THE IMPACT OF BRIDGE SCOUR ON LONG-TERM ESTUARY MORPHOLOGY

JOHN HARRIS AND ADRIAN WRIGHT

ABP Marine Environmental Research Ltd, Pathfinder House, Maritime Way,
Southampton, SO14 3AE, UK. Email: jharris@abpmer.co.uk

A new bridge crossing has been proposed over the Upper Mersey Estuary, UK, to relieve the existing traffic congested road bridge. The approach adopted for this study has been to use a combination of historical evidence and state-of-the-art modelling to develop an assessment of what the likely long-term morphological changes will be due to placing a new bridge crossing within the estuary. The paper presents an overview of the historical changes, some initial results from the modelling study and highlights some of the limitations with this approach.

1 Introduction

1.1. *Background*

A new bridge crossing over the Upper Mersey Estuary has been proposed to relieve the congested Silver Jubilee Bridge connecting Runcorn and Widnes. ABPmer was commissioned by Gifford and Partners, on behalf of the Mersey Crossing Group, to undertake hydrodynamic and morphodynamic studies to assess the impact of a new crossing.

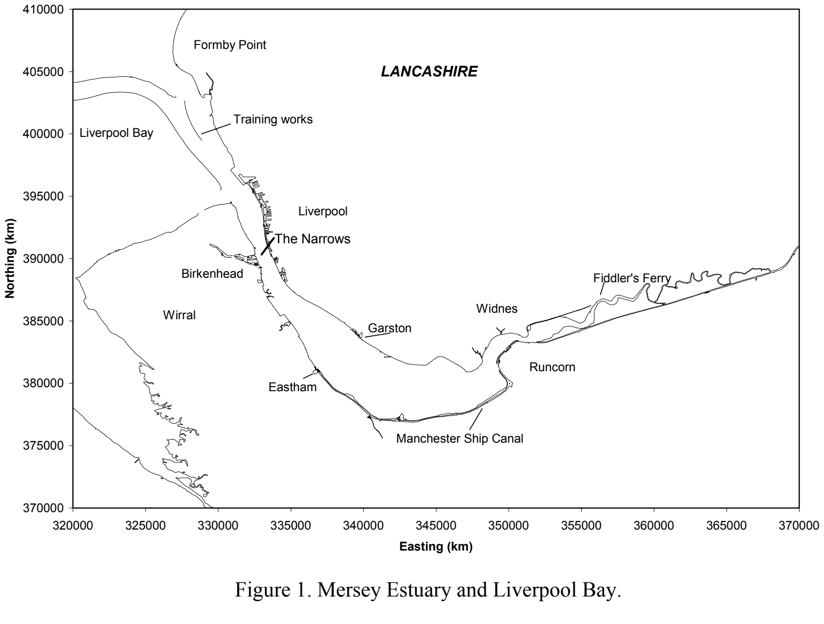

Figure 1. Mersey Estuary and Liverpool Bay.

The Mersey Estuary is located in the north west of the UK and is highly dynamic with a large tidal range (4-10m on extremes). Within the Narrows and Crosby Channel tidal currents exceed 3m/s on spring tides. At low water almost all the tidal basin dries out. In the Upper Estuary in the area of the proposed new bridge crossing (Runcorn – Fiddler's Ferry) the low-water channel meanders through large areas of sand and mud banks and is characterized by a highly mobile and active riverbed. The design of the new crossing must aim to minimize any changes to this natural dynamic process. The tidal action in this part of the estuary creates strong currents (>2m/s), which are an important part of this process. The location of the proposed crossing is also close to several environmentally designated areas.

Historically the position of the low water channel in the Mersey Estuary has shown considerable movement over the period of existing records. The current study is concerned with the impact of placing bridge piers in the upper estuary and their acting to prevent the channel from moving position.

It is essential to identify the current morphological status of the estuary to enable a prediction of how any future development will impact upon the morphology. Morphological impacts are known to spread both upstream and downstream from the point of disturbance due to the process feedback mechanisms that operate within a fluvial system. Of key importance to evaluating the future response of an estuary is the understanding of how the system responded to past alterations, both natural and manmade.

1.2. *Historic Changes*

Changes in the tidal capacity of the Mersey Estuary can be generalized to be the result of three main causes:

(1) Natural changes due to erosion and accretion.
(2) Dredging.
(3) Construction.

