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Autor(en): **Pinkney, Michael / Wilson, E.A.**

Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **63 (1991)**

PDF erstellt am: **24.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-48489

Tidal Power and the Environment on the River Mersey
Energie marémotrice et environnement de la rivière Mersey
Gezeitenkraft und die Umwelt des Mersey-Flusses

Michael PINKNEY
Assist.Dir.
Rendel Parkman
London, UK

Michael Pinkney, born 1951, read Engineering Science at Oxford and obtained an MSc at Imperial College. Now assistant director with consultants Rendel Palmer and Tritton, London, he specialises in the design of marine structures. The work on the Mersey Barrage is in association with Parkman Consultants, Liverpool.

E A WILSON
Eng.Mgr.
Mersey Barrage Company
Liverpool, UK

Adam Wilson, born 1951, read Engineering Science at Cambridge. An employee of Costain Civil Engineering, contractors, he was seconded to the Mersey Barrage Company in 1987 and is presently Engineering Manager at the Mersey Barrage Company.

SUMMARY
A large tidal power resource exists in the UK and the Mersey Barrage is a promising proposal to exploit this for electricity generation. This massive engineering project would produce a clean predictable and renewable source of energy with a long life. Against the environmental benefits must be offset the costs to shipping and the local estuary environment which arise from the changed tidal regime, although scope does exist for mitigation of these costs. Consultations are essential to establish a publicly acceptable balance between the contrasting engineering, economic and environmental demands.

Energie marémotrice et environnement de la rivière Mersey

Résumé
Un site potentiel considérable d'énergie marémotrice existe au Royaume Uni et le barrage de Mersey est une proposition intéressante de production d'énergie électrique. Ce projet d'ingénierie important produirait une source d'énergie à long terme, sûre et renouvable. En opposition aux avantages pour l'environnement, il faut mettre les coûts de transport maritime et les conditions d'exploitation dans l'estuaire, qui résulteraient d'un changement de régime des marées. Une solution semble exister pour compenser ces coûts. La consultation est essentielle pour accorder les besoins divergents de l'ingénierie, de l'économie et de l'environnement.

Gezeitenkraft und die Umwelt des Mersey-Flusses

Zusammenfassung
Eine grosse Gezeitenkraftresource existiert im Vereinigten Königreich, und die Mersey-Sperre ist ein vielversprechender Vorschlag, um sie für Elektrizitätsgewinnung zu nutzen. Dieses massive Ingenieurprojekt würde eine klar voraussagbare und erneuerbare Energiequelle mit langer Lebensdauer produzieren. Gegen die Umweltvorteile müssen Nachteile für die Schiffahrt und die Oekologie der Flussmündung infolge der Gezeitenänderung aufgerechnet werden, obwohl für die Herabsetzung dieser Kosten ein Spielraum existiert. Beratungen sind notwendig, um ein öffentlich akzeptiertes Gleichgewicht zwischen den gegensätzlichen Ingenieur-, ökonomischen und Umweltanforderungen zu erreichen.

1. INTRODUCTION

1.1 Tidal Power in the UK

Renewable energy sources can reduce pollution by displacing thermal generation of electricity. In the UK, tidal power represents one of the largest available renewable energy resources and is estimated to be capable of replacing 17% of annual electricity demand [1].

Despite its beneficial effect at the macro-environmental scale each tidal power scheme must demonstrate that it does not produce environmental disbenefits at the local scale. By its nature tidal power generation produces radical changes in the estuarial environment. The most important of these are associated with a rise in the water level and modifications to tidal currents.

1.2 The Mersey Barrage

The proposed Mersey Barrage is sited in the northwest of England (Fig 1) and is currently leading in the race for large scale development of tidal power in the U.K. With industry backing, the scheme is currently being prepared for a Parliamentary Bill. As well as generating electricity the scheme will bring additional social and financial benefits to the area and it enjoys considerable local support. Navigation, business and environmental interests which would be affected are being consulted through working parties [2].

