CHAPTER 83

THE BRISTOL CHANNEL BARRAGE PROJECT

by

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Abstract: The paper outlines a proposal to barrage the Bristol channel between Cardiff and Weston-supermare. The benefits from energy generation and to road communications are assessed in detail and in monetary terms. Benefits to navigation and drainage are discussed but not assessed. The effect of the barrage on tidal range, siltation and sediment movement is considered and a suggestion, previously made by others, for a larger international airport on land reclaimed from the enclosed area, is developed.

Cost estimates for the proposal are made and it is shown that the benefit/cost ratio is greater than unity even when only energy and traffic are considered.

1. Introduction

The Severn Estuary and the Bristol channel together form a deep cleft in the western coast of England and Wales extending about 125 miles (200 km) from the Irish Sea in a generally N.E. direction towards the Midland region of England.

The tides of the Irish Sea are accentuated as they move up the channel, partly by resonance and partly by the convergence of the estuary sides, so that the mean tidal range in the upper part of the inlet is about 30.5ft (10 m).

This exceptional tidal range made possible the development of Bristol, Cardiff and Newport as ports since large, deep-draught ships were able to penetrate far up the channel. It has had disadvantages in making bridge building difficult and keeping large amounts of silt and sand in suspension, which foul the waters and silt up the navigation channels.

The estuary* has grown in importance over the last 20 years. The new Severn Bridge, linking S.W. England with Wales and cutting 81 miles (130 km) from the journey between Bristol and Cardiff, was opened two years ago. Three nuclear and three fossil-fuel power stations have been built on its shores. Large steel and chemical plants are to be found on

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* The term 'estuary' is used to describe both the Bristol channel and the River Severn estuary.

both sides of the channel. Yet its disadvantages are at the same time more evident than before. With the advent of really big ships, its narrow navigation channels and swift currents make it less attractive to bulk carriers and oil tankers. New port developments are proposed but they are on a smaller scale than their neighbouring Continental developments at Le Havre, Dunkerque and Europort.

The regional area which includes the estuary has excellent communications by rail and road with S.E. England and the Midlands but is relatively lightly populated and capable of substantial further development.

The large tidal range has prompted proposals for the generation of tidal energy in the past, notably in 1933[1] and 1945[2] on government initiative and by several private investigators. None of these schemes has proceeded beyond the report stage, primarily because, with the exception of the 1933 scheme, they were not considered as multi-purpose developments and the entire project costs were levied against energy production.

It is now proposed to build a barrage across the estuary on the line shown in Fig 1 from Lavernock Point on the Welsh shore, through the island of Flat Holm to Sand Point on the English shore, a length of 9 miles (14.6 km) excluding the island. This barrage equipped with navigation locks, roadways and turbogenerators would provide benefits in the form of improved communications, improved shipping access to ports and large amounts of electrical energy.

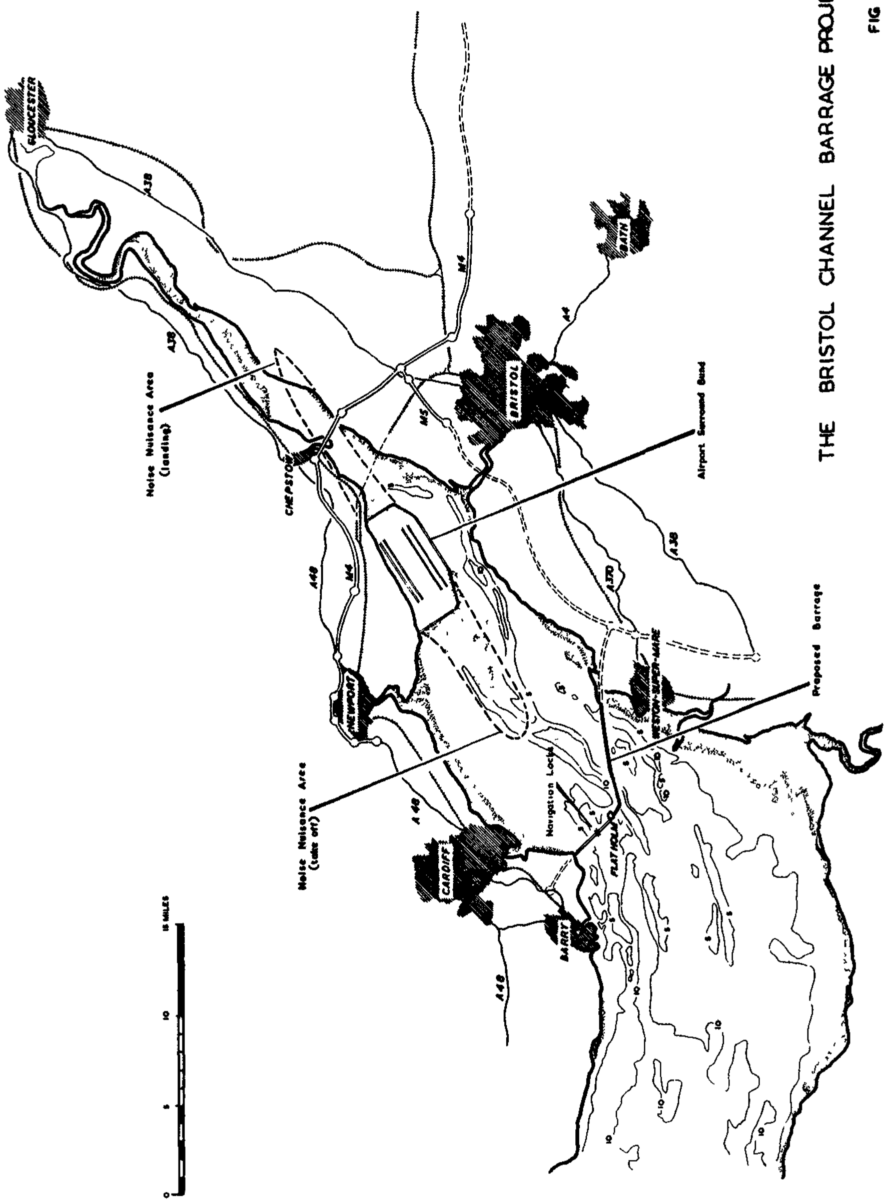
2. Geology and Hydrography

There is little information available about the geology of the sea bed. Donovan[3] suggests that considerable areas have been swept clear of superficial deposits, though there is such cover to the underlying New Red Sandstone and Jurrasic formations on both flanks. There is at present a regular removal of sand from the barrage line near Flat Holm by suction dredgers. The quantity being removed annually is of the order of 4½ million tons.

