Study of Tital Power Projects in the UK, with the exception of the Severn Barrage

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I ■ INTRODUCTION

The UK has many estuaries with high tides, some higher than La Rance. As at Rance and other locations in France, many tide mills were built in the UK as long ago as the 12th Century. Early in the present Century, engineers from the UK, France and other countries studied the possibility of constructing major barrages to generate electricity. The Severn Estuary received close attention because of its great energy potential and its location close to industry and a large population.

However, when this scheme was actively promoted in the 1920s there was high national unemployment and the scheme was politically unpopular with the nearby coal industry who viewed it as being in competition with their power station market. This reaction also probably deterred serious interest being given to other possible schemes in the UK at that time, and it was not until the sharply contrasting circumstances of the 1970s arrived that the country again seriously considered the energy potential of its tides.

By that time the Rance scheme had been commissioned and was generally working well. However, a new factor had begun to emerge, namely concern about the environmental consequences of all forms of development, including power stations. The effects of the Rance project were, of course, considered when it was being designed, though much of the basic scientific information needed to make predictions was not then available.

Etude des projets marémoteurs en Grande-Bretagne, à l'exception du barrage de la Severn

La Grande-Bretagne comporte plusieurs estuaires pouvant être équipés de barrages et d'usines marémotrices et plusieurs projets ont été étudiés entre la fin des années 60 et la privatisation de l'industrie électrique en 1989.

Cinq projets se sont révélés plus prometteurs que les autres :

— l'estuaire de Conwy au nord du Pays de Galles, pour lequel l'étude a conclu que la réalisation n'entraînerait pas trop de problèmes écologiques,

— Duddon, un peu plus au nord, qui n'apparaît pas comme intéressant sur le plan économique,

— Loughor, au sud du Pays de Galles, de petite taille, pour lequel on n'a pas fait d'études poussées de conséquences écologiques,

— Mersey, près de Liverpool, le plus important projet (700 MW) qui a le plus de chances d'être réalisé,

— l'estuaire de Wyre, entre Duddon et Mersey, pour lequel le coût semble prohibitif.

Les conditions économiques au tournant des années 80 sont largement responsables de l'absence de construction de ces usines, le coût de production du kWh étant perçu comme deux fois plus élevé que s'il provient d'une centrale classique. Evidemment, ce coût tient compte des mesures à prendre pour la protection de l'environnement.

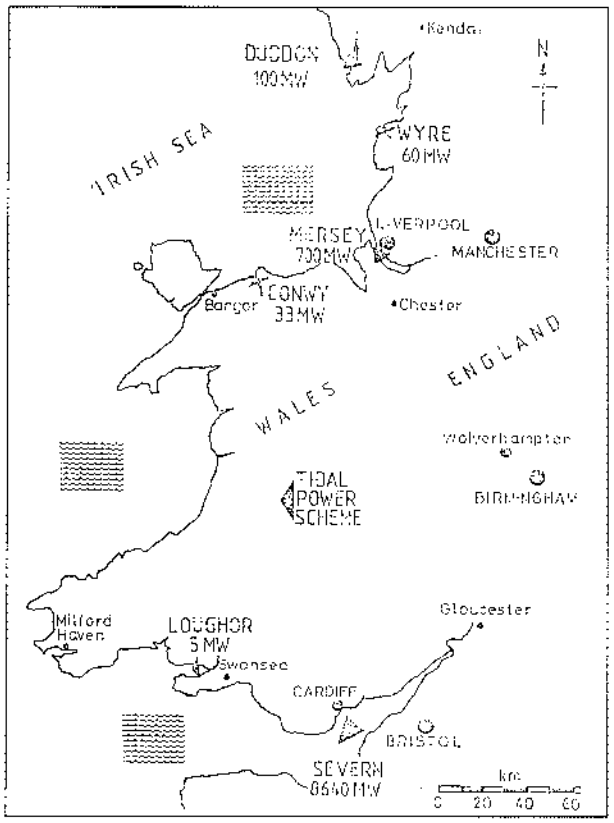
The Maritime Laboratory at Dinard, which has been and remains so prominent in monitoring and assessing the results of the Rance project, contributed much to those studies. In the UK, lack of a similar reason to study estuarine ecology in the context of tidal power meant that this subject was not seriously pursued until completion of Rance stimulated interest in the ecological effects of the Severn scheme in the late 1960s [1].

The UK's interest in tidal power increased steadily from that time until its electricity industry was privatised in 1989. Since then, the economics of harnessing this source have remained unfavourable, a situation unlikely to improve until either the basic cost of producing fossil fuels or the environmental cost of burning them change radically.

During the 20-year period of the 1970s and 1980s, the UK Government initiated investigations of the technical, economic and environmental implications of tidal power barrages in many of the UK's more suitable estuaries. The bulk of this work centred on the large project which has been favoured for the Severn Estuary since the mid-1960s. However, many smaller schemes in other estuaries were also studied, initially in outline [2].

