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Sedimentological implications of building the Cardiff-Weston barrage in the Severn Estuary

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A feasibility study is currently in progress into one of the major potential renewable energy resources in the UK, namely harnessing of the tides in the Severn Estuary for the purpose of generating electricity. It is clear that such a scheme is technically possible and that foundation conditions are unlikely to lead to undue problems. However, one of the major factors which will determine whether the scheme is feasible is its likely environmental impact. The estuary has a high mobile sediment population and the principal environmental change arising from construction will be to the suspended and deposited sediment regimes. The sediments consequently have a wide impact, extending from their influence on aspects of barrage design itself, through navigation, dredging, coastal stability, land drainage and recreational beaches to water quality and all aspects of the estuarine ecosystem. The impact upon higher organisms will extend to fish, birds and to man himself. The impact of the latest design on this broad range of issues is assessed.

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Introduction

Tidal power goes part way to satisfying one of man's Utopian dreams for an inexhaustible, free, and non-polluting energy source with negligible impact upon the surrounding environment. Whilst the energy source is indeed inexhaustible and non-polluting, the cost of harnessing the power-source, by building a barrage, is such that it can hardly be regarded as free. Similarly, the impact upon the natural environment is larger than that of many other energy sources.

Tidal power is believed to be one of the more promising prospects of the alternative energy programme currently being funded by the UK government. The scheme receiving the largest attention is that to investigate a barrage across the Severn Estuary, roughly on a line from Weston-super-Mare to Cardiff, a site which offers the greatest potential of any in Europe. It would involve building a barrage 16km in length across some of the most hostile waters ever faced by a major civil engineering scheme.

Such a barrage would cost close to £5.5 Billion at 1984 prices, generate somewhere between 6 and 9% of the national electrical energy needs and be equivalent to at least 2 of our major nuclear power stations. The cost of generating power from such a scheme is calculated to be not dissimilar to that from nuclear sources and domestic coal.

The present phase of studies is due to end in late 1988 and the programme is charged with establishing whether any major problems are likely to arise such that the scheme would be impractical or prohibitively expensive. Should current studies prove that the scheme is feasible, a further 3.5 years of study and design would lead to a decision to construct, should the government agree. The timescale for construction is estimated at 9 years with the result that an operating barrage cannot reasonably be envisaged much before 2005.

Three major problem areas are being investigated during the present phase; optimisation of the plant itself, study of the foundation conditions and an assessment of the environmental impact of the scheme. The greatest degree of uncertainty attaches to predicting this latter aspect.

Constructing a barrage will alter the hydrodynamic regime over a large area, both above and below the barrage. Many factors are directly linked to the hydrodynamic changes, which will be of large scale (Keiller 1987). For example, the tidal range inside the basin will be halved, tidal current velocities will fall by a similar amount and the rise in mean water level will lead to more than half of the existing tidal flats being permanently covered. However, as a result of the power law relationship between current velocity and its carrying capacity, by far the greatest influence will be upon the sedimentary regime (Kirby 1988 in press). The quantity of fine sediment transported on spring tides will decrease from more than 30M to about 2M tonnes in the area above the barrage (Kirby 1986).

As a result the sediments have an almost all pervasive effect upon the scheme. Their relevance ranges from many attributes of the design of the barrage itself, through land drainage, coastal stability, amenity beaches, navigation, dredging, to water quality and including invertebrates, birds and fish (Shaw 1987). To understand what the effects of the barrage are likely to be, it is necessary to know something of the present sedimentary regime and the proposed barrage itself. This knowledge must then be used to forecast the effect of the barrage upon the regime.

Present sedimentary regime

The Severn Estuary is well known for the large amounts of fine sediment perpetually cycled between its bed and the water column (Kirby and Parker 1983). Indeed, the present ecosystem of the estuary, unlike any other estuary in Europe, is suppressed owing to the high and variable suspended load and the mobility of the bed sediments (Kirby 1988 in press).

Thus is may seem contradictory to point out that perhaps the most notable feature of the sedimentary regime at present is the relatively small quantity of sediment contained within the estuary. Fig. 1 shows the existing sediment distribution, from which it is apparent that large areas of the bed of the Bristol Channel are bare rock, whilst in the Severn the unconsolidated sediments are generally only a thin veneer above bedrock (Evans 1982). This limited amount of sediment probably results from the strong currents typifying the area.