The Mersey estuary possesses characteristics which make it an attractive location for a tidal power barrage;

- the tidal range is favourable with a mean spring tide range of 8.4 metres.
- the broad upper estuary provides an upstream basin of large area.
- the basin discharges to Liverpool Bay through a narrow channel which could be closed with a barrage of economical length.

Large gated sluices in the barrage allow the flood tide to flow into the basin. During the ebb tide water is released through the turbines to generate electricity.

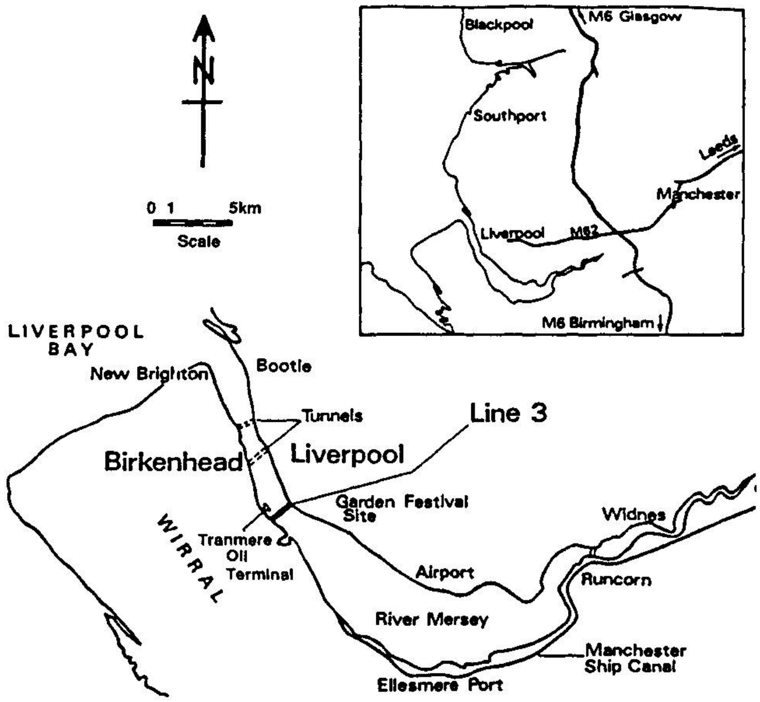

Figure 1 - Mersey Barrage Location

On normal tides it is found to be economic to pump water into the basin for a short period at the top of the tide after the sluice gates have been closed, thus increasing the volume of stored water to be released later at a greater differential head.

The preferred scheme is on a line some 2km upstream of a large and busy oil terminal at Tranmere. The barrage is some 1.7km long and 35m high in the deepest channel with an installed generation capacity of up to 700MW. Ships locking into the upriver docks and the Manchester Ship Canal have to pass the barrage.

This paper outlines the decision processes that have determined the siting of the proposed barrage, the layout of the structures and the operational constraints. The role of physical, economic and environmental factors in the design process is discussed.

2. BARRAGE DESCRIPTION

2.1 Line

Initially three possible lines were considered, line one near the mouth of the estuary, line two in the narrows between Liverpool and Birkenhead and line three upstream of the narrows. The line across the narrows was quickly rejected because there was insufficient width of river to accommodate all the necessary structures and because of the difficulty of construction access and the fast tidal currents. The downstream line was initially preferred but, being exposed, needed protection by a large breakwater to allow vessels to enter the locks.

The leisure benefits would be maximised by a downstream barrage which would provide the largest potential for water recreation and the development of disused dock areas. However Liverpool is still a busy port and the downstream line was eventually rejected primarily because of the cost of providing a sufficiently large lock to accommodate VLCCs berthing at Tranmere Oil Terminal and the uncertain environmental consequences of constructing a large breakwater. Therefore the upstream (line 3) location was selected for further development.

