Sustainable Development Commission

Tidal Power in the UK

Research Report 3 - Severn barrage proposals

An evidence-based report by Black & Veatch for the Sustainable Development Commission

October 2007

Tidal Power in the UK

Research Report 3 – Review of Severn Barrage Proposals

Final Report

July 2007

In association with ABPmer, IPA Consulting Ltd., Econnect Consulting Ltd., Clive Baker, and Graham Sinden (Environmental Change Institute)

REVIEW OF SEVERN BARRAGE PROPOSALS

EXECUTIVE SUMMARY

This evidence-based report has been prepared for the Sustainable Development Commission (SDC) as research report 3 to support and inform the SDC's Tidal Power in the UK project.

Background

Following an introduction to the importance of the Severn estuary, an overview is provided of the extensive studies carried out on the Severn estuary mainly over the last 25 years covering both single basin and two-basin barrage schemes. The studies have shown consistently that tidal power schemes requiring long lengths of embankment (two-basin schemes) result in significantly higher unit costs of energy than equivalent schemes where length of embankment is kept to a minimum. The study considers two schemes for more detailed analysis as follows:

- The Cardiff-Weston barrage, as developed and promoted by the Severn Tidal Power Group (STPG) and located between Cardiff, Wales and Weston-super-Mare, Somerset, South West England
- The Shoots barrage (formerly the English Stones barrage) as presently proposed by Parsons Brinkerhoff (PB) and located just downstream of the second Severn crossing

Studies using various models have shown ebb generation is the preferred mode of operation at the Shoots barrage sites and ebb generation with flood pumping optimises energy output at Cardiff-Weston providing about 3% more energy output than simple ebb generation.

There are two large-scale tidal barrages in operation at present:

- The 240MW barrage on La Rance, near St. Malo on the Brittany coast
- The 20MW Annapolis Royal tidal power plant on an inlet to the Bay of Fundy, Nova Scotia

The Rance barrage was commissioned in 1966 after a six-year construction period. Following some initial issues with generator fixings which were repaired without great difficulty, the barrage has operated successfully for 40 years, confirming the reliability of well-designed marine concrete and the operation of the bulb turbines (favoured by STPG for Cardiff-Weston). Operation has also shown that one-way ebb generation is generally preferable to two-way ebb and flood flow generation (as shown by the UK studies). The much smaller Annapolis Royal scheme, commissioned in 1984, has provided operational experience of the more compact Straflo (straight flow) turbine design favoured by PB for the Shoots barrage. After commissioning, there were some problems with rotor seals. This was resolved and otherwise, high reliability has been reported.

Technology

Chapter 4 of the report reviews in detail the technological aspects of the two Severn schemes (Cardiff-Weston and Shoots) covering design and construction. The key components of both barrages (powerhouses, sluices and ship-locks) would be constructed in suitable work-yards in the dry, floated to site and carefully sunk into position. Reinforced concrete is the preferred construction material. For Cardiff-Weston, each turbine caisson would house four 9m diameter bulb turbines that would generate on ebb flow but would also pump from the sea into the basin at high tide to maximise energy output. For Shoots, each turbine caisson would house two 7.6m diameter Straflo turbines that would generate on ebb flow. Both schemes also include caissons for sluices, plain caissons, ship-locks and lengths of embankment to connect the main parts of the barrage to the shore. The sluices on the Shoots proposal are set at a higher level to try to mitigate the risk of basin siltation. STPG considers that the Cardiff-Weston scheme could be constructed in 7, 6 or even 5 years depending on the number of work-yards producing caissons and the size of the ship-lock required. PB considers that the much smaller Shoots barrage could be constructed, ready for commissioning, in about 4 years.

Based on various modelling studies, the average annual energy output of the two schemes is estimated as 17TWh and 2.75TWh respectively. Using the present standard value of carbon savings for electricity generated by non-thermal plant of 0.43kg/kWh, the annual and nominal lifetime (120 years) carbon savings (expressed as CO_2) for the two barrages are shown below:

	Annual energy (TWh)	Annual carbon saving (Mt of CO_2)	Lifetime carbon saving (Mt of CO_2)
Cardiff-Weston barrage	17	7.3	877
The Shoots barrage	2.75	1.18	142

Both structures would provide significant benefit in terms of flood protection against storm surges in the upstream basin. This benefit would increase as sea level rises with climate change but would be lost if the barrage was decommissioned.

Tidal barrages would not be compatible with tidal lagoons in the Severn. Of the four large areas suitable for tidal lagoons, only Bridgwater Bay could remain as a viable option, although a barrage at Cardiff-Weston would reduce its output by 20%. Tidal current devices would not be viable within the upstream basin of a barrage. Devices downstream of a barrage would experience some reduction in power output, ranging from about 30% just downstream of the barrage to a small percentage further seawards. Conditions in the Bristol Channel should remain suitable for tidal current devices.

Economics and grid implications

For the Cardiff-Weston and Shoots barrages, detailed estimates of costs were last prepared in 1988 and 1990 respectively. Escalation indices have been compared and costs updated using the All New Construction Output Price Index (COPI). The total construction cost estimates for Cardiff-Weston and Shoots are now about £15,000M and £1,500M respectively. These figures include estimates for transmission, control and reinforcement off-barrage. Construction of the Cardiff-Weston barrage would take 7 years, although this might be reduced to 5 years, depending on the size of the ship-lock to be provided and the number of work yards used to produce caissons. A 4 year construction programme is envisaged for the Shoots barrage.

The barrages would provide a variable but highly predictable electricity supply to the grid. The current planned network should have enough capacity for a barrage of the size of Shoots without requiring significant network reinforcements. The much larger Cardiff-Weston barrage would have a significant effect on the wider transmission system requiring more detailed study. A split connection sharing capacity between the transmission network on the north and south sides of the estuary is likely to be needed. Also, network modifications may be required to channel the majority of the generated energy to service the loads currently supplied by the French inter-connector.

The table below shows the estimated unit costs of the two barrage schemes with a repayment period of 40 years; the figures in brackets show the percentage increase compared to the repayment over the nominal 120 year life of the schemes. The costs are greater than conventional and established renewable energy technologies but of a similar order as less established renewable options.

Sensitivity Tests (p/kWh) (Real)	**3.50%**	**8%**	**10%**	**15%**
Cardiff-Weston 5 year programme	4.57 (28%)	8.93 (5%)	11.43 (2%)	19.15 (0.3%)
Cardiff-Weston 7 year programme	4.72 (28%)	9.67 (5%)	12.64 (2%)	22.39 (0.4%)
Shoots Mid case	4.03 (22%)	7.08 (4%)	8.79 (2%)	13.92 (0.4%)

There have been no detailed studies of decommissioning a tidal power barrage. As noted above, decommissioning would remove the benefits of flood control. Costs are highly uncertain but could be substantial (of the same order as constructions costs). Financing these over the lifetime of a barrage at even a low rate of assumed fund accumulation would make such costs potentially quite small.

There have been several studies of financing tidal barrage projects, the latest being prepared by STPG for ETSU in 2002. This report concluded that it is possible to envisage the Cardiff-Weston scheme being financed by the private sector, subject to Government policy instruments necessary to achieve the long-term security of supply contracts and with capital grants to recognise the value of non-energy benefits. There may be sufficient private sector appetite for smaller Shoots barrage without Government intervention.

Environmental impacts and policy framework

Chapter 6 describes the main features of the marine environmental legislation and policies relevant to the barrage proposals. Potential impacts of the two proposals are evaluated in terms of water levels and currents, sediment regime, morphology, water quality, ecology, archaeology and visual assessment. Assessments draw on recent work undertaken for the EA to develop a coastal habitat management plan (CHaMP) for the Severn estuary particularly in terms of sea level rise and climate change.

The promotion of either barrage option would require compliance with a wide range of environmental legislation and policy. Some of these requirements are likely to change in the coming years and new requirements may be added, for example, through the proposed Marine Act. The environment in and around the Severn Estuary is of special importance for nature conservation. This has been recognised through the many nature conservation designations that are in force and/or proposed for the area. The scale of environmental changes that would be introduced by either barrage option would also be very large. Given these major changes and the environmental importance of the area, there would need to be a very strong justification for any barrage proposal if the case for development is to override the importance of maintaining the nature conservation and wider environmental interests.

Whilst compliance with all environmental requirements would be an important requirement for a barrage proposal, the specific requirements of the Habitats Regulations are likely to present the most significant challenges in seeking approval for a project. For either barrage proposal to proceed in accordance with the requirements of the Habitats Regulations, it would need to demonstrate that there were no less damaging alternatives, that the project met the grounds for IROPI (Imperative Reason of Overriding Public Interest) and that all necessary compensatory measures could be delivered to secure the overall coherence of the Natura 2000 network.

To progress the environmental considerations relating to a barrage and to obtain realistic predictions of compensation requirements, it would be necessary to make a significant investment in additional studies to better evaluate the likely impacts of possible proposals and how such impacts may be mitigated / compensated for. This would include a series of major morphological and ecological studies. Such studies would also need to be completed in sufficient detail to inform the suggested high-level SEA and to support decisions on practicability of barrage proposals at that stage.

Aside from the requirements of the Habitats Regulations, the requirements of other existing environmental legislation and policies are not considered to pose such significant challenges, although the requirements relating to the Water Framework Directive have yet to be applied to development projects. However, marine environmental legislation and policy will continue to evolve, particularly with the implementation of a Marine Act. Such changes are likely to introduce additional legal and procedural requirements.

The Severn Estuary is recognised through a number of international, national and local environmental designations including Special Protection Area (SPA), Ramsar Site, Special Areas of Conservation (SAC) and non-statutory local designations around the estuary. The estuary has a high tidal range and shallows rapidly leading to the formation of a tidal bore at high spring tides. A tidal barrage providing ebb generation would have marginal impact on downstream water levels but would raise mean water levels in the upstream basin whilst reducing high water levels, particularly for spring tides and would prevent formation of the tidal bore. There would be locally faster flows through the turbines and sluices but in broad terms, currents in the upstream basin would be reduced leading to lower turbidity and some sediment deposition. Changes to the hydrodynamic regime, particularly upstream of a barrage, would have an impact on water quality such as dissolved oxygen depending on the barrage location and mode of operation. There would be a significant reduction of inter-tidal area in the upstream basin and a similar increase in calmer sub-tidal areas with corresponding impacts on the ecology.

Some early investigations and modelling has been carried out but there is uncertainty on the impacts of the various proposals. Considerable future studies and investigations would be required to update and enhance the knowledge of likely impacts.

