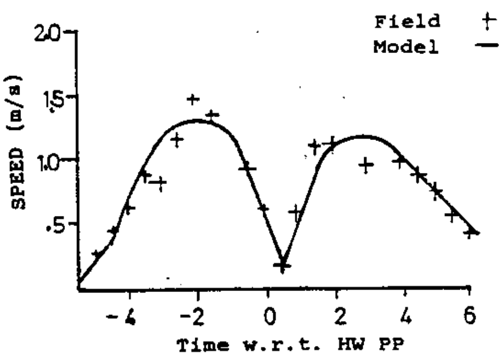


FIGURE 4 Velocities in approach channel

## 4 Model application

For its application the model boundaries were calibrated to produce five representative tides at Prince's Pier without a Barrage present; High Spring, Mean Spring, Mean Tide, Mean Neap and Low Neap.

These tides were then used to simulate a large number of alternative Barrage layouts and operating strategies. Construction stages as well as the completed structure have been examined. By this means alternatives were compared in terms of their hydraulic and consequent other impacts and the feedback obtained has allowed a progressive refinement of the preferred layout and operating regime. Some 200 model runs have so far been completed. To a certain extent these have focussed upon using the Mean Spring tide as a compromise between identifying extreme impacts and being representative. For operation and construction of the finally preferred Barrage arrangement, however, all five tides have been examined.

### 4.1 Energy Yield

To predict the annual energy yield obtainable from a given Barrage layout, MBC has separately developed a zero dimensional ("0-D") model which assumes the basin water surface level is horizontal and simulates the downstream approach channel by simple open channel flow (Reference 4). The Barrage flow algorithms it contains are identical to those in the 2-D DIVAST model, but the 0-D model is able to optimise and select its own operating regime. However, the 0-D model does not correctly predict the response of water levels to changes in Barrage flow rate and for this reason the procedure adopted to accurately predict annual energy yield is to take the optimised operating regime from the 0-D model as input to the 2-D model. Figure 5 shows the Barrage water levels and discharge rates compared to the open river values for a Mean Spring tide. The power flows are also shown. The rise in downstream water level at low water due to the continuing generating ebb discharge is apparent and this has a significant effect upon energy yield. The results for all tides are summarised in Table 2. Using the predicted histogram of tidal range frequency for a typical year (1992) and allowing for various other factors the typical annual energy yield is calculated to be 1.4 TWh with a reduction in annual tidal prism upstream of the Barrage site from 205 $m^3 \times 10^9$ at present to 170 $m^3 \times 10^9$ with an operating Barrage.