The five projects shown to be most promising were then studied in more detail. Their names, locations and expected power outputs are given in *figure 1*. They are all on the west coast of the UK, where the highest tidal ranges occur. The largest of the five schemes is on the Mersey Estuary in Liverpool, and the smallest is on the Loughor Estuary in South Wales. The main difference between these schemes is the size of the basin created by the barrage, hence the volume of water which would pass through the turbines.

The results of the UK studies show that there is a strong correlation between the energy and economic potentials of tidal power barrages. Furthermore, although the smaller schemes are arguably less environmentally damaging than the larger ones, their effects on a unit-energy basis cause concern.



1. Genral location of various sites

The purpose of this paper is to outline the work done on these five schemes. The results of the more comprehensive studies carried out for a Severn Barrage are described in the previous paper presented at this Conference by Dr. Kirby.

II ■ SOME BASIC PHYSICAL CHARACTERISTICS

It is generally known and understood that the design of the Rance Barrage was influenced by the fact that it was promoted in the 1950s when the electricity network in Brittany was relatively weak. However, by the time it was commissioned in 1996, major developments to the network to support France's expanding nuclear programme were in progress. Similar growth in the UK's electricity network was also taking place at that time, though the resources available meant that this was based on the coal, oil and nuclear industries rather than on nuclear alone.

The situation facing the design of tidal barrages in the UK in the 1970s was therefore quite different from that confronting the designers of the Rance scheme in the 1950s. As a result, the design of the British and other more recent tidal schemes is not like Rance. Instead of two-way generation and two-way pumping, the technically simpler, more economic but less versatile one-way system involving ebb generation and, probably, flood pumping has generally been preferred. These systems are illustrated in *figure 2* and show that, compared with Rance, the simpler system gives :

— a smaller but more consistent range of water levels in the basin ;
— a lower high water level ;
— a more regular tidal rhythm.

One of the principal tasks of the Rance Barrage was to provide a platform for research into all aspects of tidal power. To do that it was essential that it could be operated flexibly over a wide range of pumping and generating scenarios. The fact that, as a result of early research, the ebb generation and flood pumping modes are now most often used has been recognised in the studies of possible barrage schemes done in the UK and elsewhere.

There are several reasons for this preferred method of operation. One is economics. Another is that Rance has shown that the environmental effects of a tidal power scheme depend on its design and how it is operated. The variations in water levels and currents which then occur compared with those of the natural regime and the resultant changes to salinity and sediment movements are clearly affected to a significant degree by the design of a scheme and how it is used. As a result, the UK's preference for ebb generation (with or without pumping) means that the tidal regimes of the British schemes which have recently been studied would be affected as follows :

— the water level in the deeper part of the basin area would not fall below the former mid-tide level ;
— any pumping would be limited to that which would create a maximum level similar to the astronomic maximum in the main basin area (The higher natural astronomic levels which occur further upstream would therefore be reduced because the responsible surge effect would be smaller) ;
— high (and low) tide levels immediate seaward of the barrage would be slightly reduced (increased), these effects diminishing with distance seawards ;
— the strengths of the currents would generally be reduced but close to the turbines and sluices could be increased ;
— the directions of the currents near the barrage would be changed but otherwise would be little affected.

These hydrodynamic implications for the tidal regime have many environmental consequences. Also important is the effect of the presence of a barrage on the wave climate in the estuary because this is likely to influence the sediment regime and its associated ecosystems along coastal margins.

Mathematical modelling techniques allow these changes to be predicted accurately. It is straightforward to add salinity into a model, and the same techniques permit the dispersion and degradation of effluents from point and distributed sources to be simulated.

Sediment movements can also be predicted by models, though non-cohesive sands are more readily represented than fine-grained cohesive muds. Studies of the pre-barrage current and wave regimes will help to explain the locations in which fine sediments occur, but a detailed knowledge of the structure of the material present in any estuary will be needed to give confidence in forecasts of with-barrage conditions.