There are large working quarries in Carboniferous Limestone near the barrage on both sides of the Channel and in the Blue Lias (yielding limestone and shales) at Lavernock Point. There seems to be no shortage of suitable rockfill and armourstone within economic transport distance of the proposed line.

There is no present evidence of soft muds or silts in the areas proposed for embankment and foundation structures but further survey and investigation on this point is needed.

The amplitude of the principal tidal constituents varies widely from the Irish Sea along the Bristol Channel and into the River Severn. The mean tidal range is 20.5 ft (6.2 m) at Swansea, 27.8 ft (8.5 m) at Cardiff and 30.5 ft (9.3 m) at Avonmouth (Port of Bristol). At Cardiff, which is the nearest observation point, the flood takes an hour less than the ebb on spring tides, the two being nearly equal at neaps. At Avonmouth this disparity is more marked and during spring tides the flood



THE BRISTOL CHANNEL BARRAGE PROJECT

FIG 1

is nearly 2 hours shorter than the ebb. The effect of the barrage and its operating regime on the tides and siltation in the estuary is discussed in section 7.

3. Description of the Barrage

The principal components of the barrage are the power station, the refill sluices and the dam sections and typical cross-sections through these components are shown in Figs 2, 3 and 4 respectively.

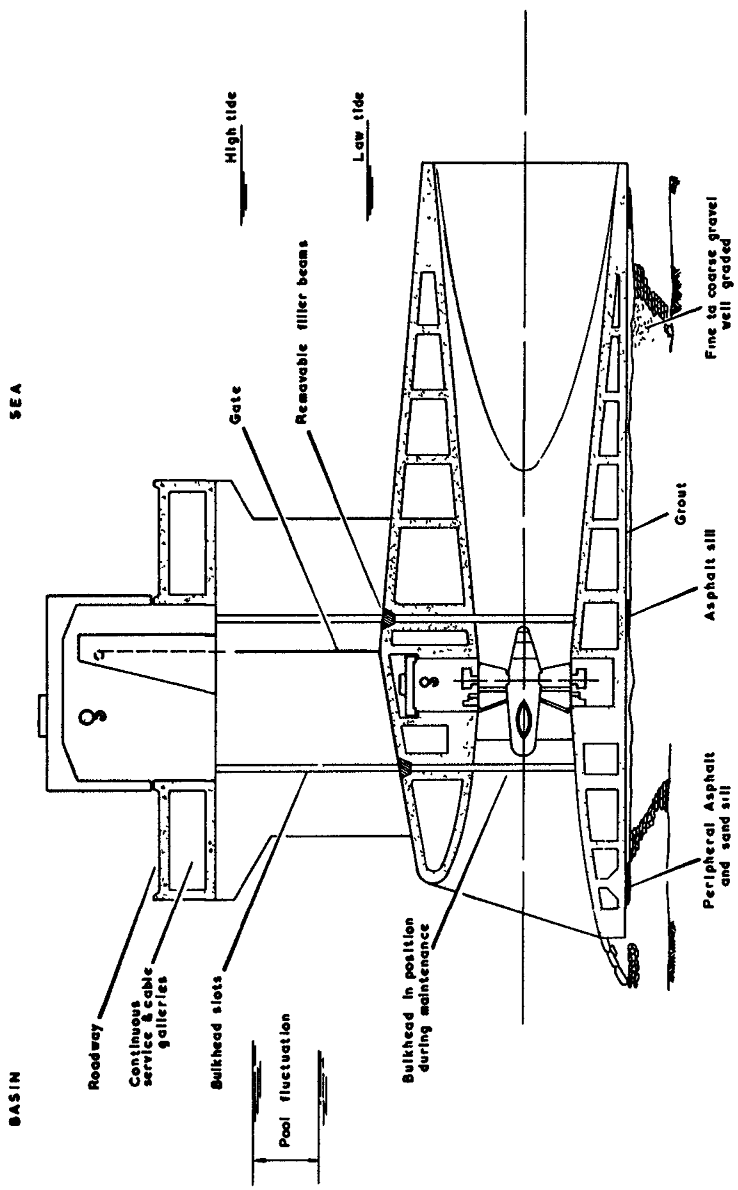
The powerhouse portion of the barrage consists of cellular caissons of composite prestressed - and reinforced- concrete construction. The substructure of each caisson houses four horizontally-mounted axial-flow turbine-generator units, side by side in individual venturi-shaped water passages.

The barrage above the turbine water-passages is formed by vertical-lift sliding gates, set in sluiceways (referred to here as "oversluices") between piers. The piers are set midway between turbines: two in each caisson are larger, and accommodate access wells serving a turbine-generatc unit on each side. Travelling cranes for servicing or dismantling purposes can also be lowered through these wells, on to tracks commanding all four machines in a caisson. The access wells, the oversluice gates, and all stoplog or gate slots, are commanded by gantry cranes travelling on the bridges supported by the piers.

The caissons are to be founded on a prepared bed of rock fill which in no case would exceed 20 ft in depth, so that settlement is unlikely to be appreciable. The alignment and levelling requirements for the machines seems unlikely to be very severe and precise levelling of each caisson would not be required. After sinking of the caissons the void compartments would be ballasted with sand and lean concrete. Scour protection of the rockfill foundation is to be by asphaltic concrete placed underwater. Total length of the power station would be 6,750 ft (2060 m) with 120 straight flow turbines of 30 ft (9.15 m) runner diameter, housed in 30 caissons.

The venturi sluice caissons will each contain four 40 ft square gates which will normally operate fully submerged. A discharge coefficient of 1.6 has been adopted for these waterways based on the laboratory tests of similar sluices proposed for Passamaquoddy[4]. The overall dimensions of the sluice caissons are 123 ft long by 205 ft wide by 112 ft high. There are to be 30 such caissons with an overall length of 6150 ft. The principle of pre-fabrication, flotation, sinking and ballasting on a prepared rock rubble foundation has also been assumed for these units.

The remaining length of the barrage will consist of a sand and rockfill structure constructed by bottom dumping from barges, hydraulic sand-pumping and with scour and wave protection by armour stones or asphaltic concrete, or both. In this length a navigation lock system will be installed. This will probably have two locks, the larger of which will be 1500 ft long by 150 ft wide with sill level at - 55 O.D. The operational research study into the optimum locking system is not completed so £8 million has been allowed in the estimates for the two locks. The locks will be equipped with 2 lifting bridges each so that road traffic can always pass.