Economic and social aspects

Chapter 7 reviews the evidence for the impacts that the barrage proposals would have on economic and social aspects (employment, navigation and ports, aggregates industry, fishing industry, land drainage, flood protection, transportation links, recreation and tourism, coastal and other regional impacts). The in-depth studies thatwere carried out for the Cardiff-Weston scheme and, to a lesser extent, the English Stones scheme mainly date back to the 1980s. No comparable work has been carried out for the Shoots barrage although impacts would be similar to those predicted earlier for the English Stones barrage. The main impacts are highlighted below:

- Employment: both schemes would generate local employment during the construction phase and the barrages may attract new investments and businesses into the region
- Navigation and ports: both barrages make provision for ship-locks but there would be some impact on waiting times: barrages would maintain water levels above the present mid-tide levels in the upstream basin and reduce the tidal range: any increased costs to present maintenance dredging for port access would need to be compensated.
- Aggregates industry: barrage construction would require large quantities of sands and gravels for fill and concrete: short-term demand may mitigate against longer-term concern of losing present licences
- Fishing industry: both barrage proposals would have an impact on the commercial viability and fishing practices mainly in the upstream basin. It is possible that less turbid waters would be able to support commercial shellfisheries or other fish-farming
- Land drainage: there would be some impact on pumping costs for drainage from low lying areas into the upstream basin

- Flood protection: a key benefit of both barrages would be the management of high water levels in the upstream basins, providing additional protection against surge tides for low lying areas adjacent to the estuary. The benefits would increase as climate change causes a rise in sea level.

- Transport links: a barrage could provide opportunity for a road or rail crossing (subject to achieving adequate clearance at ship locks) although cost recovery from traffic would need to be addressed. Cardiff-Weston scheme estimates excluded the costs and benefits of the road crossing. The Shoots scheme proposes that a high speed rail link is developed in association with the barrage but, similarly, costs and benefits are excluded from the estimates.

- Recreation and tourism: each barrage option would be likely to attract more tourism to the area by providing less severe tidal conditions in the upstream basin but would prevent the formation of a bore in the Severn. The reduction of inter-tidal feeding areas may impact on bird populations and associated recreation.

- Coastal development: further studies are needed of the impacts on land-use, planning, industry and commerce resulting, in part, from increased recreation and tourism.

Where appropriate, the report highlights the need for more detailed studies in some of these areas.

Overall comparison of barrage schemes

Chapter 8 of this report provides a summary table of the main features of the Cardiff-Weston and Shoots barrage proposals and the environmental and social aspects.

CONTENTS

1 INTRODUCTION 10

1.1 Background to the project 10

1.2 Report layout 10

1.3 Importance of the Severn Estuary 10

1.4 Location Plan 14

2 SUMMARY OF PROPOSALS FOR A SEVERN BARRAGE 15

2.1 Background 15

2.2 English stones 17

2.3 Larger Single-Basin Schemes 26

2.4 Two-basin ebb and flood generation scheme 36

2.5 Two-basin pumped storage scheme 36

2.6 Severn Barrage – Continuous Power Generation 38

2.7 Severn Lake Concept 39

2.8 Schemes Selected for more Detailed Assessment 40

3 PRACTICAL EXPERIENCE WITH TIDAL POWER BARRAGES 42

3.1 Introduction 42

3.2 La Rance barrage 42

3.3 Annapolis Royal 44

3.4 Experience in China 45

3.5 Experience in Russia 45

4 TECHNOLOGY 46

4.1 Design and Methods of Construction 46

4.2 Embedded carbon 59

4.3 Power outputs and carbon savings 61

4.4 Implications of climate change 70

4.5 Maintenance 72

4.6 Life cycle and decommissioning 74

4.7 Compatibility of barrage and non-barrage options 76

5 ECONOMICS AND GRID IMPLICATIONS 79

5.1 Costs Of Construction 79

5.2 Power generation, peak output and variability 85

5.3 Grid connection and strengthening 94
5.4 Construction programme 105
5.5 Unit costs of energy 106
5.6 Financing 112

6 ENVIRONMENTAL IMPACTS AND POLICY FRAMEWORK 116

6.2 Relevant Environmental Legislation 117
6.3 Environmental designations 130
6.4 Water levels, Currents and Waves 138
6.5 Sediment regime 142
6.6 Morphology 149
6.7 Water quality 153
6.8 Ecology 157
6.9 Archaeology 183
6.10 Visual Assessment 186
6.11 Environmental Legislation in the context of a Severn Barrage 190

7 ECONOMIC AND SOCIAL ASPECTS 199

7.1 Introduction 199
7.2 Employment 199
7.3 Navigation and ports 203
7.4 Aggregates industry 209
7.5 Fishing industry 211
7.6 Land drainage 214
7.7 Flood protection 216
7.8 Transport links 219
7.9 Recreation and tourism 221
7.10 Coastal development 224
7.11 Other Regional Impacts 226

8 OVERALL COMPARISON OF BARRAGE SCHEMES 230

9 REFERENCES 233

10 GLOSSARY OF TERMS 242

APPENDIX A: The Criteria for Identifying Wetlands of International Importance.

APPENDIX B: Institutions and Persons Consulted

APPENDIX C: Summary of reports covering regional economic and social development aspects of the proposed Severn Barrage

Document issue details:

<table>
<tr><td colspan="2">Contract Name:</td><td colspan="4">Review of Severn Barrage Proposals</td></tr>
<tr><td colspan="2">Phase:</td><td colspan="4">Final Report</td></tr>
<tr><th>Issue date</th><th>Issue status</th><th>Version no.</th><th>Origin</th><th>Checked</th><th>Approved</th></tr>
<tr><td>29/01/07</td><td>First Draft</td><td>1</td><td>B&V</td><td>JW</td><td></td></tr>
<tr><td>23/02/07</td><td>Second Draft</td><td>1</td><td>B&V</td><td>JW</td><td></td></tr>
<tr><td>04/07/07</td><td>Final</td><td>3</td><td>B&V</td><td>JW</td><td>POS</td></tr>
</table>

Reliance Notice:

This report was prepared by Black & Veatch Limited (BVL) solely for use by the Sustainable Development Commission[1]. This report is not addressed to and may not be relied upon by any person or entity other than the Sustainable Development Commission[2] and the funders for any purpose without the prior written permission of BVL. BVL, its directors, employees and affiliated companies accept no responsibility or liability for reliance upon or use of this report (whether or not permitted) other than by the Sustainable Development Commission[2] and the funders for the purposes for which it was originally commissioned and prepared.

In producing this report, BVL has relied upon information provided by others. The completeness or accuracy of this information is not guaranteed by BVL.

[1]*and the project funding partners (The Department of Trade and Investment, the Welsh Assembly Government, the South West Regional Development Agency, the Scottish Executive and the Department of Enterprise, Trade and Investment, Northern Ireland).*

[2]*and the project funding partners.*

1 INTRODUCTION

1.1 BACKGROUND TO THE PROJECT

Arising from the UK Government's latest review of energy policy, the Sustainable Development Commission (SDC) is carrying out a comprehensive study of tidal power in the UK. As part of the study, five research reports have been commissioned, namely:

- UK tidal resource review
- Tidal technologies overview
- Review of Severn barrage proposals
- Review of Severn non-barrage proposals
- UK tidal power case studies.

This report presents the evidence-based review of proposals for a barrage in the Severn Estuary (Research report 3).

The project team for this review comprised:

- **Black & Veatch** as lead consultant
- **Clive Baker** as sub-consultant on technical and modelling issues
- **ABPmer** as sub-consultant on environmental impacts and some social aspects
- **IPA Consulting** as sub-consultant on economics
- **Econnect Consulting Ltd** as sub-consultant on grid implications with assistance from Graham Sinden of the Environmental Change Institute, Oxford.

1.2 REPORT LAYOUT

Chapter 1 sets out the background to the project and outlines the importance of the Severn Estuary in terms of tidal ranges and flows, characteristics of the estuary, existing developments and environmental importance.

Chapter 2 provides an overview of the extensive studies carried out over the last 25 years to develop barrages over a range of notional and specific alignments from Porthcawl to Lynmouth in the outer estuary to just upstream of Avonmouth in the upper estuary. It also comments on proposals for two-basin schemes. Practical experience with tidal power barrages, notably at La Rance in Brittany, France is discussed in Chapter 3.

Chapters 4 to 7 focus on the proposals for single-basin barrages at English Stones (Shoots barrage) just downstream of the second Severn road crossing and on an alignment between Lavernock Point near Cardiff and Weston-Super-Mare (Cardiff-Weston barrage). These chapters review in detail the technology, economics, grid implications, financing options, environmental policy framework and environmental impacts, and the economic and social aspects of barrage development. Chapter 8 provides an overall comparison of the two barrage schemes presently being considered.

1.3 IMPORTANCE OF THE SEVERN ESTUARY

1.3.1 Tides in the estuary

The Severn Estuary lies on the south-west coast of the UK between Wales and England at the mouth of the Severn, Wye and Avon rivers. Its potential as a source of tidal power has been the subject of studies for over 60 years. More recently there has been increased interest in the potential environmental and regional effects of tidal power schemes.

The estuary has the second highest tidal range in the world after the Bay of Fundy, Canada with a mean tidal range of 4.68m at Milford Haven and 8.52m at Avonmouth. The tidal range has resulted in around 200km^2 of inter-tidal zone in the Severn Estuary which supports a wide variety of fauna. A high tidal range as is exhibited in the Severn Estuary is caused by the combination of estuary shape and the velocity at which the tide wave propagates causing tidal resonance, and as a result, the high spring tides at Avonmouth can exceed 14m.

The tide curve at the entrance to the Bristol Channel is a sine curve. As the flood tide propagates up the estuary, friction causes the sine curve to be modified, with the flood tide rising more steeply and the ebb tide falling more slowly. Ultimately, upstream of Avonmouth, the rise is so steep that a bore forms, effectively an instantaneous flood tide rise.

Storm surges are often the cause of flooding in many estuaries around the UK, particularly in the Severn Estuary. The occurrence of a surge in the estuary has been found to be linked to a specific chain of events. If a depression enters the estuary from the Celtic Sea moving inland, or westerlies have been blowing into the estuary for a period of 2 to 3 hours, a surge will occur in the estuary. Low atmospheric pressure also increases mean sea level.

High sea levels in the estuary have been studied extensively in an attempt to predict potential future levels in the estuary, and are therefore well documented and understood. The most recent study by Posford Haskoning[1] predicts the 100-year and 500-year still water tide levels at Avonmouth for the year 2002 as 8.98 and 9.25mOD respectively. These levels will increase as sea level rises. Abnormal high levels that have occurred at Avonmouth include 30th January 1607 - 9.2mOD, 8th December 1703 – 9mOD, and 15th December 1910 – 8.72mOD.

The tidal range, the threat of surges and the potential for high sea levels all help create what is a highly valuable area but also threaten the populations that live in low-lying areas along the coast.

When histograms of tidal range over several years are compared they are seen to vary substantially. This is due to a lunar cycle over an 18.6 year period. During this time period, the average tidal range in the estuary varies by ±4%. This affects the annual energy output of a potential tidal power barrage, which therefore varies by around 6-7%.

1.3.2 River flows and floods

The extensive array of river systems and tributaries that run into the Severn Estuary and the Bristol Channel make the estuary one of the most complex hydrological systems in the UK. The threat of flooding occurs when there is a storm surge which coincides with a high tide, or when large river flows coincide with high tides. The recent developments in river modelling techniques have greatly improved the information available on the potential for flooding in the area. Natural as well as built-up areas around the Severn Estuary are protected against flooding by sea defences but these are not all robust, nor were they designed for significant rises in sea level.