Within this regime non-cohesive sediment circulates from a bedload parting extending between Minehead and Abertaw (Stride 1963). To the west, sand is apparently moving westwards towards the shelf-edge, whereas to the east it is moving inexorably into the Severn Estuary. In contrast, fine grained sediment is circulating chiefly between source and sink areas in Bridgwater Bay (Parker and Kirby 1982) and is constrained by oceanographic factors to reside chiefly close to the English coast (Fig. 2) (Kirby and Parker 1982).

It is across these two sediment circulation systems that a barrage will be built and the present studies are attempting to predict how these will be influenced by construction.

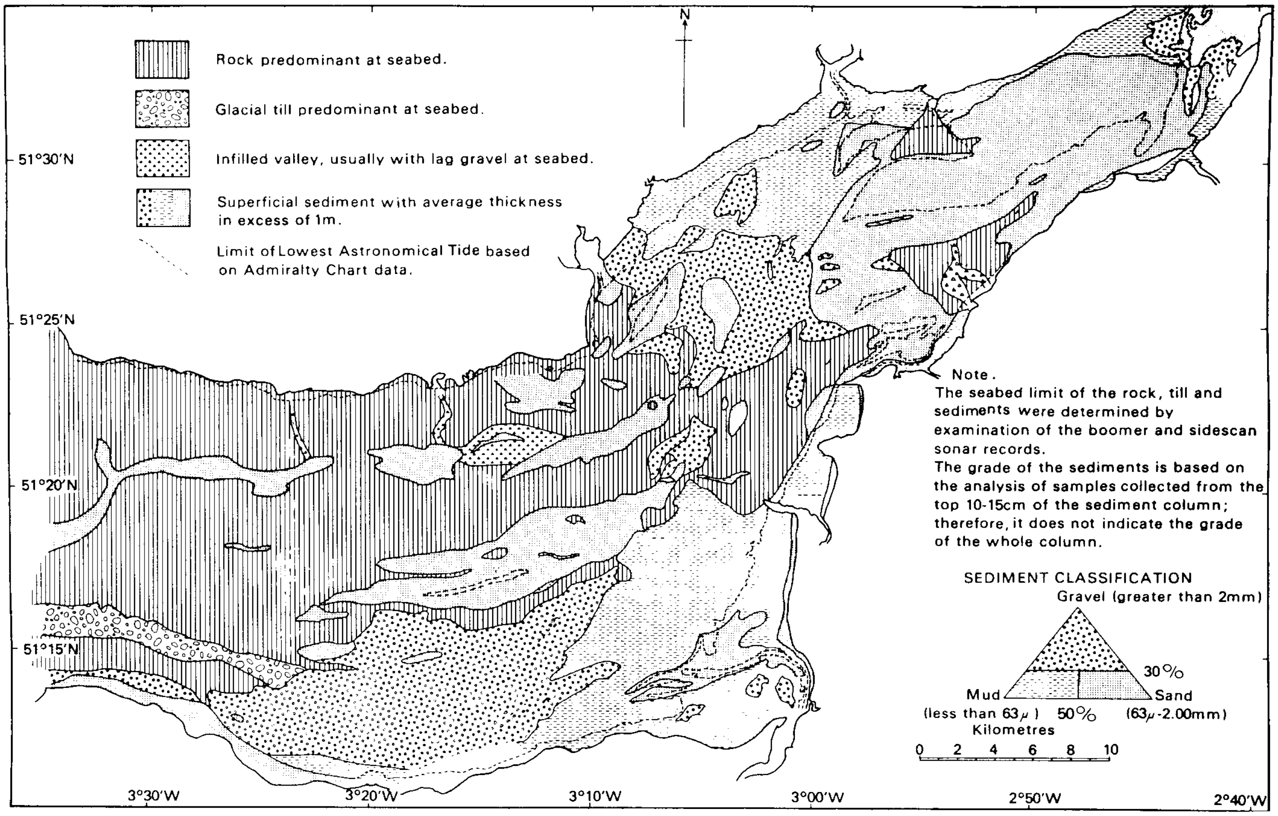

Figure 1. Map showing distribution of superficial sediments in the Inner Bristol Channel and Severn Estuary. Extensive areas in the Bristol Channel are bare rock whilst the depth of superficial sediment cover in the Severn is frequently limited (after Evans 1982).

Barrage design

The present design envisages the use of initially-open prefabricated sluice and turbine caissons (Kerr et al. 1987) (Fig. 3). It is intended that these will be constructed in facilities similar to those used for large gravity structures in the oil industry. The completed caissons will be towed-in from their construction yards and sunk to form the barrage line. Three types of caisson will be required, those to contain the turbines, those to carry the working sluice gates to allow filling of the basin and also the temporary, initially-open caissons.