LONGITUDINAL SECTION THROUGH TURBO-GENERATOR CAISSON

FIG 2

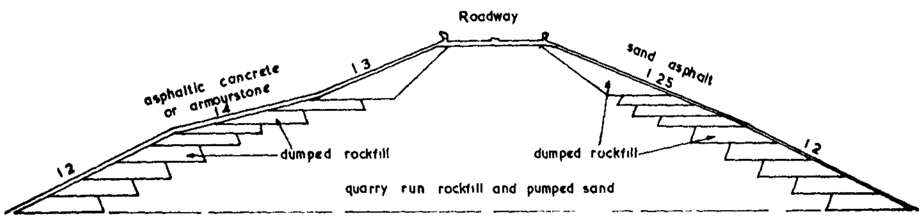


FIG 4 TYPICAL EMBANKMENT SECTION

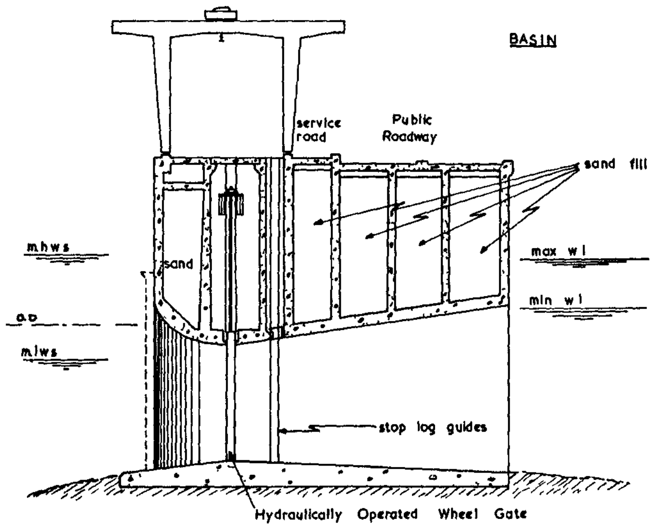


FIG 3 PROPOSED REFILL SLUICE SECTION

Both power station and sluice caissons carry dual-carriageway roads for public traffic as well as service roads. The public roads across the barrage will be continuous over all elemente of the structure with alternate routes at the locks to prevent traffic interruption. As designed, they consist of two 26 ft wide, two-lane carriageways and inter-connection to the trunk road system on the Weleh side, and to M5 motorway on the English side is proposed. Railways are not proposed on the barrage. A plan of the proposed structure is shown in Fig 5.

4. Energy and power

The annual output of energy from the barrage will be 10,432 GWh, generated at powers between 1200 and 4560 MW. The output was computed using the single tide optimisation method[5] on an ICT 1907. Sixteen basic combinatione of numbers of turbines and venturi sluice areas were studied initially and, following a primary economic optimisation, six further combinations were chosen. The annual outputs for all these combinations are ehown in Fig 6. The number of turbines and venturi sluice areas were selected using the economic optimisation method[5] and the resulting optimum combination is 120 turbines coupled with generators having a rated capacity of 38 MW and 120 submerged venturi sluices each 40 feet square. The generator rating was chosen by comparing the energy outputs of different ratings and equating them with total project cost to find the lowest cost of energy. The energy outputs for this analysis were taken from the annual power duration curve of Fig 7.

The maximum generator rating required to utilise all the power developed would be 54 MW and the energy loss by installing generators of 38 MW capacity is only 4.3%. This figure may be obtained by measuring the area beneath the power duration curve above the 38 MW power level.

During the energy computations, time allowances were made for the turbines to start up and the generators to synchronise. The turbines are grouped in fours and it was assumed that two groups of four would be started up each minute with all the turbines discharging after 15 minutes. The generators were assumed to be synchronised four minutes after the turbines began discharging.

The refilling sluices were assumed to be fully discharging 15 minutes after the levels of the tide and reservoir become equal. This figure was applied to both the fully submerged venturi sluice and the oversluices which are installed in the same caissons as the turbines. Fifteen minutes was chosen as a compromise between expensive machinery to lift the gatee rapidly and allowing excessive differential head to develop on the gates while being raised.

The introduction of tidal energy into an existing electrical system requires the availability of pumped storage capacity. The relative merits of the different ways of achieving this have been extensively disoussed in the literature[6]. For the British system which will have 1000 MW of pumped storage capacity interconnected by 1975, ebb-flow generation ie likely to be most advantageous. However, the annual production of 10,432 GWh of tidal energy will require further pumped storage capacity to increase the total to around 4000 MW. This will alter the load factors of all existing plant and alter the building priorities of new