1.3.3 Geological setting

The Severn Estuary was formed as a result of the drowning of river valleys by rising sea levels following the last ice age. The topography comprises a broad bedrock bench into which channels have been incised by the rivers flowing into the estuary during times of low sea level. Subsequently, sediments ranging from gravels to peats have been deposited on the bedrock, with the greatest thicknesses in relatively sheltered areas, such as Bridgwater Bay and the English and Welsh Grounds, and buried river valleys. As a result, much of the coastline is low-lying and ‘soft’, having advanced and retreated over the last several thousand years. At the site of the proposed Cardiff-Weston barrage, the notable features of Brean Down and the Holm islands are carboniferous limestone overlying Triassic and Lias rocks.

[1] Posford Haskoning for the Environment Agency: “South West Region: Report on Extreme Tide Levels based on Proudman Institute Methods”, 2003.

1.3.4 Sediments and sediment movements

Sedimentary processes in the Severn Estuary are complex. The sediments of the estuary have formed into a combination of organic and inorganic materials which strongly influence the estuary's ecological and environmental characteristics.

The tides and waves both impact the sediment regime. During the highest spring tides over 30Mt of suspended fine sediment is mobilised. During neap tides the total drops to about 3Mt. In 1986 it was calculated that over half the 1000Mt of sediments settled in the estuary had accumulated in Bridgwater Bay. The upper foreshore in Bridgwater Bay is eroding, mainly due to wave action, while the sub-tidal part is accumulating sediment.

In other areas of the estuary there are large sandbanks, such as Culver Sand and Cardiff Grounds, whose location and area vary with time. These support an important aggregate dredging industry.

The high levels of suspended sediments and therefore the unstable nature of the sea-bed are thought to be a major contributor to the low levels of zooplankton in the estuary. This has ultimately resulted in a food chain within the estuary that is based upon detritus feeding fauna.

The large areas of intertidal mud flats, such as those in Bridgwater Bay and the Wentloog Levels, form an important feeding area for wading birds.

1.3.5 Coastal topography

The Bristol Channel and Severn estuary are bordered by the Somerset, Devon and Cornwall coast to the south and South Wales to the north. At the mouth of the estuary (seaward boundary) the estuary is 40km from the Welsh Coast to the north of the estuary to Ilfracombe on the south coast. From this boundary to Avonmouth is an axial length of ~100km. At Avonmouth the estuary has narrowed to a width of ~6km[2].

Sea-cliffs are the main feature from the mouth of the estuary along the Devon and Cornwall coast up to Minehead, and from the mouth on the South Wales coast to south of Cardiff. The remainder of the channel and the estuary coastal areas is generally bordered by low-lying coastland. Saltmarshes cover a large area in the Severn Estuary and around Bridgwater Bay, and are present in smaller areas along the Devon and Cornwall coastline. There are three major sand dune systems along the estuary coastline which are over 500 ha in area, the Penhale Sands, Kenfig and Braunton Burrows. Adjacent to the estuary there are vast areas of wet-grassland including the two most important areas in Britain, the Somerset and Gwent Levels. Traditionally the area around the estuary, in Devon and Cornwall in particular, has been used for extensive low intensity farming and therefore development has been limited in many parts. The entire estuary has been recognised for its ecological importance and for the importance of conservation in the area.

1.3.6 Existing developments

Historically low-intensity farming dominated large areas around the Severn and as such these areas have remained relatively rural. There are also a number of large industrial centres that have built up along the estuary. Bristol (402,292), Gloucester (112,415), Cardiff (322,904) and Newport (141,173) are the largest towns on the Severn Estuary and along with the populations as they have risen, leisure and tourism have followed[*]. Transport links include the two Severn Bridges and the Severn railway tunnel which link south Wales with south-west England.

Historically the majority of trade developed around the coal and mining industries. However, recent developments have seen trade move to electronics and the chemical industries. The

[2] Severn Barrage Committee: "Tidal power from the Severn Estuary". HMSO EP46, 1981.Volume II

[*] Populations given are estimated 2007 based on National Statistic estimated population growth rates.

regeneration of docks for leisure, tourism and property development is currently a popular option for disused or unproductive areas.

Cardiff, Newport and Avonmouth are the main industrial centres and remain as major trading ports within the estuary. In addition to these ports, Sharpness, Barry, Swansea, Milford Haven and Port Talbot are also major trading ports and together they make the Severn Estuary and Bristol Channel one of the most active shipping estuaries in the UK. Cardiff, Newport, Avonmouth and Sharpness would all be within the boundary of the Cardiff-Weston barrage. Only Sharpness would be affected by the English Stones scheme (Shoots barrage). The individual port capacities below give an indication as to the size of vessel that enter and leave the ports daily.

Swansea port primarily handles steel for Corus but also handles some forestry products, dry bulk and containers. Vessels up to 200m long and 30,000 deadweight tonnage (dwt) are able to enter Swansea port.

Port Talbot has the deepest facilities in the estuary with the capability to take vessels up to 180,000dwt. There are a number of inner docks that can accept smaller vessels. The majority of imports and exports in this port are for the Corus steel works at Port Talbort and Llanwern.

Cardiff Port is located in Cardiff Bay in close proximity to the city and the port can accommodate vessels of around 35,000dwt. The port handles a variety of exports and imports which include dredged aggregates, general cargo, steel rod and wire exports, and forest products.

One of the docks at Barry port has been redeveloped into commercial buildings and a new housing area. The second dock remains operational and can take vessels up to 23,000dwt.

Newport currently handles steel from the Llanwern Corus site. However, the port can accommodate vessels up to 40,000dwt and there is a dry dock which is 138m long and 19.5m wide. It is also a Freight Service Operator for the Channel Tunnel.

Avonmouth port is the largest port facility with the capacity to take vessels that are up to 120,000dwt, with a 14.5m draught[*ii] and a 41m beam. By 2002 the bulk handling in the port had risen to 25,000t per day. In total every year 500,000 cars are imported and exported through this port which has the land to accommodate such large cargos.

The most easterly of the ports, Sharpness, handles approximately 400 vessels per year (which equates to approximately 560,000t of cargo). The limitations on vessel size are a 6.55m draft and a 16.67m beam[3].

1.3.7 Environmental importance

The entire area of the Bristol Channel and the Severn Estuary is recognised ecologically as being extremely important. The Severn Estuary has been made a Special Protection Area (SPA), designated a RAMSAR site and has been elected as a possible Special Area of Conservation (pSAC). The entire area contains 157 Sites of Special Scientific Interest (SSSIs), 5 National Nature Reserves (NNRs), 2 SPAs (including the Severn Estuary) and 13 of Britain's Heritage Coasts. Additionally, many coastal areas are also designated as Areas of Outstanding Natural Beauty (AONB). The allocation of these sites has meant that much of the area of the Severn Estuary is now protected under the Habitats Directive. This will be explained fully in Section 6 of this report.

[*ii] Draught represents the depth to the lowest point of a ship's hull below water level. Beam represents the maximum width of a ship.

[3] Sir Robert McAlpine Ltd on behalf of the Severn Tidal Power Group: "The Severn Barrage – Definition Study for a new appraisal of the Project – Main Report", DTI/Pub URN 02/644, 2002 *Appendices*

1.4 Location Plan

Figure 1.4 shows the main features of the estuary from Minehead to Chepstow. It also shows the location of the two key single-basin barrage schemes that are discussed in the following chapters.

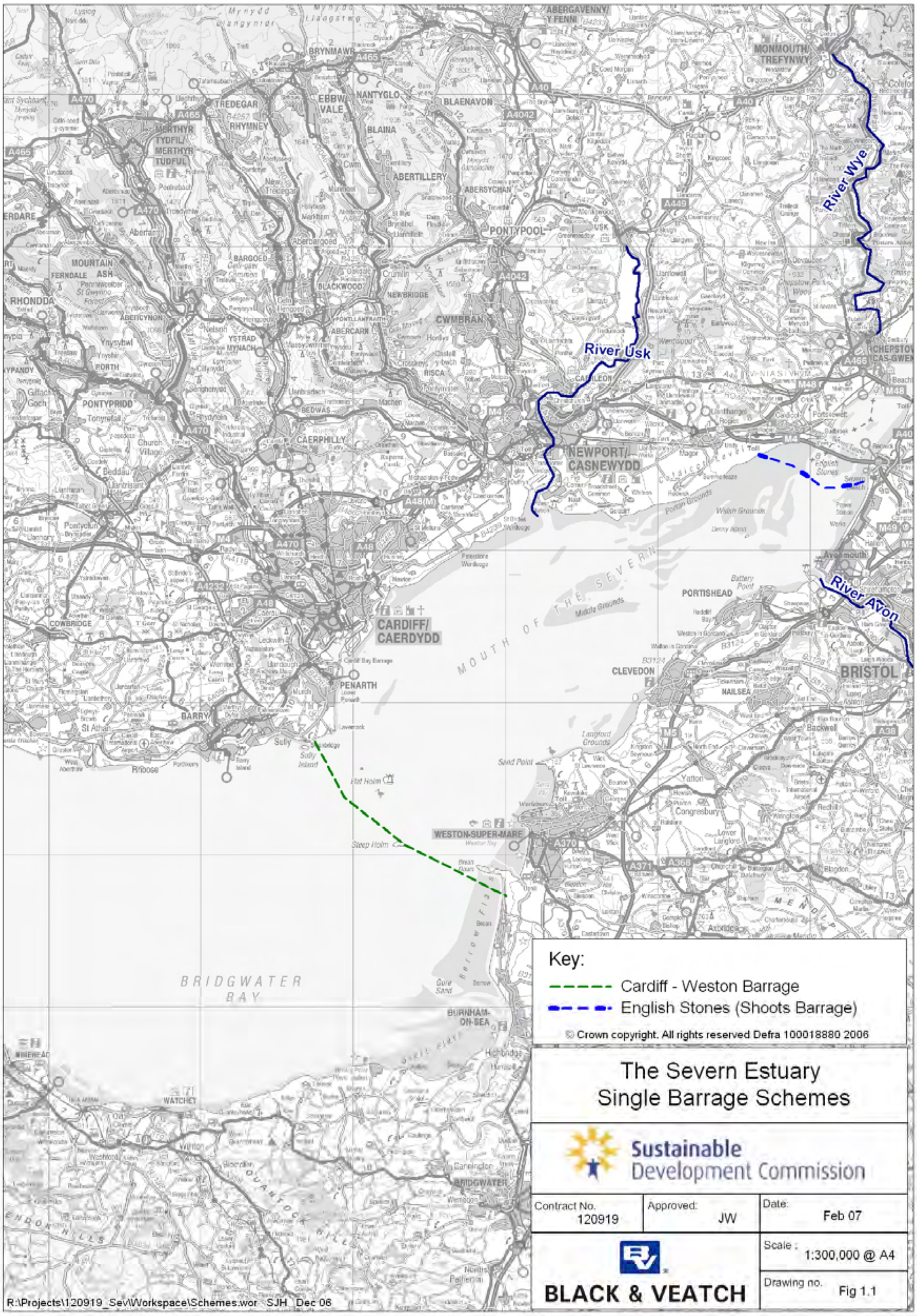


Figure 1.4: Layout of the Cardiff-Weston Barrage and the Shoots Barrage

2 SUMMARY OF PROPOSALS FOR A SEVERN BARRAGE

2.1 BACKGROUND

2.1.1 General

This section presents a brief description of the background, main features and method of operation of each of the short-listed barrage-based schemes proposed to be included in this study. The short-list has been selected from the following Severn tidal barrage schemes:

- **English Stones or Shoots scheme:** A barrage at or near English Stones, generating with a flow from basin to sea, mainly during the ebb tide – "ebb generation mode". This scheme was originally proposed during the 1920s, and is now being proposed by Parsons Brinckerhoff, who refer to the scheme as 'The Shoots barrage'.
- **Hooker scheme:** A barrage near English Stones with a second basin to seaward, on the Welsh Grounds. The barrage would operate in ebb generation mode. The second basin could be operated out of phase with the barrage, during the flood tide – "flood generation mode" or in phase as ebb generation mode. This scheme was originally proposed by A V Hooker of W S Atkins, Cardiff in 1977.