Many aspects of the design, including the orientation, construction sequence, as well as the construction method, have a major influence upon the sedimentary regime. This construction technique has been developed partially to satisfy many of the sedimentological demands posed by the extremely mobile and erodible regime. The construction technique, reminiscent in some ways of that devised for the Mulberry Harbours used on D-Day, will result in a complete crossing of the estuary being achieved whilst the water is still free to flow through the barrage. In this way it is envisaged that the minimum disturbance to the flows will lead to the smallest influence possible upon the sedimentary regime during the prolonged construction period. When the scheme is brought into operation the temporary sluice gates will be permanently sealed and the turbines and operating sluice gates will begin working. At this stage electricity generation will begin.

Impact of construction on the sedimentary environment

In terms of their impact upon the environment, three quite separate phases can be identified:

1. The construction period, during which the main concern is to minimise fine sediment erosion and redistribution. The timescale is approximately 9 years.
2. The closure period when the scheme is brought into operation and the main concern is deposition. The timescale will be short but remains to be established and is an important element of the design.
3. The post-closure sedimentary regime which will develop over months or years.

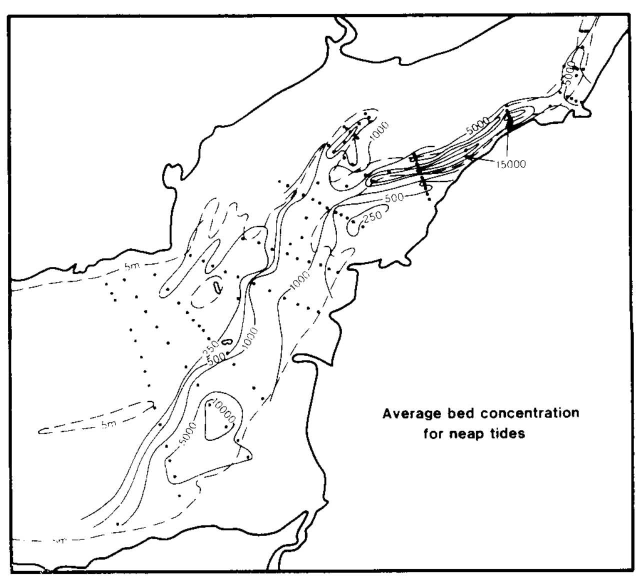

Figure 2. Map showing the average bed suspended solids distribution in the Inner Bristol Channel and Severn Estuary on a neap tide. Notable are the extremely high concentrations and the fact that the high turbidity zone is constrained to lie along the English coast.