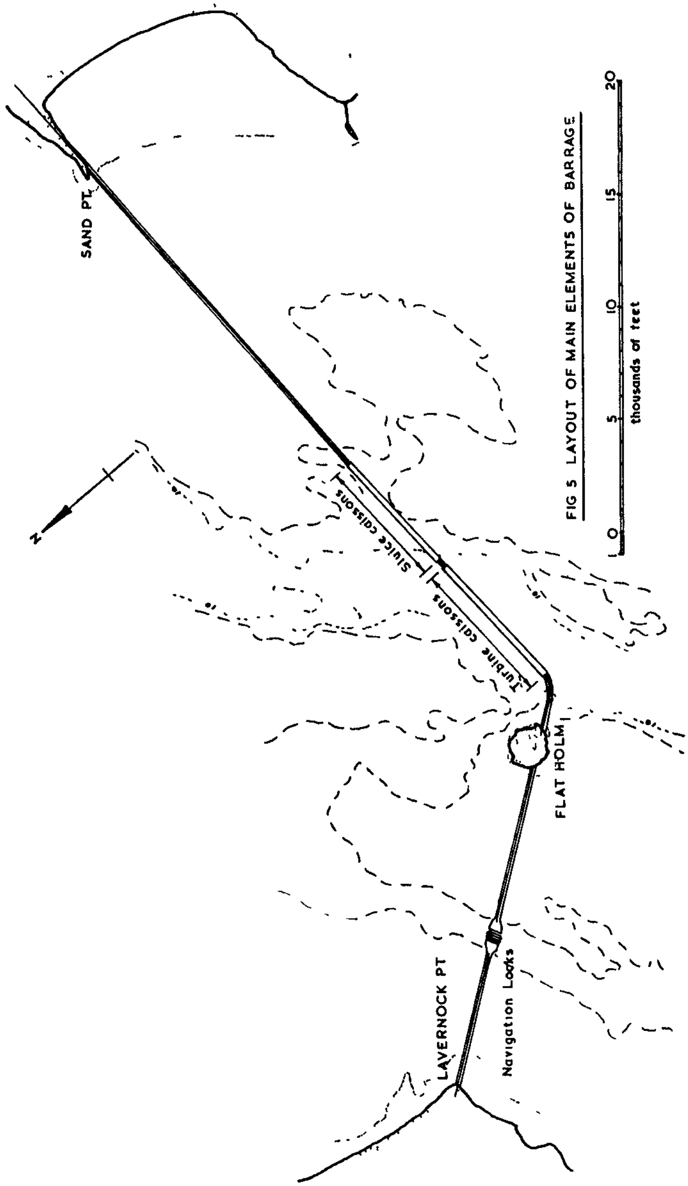


FIG 5 LAYOUT OF MAIN ELEMENTS OF BARRAGE

stations so that the actual value of the tidal energy to the system can only be assessed by comparing the whole system cost with and without it, over a period of about 20 years.

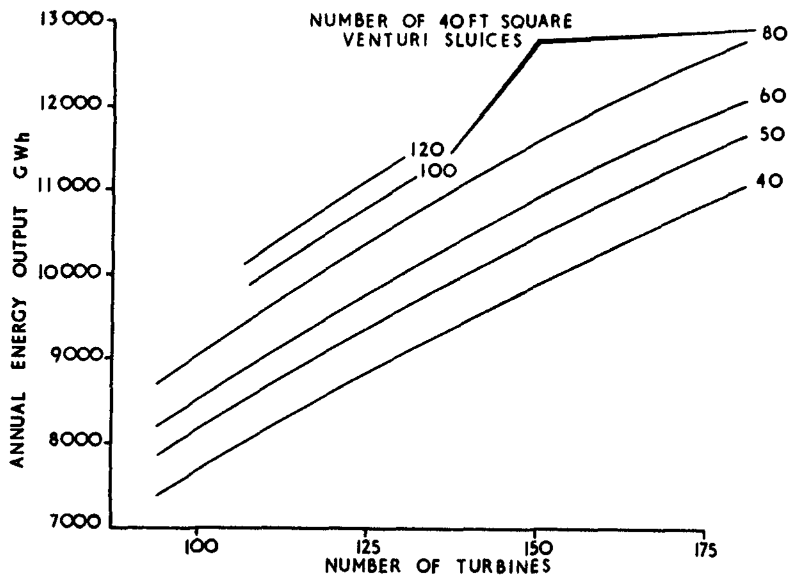
Since it is not practicable for the authors to undertake an investigation of this complexity requiring large amounts of data available only to the C.E.G.B. an estimate has been made of the value of the energy based on published, generation incremental-fuel costs for the early 1970's[7]. The value of the energy only as replacement for incremental fuel undervalues the contribution of tidal energy for the reasons given above and because some 35% of it occurs at peak generation periods and it is entirely predictable in time and quantity.

Fig 8 shows the Authors' estimate of power levels in 1975 and the likely generation incremental fuel cost then, derived from Berrie and Betts. The position of the winter and summer minima for base loads are shown and so weighted values for various blocks of Bristol Channel energy have been derived and are listed in Table 1 below.

%	Winter		Summer	
	GWh	Av value d/kwh	GWh	Av value d/kwh
35	1826	0.6	1826	0.42
65	3390	0.41	3390	0.38

Table 1. Incremental value of Bristol Channel energy.
Mean average value per unit = 0.435 d/kwh. The annual value of the years output is therefore 10,432 x 10^6 x 0.435^d = £18.92 m.

If this value is discounted back at 6% p.a. to 1975 the present worth of the electricity over the assumed economic life of the machinery (taken at 30 years) amounts to £276 million.



ANNUAL ENERGY OUTPUT FOR COMBINATIONS OF TURBINES AND VENTURI SLUICES

FIG 6

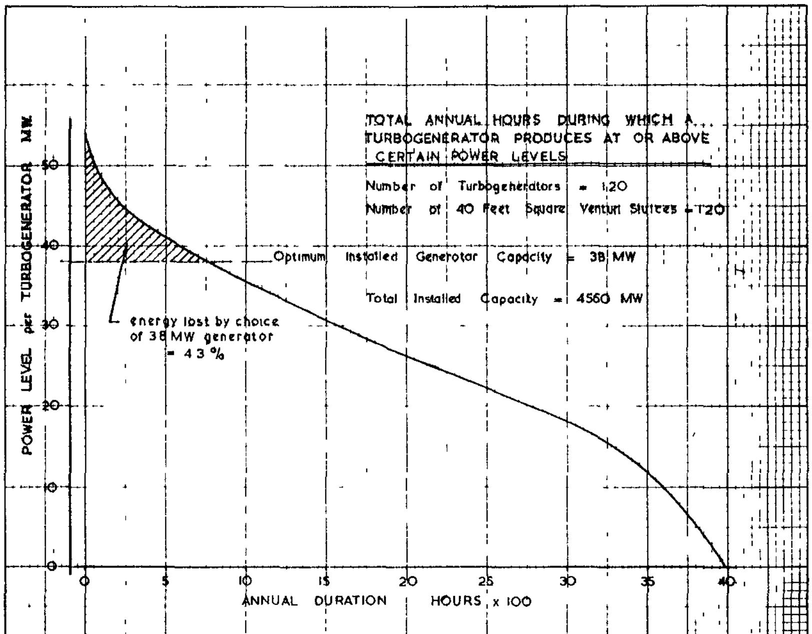


FIG. 7

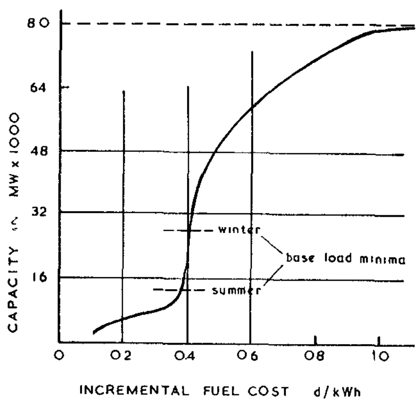


FIG 8
(after Berrie and Betts)

5. Communications

The Severn road bridge opened to traffic in October 1966 and provided a much-needed link between Wales and the west and south-west counties of England. In its first full year of operation (1967) the bridge carried 5.7 million vehicles and was showing a steady increase on this rate in the first half of 1968.