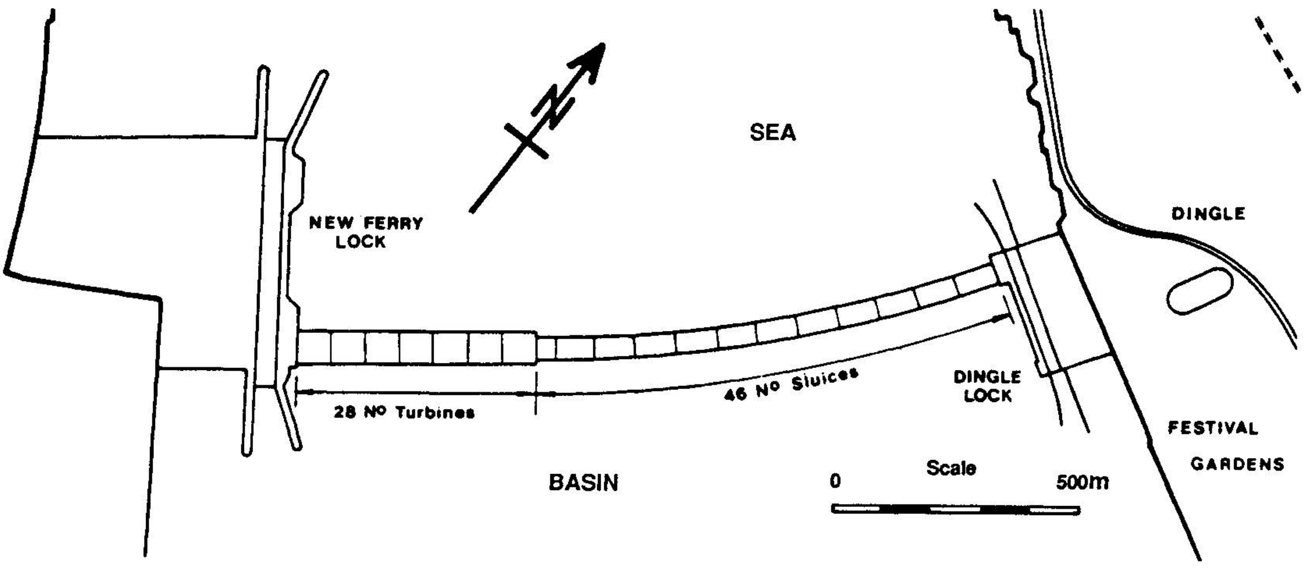

Figure 2 - Barrage Layout - Line 3

2.2 Layout

The base scheme comprises twenty eight 8m diameter turbines, forty six channel sluices and two locks (Figure 2). Twenty turbines are installed in five large concrete caissons, each containing four water passages (Figure 3). The remaining eight turbine water passages are constructed in-situ within the construction pit. All the sluices are constructed as floating caissons. Most of the sluice caissons contain four gated water passages (Figure 4). Between the sluices and the turbine generators there is a transition structure containing only two sluice passages. The sluices are founded at -9m OD whereas the turbine generator caissons have to be founded at -21.5m OD to provide sufficient submergence for the turbines. Variations to this layout are under consideration as noted in Section 4.4.