- **Cardiff-Weston scheme:** A barrage between Lavernock Point, west of Cardiff, and Brean Down, south-west of Weston-super-Mare, often referred to as "the Cardiff-Weston barrage" or simply the "Severn Barrage", operating as an ebb generation scheme but with the ability to use the turbines as pumps at around the time of high water to increase the amount of water stored in the basin. By pumping at low head, and generating later at relatively high head, a net increase in energy is obtained. This is the principal method of operation of the Rance barrage. This scheme has been the subject of much study over the last 25 years. It is associated with the STPG and is the most well known proposal.

- **Minehead-Aberthaw scheme**: A barrage on this alignment, often referred to as the "Outer barrage", was identified by the Severn Barrage Committee as the location where the maximum energy potential of the estuary could be developed. Locating a barrage even further to seaward would result in a lower tidal range and a greater reduction in this range caused by the barrage itself. More details are given in Section 2.3.

- **Cardiff-Weston scheme with second basin:** A barrage similar to the Cardiff-Weston scheme above, operating in ebb generation mode, with a second basin on the English side of the estuary. This second basin would be designed to operate in flood generation mode. This scheme was developed to provide a method of utilising nearly the full energy resource in the estuary, about 23 TWh/year, rather than pursue a very large "Outer barrage" to seaward.

- **Shaw two-basin energy storage scheme:** A barrage similar to the Cardiff-Weston scheme above and also with a second basin to seaward. However, the second basin, equipped with deep-set pump turbines, would have its water level below minimum tide level at all times, so that power could be generated at times when the main basin was unable to do so. This would result in the scheme having a large element of pumped storage built in, and a significantly better firm power capability than the barrage alone. This scheme was originally developed by Dr T Shaw, then of Bristol University.

- **Dawson continuous power scheme:** A barrage across the outer estuary, near Minehead, equipped with two sets of sluice gates and ship locks. Between the sets of sluice gates, an embankment connects to Brean Down, near Weston, forming a second basin and including a powerhouse structure with turbine-generators. The main basin is filled through one set of sluices, the second basin is emptied through the other set. Power is generated when water flows from the main basin to the second basin. By keeping the water level in the main and second basins within the upper half and lower half of the tidal range respectively, continuous power can be generated. This scheme has been proposed by R Dawson of Dawson Construction Plant Ltd[4].

- **Severn Lake scheme:** A barrage in about the same location as the Cardiff-Weston scheme but about 1km wide and including two wave farms on the seaward side, four marinas and other features not directly associated with energy production. This scheme has been proposed by the newly-formed Severn Lake Co. Ltd[5].

Each of the above schemes is described in more detail below. Before this, a brief summary is given below of the use of computer models to simulate the operation of tidal power schemes, as this is an important aspect of their economic and environmental impact assessment.

The locations of the Cardiff-Weston barrage and The Shoots barrage are shown in Figure 1.4(1).

2.1.2 Water levels and energy output

First approximations of the energy output of a tidal power barrage are usually based on a so-called 'flat estuary' computer model. This tracks flows into and out of the basin, though the turbines and sluice gates. These flows are driven by the tide on the seaward side, by the flow characteristics of the turbines and sluices, and the geometry of the enclosed basin and, in some cases, the bathymetry of the low-water channel immediately downstream of the barrage. No account is taken of the effects of the barrage on the tides well to seaward, nor of the dynamics of the tidal flows within the basin. For relatively small tidal barrages, such as La Rance, the effect of these omissions will be small. However, for the Severn estuary, dynamic effects are very significant and have to be modelled carefully to obtain predictions of water levels and energy output in which reasonable confidence can be placed.

For the studies of the performance of the English Stones scheme and the Cardiff-Weston barrage and the Outer barrage, extensive use was made of a 1-D computer model. This was first developed to represent accurately the existing tidal dynamics of the estuary from its seaward limit to its landward limit (approximately from Ilfracombe to Maisemore Weir, the tidal limit on the Severn near Gloucester). Then the barrage is added as a set of algorithms representing the operation of the turbines and sluices. In a 1-D model the estuary is represented as a series of slices, with the flow across each slice being assumed to be uniform at any moment. This type of model can also include algorithms for sediment transport, salinity or other 'pollutants' to help assess the effects of a barrage on the environment. During the 1986 studies of both the Cardiff-Weston and English Stones barrages by the STPG[6], the same 1-D model was used for both schemes, so allowing direct comparison of results.

With 2-D models the estuary is represented as a grid of squares, with the flow across each cell being assumed to be uniform with depth. This type of model requires considerably more computational power than a 1-D model and so is used more sparingly. The 2-D models used for the study of the Cardiff-Weston and Outer barrage schemes extended much further. So they were able to consider the distant effects of a barrage on tidal propagation (e.g the Cardiff-Weston barrage reducing tide range at Ilfracombe by about 3%) as well as providing a more detailed assessment of how the barrage would change the flow patterns either side of the barrage. These models also provide a more refined estimate of the energy output. 2-D models have not been applied to the English Stones barrage so far, but would be beneficial if the scheme were taken forward. The greater definition of a 2-D model allows a more detailed representation of sediment

[4] Dawson Construction Plant Ltd: The "Dawson Plan" for sustainable, continuous tidal power generation,. 2006.

[5] Severn Lake News http://www.severnlake.co.uk/news.shmtl: accessed 19/2/07.

[6] Severn Tidal Power Group (STPG): Tidal power from the Severn. 1986.

transport, salinity and other 'pollutants' and thus a more detailed understanding of the effects of a barrage on these processes.

Sediment transport, salinity and ecological productivity processes are three dimensional processes so their representation in either one or two dimensions inevitably involves simplifying assumptions that may not always be valid. These difficulties can in theory be overcome by applying a 3-D model in which the 2-D cells are subdivided vertically into slices that can have different flow, salinity and sediment concentrations. Developing this type of detailed model in real estuaries poses major challenges as it often requires a more detailed understanding of the relevant processes than is available. So far a model simulating the movement of water in three dimensions has yet to be applied to the Severn estuary in the detail required to evaluate barrage operation.

2.2 ENGLISH STONES

2.2.1 History of scheme

A barrage at English Stones was the recommendation of the first Severn Barrage Committee under Lord Brabazon in 1933[7]. This proposal was an 800MW scheme based on vertical-axis turbines. Interest in the scheme continued after the War. However, this scheme was not included in the studies carried out under the direction of the second Severn Barrage Committee, chaired by Sir Hermann Bondi, the Government Chief Scientist at the time (the Bondi Committee). The reason was that the energy output would be small compared with schemes further down the estuary, and it would preclude development of the estuary in a cost-effective manner.

In 1983, after the report of the Bondi Committee was published[8] , Wimpey Major Projects Ltd and W S Atkins & Partners formed a joint venture to promote the English Stones Scheme. As the Severn Tidal Power Group (STPG[*]) were about to start studies of the Cardiff-Weston scheme, which had been recommended by the Bondi Committee, it was decided to extend the STPG studies to include the English Stones scheme, and also to include a Wimpey-Atkins joint venture within STPG. This would allow a like-for-like comparison of the two schemes.

The Wimpey-Atkins scheme was designed to include a main road crossing of the estuary. However, this was excluded from the STPG studies and this feature has been superseded by the construction of the Second Severn Crossing.

STPG's studies were wide-ranging, covering engineering, energy generation, environmental and economic aspects[9]. A summary is given in the following sections.

Recently, Parsons Brinckerhoff, in association with Mr A V Hooker, have proposed a barrage at the English Stones, referring to it as 'The Shoots' barrage, on an alignment which would allow a high speed railway to cross the estuary. This railway would improve rail connections between England and south Wales, which presently rely on the single-track Severn tunnel engineered by Brunel.

2.2.2 STPG studies of English Stones barrage

Main features

The STPG studies concluded that the English Stones barrage would have the following features:

---

[7] Report of the Severn Barrage Committee, 1933; HMSO.

[8] Severn Barrage Committee: Tidal power from the Severn Estuary, 1981; HMSO.

[*] The Severn Tidal Power Group was formed, following the Bondi Committee report, to develop the Cardiff-Weston Scheme. See Section 3.1.2 for the constitution of the Group.

[9] Severn Tidal Power Group (STPG): Tidal power from the Severn. 1986.

Operation:	Ebb generation with flood pumping
Length of barrage	7.1 km
Length of powerhouse caissons	605m
Turbine runner diameter	7.5m
No. of turbines	36
Generator rating	27 MW
Total capacity	972 MW
Average annual energy output	2.7-2.8 TWh
Sluice type	Submerged venturi
Sluice gate size (width & height)	12m x 11m & 12m x 14m
No. of sluice openings	30 + 14
Ship lock size	140 x 20m (6000 dwt* ship)
	or 200 x 37.5m (LASH*i)
Capital cost (1984 prices)	£746-792M, depending on ship lock size
Unit cost of energy (5% discount)	2.89 – 5.27p/kWh (depending on rate of siltation of basin)
Time for construction	5 years to first power,
	6 years to full power

The working parts of the barrage, i.e. the turbines and sluice gates, would be housed in cellular concrete structures designed to be built in purpose-designed workyards and floated into position – referred to as ‘caissons’. This is the same method proposed for the Cardiff-Weston barrage and avoids the cost and adverse environmental effects of building very large temporary cofferdams within which the permanent structure is built. Cofferdams were used at the Rance barrage and the complete closure of the estuary for two years followed by restricted opening for a further four years had a significant adverse environmental impact on the enclosed basin.

Layout of barrage

STPG studied four different alignments of a barrage at English Stones, and two sizes of ship lock, as indicated above. The preferred alignment is shown on Figure 2.2(1). In summary, the powerhouse structure is located in the deep channel, with the ship lock and sluices on either side. Embankments link the concrete structures to the shore and provide access and a cable route.

* Dwt = dead weight, tonnes.

*i LASH = Lighters aboard ship.