It was estimated by the Ministry of Transport before the bridge opened that the bridge traffic would increase in time as shown in the lower curve of Fig 10, with full capacity reached in 1988 with 17.5 million vehicles per annum. The data to date is shown on the same figure as the two points for 1967 and 1968 (4 months data only) and the upper curve has been drawn as a conservative revised estimate of traffic growth.

In the latter half of 1967, origin and destination surveys of traffic crossing the bridge were made by the Severn Bridge Research Project team for 'light' and 'heavy' traffic. The results of these surveys are given in the Interim Report published in July '68 and full use of the tables therein has been made. The percentage of total light traffic moving on an August 1967 Saturday in both directions was calculated from the o. and d. surveys quoted. Light traffic was considered as all cars and vans plus half the motorcycles. Heavy traffic was taken as all lorries and coaches. It had been separately sampled on a Tuesday (eastbound only) in the same month. The data was analysed as follows:-

1. All traffic using the bridge was assumed to be moving between two of the 18 point/areas shown in Fig 9, and the percentage moving between each possible pair calculated.

2. Of the 153 possible pairs 28 were considered likely to be given a shorter alternative route if the barrage crossing existed.

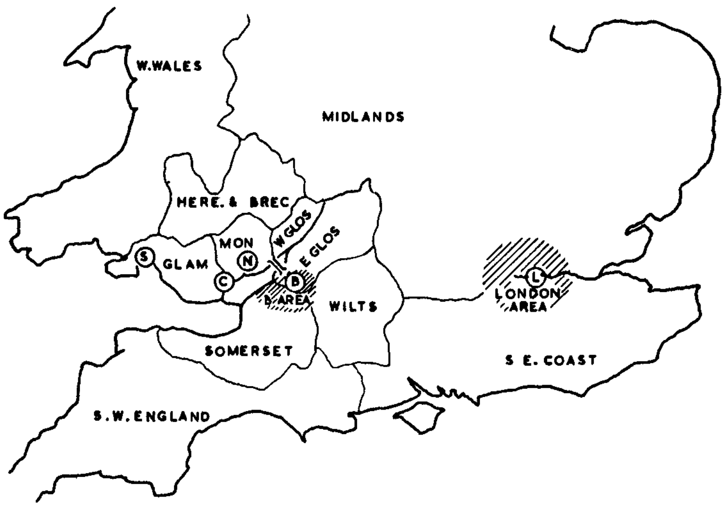
3. For each of these 28 journeys an arbitrary split was made of 'barrage' and 'bridge' traffic depending on the mileage saved and the road types, conurbations etc to be traversed.

4. This 'split' was applied to the 28 percentages affected, previously calculated under 1.above, and a new 'barrage' percentage only obtained.

5. For each shorter route-alternative journey, the mileage saved was computed from road maps. It was assumed that there was no motorway westward of Newport and that the Weston - M4 spur motorway existed.

6. Arbitrary overall journey speeds were assessed of 35 m.p.h. and 30 m.p.h. for light and heavy vehicles respectively and the journey time saved for the 'barrage' traffic was found for each class of vehicle in percentage terms.

7. Costs of running vehicles were taken from previously published data, updated by applying annual percentage increases. The costs adopted were £1.67 per hr and £2.33 per hr for light and heavy vehicles respectively.



ORIGIN & DESTINATION AREAS USED IN TRAFFIC ANALYSIS

FIG 9

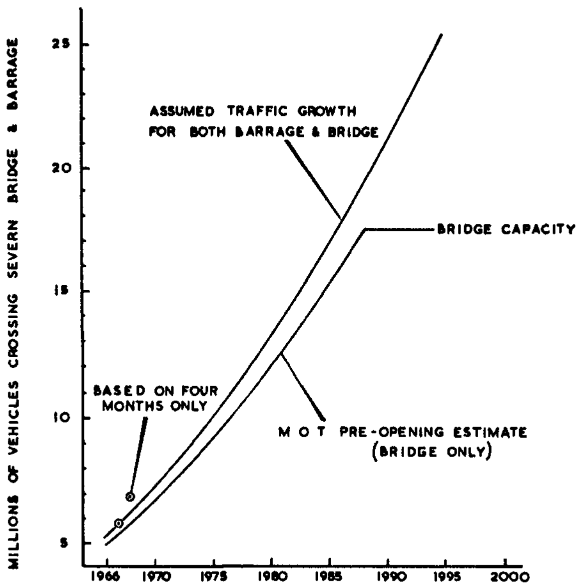


FIG 10

8. The appropriate figures from 6 and 7 were multiplied and the product applied to the future estimated vehicular traffic of the upper curve of Fig 10 (now extrapolated beyond 1985 because of the barrage addition to the road crossings) for each vehicle class. To do this it was necessary to assume a percentage of total vehicles for each class. Since the Severn Bridge traffic has so far shown a high proportion of heavy lorries and coach traffic (about 24% in its first year) and the trend is increasing in the current year, the same proportion has been assumed throughout the 30 year period commencing in 1975.

9. The value of time saving on the forecast traffic was computed for each of the years 1975-2004 and 'discounted back' to 1975 which is the earliest date the barrage could be operative. The results are shown in the following table for the first 5 years of operation and for the year 2000.

Year	Total number of vehicles/yr in millions	Benefit value in millions £ (1968 prices)	Benefit discounted to 1975 in millions £ at 6% p.a.
1975	10.1	3.74	3.74
76	10.7	3.97	3.75
77	11.35	4.20	3.74
78	12.0	4.45	3.74
79	12.7	4.71	3.73
2000	30.4	11.28	2.63
	1975-2004 Cumulative totals		£95.5

It will be seen that in 2000, the traffic benefit will be over £11 million. However by this time both bridge and barrage routes will be at saturation and no further increase in traffic or benefit is expected. Accordingly the discounted benefit falls off more steeply thereafter.

6. <u>Navigation</u>

The major ports upstream of the barrage are Cardiff, Newport and Bristol. Smaller ports exist at Penarth, Sharpness and Lydney. Fig 13 shows the mean arrival rate of ships and gives histograms of arrivals and net registered tonnages at these ports for 1966. Fig 11 shows the correlation between n.r.t. and deadweight tonnage. Table 2 shows relevant statistics for goods handled there in 1965 or 1966.