The latter two causes could be classified under one heading as anthropogenic changes, but for current purposes they will be kept separate.

Table 1. Construction works resulting in a reduction in tidal capacity of the Upper Estuary. (From Cashin,1949).

Works	Date	Loss (x 10^6 m^3)
Manchester Ship Canal and	1887 – 1896	3.2
River Weaver diversion		2.0
Reclamation of Tranmere foreshore	1901 – 1906	1.4
Dingle embankment	1906 – 1931	1.5
Otterspool Promenade	1926 – 1931	2.8
Bromborough Dock	1921 – 1931	
Alterations to river walls and entrances		0.4

Cashin (1949) identified losses in tidal capacity as a result of engineering works (Table 1). From Table 1 it is seen that construction works in the Upper Estuary have accounted for a reduction in tidal capacity of 11.3 million cubic metres since 1861.

Price and Kenderick (1963) undertook a detailed investigation into the reasons for siltation in the Mersey Estuary. They looked at the contribution that the training works, low-water channel movements and dredging had had on siltation in the upper estuary. They identified the importance of the meandering of the low-water channels in the erosional processes in the Mersey, providing the mechanism by which accumulations of silt are kept under control and thus preventing a progressive deterioration in the tidal capacity.

O'Connor (1987) undertook an assessment of both the short- and long-term changes in estuary capacity in the Mersey. He demonstrated that the principal source of sediment into the estuary was from sea and coastal sources in Liverpool Bay. He also suggested that the estuary did not appear to be in a state of dynamic equilibrium, although changes in the capacity were smaller in magnitude prior to 1906.

Construction of the training walls in Liverpool Bay were started in 1901 to fix the position of the main navigation channel to the Port of Liverpool. The outcome of this change was to suppress channel meandering, confining more of the ebb tide to the trained channel and leading to a strengthening of the flood tide along the Lancashire and North Wirral coastlines. Enhancement of the flood tide would have contributed to an increase in siltation in both the trained navigation channel and the estuary itself.

The construction of the Manchester Ship Canal and the diversion of the River Weaver may have brought about a reduction in the flushing capacity of the rivers causing a landward movement of the estuary's gravitational circulation to occur. Sediment trapping due to the gravitational circulation would have caused a permanent loss in estuary capacity (O'Connor, 1987).

O'Connor (1987) suggested that the Mersey Estuary was over-deepened and over-widened in the last 10-20,000 years as a result of glacial and tidal action. In the absence of engineering works, the estuary capacity would probably have reduced at a relatively slow rate. However, the result of the engineering works has been to greatly accelerate this process.

2 Methodology

2.1. *Introduction*

The study to date has been carried out in two phases. Phase I looked at a range of possible bridge layouts and alignments using a relatively coarse grid numerical model. This phase was undertaken as a comparative study making a broad assessment of the likely impacts of the various proposed bridge options. The scale of the model grid was a compromise between the number of tests to be carried out and the level of accuracy to be achieved. Bridge piers were represented in the model by the use of added friction terms. Both hydrodynamic and morphodynamic simulations were undertaken.

Based on the results of this modelling together with other selection criteria (such as the transportation study) a preferred bridge layout and alignment option was selected. This scheme (Route 3A) was then taken forward into Phase II of the study which involved carrying out detailed hydrodynamic and morphodynamic modelling.

2.2. *Hydrodynamic Modelling*

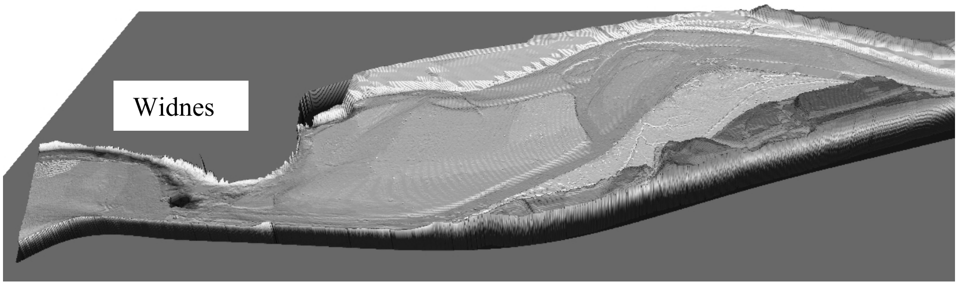

Figure 2. Bathymetry in the area of the proposed bridge crossing as derived from data collected by the Environment Agency, 2002.