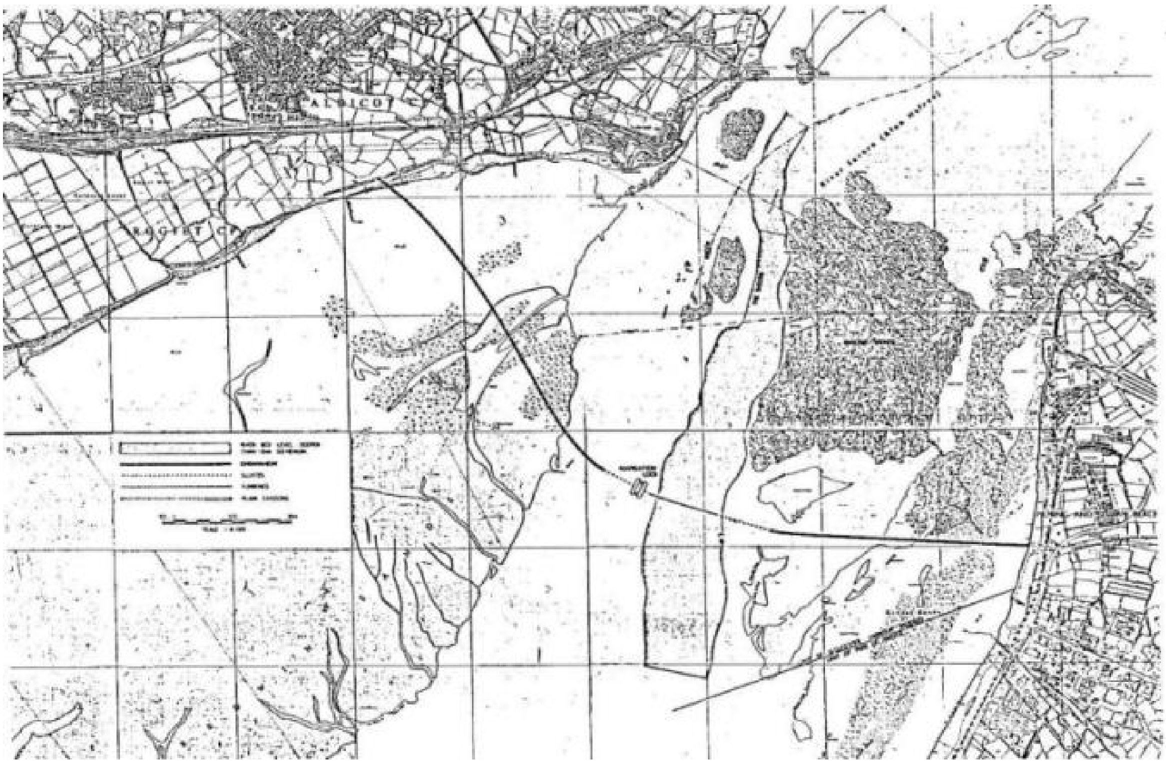


Figure 2.2(1): Location of English Stones barrage studied by STPG

Construction sequence

The construction sequence is shown on Figure 2.2(2). It is designed to allow ships travelling to Sharpness docks to pass safely through the part-completed barrage. Therefore the first structures to be completed are the ship lock and the first turbine and sluice caissons. The embankments would be last, built out from the shoreline as largely a land-based operation. The Welsh-side embankment would be the first to be finished, allowing the power cable connection to the local grid to be ready for first power generation.

STPG estimated that construction would take five years to first power, and six years to full power.

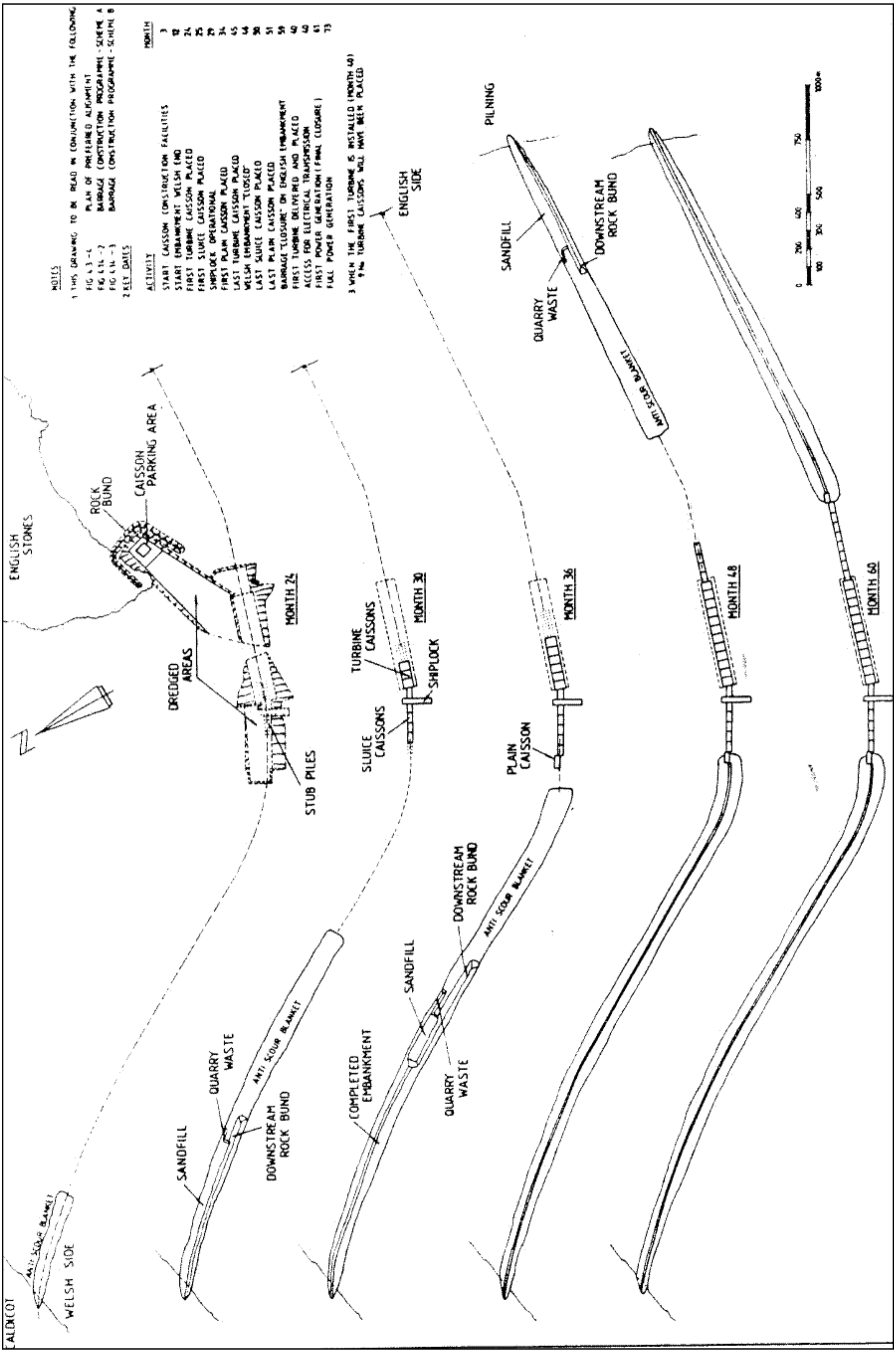


Figure 2.2(2): English Stones barrage construction sequence

Post-barrage water levels

Figures 2.2(3) and 2.2(4) show the tide curves at the barrage for a mean spring tide and a mean neap tide respectively. Figure 2.2(5) shows the envelopes of maximum and minimum water levels along the estuary upstream of Ilfracombe.

A key result of the studies was that the peak tide levels at Sharpness, crucial for ship movements, would be reduced by about 0.15m but less than 0.1m for tides with high water below 4m OD.