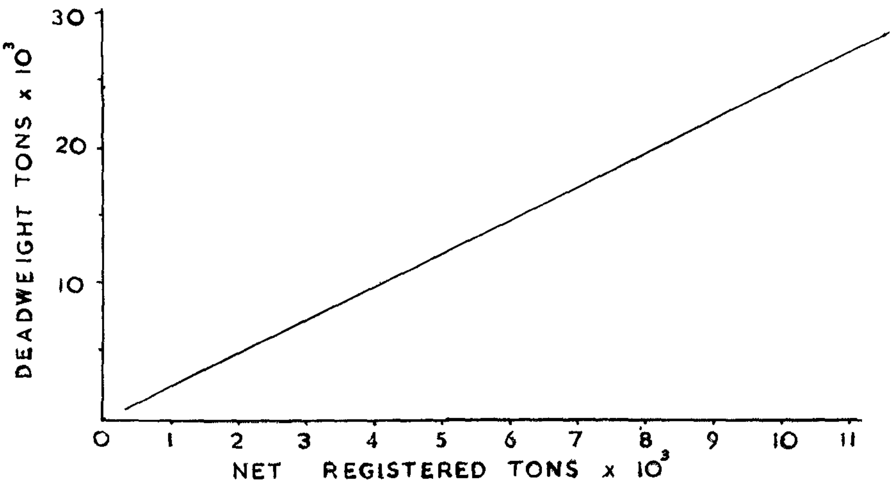


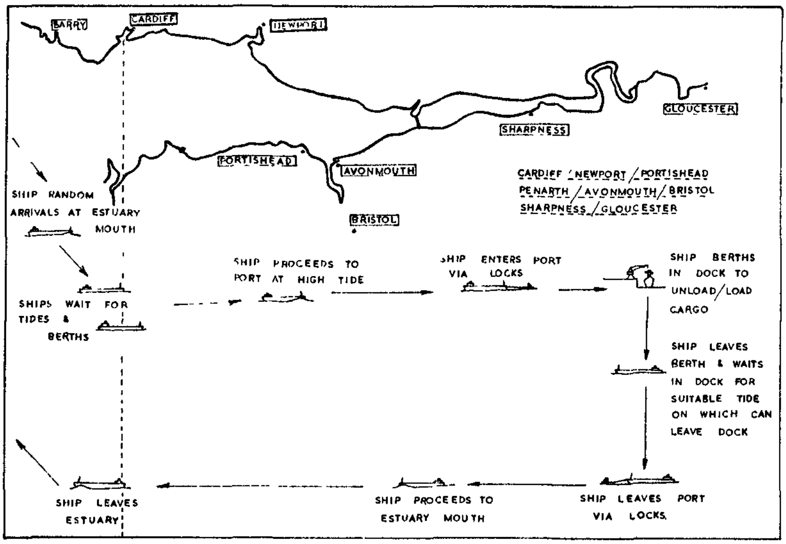
FIG. 11

Port	Imports Tons	Exports Tons	Principal Goods Handled
Cardiff (1965)	2,504,000	140,000	Iron ore, Petroleum, Building materials.
Newport (1965)	3,033,000	889,000	As for Cardiff.
Bristol (1966)	7,563,000	1,049,000	Petroleum, Grain, Animal foodstuffs.
Sharpness (1965) Lidney (1965) Penarth (1965)	1,002,000	None	-

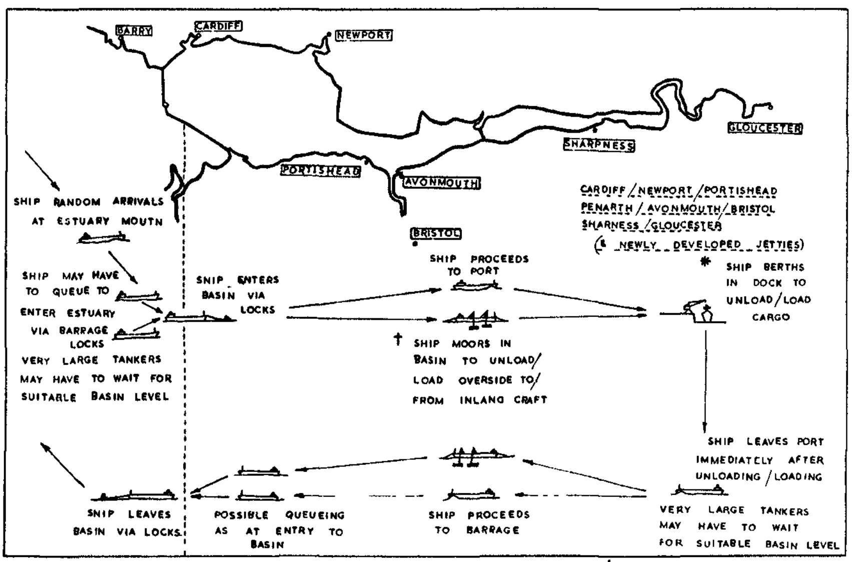
Table 2

Fig 12 indicates navigational movements in the estuary before and after barraging. The tidal range behind the barrage after closure will not exceed 12 feet. Due to this reduction in range and the modified tidal cycle due to power generation, there should be a time saving to shipping on entering and leaving the estuary. However, the possibility of queuing at the barrage locks might reduce the savings due to more favourable water levels.

It had been hoped to present the results of an operational research study into these aspects, based on the regime of Fig 12 and the mean arrival and departure rates of 1966 shipping at the estuary ports shown in Fig 13. This study[8] which should be completed shortly will assess the benefit to existing shipping in terms of time saving for ships and cargo.



EXISTING REGIME



PROPOSED REGIME

† depending on cargo
* existing locks at dock entrances are not shown though they may be retained