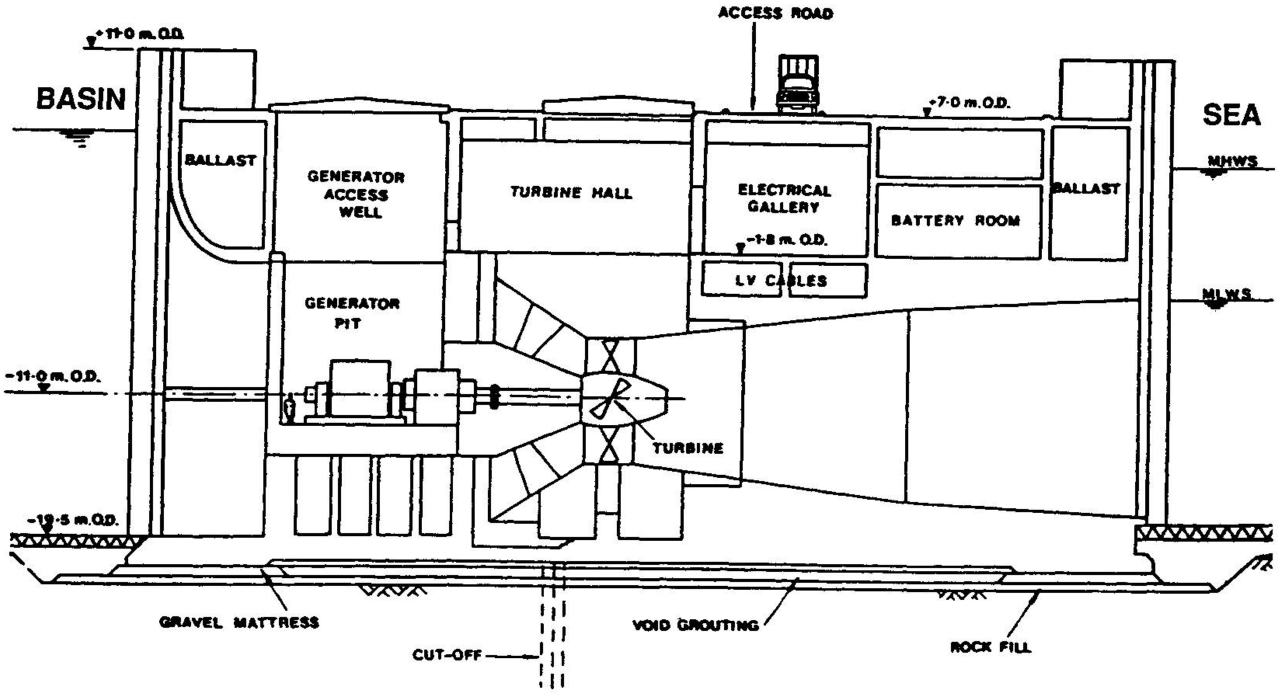

Figure 3 - Turbine-generator caisson

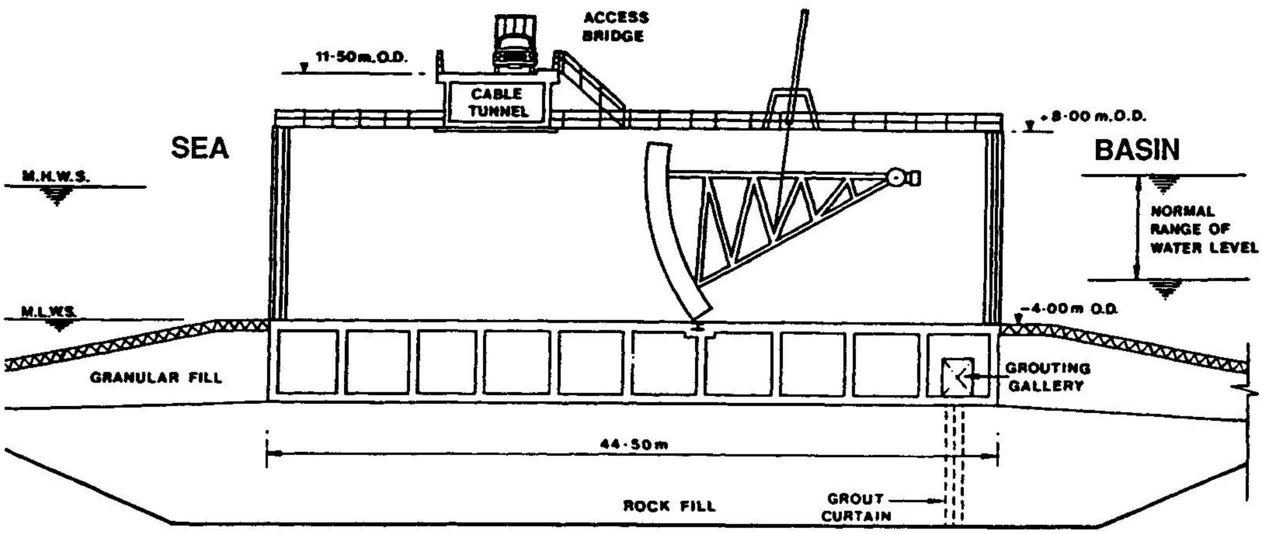

Figure 4 - Sluice caisson

2.3 Foundations

The chosen layout was designed to take maximum advantage of the limited amount of firm rock foundation available, and was identified after a seismographic survey extending some 1km upstream and downstream from the chosen line. Although sandstone outcrops on both banks the rockhead drops gently from the