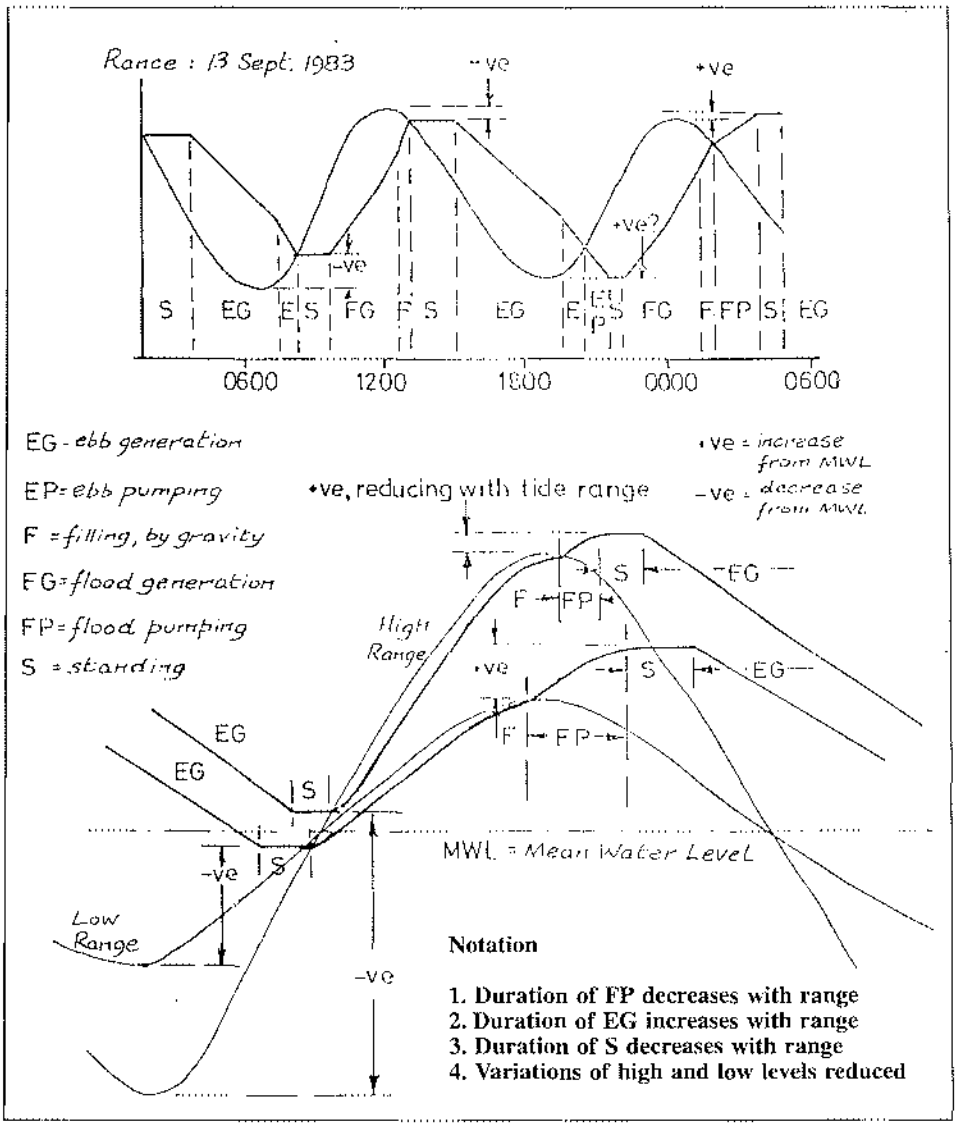
III ■ ECOLOGICAL EFFECTS OF FIVE PROPOSED UK BARRAGE PROJECTS

Figure 1 shows the locations of the five projects (excluding the Severn) reported here. The schemes are shown on *figures 3-6*. The physical effects of each project would be as given in Section 2. Each estuary has extensive sand deposits towards its seaward limits, with fine sediment in more upriver and sheltered areas. The wider estuaries (e.g., Conwy and Duddon) are more exposed to wave action, hence their sediment regimes mainly comprise sand : fine material is more localised. The Mersey is similar towards its seaward limit but, because the site proposed for that barrage is well upstream within the tidal river reach, the environment which it would affect is principally muddy. The sites of the other two barrages are mainly sandy.

3.1 Conwy Barrage ([3], *fig. 3*)

The historic town of Conwy looks out over the Conwy estuary from within a fine stone wall. Its castle occupies a prominent location beside the estuary and is popular with visitors. The setting of the town and estuary have been nationally recognised as an « Area of Outstanding Natural Beauty ». The location chosen for the barrage would make it a feature within this setting. Its design and operation had to recognise this constraint.

In addition to the tidal conditions referred to in Section 2, the Conwy Estuary is low-lying and hence subject to flooding from a combination of high tides and large river flows. The barrage study made the assumption that the scheme must not increase this risk. However, *figure 2* shows that although a barrage need not raise high tide level landward of



2. Working curves at la Rance tidal power station.

the barrage, it will increase the time for which high water is maintained. In order not to magnify the risk of flooding, action would have to be taken to release water early from the basin when river flows are high.