FIG 12 THE EFFECT OF BARRAGING ON NAVIGATION

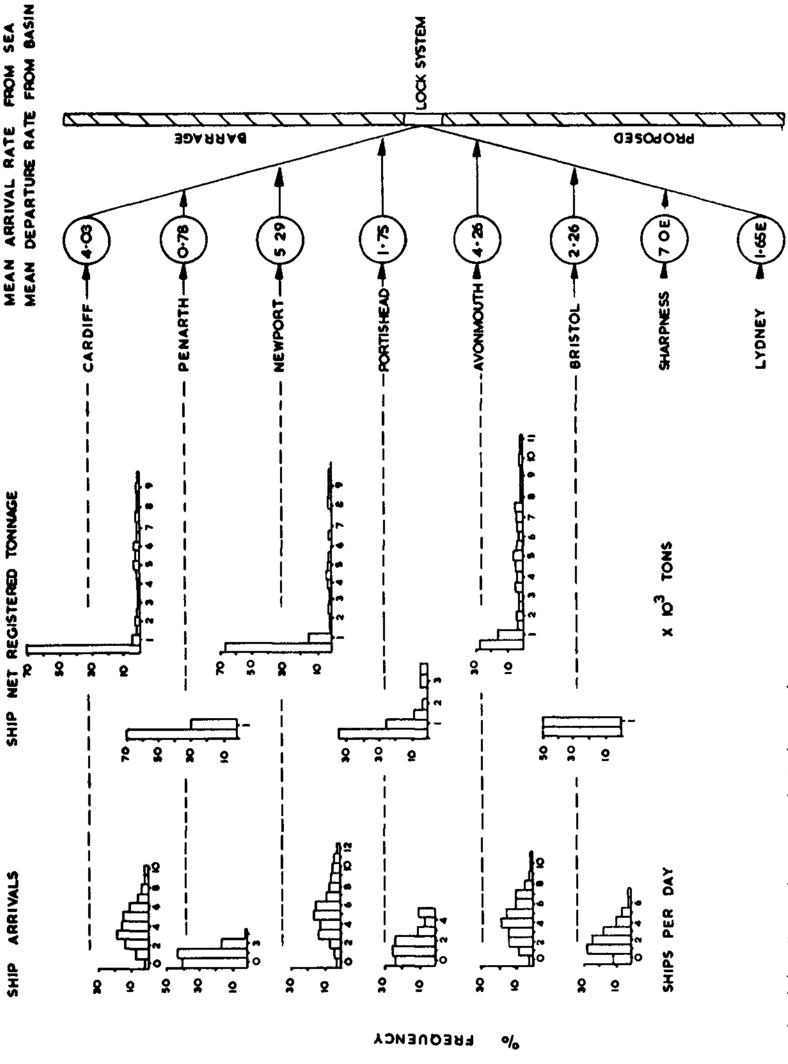


FIG 13

STATISTICAL DISTRIBUTION OF PRESENT NAVIGATION

Mean arrival and departure rates assumed to be equal
Net registered tonnage histograms for arrivals and departures will be equal
Net registered tonnage of ships to Lydney and Sharpness are below 500 tons
E = estimated arrival rate, given total number of arrivals per year

The presence of a subtantially altered water level in the estuary will radically change any planned expansions for the existing ports. New ports and tidal jetties could be developed in the estuary utilising the deeper water and more stable sea-bed conditions. New navigation channels could be dredged and existing channels modified to accommodate larger vessels. Lock gates at some of the existing docks could be removed, permitting ships to enter and leave on any water level in the estuary. This would necessitate the dredging of such docks to a greater depth than at present, and in many cases it would be simpler and more economical to operate the existing dock levels for an extended access time, while developing new facilities without locks.

The guiding principle behind the expansion of general cargo berths and facilities at modern European ports is to provide the port user with space to expand his activities rather than trying to rebuild old-fashioned layouts. The idea is to give space not only for new quays, but also for transport, handling and storage facilities. Dutch ports reclaim this land from the sea, and it is this kind of space that many British ports do not have and cannot get. The Bristol Channel, as yet relatively under-developed, has great potential in this way for development as a unit, rather than by piecemeal port expansion.

The barrage proposed in this paper would present completely new opportunities to the estuary ports in a protected basin of low tidal range.

7. The effect of the barrage on tidal range and estuary contours

It must be admitted that this is both the most important topic, and at the same time the most imponderable, of the whole proposal. Any major interference with the existing natural regime such as would be provided by a barrage will have an effect on the tidal range. Heaps[9] has shown the effects of barraging the estuary at various places along its length in terms of the amplitude of the M_2 constituent. The present proposal corresponds approximately with Heap's section 10, where he showed the amplitude of the M_2 constituent to be reduced by 1.25 ft. The other principle semi-diurnal constituent, the S_2, would probably have a pro-rata reduction giving a spring tide range of about 3.2' less than the present and a neap tide range of about 1.6' less.

The present proposal however is rather far removed from complete closure and involves a phase-shift of about 2 hours in the discharge. Published results of such a regime are not available but investigations on this point are currently proceeding in France and Britain. The authors have based their energy analysis on an arbitrary assumption that their regime will cause a range reduction of 2.5 ft at a 36 ft range and 1.5 ft on an 18 ft range. The histogram of actual tides was altered to account for this during the computation.

There is less information available about the effect of the barrage on sediment dispersal and movement. Like most estuaries with large tidal ranges the Bristol Channel has a fairly heavy silt load. This is to a large extent due to the current velocities produced by a large volume of water being released into or drained from the estuary every six hours. Fine material that in estuaries of lesser volumetric exchange would settle out is kept almost permanently in suspension in a captive, oscillatory state. The coarser sediments, fine and medium sands, form wide flat and relatively static sand banks in certain areas while a considerable expanse of the sea floor is swept clear[3].

The configuration of the barrage shown in Fig 5 would lead to a change in the tidal current pattern and velocities. Generally the current velocities would reduce somewhat since there would be a reduction in tidal range and in volumetric exchange due to the imposed regime of the tidal power station. Accordingly the trend would be to greater sand bank stability and a reduction of the captive, silt load. Locally at the barrage, current velocities might increase near the turbine and sluice sections while decreasing on the embankment flanks. Here the tendency would be to remould the loose boundary to conform to the new pattern, obviously giving rise to both accretion and erosion.

It will be seen from Fig 5 that the fastest (turbine) currents will be in the deepest clear-swept channel and the slackest water is likely along the N.W. embankment between Lavernock Point and Flat Holm. It is from this area that sand-suction recovery vessels currently remove about 4 m tons per annum for use as building material.

The amount of sediment entering the estuary has also to be considered. Gibson estimated that the Severn and Wye rivers together brought down about 650,000 tons per annum. This is fine sediment and may be the principal source of the captive silt in suspension. Most of this material would continue to be kept in suspension under the new regime though there might be areas of slack water where silt accretion would increase. If it were all to settle out evenly over the basin area it would form a layer about 1 mm thick per annum. Accordingly, if Gibson's estimate is correct the input of silt is not a problem, only its distribution.

The only practicable way to find answers to the questions raised by the redistribution of the estuary sediment is to build loose boundary hydraulic models of the estuary and Channel. The indications seem to be that the overall picture will be better rather than worse though local accretion might be troublesome.

8. Other considerations

(a) Drainage and coastal protection: The low-lying land bordering the estuary upstream of the barrage at present is drained into deep drainage channels which discharge through tidal flaps at low tide. Since the barrage would retain a pool with a 12 ft fluctuation in the upper half of the present tidal range, pumped drainage of this land would become necessary. Estimates previously made[10] for this work indicate annual costs less than £50,000 and no account was then taken of the betterment to the land through a controlled phreatic surface.