West bank until at a depth of about 25m below OD, approaching mid river, it dips sharply forming a deep buried channel. The subdrift level on the eastern half of the river is very irregular with many deep holes consistent with subglacial erosion. One borehole failed to reach rock at -60m OD. The alluvial deposits are variable weak to stiff boulder clays and sands. Various schemes for founding turbine-generator caissons and deep sluices over the buried valley were investigated [3]. These included piles of various types and soil replacement but all were rejected on economic grounds. However, it was determined that shallow channel sluice structures could be founded at about -9m OD directly on the firm boulder clay and the possibility of founding smaller turbine units there is also being examined.

The foundation conditions at the chosen line threrefore effectively restricted the larger turbines to the western half of the river and the sluices, and possible smaller turbines, to the eastern half.

3. ESTUARY CLOSURE

3.1 Closure Sequence

The closure sequence of any estuary barrage is an environmentally sensitive operation and early studies concluded that the complete cutting off of tidal flows would be ecologically unacceptable. However, by installing the sluices first and the judicious use of dredging it is possible, in the case of a tidal power barrage, to maintain the existing tidal prism well into the construction phase. The aim thereafter should be that the tidal prism is never reduced below that of the operational barrage. A further restraint is that shipping access to upriver ports must be maintained at all times.

A number of schemes have been developed for staged in-situ construction of the Mersey Barrage [4] and these were compared with caisson methods. The studies concluded that in-situ construction gave a similar cost to caisson construction but with an extended programme. Caisson construction was therefore selected as the preferred method for a combination of environmental and economic considerations.

3.2 Caisson Construction Method

In the preferred method of construction all the major structures except Dingle Lock are constructed within dewatered cofferdams constructed close to the western bank. The cofferdams will enclose the New Ferry Lock and a section of adjacent barrage together with all the remaining barrage structures which are constructed as floating caissons. The cofferdam is divided to allow staged installation of the sluices, starting at the east bank. Dingle Lock has been planned to be constructed either in an existing dry dock within the estuary or in-situ as a double wall sheet pile cofferdam.

4. BARRAGE OPERATION

4.1 Operating Cycle

The proposed barrage will operate as an ebb generation barrage with flood pumping. Water levels, currents and power are predicted using a 2D hydraulic model of the estuary extending into Liverpool Bay and reducing to a 25 m grid at the barrage line. This model allows rapid evaluation of the effects of changes to the operational regime and design as well as investigation of the construction stages. A physical model at Hydraulic Research, Wallingford, has also been used.

Water levels upstream and downstream of the barrage are shown during a typical operating cycle in Figure 5 for a mean spring tide. High water downstream is almost unchanged as compared to existing conditions but low water downstream of the barrage is slightly raised. The upstream water levels exhibit a reduced tidal range with low tide at about present mid tide level and an increäse in the high water stand period.

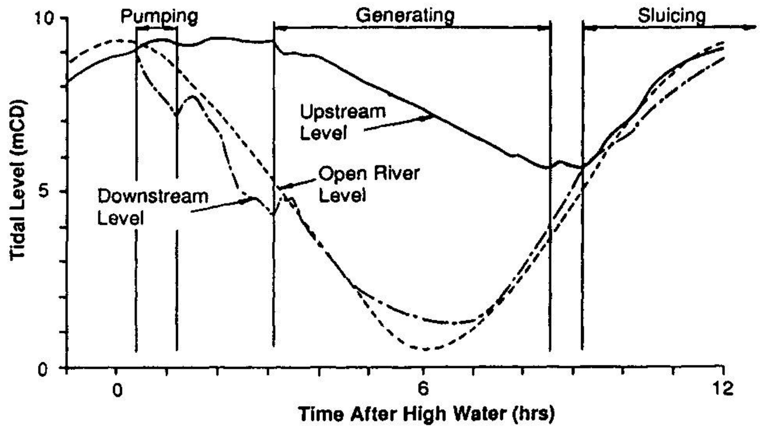

Figure 5 - Operating Water Levels - Spring Tide

4.2 Effects of Barrage Operation

4.2.1 Water Levels

The increased durations of higher upstream water levels has a direct beneficial effect on navigation, in that restrictions on access to upriver ports caused by Bromborough Bar are reduced.