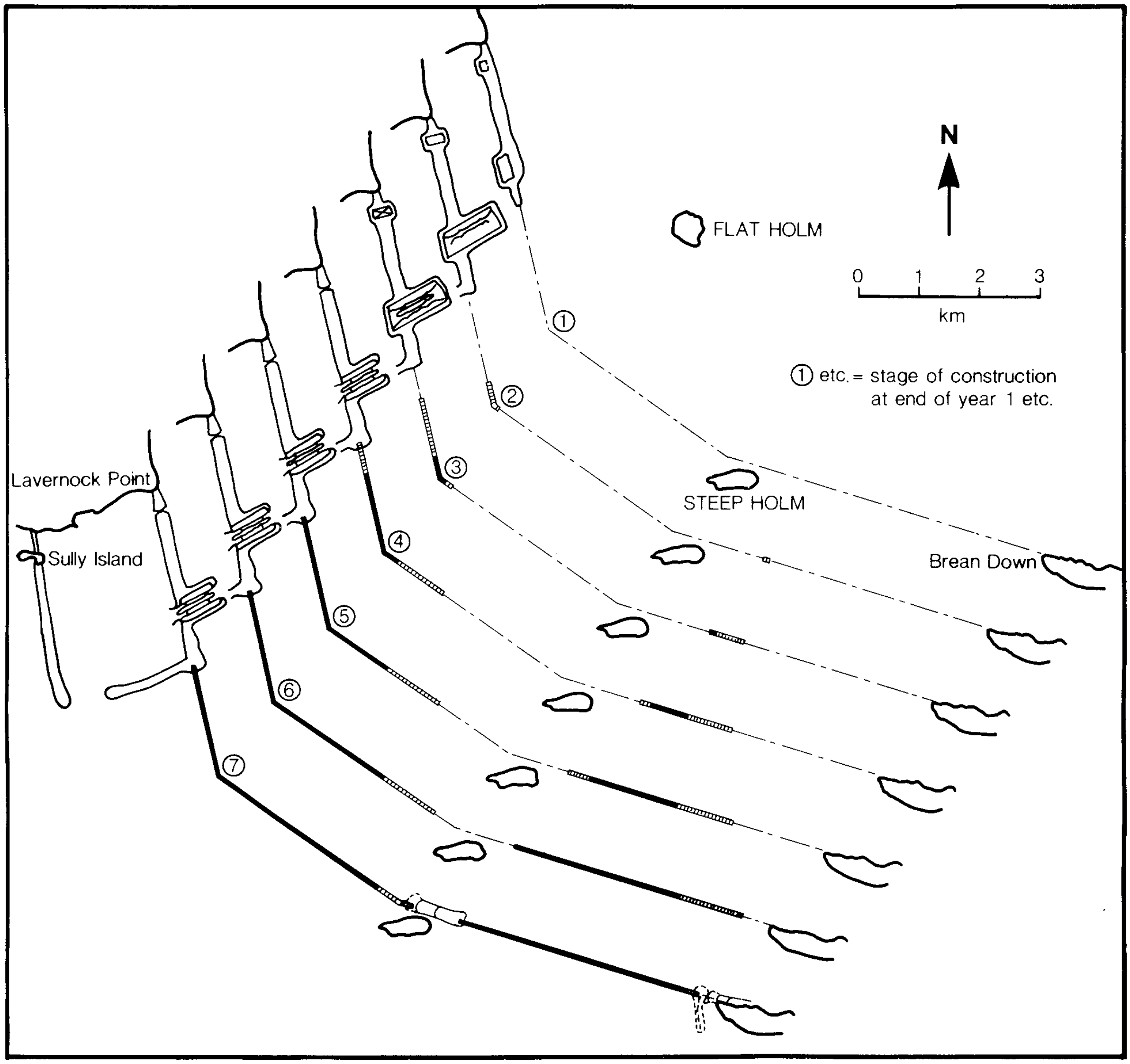

Figure 3. Plan view of seven yearly stages in construction of a Cardiff-Weston Barrage using prefabricated caisson construction (courtesy of STPG).

Phase 1. During this period a construction sequence has to be developed (Fig. 3) which will satisfy various needs, such as providing the sea locks for commercial and recreational shipping, at appropriate times. Another major consideration is to extend out from the English coast as rapidly as possible in such a way as to reduce the potential for eroding Bridgwater Bay sediment. The object of using the sluice caisson construction in Bridgwater Bay is to provide some shelter and diminish the velocity enhancement which might otherwise lead to rapid fine sediment erosion.

It has been calculated that the tidal range, and hence velocity and carrying capacity for sediment, does not diminish until more than 80% of the cross-section of the estuary has been blocked (Fig. 4) (Kirby 1987). When the estuary crossing is complete but all openings are in use the percentage of the cross-section remaining open will be in excess of 20%. In this way it is anticipated that the present sedimentary regime, with its associated environmental impact, water quality, dredging and spoil disposal practices etc. will continue uninfluenced during the nine year construction period.

Phase 2. At the time of closure a second major virtue of using perforated sluice caisson construction becomes apparent. This is that during closure a large degree of control is possible. At closure the scheme will be brought into operation and the tidal range and velocities will then be changed, accompanied by the rise in mean water level within the basin. The main sedimentological change associated with the harnessing of the tides will be large scale and widespread deposition. Deposition will be equivalent to that occurring on an existing neap tide and will only differ in that rapidly deposited flocculent layers will progressively consolidate to form settled mud deposits. The accompanying rise in mean water level should more than compensate for the sudden deposition.

The importance of the perforated sluice caissons is that they offer the potential for sedimentation engineering to distribute the sediment to sites where it will have least impact or even the most benefit. Closure can be arranged to occur after just one tide or many, after ebb or flood tides, or on springs or neaps. Similarly any closure sequence, starting on one side of the estuary or the other, in the middle or working out, on the margins and working in etc. can be adopted. One future modelling task will be to

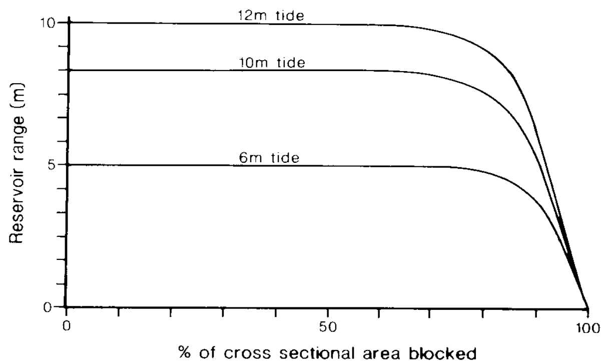

Figure 4. Graph showing the influence of works upon the tidal range. Tidal range does not become noticeably modified until after more than 80% of the cross-section is blocked. By this stage a crossing will be completed.

optimise the closure sequence with a view to distributing the sediment which will be permanently deposited above or below the barrage or to either side of the estuary as may be deemed appropriate. Thus the major benefit of the perforated sluices is to offer control and choices on final closure.