Figure 2 shows the interpolated bathymetry in the area of the proposed bridge crossing. Note the scour hole downstream of the constriction at Widnes, this is due to the existing rail bridge.

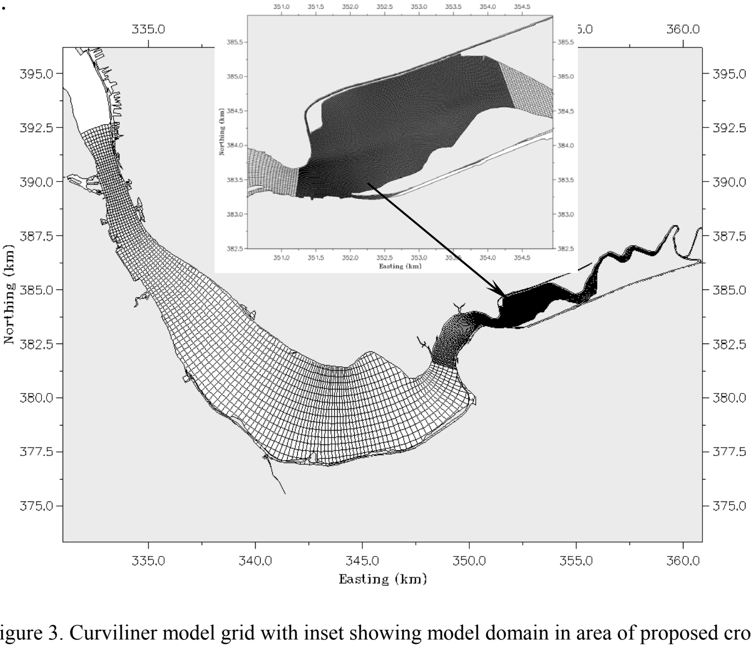

Figure 3. Curviliner model grid with inset showing model domain in area of proposed crossing.

During Phase I of the project a single grid Delft-3D model of the Mersey Estuary was configured, calibrated and validated to provide a means of assessing the local hydrodynamic regime and any associated changes due to various bridge options. In Phase II of the study a multi-domain model was set-up using the domain decomposition module within Delft-3D. The sub-division was based on the horizontal and vertical model resolution required to adequately simulate the key physical processes under consideration. Domain decomposition allows for local grid refinement in both the horizontal and vertical directions. Figure 3 shows the grid layout.

The computational grids have been set up to include the inner part of the Mersey Estuary up to the tidal limit at Howley Weir together with a tidal boundary at Gladstone Dock. A total of 57 tidal constituents were used to generate the tidal boundary conditions. Figure 4 shows a comparison of a model result against UK Hydrographic Office (UKHO) water level predictions at Eastham.

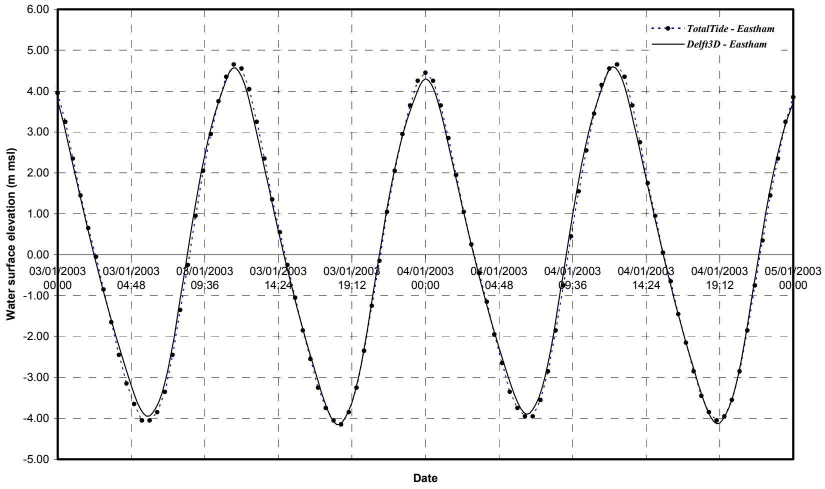

Figure 4. Comparison of water levels at Eastham between Delft-3D model and UKHO prediction.