The higher water levels cause some problems with land drainage and accommodation works to alleviate these effects are being studied.
The barrage could also be used to control upstream water levels and act as a storm surge barrier. This may be required as the mean sea level rises. Use of the barrage as a storm surge barrier would have a minor effect on the structural design.

4.2.2 Tidal Range

The reduction in tidal range upriver reduces the tidal prism and therefore increases retention times for effluent as well as reducing the areas of exposed intertidal mudflats which are internationally important as roosting and feeding grounds for wintering wild fowl. Those areas which are exposed only below mid tide at present would be completely submerged with the barrage operating. Figure 6 shows the effect of the barrage on the areas exposed by a mean spring tide. Figure 7 shows the relative importance of the various exposed areas to bird life. It is notable that the intertidal areas lost by barrage operation are generally of little importance. The tidal prism and the duration of exposure of the mudflats can be modified by adopting different numbers of sluices and turbines and by different operating regimes.

4.2.3 Tidal Currents

Tidal currents will generally be reduced because of the lower total flow. However, around low water, currents downstream of the turbines will be higher than at present. Not only tidal current rates but also the current directions will be modified. Figs 8 and 9 show the effect of the operating barrage on currents during a mean spring tide. The output from the 2D hydraulic model will be transferred to a ship handling simulation model to determine time windows during which access to the barrage locks is possible taking account of both draft and cross-current limitations.

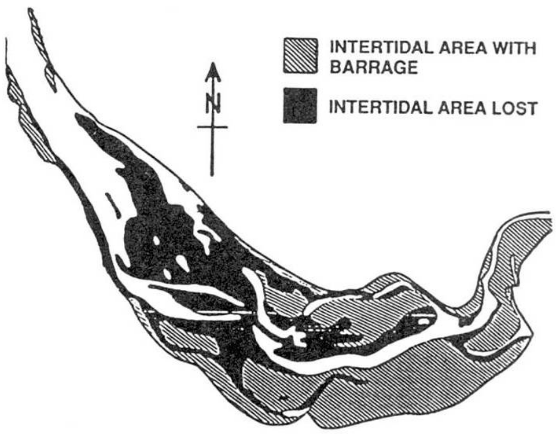

Figure 6 Intertidal Areas

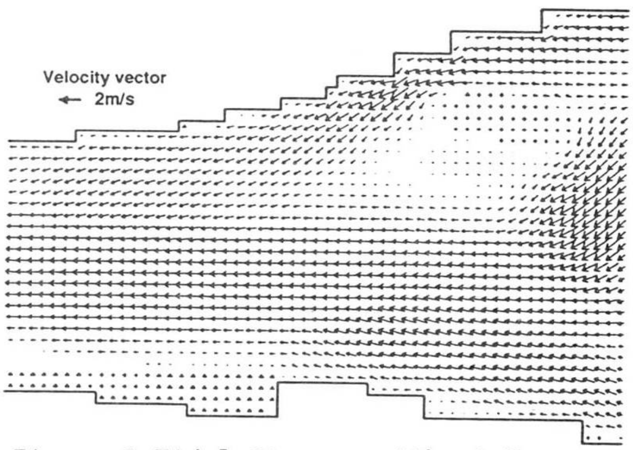

Figure 8 Tidal Streams without Barrage (HW+4 hrs)