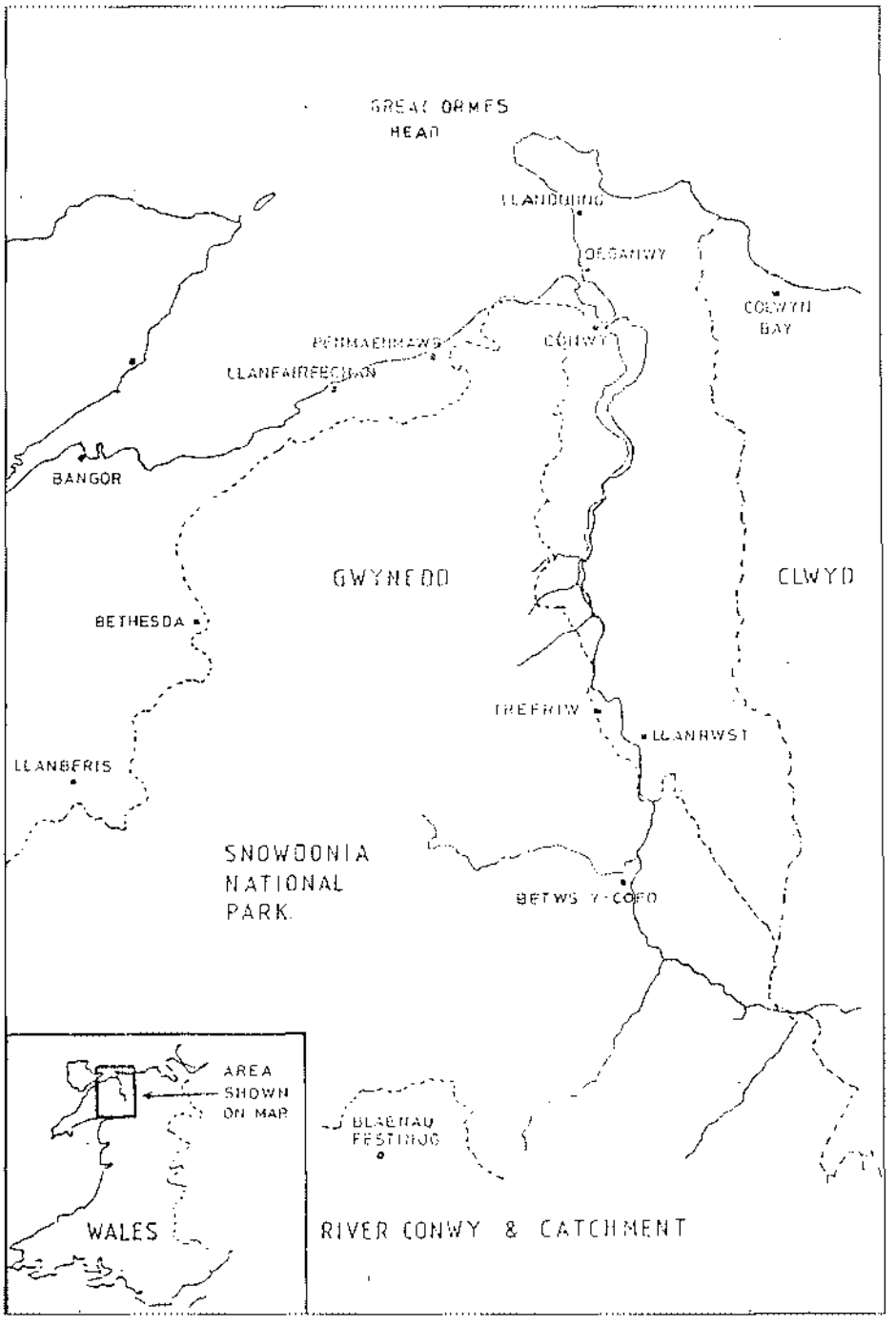
The low-lying areas around the Conwy Estuary rely upon gravity drainage to maintain a reasonable water table level. The efficiency of the existing drainage system would be threatened by extended high tide periods. If this efficiency is not improved, a barrage would raise the water table in these areas. Some pumping would be needed to maintain the *status quo*.

Although sand is predicted to enter the basin from seaward, it was estimated that it would take about 200 years for half the capacity of the basin to be filled. This estimate does not take into account the way in which storms mobilise existing banks of sand in the outer estuary and how this would be redistributed.

The barrage is predicted to cause a small rise in the average salinity of the basin, though the salinity of the coastal margins is projected to decrease. The concentration of dissolved oxygen is forecast to fall slightly, and there would be a small improvement in other water quality parameters.

The scheme may inhibit the development of saltmarsh in the estuary due to the reduction of tide range though, with the exception of redshank (*Tringa totanus*), this estuary is not of national importance for sea-birds.

The Conwy is an important river for migratory salmonids. The design of the barrage therefore includes fish-passes to