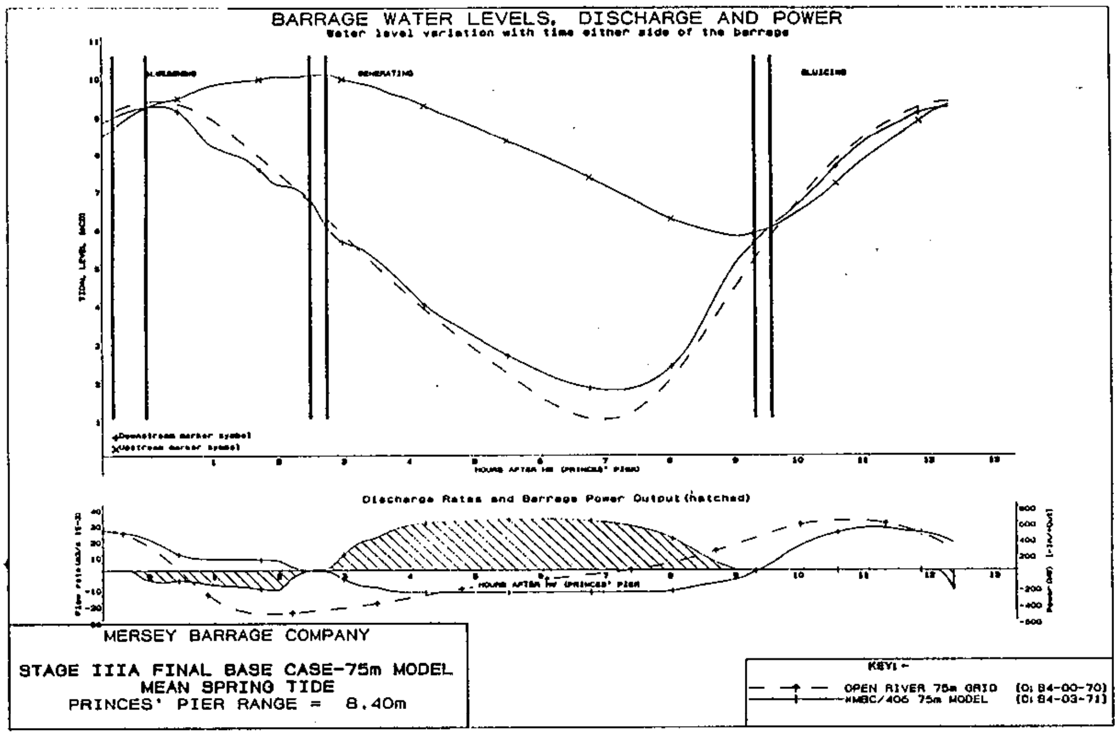


FIGURE 5 Open River and Barrage results compared

**TABLE 2 Energy yield predictions per tide**

| TIDE | PRINCE'S PIER TIDAL RANGE (m) | IMPORTED ENERGY (MWh) | NET OUTPUT (MWh) | TIDAL PRISM ($m^3 \times 10^6$) |
|---|---|---|---|---|
| Low Neap | 3.2 | 327 | 368 | 150 |
| Mean Neap | 4.5 | 289 | 860 | 181 |
| Mean | 6.5 | 229 | 1,675 | 247 |
| Mean Spring | 8.4 | 258 | 2,641 | 279 |
| High Spring | 10.0 | 71 | 3,404 | 298 |

## 4.2 Shipping

Shipping is of prime importance to Merseyside and upstream of the Barrage location are the ports of Eastham and Garston. Fundamental to assessing the impact Barrage locks may have upon shipping traffic is an understanding of the hydraulic conditions which limit lock capacity.

The local model was used to provide flow data input to a real time shiphandling simulator. In addition, comprehensive tabulated data of predicted levels and cross-currents at the entrances and approaches to locks and jetties was provided.

A typical detailed velocity field at the Barrage lock approach during sluicing for an early Barrage layout is shown in Figure 6. Strong and unacceptable cross-currents at the lock entrances are apparent. In Figure 7 the same area is shown for the final Barrage layout. Marked improvements are clear. These arise firstly from locating turbines rather than sluices adjacent to the lock so reducing the local flood velocities and secondly from the introduction of lead-in jetties to provide areas of slack water.