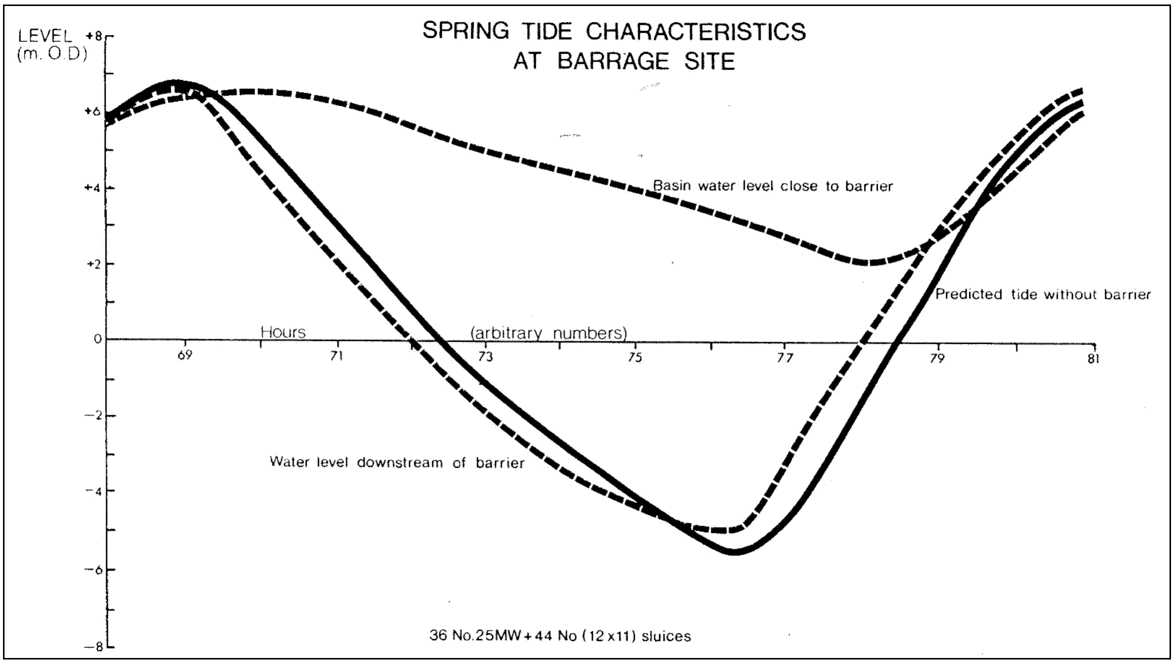


Figure 2.2(3): English Stones barrage: spring tide water levels

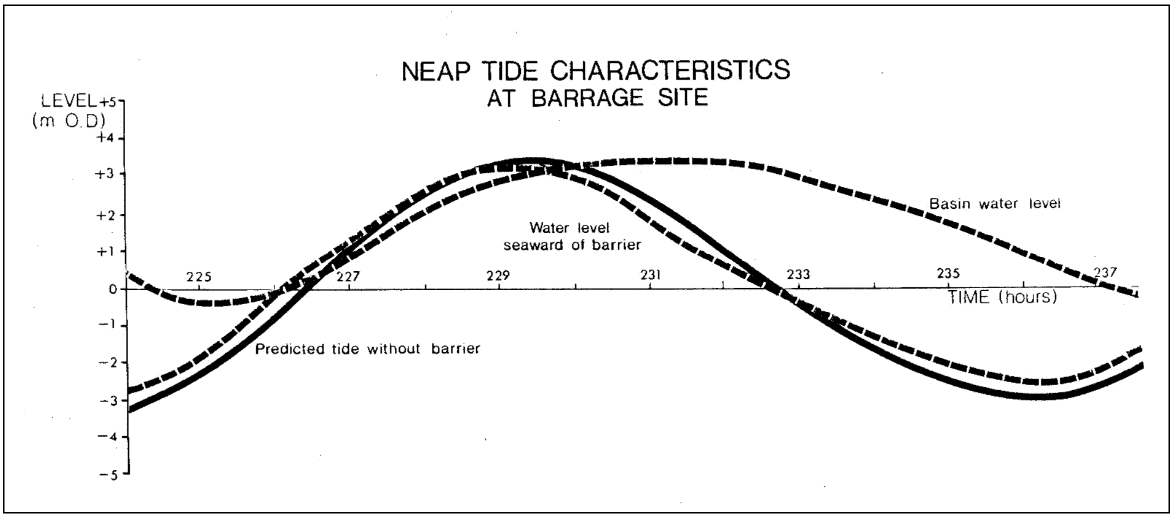


Figure 2.2(4): English Stones barrage: neap tide water levels

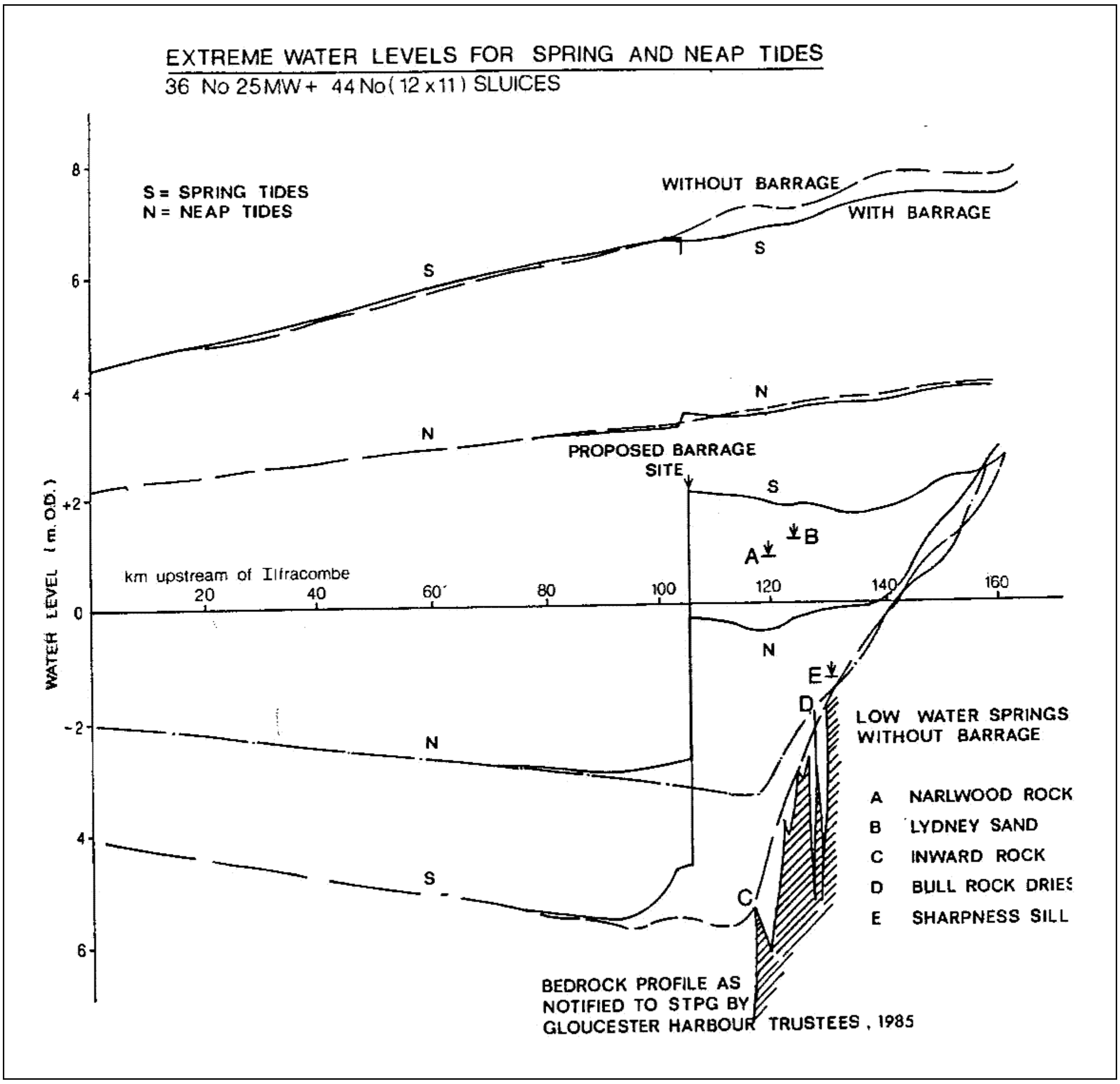


Figure 2.2(5): English Stones: envelope of high and low water levels

Effect of barrage on tide range to seaward

The high tidal range in the Severn estuary is a result of the favourable geometry – a steadily narrowing width, and also the result of resonance, as the length of the estuary approximates to a quarter-wavelength. A tidal power barrage would change the effective geometry of the estuary and also extract energy from the tides. Both effects will tend to reduce the tidal range along the estuary. The 1-D model indicated that the English Stones barrage would reduce the tidal range on its seaward side by about 8%, the percentage reduction reducing progressively down-estuary.

Energy output

Based on results from flat-estuary modelling and the 1-D model, STPG estimated that their preferred scheme would generate about 2.7-2.8 TWh in a year of average tides. This gives a load factor for the turbines of 32%, significantly higher than for the Cardiff-Weston scheme (23% in 1986, 22.5% in 1993 – see later). Over the principal long-term tidal cycle of 18.6 years, the energy output would vary from about 2.5 to 2.9 TWh/year.

The energy benefit of flood pumping to increase the amount of water stored in the basin each high tide was estimated at about 5%, based on results for the Cardiff-Weston barrage. Simulations with the latest turbine pumping characteristics were not undertaken.

Sedimentation

The 1-D model of the estuary was used to assess potential rates of sediment transport upstream and downstream of the barrage. The overall conclusion was that there would be a net movement of sediment upstream through the barrage and that, as a result, the basin could lose half its capacity between 10 and 100 years. This adversely affects the overall unit cost of energy, as indicated in Section 2.2.1.

2.2.3 The Shoots barrage proposal

Main features

The Shoots barrage, now being proposed by Parsons Brinckerhoff[10], would be located slightly upstream of the alignment developed by STPG (Figure 2.2(6)). Its main features are as follows:

Operation	Ebb generation
Length of embankments	4.1 km
Turbine runner diameter	7.6m
Type of turbine	'Straflo'* with fixed runner blades
Generator rating	35MW at 8.1m rated head
No. of turbines	30
Total capacity	1050 MW
Average annual energy output	2.75 TWh
Sluice type	Open-topped radial gate
Sluice gate size	32m wide, with sill at +3m OD
No. of sluice openings	42
Ship lock size	225 x 37.5m (10,000 dwt)
Capital cost (1990 prices)	£1080M
Capital cost (2006 prices)	£1800M
Unit cost of energy (5% discount)	4.83p/kWh (6.53p/kWh at 7.5%).

[10] Parsons Brinckerhoff Ltd: "Severn Estuary, Shoots Tidal Barrage – updated financial assessment". November 2006.

* The 'Straflo' turbine has the generator rotor mounted on the tips of the runner blades. This results in a more compact installation than for an equivalent bulb turbine but the turbine cannot readily be used to pump in the reverse direction of flow. A single prototype large machine of 7.6m runner diameter has been in operation at Annapolis Royal, off the Bay of Fundy, since 1984.

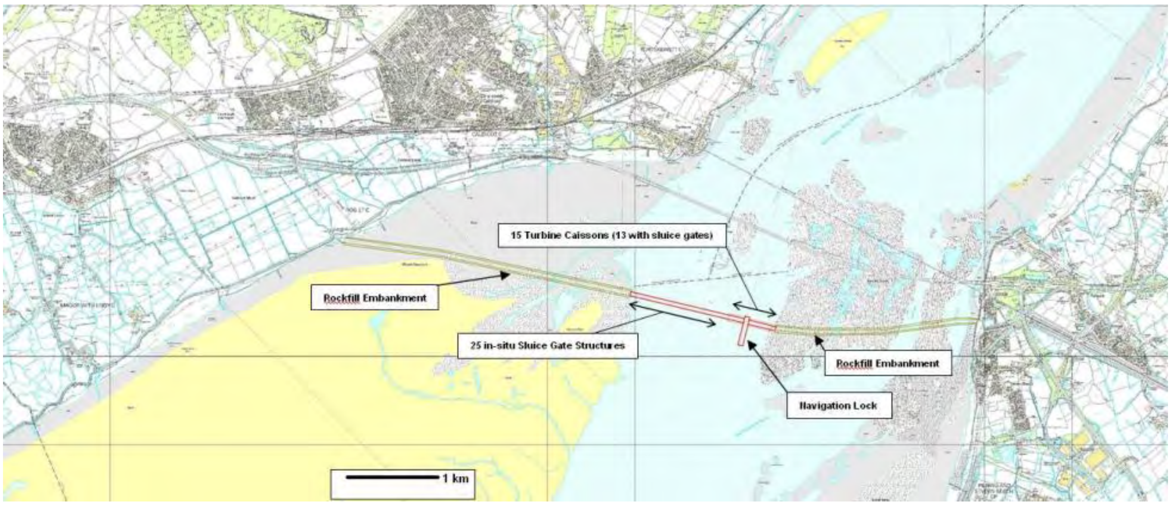


Figure 2.2(6): Location of the Shoots barrage proposal

Two features distinguish the Shoots barrage from the scheme developed by STPG and described above:

- The alignment has been chosen to allow a high speed rail link between England and south Wales
- The sluice gates are at high level, with their sills at +3m OD, with the aim of reducing the amount of sediment carried into the basin on the flood tide. In STPG's studies the gates are at low level, and the turbines would be allowed to free-wheel in reverse and so act as additional sluicing capacity to maximise the amount of water stored in the basin each tide.

State of development

The studies carried out to date by Parsons Brinckerhoff have not been to the same level of detail as the STPG work. However, the Shoots barrage proposal and the STPG English Stones barrage proposal are sufficiently similar to give the claimed energy performance of the Shoots barrage credibility.

Sediments

The Shoots scheme has been designed with high-level sluice gates. When refilling the basin during the flood tide, the turbines would be kept closed. It is expected that, with this arrangement, the more sediment-rich lower part of the flow would be excluded from the basin and thus the rate of sedimentation of the basin, as predicted for the English Stones scheme, could be reduced. This would extend the working life of the barrage. The success of this strategy would depend on the turbulence of the flow approaching the barrage. If successful in reducing siltation of the basin, there may be a side effect of increased deposition of sediment on the flanks of the estuary immediately to seaward of the barrage. A definitive assessment of this aspect would need some sophisticated computer modelling and associated data collection.