3. Conwy estuary.

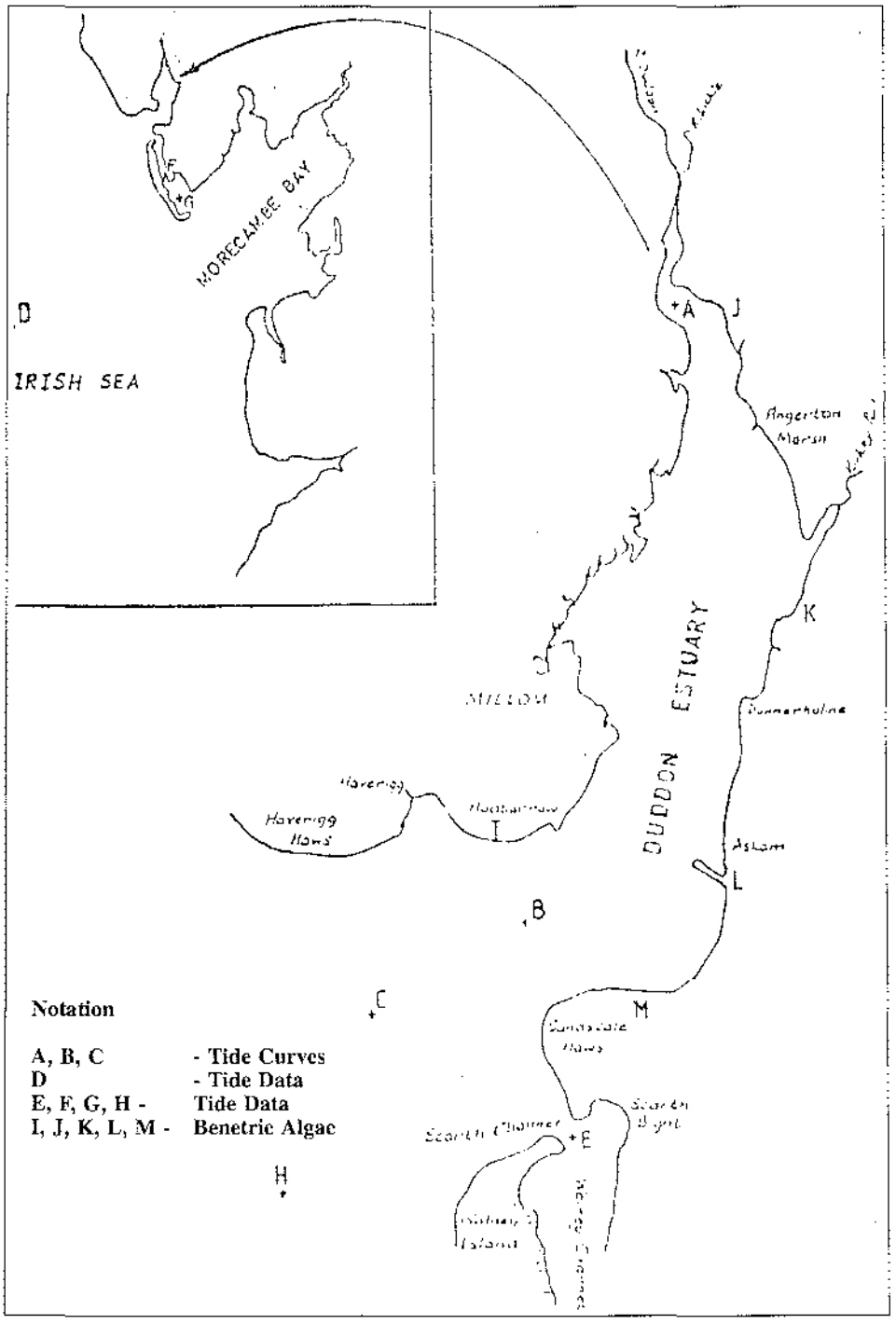
assist movement at specific phases of the tide. The design of these passes also allows them to assist emptying and refilling the basin. It is proposed that the ebb-flow turbines are screened to prevent adult fish from passing through them.

The study concluded that there were no serious environmental constraints on the project and that the issues which deserved more careful attention and resolution could be dealt with at the detailed design stage. The estuary is well suited to a tidal power scheme and this need have no permanent adverse effects.

3.2 Duddon Barrage ([4], *fig. 4*)

The physical characteristics of this estuary are also similar to those outlined in Section 2. Its sediment regime is essentially sandy, fine sediments only occurring in sheltered areas protected from the currents and wave action. As at Conwy (and Rance), the amount of fine sediment occurring at sea bed level in this estuary is small, hence the levels of turbidity caused by its suspension are also small and localised.

The preferred location of the barrage is also towards the seaward limit of the estuary due to the need to locate the tur-



4. Duddon estuary.

bines in adequately deep water in positions closely connected with the sea. However, at this location the estuary is much wider than is needed for the turbines and sluices, hence much of the length of this barrage is necessarily made up of embankments, a large proportion of which would be in very shallow water.

Most of the area of this shallow estuary landward of the barrage is reduced to a central channel at low tide. The sands responsible for much of its geometry are mobilised by the currents, and the near absence of fine material in the sand means that they do not support a significant biomass. Only the protected areas which lie closer to high tide are significantly productive, and these would remain intertidal though differently exposed through the tide cycle.

The water quality of this estuary is generally good. The main contaminant in solution used to result from radioactive waste discharged from the nearby reprocessing plant at Sellafield, but these levels are now much reduced. The river catchment is also not now a significant source of pollutants.

The estuary supports significant populations of sea-birds, mainly for feeding though some species also roost and nest in the extensive saltmarshes which feature over much of its periphery. The effect of the modified tide range on the productivity of these feeding grounds will depend on their elevation within that regime and how its sediment composition will change.

Although the study was unable to reach a definitive position on this important issue there was reason to conclude that, because the currents would be less strong and the area more protected against the severe wave action which mobilises material, the fine sediment fraction and hence the capacity of the intertidal area to support invertebrates and therefore birds and fish could be expected to increase.