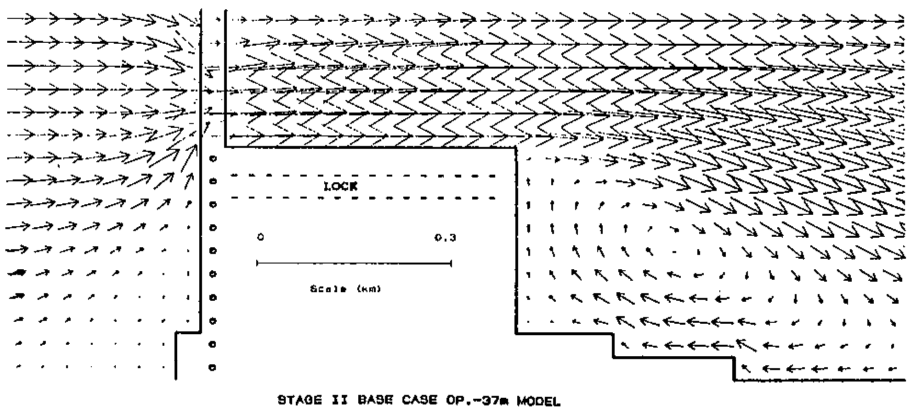


FIGURE 6 Line 3A velocity field at lock

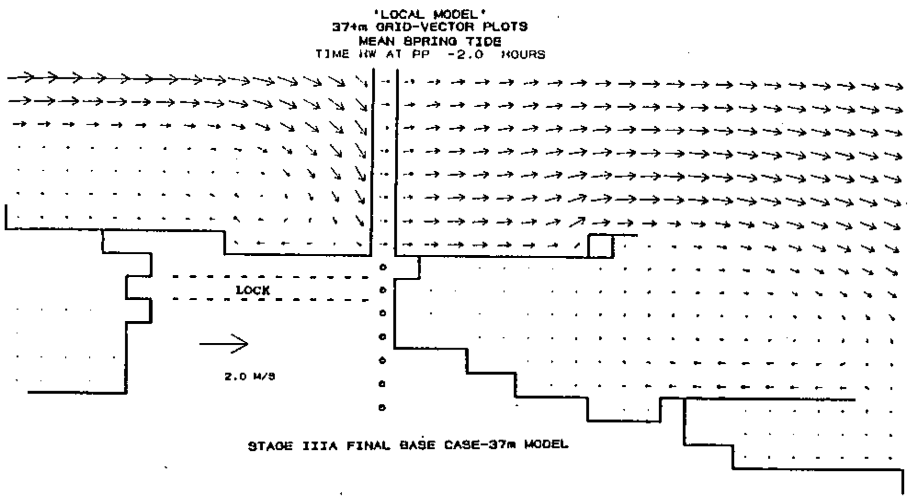


FIGURE 7 Line 3F velocity field at lock

## 4.3 Accommodation works

The accommodation works necessary because of the impact of a Barrage upon tidal propagation principally arise from flood defence and land drainage requirements, although groundwater effects must also be addressed. The principal input to these studies is annualised level exceedence graphs created for selected stations along the Estuary. Examples for stations at Eastham and Howley Weir are shown in Figure 8 and Figure 9 respectively. It may be calculated that immediately upstream of the Barrage the average water level is raised by approximately 2.5 m. This effect attenuates with increasing distance upstream, such that at Howley Weir the average water level is raised by approximately 0.5 m.

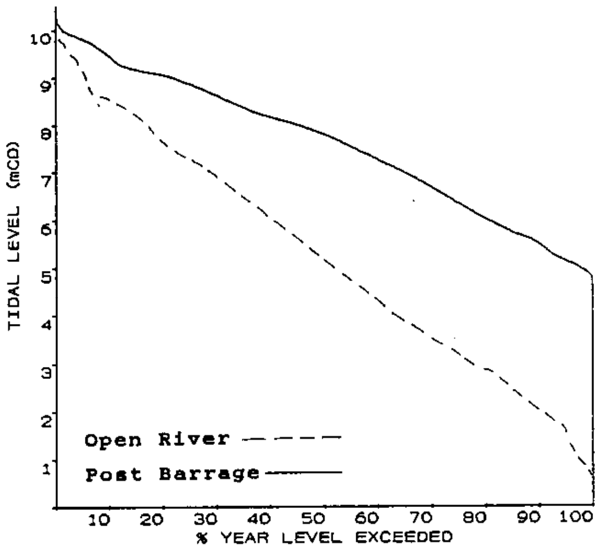


FIGURE 8 Eastham level exceedence

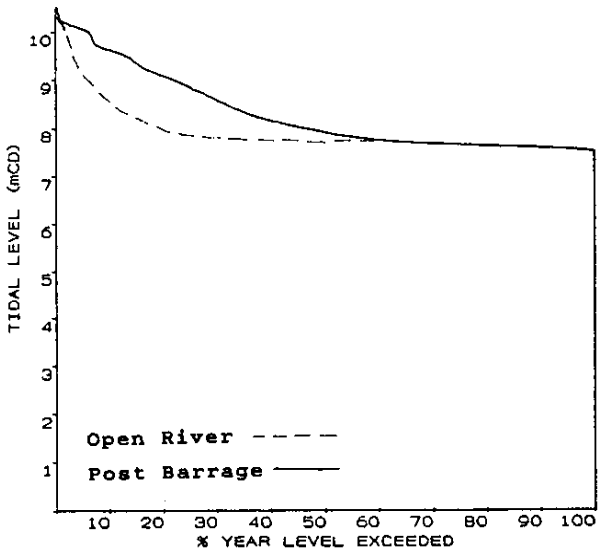


FIGURE 9 Howley Weir level exceedence

## 4.4 Environmental

The Mersey Estuary is a Site of Special Scientific Interest and in particular is currently internationally important for Shelduck, Teal, Pintail, Dunlin and Redshank which winter on the Mersey. In Figure 10 the important feeding areas in the Middle to Upper Estuary are shown. To assess the impact upon these feeding grounds, exposed area plots for intervals throughout the tide were prepared comparing the with and without Barrage predictions. An example is shown in Figure 11. Comparison to the previous figure shows that much of the intertidal area lost due to a Barrage is of little importance to wintering waterfowl, although allowance must also be made from the reduced time periods for which the remaining intertidal mudflats may be exposed.