Although some 30M tonnes will be deposited rapidly at closure there is reason for optimism that a means has been found to minimise the impact of such a large scale and permanent event. If this scenario, qualitatively established, proved achievable then no additional short term dredging need would arise in the approaches to the major ports.

Phase 3. The sedimentary predictions necessary for the postclosure operational phase are: to be confident where fine sediment will be deposited in the sub-littoral zone, to know how substrate mobility and lithology may be modified in the short and longer term and particularly how the intertidal zone will be affected. The intertidal zone is especially important in view of its internationally recognised status as an over-wintering area for wading birds and ducks. Post-closure regime predictions need to consider whether new areas of tidal flat will develop, whether the sedimentary regime of the tidal flats will change and if so how; what the cross-sectional shape of new tidal flats will be if different from that at present and even quite small scale features such as the grain-size, stability and shear strength profile of the surface sediment layer. Finally, it is necessary to know whether the new sedimentary regime will become established over a period of a few months or whether many years will be required before the regime fully adjusts to the engineering works.

The long term consequences for the tidal flats involve a range of sediment impacts. Coastlines may become erosional or depositional. Either could influence amenity beaches, salt marsh generation, land drainage, cooling water intakes and effluent outfalls. Similarly, the response of invertebrates and the dependent birds and fish are involved.

The requirements impose severe demands on "the state of the art" for modellers and sediment physicists. We know that rather more than 60% of the intertidal area will be lost, what we need to know is whether any improvements in the quality of the intertidal sedimentary regime which remains will compensate for the loss in area.

The water and bed quality in respect of sediment will be greatly improved in the post-closure regime and many ecological benefits are certain to accrue from this. Possible disbenefits still to be evaluated include the risk of retention of pollutants and the risk of eutrophication arising if riverine nutrients and sewage continues to be input at the present rate.

In the post-closure regime river inputs of sediment will remainunchanged at approximately 0.75M tonnes/year. This is a low input rate compared to the size of the basin created. Problems are only likely to arise from such inputs if their deposition was very sharply focussed. The tidal range outside the basin will be only marginally changed but tidal current velocities will be greatly reduced (Hydraulics Research Station 1981). Inputs of sediment from seaward at present are unknown. However, much of the erodible sediment will be contained within the barrage and the bed of the Bristol Channel to seaward is largely devoid of erodible sediment. It is likely that the major inputs of sediment from seaward in the post-closure regime will result from storm wave erosion of the Bridgwater Bay muds.

Within the enclosed basin flood currents will remain strong, albeit at the strength of the present neap velocities. However, ebb velocities will be greatly reduced, enhancing the present flood/ebb inequality. As a result any flood transport of sand or mud grade sediment will not be compensated by any significant return flow. Whether the new residual transport will have any deleterious impact on the lower reaches of the river estuaries is one of many aspects receiving special study.

Conclusion

The existing sediment regime in the Severn, the latest design for a barrage along the Cardiff-Weston line and the influence such a barrage would have upon the sedimentary regime have been outlined. The effects will be large in scale, such that almost every engineering aspect of the scheme itself as well as engineering aspects of the local hinterland, have a sedimentological connotation. Similarly, almost every aspect of the estuarine ecosystem is affected by sediments.

Unlike the foundation geology, where the technology for its investigation is well established and the problem is both static and local in scale, environmental changes represent a higher order of difficulty and uncertainty. Here the problems are of a regional scale, are dynamic in nature, involve complex interactions of physical, biological and chemical processes which are often in themselves not well understood. Further, the technology for investigating environmental change is often primitive and not entirely reliable.

The government has made it clear that the scheme will only proceed if the environmental problems can be shown to be surmountable. This issue remains the central one in determining the ultimate viability of the scheme. Although these issues cannot be over ridden, financial and political factors are, in my view, ultimately going to decide whether the Utopian dream is ever realised.

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