2.3. *Morphodynamic Modelling*

It is important to understand the mechanism for the migration and switching of the low water channels. A morphological investigation of the estuary is required to assess if the placement of bridge footings in the upper estuary will ultimately prevent the ability of the channels in this part of the estuary from being able to migrate. This will be undertaken using both an assessment of the historic change and results from the numerical modelling.

Delft Hydraulics' Delft3D-Online sediment module was used to solve the transport equation for various fractions of sediment (sand and silt) within the flow calculation. This was used to determine the effect of sediment concentration on density, turbulence damping and density currents. Changes in current patterns due to the morphological changes (alterations in bathymetry) are taken into account during the flow computation. At each time-step, the transport of sediment is calculated by solving the three dimensional advection-diffusion (mass-balance) equation for the suspended sediment;

$$\begin{aligned}&\frac{\partial c}{\partial t}+\frac{\partial}{\partial x}(uc)+\frac{\partial}{\partial y}(vc)+\frac{\partial}{\partial z}[(w-w_s)c]-\\&\frac{\partial}{\partial x}\left[\varepsilon_{s,x}\frac{\partial c}{\partial x}\right]-\frac{\partial}{\partial y}\left[\varepsilon_{s,y}\frac{\partial c}{\partial y}\right]-\frac{\partial}{\partial z}\left[\varepsilon_{s,z}\frac{\partial c}{\partial z}\right]=0\end{aligned} \tag{1}$$

The bed level is updated during each time-step of the flow computation, taking into account the exchange with the suspended sediment through the vertical and the gradient of the bed load transport. Both terms can be multiplied by a morphological scaling factor and this is applied at every time-step. However, currently during Phase II of the study no scaling factor was applied. The effect of fixed layers can be taken into account, by gradually reducing the vertical exchange and bed load transport terms to zero as the sand layer thickness approaches zero.

3 Results

The hydrodynamic model was run for a spring-neap tidal cycle for both a baseline case (existing condition) and the preferred scheme layout. Difference plots were then generated (Scenario – baseline) to assess the impact of the scheme on the hydrodynamics. Figures 5 – 6 show typical output from the model for speed and bed

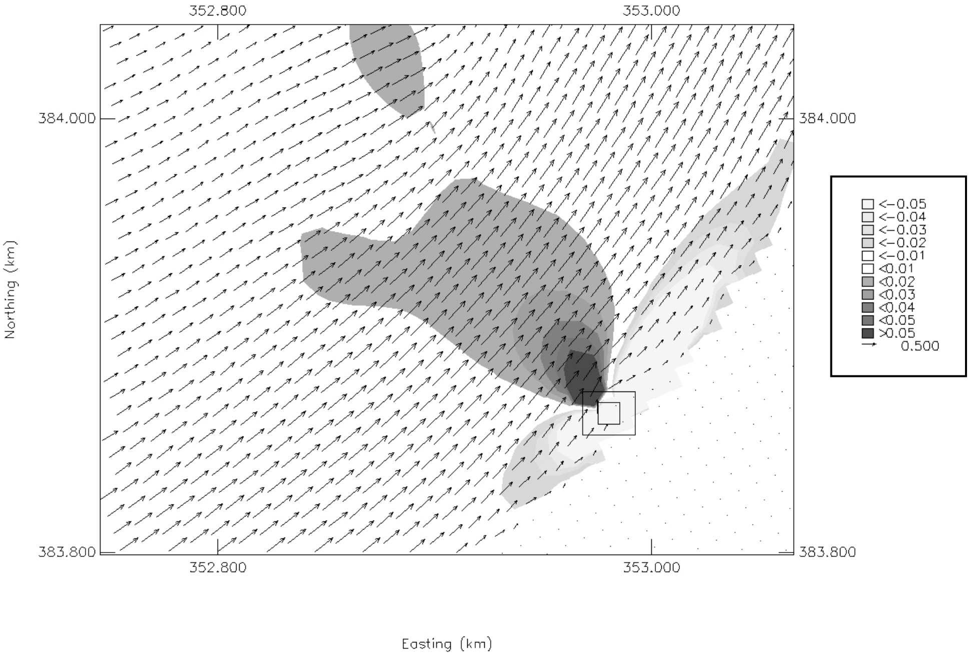

Figure 5. Plot showing differences in speed between scheme and baseline case around one of the bridge towers. The vectors represent instantaneous near-bed velocities in the scheme.

shear stress.