The maintenance of the sea walls and embankments which now protect this land is more difficult to assess. The barrage would effectively prevent basin levels rising above about 20 O.D. while occasional tides in the past have risen to 28 O.D. and the top embankment levels are generally above 30 O.D., some being as high as 35 O.D. while the fetch length to some of the more critical places is reduced by the barrage, it still may be as much as 25 miles and so waves of 7 feet are quite possible. The Authors believe that the maintenance of sea defences will be made simpler and in the long run, less costly than it is now, but it is fair to point out that some of those most concerned, who have written[11] about the problems which will arise, do not agree with this view.

(b) Fisheries: The Severn and Wye are important fishing rivers, though not on a commercial scale. The passage of descending salmon smolts and ascending adult spawning fish might be adversely affected by an alteration in the natural cycle of the estuary. Marine biologists who have been consulted by the authors are reluctant to do more than speculate. However experience in Scottish rivers and power schemes have shown that fish may safely pass through smaller and faster running turbines at higher heads than those proposed here and it is tentatively concluded that there should be little, if any, effect on the passage of existing fish populations.

(c) Airport location: A modern international airport, if it is to cater for foreseeable air transport requirements will need an unobstructed flat land area about 6 miles long by 3 miles wide, with four 4000 yd long runways in two pairs 2500 yds apart. The width of the noise swathe will extend a mile beyond the outer runways on each side, 10 miles along the approach paths and 8 miles along the take-off paths. Since the prevailing winds in S. England are S.W., a strip of air space 24 miles long by 4 miles wide on a S.W. - N.E. axis, is required with the actual airport nearly central.

To find a requirement like this in S.E. England, free from urban concentrations is virtually impossible and the only prospect of achieving it is in the suggested Foulness site where the airport must be built on land reclaimed from the sea with a retaining bund some 12 miles long subject to North Sea wave action and surge. The Foulness site would require the construction of road and rail links, is 50 miles from central London and would serve virtually nowhere else.

If the search is shifted from S.E. England to the Bristol region a possible site is immediately apparent in the area contained by the barrage[12]. The proposed site is on the land known as the Welsh Grounds and is the required size. The take-off noise area is absolutely clear of habitation and so power restriction would not be required during take-off. The landing approach noise-area is also almost completely clear, as may be seen from Fig 1. The axis of the entire area as delineated lies 10° from true N.E. - S.W. at 35°. To surround the airport area would require a bund about 11 miles long but now protected from surges, high spring tides and all except minor waves. The main S. Wales - London railway line and the M4 motorway touch the N.W. corner of the airport site, which is therefore already served by fast rail and road links to London, S. Wales, the Midlands and S.W. England. Distance to central London is 120 m, to Brimingham 72m, Cardiff 24m and Bristol 14m. An Advanced Passenger Train, already designed by the Advanced Projects Group of British Rail has been scheduled in recent performance studies to cover the distance between Severn Tunnel Junction, on the northern extremity of the site, and Paddington in 70 min (including contingency time). Apart from the freedom from noise and excellent communications, the project has the great advantage of requiring no land.

9. Project cost summary

Detailed cost estimates for the barrage have been made and a summary is given below.

		£
Civil		
Foundations, preparation and earthworks		30 770 000
Powerhouse caissons (30 no 4 machine units)		62 880 000
Sluice caissons (30 no 4 gate units)		36 156 000
Miscellaneous works		900 000
Lock system		8 000 000
Mechanical		
Gates and assoc. equip. in powerhouse		16 100 000
Gates and assoc. equip. for refill sluices		16 700 000
Miscellaneous mechanical equipment		1 962 000
Electrical		
Turbo-generator units		90 000 000
Powerhouse equipment		14 950 000
Sub-station equipment		3 730 000
	Total construction cost	282 148 000
Contingencies (10%)		28 214 800
	Sub-total	310 362 800
Engineering and Administration ($6\frac{1}{2}$%)		20 173 200
	Gross construction cost	330 536 000
Interest during construction @ 5% p.a. for $4\frac{1}{2}$ yrs say $11\frac{1}{4}$% =		37 200 000
	Total project cost	£367,700,000

Annual costs

Amortisation over 50 years @ 8%	643 000
Maintenance £0.25/kw	1 114 000
Interest on capital @ 8%	29 440 000
	£ 31,197,000

Benefits discounted for 30 years to 1975 @ 6%

1. Electricity (on incremental fuel cost basis) = £276 million
2. Traffic (on basis of text and Fig 10) = 95
3. Navigation (a) shipping and cargo time =
   (b) port expansion =
4. Riparian site values for industry and power =
5. Agricultural land betterment =
6. Amenity (a) prevention of thermal & atmospheric pollution =
   (b) recreation
   (c) international airport site =

Total (1) and (2) = £371

Benefit/cost ratio > 1.

Many of the items listed above are difficult to evaluate though the authors hope shortly to publish values for 3(a). Other indirect benefits are not listed. These are concerned with wider political issues of new centres of population, energy from fuel paid for in foreign currencies, the preservation of a tolerable environment for urban populations and so on.

10. Further investigation and research required

This paper represents the results of a detailed desk study and inevitably it raises questions as well as giving answers. These can only be answered by further studies on the following points.

(a) The quantity and extent of siltation. An estuary hydraulic model is needed to investigate the affect of the barrage on current and flow patterns; on sediment transport and on the siting of locks, turbines and sluices; also for the siting and alignment of new port works.

(b) The modification of natural tides due to the barrage. A programme of computations will be required to assess the effect of the barrage on the tides. If the reduction assumed in Section 4 did not occur, electricity production could be increased by nearly 30% at marginal extra cost. (44MW generators instead of 38MW). Initial work on these lines is currently proceeding at Liverpool.

(c) Estuary bed surveys. A programme of bed surveys needs to be initiated (geophysical profiling, sampling and boring) to establish permeability, cohesiveness, consolidation, gradings, shear strengths etc to enable foundation analysis and settlement calculations to be made.

(d) Turbo-generator research. The present programme of the English Electric Co Ltd, supported by the Ministry of Technology, covers the machinery stipulated in the paper. It would possibly require extension to consider stability under large wave conditions and corrosion in sea water.

(e) Communications. More precise traffio surveys and market research in shipping agencies to assess the potential of a unified estuary port.

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