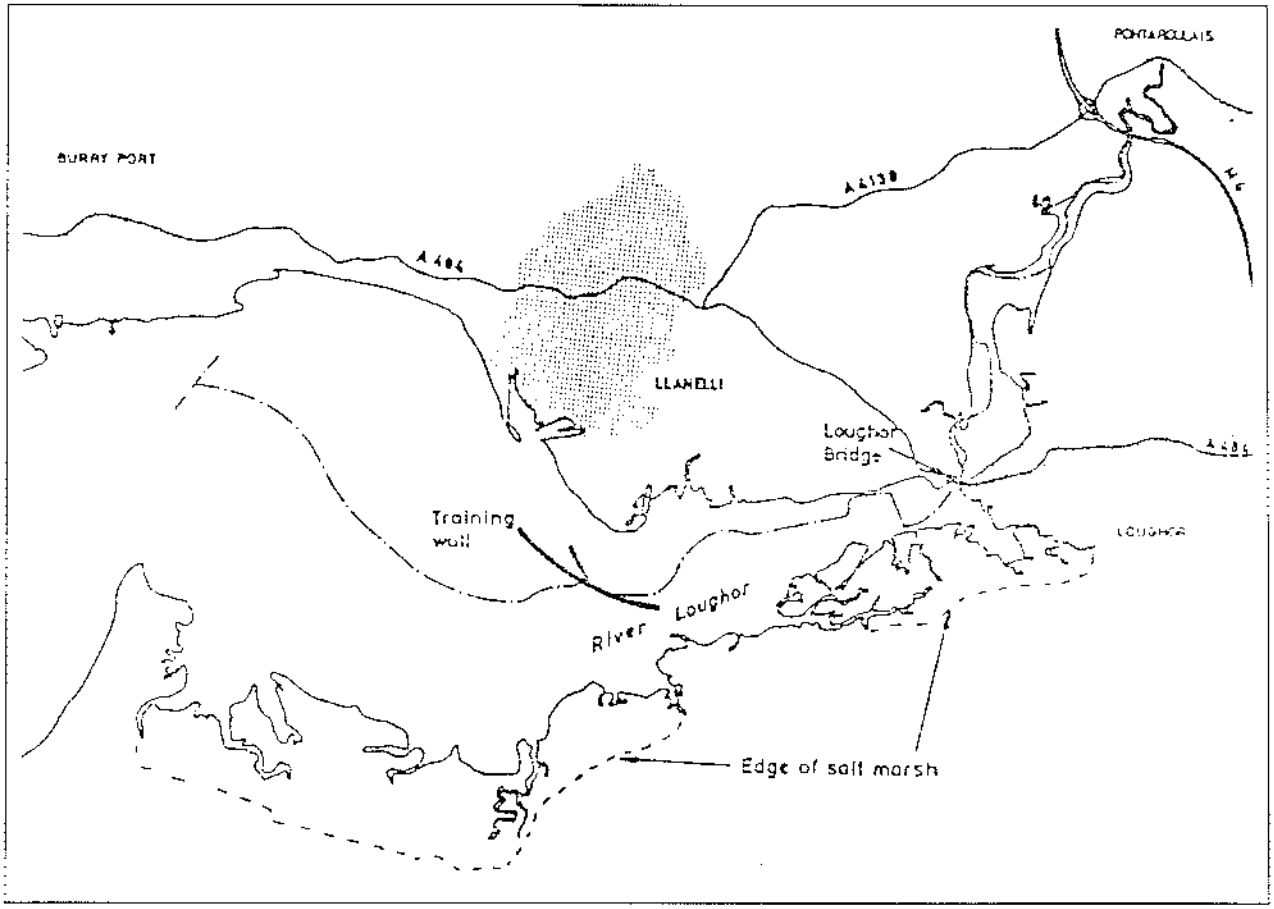
The study concluded that it was premature to decide whether special provision should be made for fish passage through the barrage. When this study was being carried out in the early 1990s, the UK Government and other UK agencies were involved with detailed investigations into both fish mortality in turbines and means to deter them from entering these machines. Since the results of that work were clearly likely to influence decisions on these topics, there was no case for speculating about them in the conclusions to the study.

However, the study clearly established that the capital cost of the Duddon Barrage would not make this a commercially viable project for power generation against the criteria which applied at that time (and since). Furthermore, the other facilities which it could provide for the area were insufficient to make up the considerable economic shortfall.

3.3 Loughor Barrage ([5], *fig. 5*)

The economics of the tidal power scheme proposed for this estuary were adversely affected by its small size (about 5MW), and its prospects were further damaged by proposals to maintain a high water level in the basin so that the area could be used for recreation and amenity purposes.

The possibility of allowing the basin level to vary more during the winter in order to increase the energy produced during those months was assessed but no agreement on this was reached.



5. Loughor estuary.

The environmental consequences of reducing the amounts of water passing across the barrage line were studied briefly. It was concluded that some adverse effects on water quality in the basin area could arise but these and the prospects of increased sedimentation (sand) in the basin were not quantified in detail.

3.4 Mersey Barrage ([6], *fig. 6*)

The tidal power scheme proposed for the Mersey Estuary was, and perhaps still is, the most likely to be constructed in the UK. It is large enough (700 MW) to benefit from economy of scale, and by being located in a relatively narrow (1 900 m) waterway it is not burdened by the cost of unproductive embankments. Its layout therefore has much in common with the Rance project.