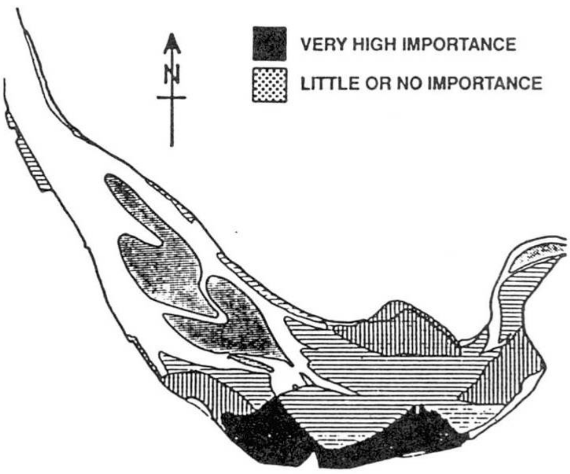

Figure 7 Relative Importance of Intertidal Areas to Birds

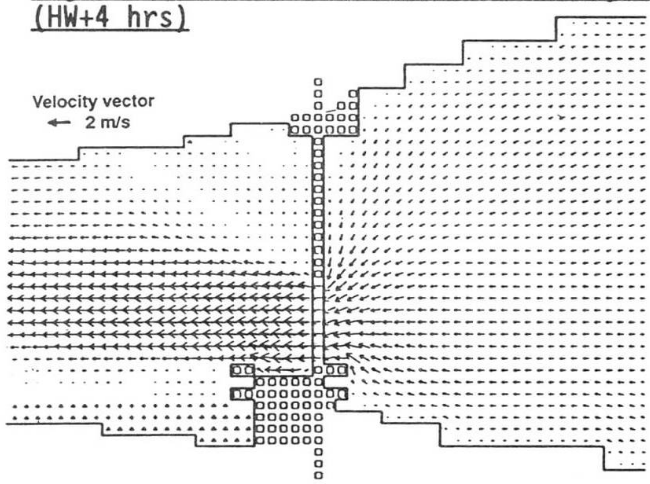

Figure 9 Tidal Streams with Barrage (HW+ 4hrs)

4.2.4 Sedimentation

Taking the complete morphological system which includes Liverpool Bay and the Mersey Estuary the barrage is expected to increase the rate of accretion of sand downstream from the barrage but reduce the accretion upstream which will become more silty. The net effect on dredging for shipping is not likely to be great. However, modelling of this complex phenomenon is at an early stage and it is too early to draw definitive conclusions.

4.3 Environmental Assessment

A preliminary stage in the Environmental Assessment process has been completed [5], [6] and further work is underway. The estuary currently has poor water quality with low oxygen concentrations although a clean up campaign has been started. The increased pollutant retention time caused by the barrage would be largely offset by the greater basin surface area and volume. The possibility of algal blooms leading to "red tides" must also be considered. There is a low fish population and a poor or impoverished invertebrate fauna. However the Mersey contains about 660 ha of saltmarsh which is important for bird roosting and feeding. Preliminary estimates [6] predict a reduction in availability of feeding grounds due to reduction in areas of exposed mudflats of 20% - 40% depending on species. However there is scope to ameliorate the effects by designing the barrage to maximise the tidal prism and hence area of intertidal mudflats by incorporating post-generation ebb sluicing and flood tide pumping into the operating cycle [7].

The environmental benefits of constructing the Mersey Barrage are considerable and must also be assessed. By displacing the generation of 1.5 TWh per annum of electricity from thermal power stations the quantity of CO_2 released into the atmosphere will be reduced by over 1 million tonnes per annum. Over the operating life of the project, which is expected to be 120 years the consumption of 50 million tonnes of coal or its equivalent may be saved.

4.4 Influence of Environmental Effects on Design

The environmental effects in the broad sense of the term, including effects on currents and water levels which affect shipping rather than the ecology will, along with certain overriding physical and economic constraints, determine the layout of the barrage.

Features currently under consideration to improve hydraulic performance and reduce environmental effects include:

- smaller diameter turbines
- lower sill levels for some sluices
- training walls
- rearranging a limited number of sluices and turbines.

5. CONCLUSIONS

Besides the more usual engineering and economic considerations many significant environmental aspects require study and consultation with the appropriate authorities when determining the feasibility of a tidal power barrage. By the use of a caisson construction method and the inclusion of flood pumping environmental impact of a Mersey Barrage may be minimised but not eliminated. Consultation is required to determine a publicly acceptable balance between the contrasting demands.

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