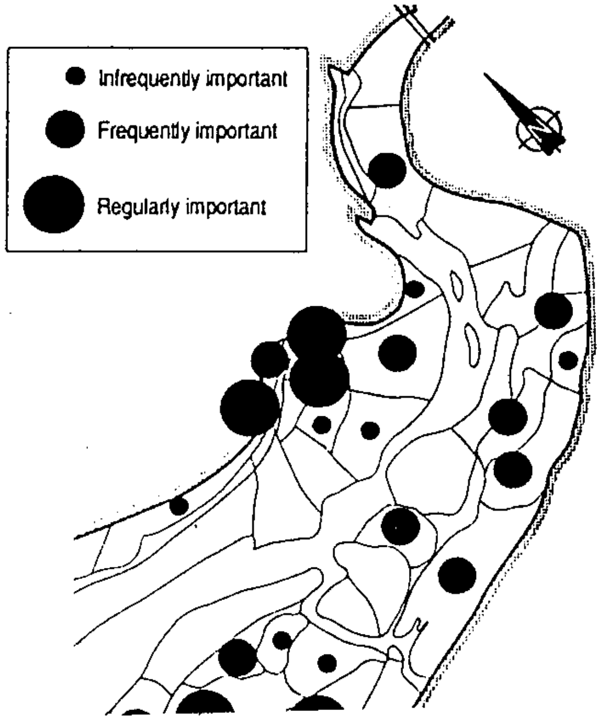


FIGURE 10 Bird feeding areas from Stanlow to Runcorn

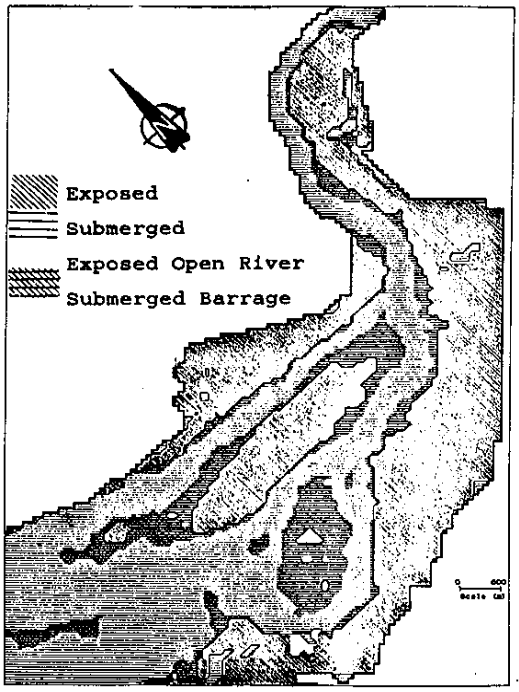


FIGURE 11 Exposed areas from Stanlow to Runcorn at HW +9 hours

Another prime environmental concern is the impact a Barrage may have upon water quality particularly since the National Rivers Authority wish to see the Mersey improve from its present status of Class 4 (badly polluted) to Class 1 (good) or Class 2 (fair) by the year 2010. Environmental Resources Limited are presently setting up on behalf of MBC the DIVAST model to simulate multiple water quality parameters.

## 5 Concluding remarks

The personal computer based hydraulic modelling system adopted by MBC for its studies has performed most satisfactorily and has endorsed the view that such a capability must be retained for future studies. Indeed it is already envisaged that developments of this system coupled with development of the in-house 0-D optimising program may eventually be used in managing operation of the completed tidal power barrage.

Nevertheless, there are significant dangers in over reliance upon the wealth of detailed output provided by such a model, simply because it is readily available and cannot easily be cross-checked.

Therefore, it is equally considered essential that outside specialist expertise should continue to be retained to provide authoritative advice in critical areas. In this respect, comparisons of detailed velocity fields from other numerical models for the same layout and bathymetry have shown noticeable discrepancies in eddy formation in the vicinity of the Barrage whilst retaining excellent level and general flow rate agreement. Consequently, it is presently anticipated that a local undistorted scale physical model may be required to provide definitive detailed flow patterns which are necessary when considering shiphandling at lock entrances. However, it is expected that all other Estuary hydraulic modelling will be numerical.

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