2.2.4 The A V Hooker two-basin scheme

The concept

This is a two-basin scheme, proposed by Mr A V Hooker of W S Atkins, Cardiff which was evaluated during the Bondi Committee studies. Its layout is shown on Figure 2.2(7). The concept was based on the following factors:

- Access to the main ports would not be obstructed;
- the barrage across the estuary would operate in normal ebb-generation mode;

- the second basin would operate in flood generation mode, thus resulting in four periods of energy generation per day and no extra transmission costs;
- the embankment forming the second basin would be built along the –5m OD contour, i.e. at about the level of low water of spring tides, thus minimising its height and cost.

The tidal range in the second basin would be from about mid tide level to about low tide level – the lower half of the cycle. Therefore the second basin would be relatively very shallow, restricting energy output, and about half the area of presently inter-tidal foreshore would be permanently exposed. To improve the effective volume of the second basin, the scheme included dredging of the second basin and using the dredged material to build a large area of reclaimed land near Newport.

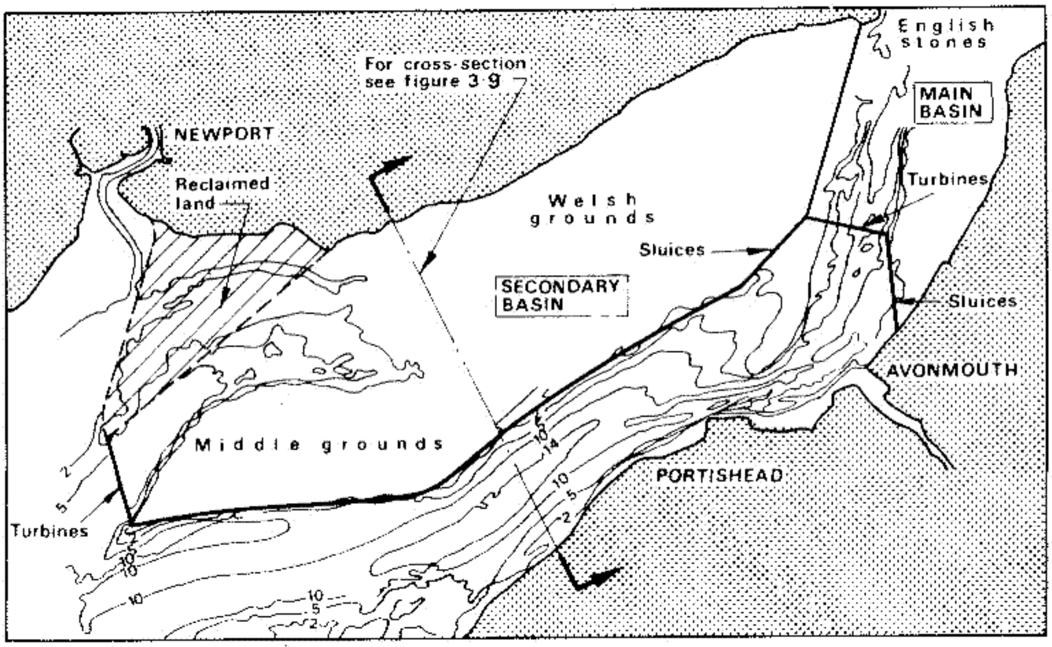


Figure 2.2(7): Plan of scheme proposed by A V Hooker

Results of evaluation

The Hooker scheme was evaluated on a like-for-like basis, using the same building blocks as were used for other schemes being studied at the time (concrete caissons to house the rubines and sluice gates, bulb turbines, embankments, transmission costs, etc). In addition, the energy output was estimated by computer model. Figure 2.2 (8) shows a simulation of operation over a spring-neap cycle, including the water levels in each basin and the power output of each basin.

The main results of this evaluation were:

- The annual energy output of the two basins would be about 4.2 TWh/year. This is about 55% more than for the Shoots barrage but still only about 1/3rd of the output then being predicted for the Cardiff-Weston barrage.
- The unit cost of energy would be 29-38% greater than that for the Cardiff-Weston scheme, depending on the cost of turbine/generators. The main factor in this disappointing result was the cost of the long embankment for the second basin.
- The embankment for the second basin, along the edge of the Welsh Grounds, would be founded on deep, erodible, sediments (Figure 2.2(9)) which would present difficulties during construction and may be subject to major redistribution during scheme operation.
- Navigation to Newport docks would be affected by the discharges from the turbines at the seaward end of the second basin. Any other location for the turbines would affect ships travelling to Avonmouth.

- This scheme would preclude further development of the estuary in a cost-effective manner, as any tidal power barrage downstream would result in a greatly reduced tidal range in the basin. This would reduce the energy output of the scheme to around 25% of its normal value.

These results led to the scheme being dropped from more detailed evaluation by the Bondi Committee, and it is no longer being proposed.

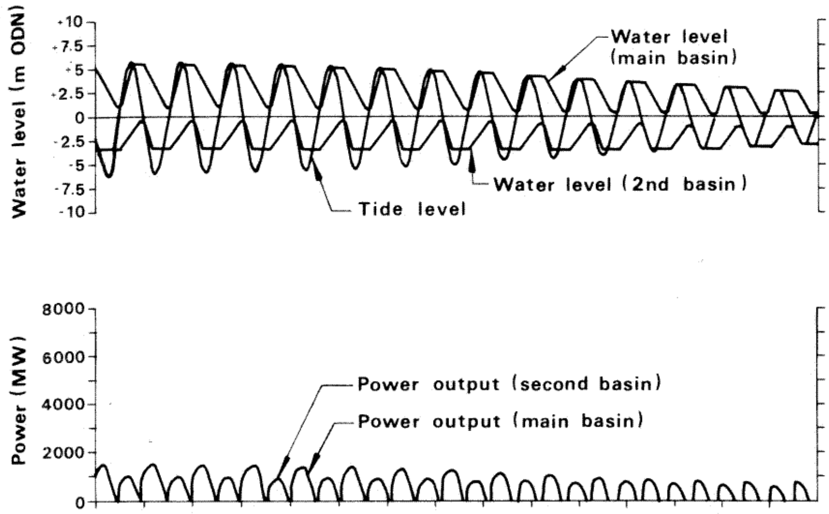


Figure 2.2(8): Operation of Hooker two-basin scheme over spring-neap cycle

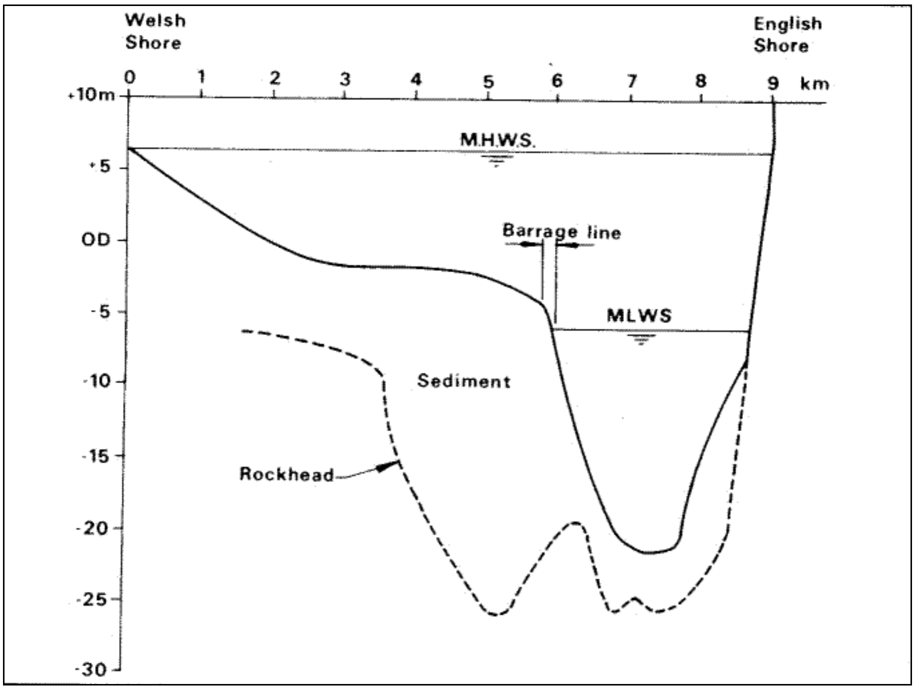


Figure 2.2(9): Cross-section of A V Hooker scheme showing depth of sediment

2.3 LARGER SINGLE-BASIN SCHEMES

2.3.1 Studies by Second Severn Barrage (Bondi) Committee

During 1978-81, wide-ranging studies of tidal power in the Severn Estuary and inner Bristol Channel were carried out for the Department of Energy under the direction of the second Severn Barrage Committee (the "Bondi Committee"). Initially six notional lines were studied, each much larger than the Shoots scheme, ranging from Line 1 between Porthcawl and Lynmouth to Line 6 just downstream of Avonmouth (Figure 2.3(1)).

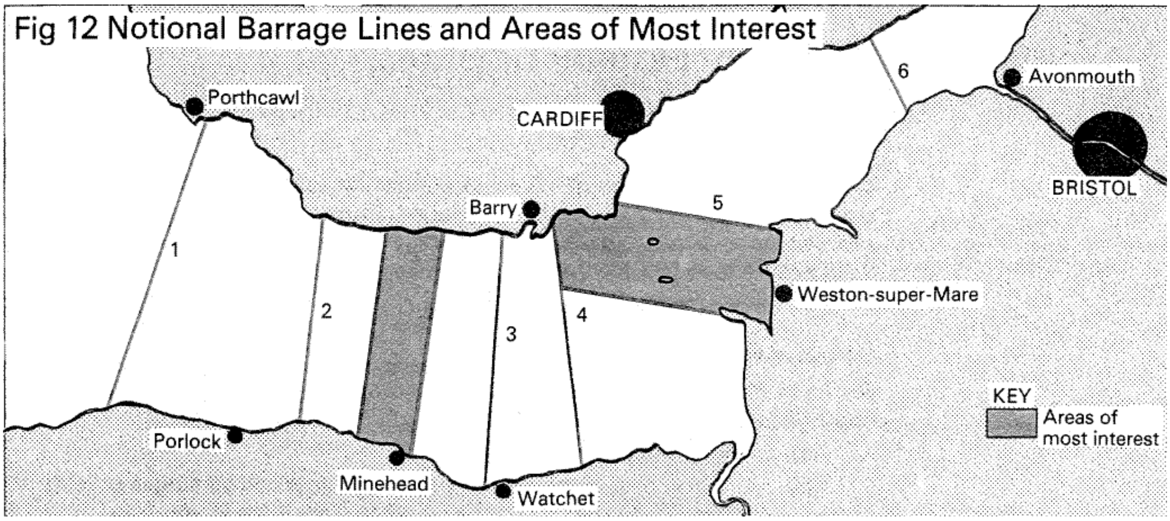


Figure 2.3(1): Locations of notional barrage sites

In order to be able to compare and rank the notional lines on the basis of unit cost of energy, the same set of 'building blocks' mentioned above for the evaluation of the Hooker scheme was used to estimate capital costs for a range of turbine and sluice numbers on each line. At the same time, energy outputs were evaluated, using 'flat-estuary' computer models but including preliminary assessments of the reduction in tidal range to be expected at each line. Combining capital cost and energy output allowed the likely optimum number of turbines at each line to be identified, and the resulting unit cost of energy compared, as shown in Figure 2.3(2) below.