Furthermore, it was envisaged that by locating the scheme close to the middle of Liverpool (on the north side of the estuary) and Birkenhead (on the south side), it would also create significant infrastructure and amenity benefits. One of the most difficult issues to resolve proved to be the effects of the scheme on commercial shipping in the estuary.

The site finally selected for the barrage sought a compromise between both business and social issues and the particular ecological interests in the estuary which the scheme was predicted to affect. As was noted in Section 2, by being well upstream from the mouth of the Mersey Estuary, the sandy regime which, as elsewhere, features in the seaward reaches of this river is replaced by the more typical muddy conditions found in many river estuaries (including the upper reaches of the Rance Estuary above Pont St Jean).

As a result, this barrage would be located within a zone of high turbidity, where the water column is partially mixed (some salinity stratification) and where relatively large intertidal areas significantly reduce the width of the estuary at low tide.

The water quality of the estuary is generally poor due mainly to the heavily industrialised catchment of the River Mersey and its tributaries. Large discharges of organic wastes, trace metals and micropollutants are the principal contaminants, one result of which is low dissolved oxygen levels. The need to improve this situation has been accepted by the responsible authorities and major investments in remedial works are now being made.

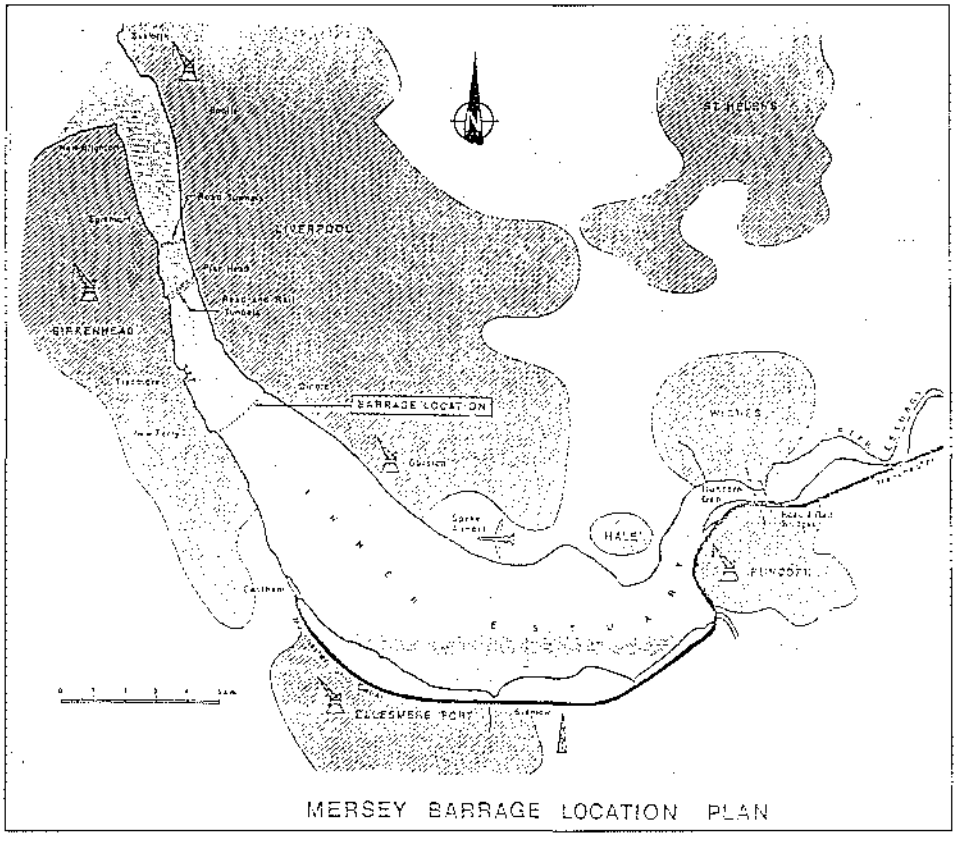
The high turbidity of the estuary is only partly due to pollution. It is mainly caused by the erosive capacity of strong currents on the unconsolidated fine sediments which (as noted above) are a feature of many inner estuaries. By generally reducing the currents (Section 2 above), the barrage would stabilise much of this material, allowing more sunlight to enter the water column, increasing phytoplankton productivity from its present very low level.

The poor water quality of the estuary means that it does not support significant fish populations, hence it is not an important spawning area or nursery ground for juvenile fish.

However, the estuary is of substantial national and international ornithological importance due to the presence of suitable sand and mudflats, also saltmarshes. These support five wader and wildfowl species in internationally significant numbers, ranking the Mersey in the UK's top three for overwintering wildfowl.

The inner estuary is judged to warrant designation as a « Ramsar » site and an SPA under the EC's « Wild Birds Directive ».

The proposed barrage is predicted to have a profound though by no means wholly unbeneficial effect on this regime. The main physical changes are expected to improve the water quality, but some remedial works to specific discharges additional to the general improvements now being made will be necessary to counter possible adverse effects.