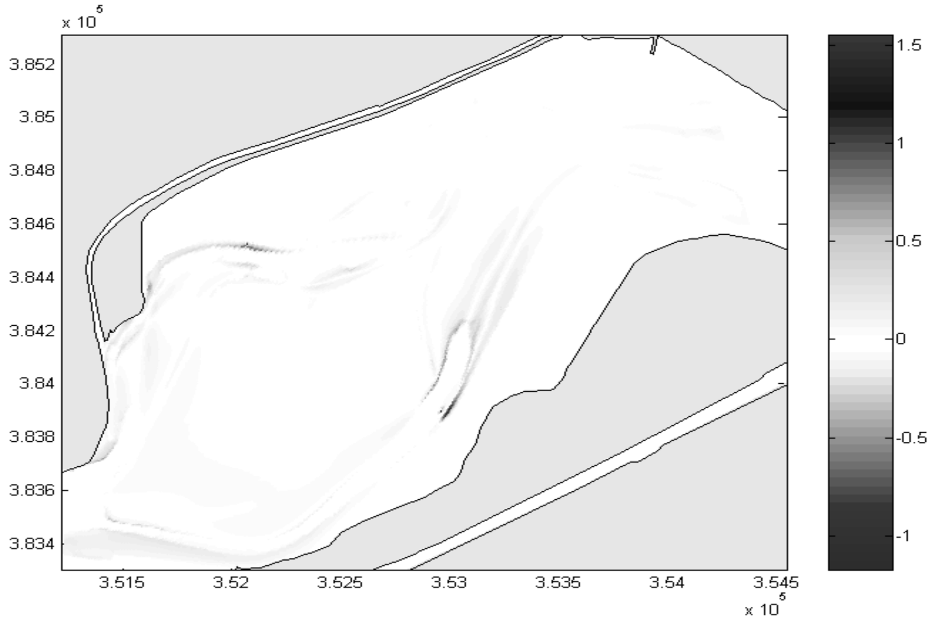

Figure 6. Differences in sediment thickness (m) between the proposed bridge scheme Route 3a Medium – operational phase scenario and the baseline over a morphological tide.

4 Discussion and Conclusions

The approach adopted here has been to use a combination of historical evidence and state-of-the-art modelling to develop an assessment of what the likely long-term changes are due to placing a new bridge crossing within the estuary.

The Mersey Estuary is constrained geologically. For example, the Narrows and the narrowing of the estuary at Widnes/Runcorn act as control points in the estuary and this appears to be supported by historic evidence. For example, the analysis of the low water channel positions presented by Cashin (1949) suggests that the construction of the earlier rail and road crossings at Widnes/Runcorn has fixed the position of low water channel through this point. This will influence the behaviour of the channels upstream of this point and may be a principal reason why the movement of the channels has been less dramatic in this area over the last century.

The hydrodynamic model shows changes local to the proposed bridge scheme. Differences in speed show the large-scale flow changes due to separation in flow around the bridge structures. However, running models of this type at this level of grid refinement is still computationally prohibitive and this is a limiting factor in this approach. In addition, morphological models are still limited in their ability to represent these long-term changes, since the mechanisms for such change maybe as a result of several physical processes, which have been ‘averaged out’ in the model set up. For example, a shift in the channel position may be brought about by a particularly low fluvial flow combined with a strong tidal flow with the flood tide breaking through the ebb channel. However, representing the exact sequence of physical processes in the morphological simulation to bring about this change is not necessarily straightforward to define.

The current approach has been to use a combination of analysis of historical records and short-term numerical modelling to create an overall view of the likely impact of the proposed bridge on long-term morphology. However, this is by no means an absolute, and still requires a certain level of "engineering judgement".

References

Cashin, J. A. (1949) "Engineering Works for the Improvement of the Estuary of the Mersey", *Journal of the Institution of Civil Engineers*, No. 7, 296-368.

O'Connor, B.A. (1987). "Short and long term changes in estuary capacity", *J. Geological Soc.*, London, Vol. 144, 187-195.

Price, W. A. and Kendrick, M. P. (1963). "Field and Model Investigations into the Reasons for Siltation in the Mersey Estuary", *Proc. Inst. Civil Engrs.*, Vol. 24, 473-518.