6. Location of the Mersey barrage.

The major ecological implication of the barrage would be its anticipated impact on sea-birds. This is because important feeding areas would be made less accessible by the change in tide regime, both the overall area and the time for which this is exposed being reduced. It is also anticipated that the floral composition of the saltmarshes could be changed with consequences for feeding and grazing, and these areas would also become less available for roosting.

Much further research is needed to quantify the possible ecological changes identified in the initial studies. The opportunities open for mitigation measures also remain to be assessed and optimised. However, no further work is at present being carried out. Environmental considerations are one of the reasons why it is not being pursued. Economic and infrastructure factors were also prominent reasons for deferring further work.

3.5 Wyre Barrage [7]

The Wyre Estuary displays a similar sand regime to that in the Conwy and Duddon Estuaries, which also occurs at the mouth of the Mersey Estuary. The proposal to locate a barrage close to its seaward limit means that, like Conwy and Duddon, this would be within the sandy regime rather than upstream in the more muddy zone as for the Mersey scheme.

The hydrodynamic forces needed to keep the body of the Wyre Estuary clear of fine sediment are also sufficient to ensure that the sand is at times highly mobile, a situation which again resembles that at the other UK estuaries studied here, as well as at Rance. The barrage would reduce this movement and thereby produce a more stable and ecologically productive regime.

There are some concerns about water quality in this estuary but these are being dealt with as part of general improvements to the UK's coastal environment. The barrage would not significantly worsen the situation which is expected to exist at such time as the project could be constructed.

The estuary is used by some migratory seabirds though these are generally not statistically important, and both salmon and sea trout also pass through in small numbers. The changes in foreshore submergence and invertebrate distribution may affect bird roosting and feeding but the study concluded that there are acceptable local options to any loss of existing opportunity.

Uncertainty about the effects of turbine operation on fish passage led to the proposal that diversion systems guiding fish to passes should be installed.

As for the other schemes, small changes in salinity are expected and the possibility that locally raised water tables might make it necessary to install pumps to drain affected area were again features of the solution proposed for this project.

Further work on this project was deferred due to the unacceptable cost at which it would produce energy.

IV ■ CONCLUSIONS

The economic conditions which existed in the UK at the turn of the 1980s were principally responsible for the decision to curtail work on all of the tidal power projects reported here. The gap between the cost of producing electricity from the tides compared with that from the established sources was typically in the ratio 2 :1, though the larger Mersey (and the even larger Severn) scheme came closer to being commercially viable.

Ecological issues received careful consideration in all of these studies, indeed it may be true to conclude that this aspect of tidal power projects made more progress during the 10-year period of the UK studies than any other. The fact that concerns were voiced about the effects of each scheme confirms the perceived importance of estuarine environments for ecosystems. However, it must be equally true to conclude that the lack of proper evidence about these ecosystems and how they would be affected by the modified tidal regimes created by barrages prevented many of these concerns from being dealt with positively.

With the exception of the Mersey project *(fig. 6)*, the four schemes covered in this Paper (and the Severn) are in estuaries which have much in common with Rance. Furthermore, by being close to the mouth of its estuary, the Rance Barrage is similarly located to these four proposed schemes. Their tide ranges are all high and they are to varying degrees exposed to wave action.

However the UK studies made surprisingly little reference to experiences at Rance despite their need for real information. I suspect that this was because it was quite wrongly believed that Rance had little to offer because of the way in which the barrage was constructed and the fact that it is equipped with two-way turbines generally not favoured in the UK in the 1980s.

If this is so it is totally at odds with my stimulating and beneficial association with the Rance project, which dates from shortly after it was commissioned. In particular I have benefitted greatly from many visits to and discussions with the staff of the Dinard Maritime Laboratory, without whose guidance we would be much the poorer.

In particular, I cannot conclude from the available evidence that tidal power inevitable damages estuarine ecosystems. Yes, there will be changes, and some features of the resulting environment will inevitably not please everyone, especially those for whom any change will be a cause for concern.

However, there is surely little reason to conclude from Rance that tidal power schemes cause severe and intolerable damage to the environment, though it must be asked how the Rance scheme would now be designed and operated to meet the environmental criteria of the 1990s with the benefits of the knowledge which has come from it ?

Notwithstanding the lessons from Rance, we still have much to learn before we can have confidence in our predictions of the effects of tidal power schemes according to their designs and how they are constructed and operated. We cannot therefore expect conservation interests to accept our recommendations about the consequences of projects and how any adverse effects may be minimised and offset by mitigation and compensatory measures.

Unfortunately, in the UK at least there is little immediate sign that funding sources are available to support this work because the tides continue to be viewed as an expensive energy option. This was also the case prior to the 1970s, but once the situation reversed as a result of the oil « crises » there was immediate pressure for results and little time for considered thought and research. Tidal power will fail to play its fair role in meeting world energy demands until a more far-sighted view is taken.

The one bright prospect is that Rance continues to generate invaluable information. Where would tidal power be without it ?

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