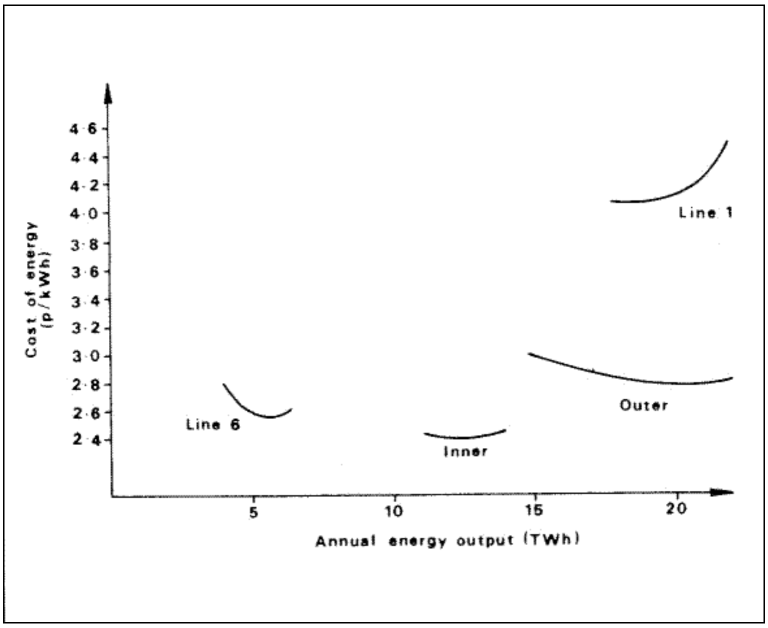


Figure 2.3(2): Overall comparison of energy outputs and unit costs for notional sites

As a result, the studies first identified two main areas of interest, shown shaded in Figure 2.3.1, and led on to the selection of a barrage located between Lavernock Point, near Cardiff, and Brean Down, south-west of Weston as the scheme recommended for further study. The main factors leading to this recommendation were as follows:

1. In terms of unit cost of energy, Cardiff-Weston would be the least-cost location for a barrage, noting that later studies have shown that a barrage at English Stones could result in a similar unit cost but would generate only about $1/6^{th}$ of the energy.
2. The bathymetry of the estuary is suited to the depth requirements of the working parts of the barrage – the turbine and sluice caissons.

3. The seabed is suitable as a foundation for the barrage structures, with some dredging.
4. The maximum energy potential of the estuary would be developed by a barrage between Minehead and Aberthaw (the 'Outer barrage' in the shaded area between lines 2 and 3 in Figure 2.3(1), shown in more detail in Figure 2.3(3) below). Here a barrage with 12,000 MW of turbine generators would produce about 20 TWh/year of electricity. However, the unit cost of energy would be significantly higher and the environmental effects correspondingly greater than for the Cardiff-Weston scheme.
5. Any barrage further seaward than the Outer barrage would not generate any more energy for two reasons:
   - The natural tidal range reduces. The mean spring tide range of about 11m at the Cardiff-Weston line reduces, for example, to about 8m at Ilfracombe.
   - The extraction of energy by a tidal barrage and the effect of a barrage in changing the shape of the estuary are predicted to result in the natural tidal range being reduced. At the Cardiff-Weston line the reduction would be about 11%. The outer barrage would reduce the natural range by about 20%.
6. The Cardiff-Weston barrage could be designed to allow a second basin to be added later. This is discussed below. The two basins would have a combined energy output approaching that from the Outer barrage and therefore almost fully develop the energy potential of the estuary.

The following table shows the comparison of the Cardiff-Weston barrage, the Outer barrage and the two-basin scheme based on the Cardiff-Weston barrage, as presented in the report of the Bondi Committee. Prices are at 1979 levels except where stated. The two-basin scheme is discussed in more detail later.

			Two-basin staged scheme	
	Cardiff-Weston	**Outer barrage**	**Cardiff-Weston**	**Second basin**
Length (km)	17	20	17	30.5
No. of turbines 9m dia.	160	300	160	125
Annual energy (TWh)[♦]	12.9	19.7	10.4*	7.7
Total energy (TWh/year)	12.9	19.7	18.1	
Capital cost (£M)	4342	6817	4342	3618
Total cost (£M)			7960	
Approx. cost at Dec 2005 (£M)	15,000	24,000	28,000	
1979 cost of energy (p/kWh)	**2.41**	**2.79**	**2.87**	

Note: The addition of the second basin was predicted to reduce further the tide range at the first stage.

The energy outputs shown in the table above were based on achieving the lowest cost of energy, by adjusting the numbers of turbines and sluices, and using the cost data available at the time.

The costs at December 2005 prices have been based on indexation of the 1988 cost estimate for the Cardiff-Weston barrage prepared by the Severn Tidal Power Group and discussed in Section 5.1. This estimate was based on 216 turbines instead of 160, and associated greater annual energy output. The simple pro-rata costs shown for the Outer barrage and Two-basin staged scheme would also cover barrages with increased numbers of turbines and greater annual energy output.

As an indication of available energy, graphs presented in Volume 2 of the report of the Bondi Committee[2] show maximum numbers of turbines studied and the resulting annual energy outputs as follows:

♦ The energy outputs assessed during the Bondi studies were based on achieving the lowest unit cost of energy with the construction cost data available at the time, and were consistent between different schemes. STPG have developed the Cardiff-Weston barrage with more turbines, giving more energy output, so that the previous results are no longer directly comparable.

Scheme	Cardiff-Weston	Outer barrage	Two-basin, staged scheme	
			Cardiff-Weston	Second basin
Max. No. of turbines studied	180	400	180	200
Max. annual energy (TWh)	14	23	11	9.5

For the Cardiff-Weston barrage, the maximum number of turbine studied was limited by the width of the deep water channel where the turbine caissons would be located. In their subsequent studies, STPG elected to carry out more dredging to provide the space for the extra turbines.

Outer barrage (Minehead-Aberthaw)

The main features and possible cost of the Outer barrage are discussed above. Somerset County Council has indicated its interest in the Outer barrage in preference to the Cardiff-Weston scheme, as the former can be expected to provide greater protection to a larger area against flooding due to sea level rise and tidal surges for the large areas of low-lying land in the county. This area includes important infrastructure such as the M5 motorway and rail links. Similar protection would be provided by the Cardiff Weston barrage and second basin of the staged scheme. This aspect is discussed in more detail in Section 7.6.

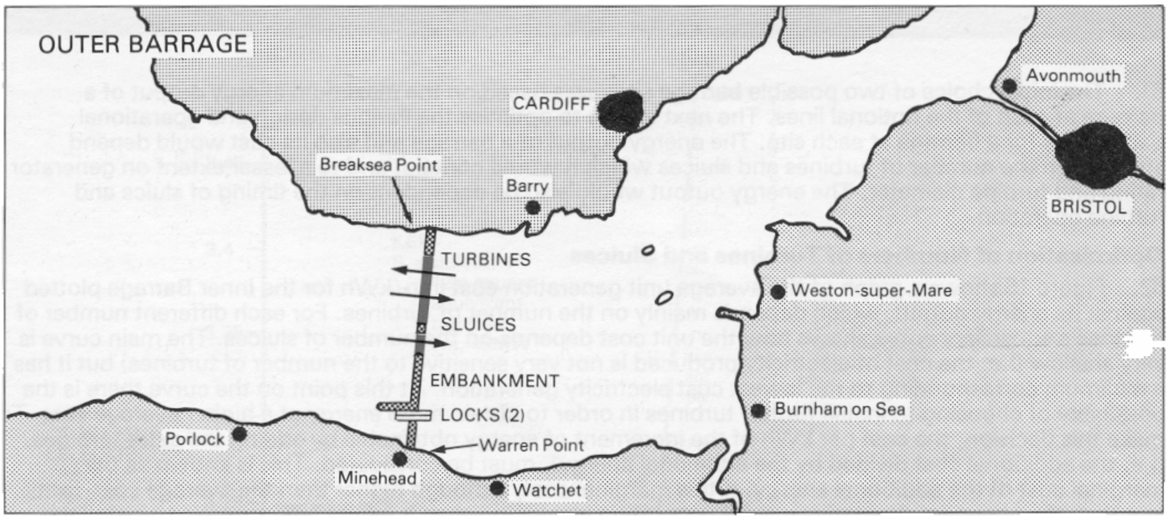


Figure 2.3(3): General arrangement of Outer barrage

Recommendation of the Bondi Committee

The Cardiff-Weston scheme recommended for further study by the Bondi Committee had the following main features:

Operation	Ebb generation
Length	16 km approx.
Turbine runner diameter	9m
Type of turbine	bulb
Generator rating	45 MW
No. of turbines	160
Total capacity	7200 MW
Average annual energy output	12.9 TWh

Sluice type	Submerged, vertical-lift wheeled gate
Sluice gate size	12m x 12m
No. of sluice openings	150 of equivalent total area
Ship locks sizes	370 x 50m + 366 x 43m (150,000 dwt)
Capital cost (1980 prices)	£5660M
Unit cost of energy (5% discount)	3.1p/kWh

Later studies by the Severn Tidal Power Group (STPG) have resulted in further development of the Cardiff-Weston scheme, discussed below.

2.3.2 Studies by the Severn Tidal Power Group

After the publication of the report of the Bondi Committee[11] a consortium of contractors and manufacturers was formed as the Severn Tidal Power Group (STPG[*]) to develop the Cardiff-Weston scheme further. STPG have carried out two major studies and produced two sets of reports:

1. Tidal power from the Severn – 1986[12]. This reported on the results of interim studies which included:
    - Technical studies of the Cardiff-Weston barrage and its elements.
    - An evaluation of the English Stones barrage, discussed in Section 2.2 above.
    - The effects of the Cardiff-Weston barrage on the regional environment and infrastructure.
    - The implementation of the barrage.
    - An appraisal of construction risks
    - The financing of the construction of the Cardiff-Weston barrage.

2. The Severn Barrage Development Project – 1989[13]. This study had the following aims:
    - To reduce uncertainty on the costs and performance of a tidal barrage near Cardiff.
    - To examine further the regional and environmental effects of the barrage in consultation with other interested parties.
    - To re-assess the economic viability of the barrage.
    - To study the legal aspects of the barrage.
    - To define the further work required prior to any decision to construct the barrage.

The results of the Development Project were presented in a six-volume report – a General Report (EP57, 1989) and a Detailed Report (five volumes, 1990).

In STPG's 1986 report, the principal changes from the scheme recommended by the Bondi Committee were:

- The alignment was straightened, with no concession for the possible addition of the second basin.

---

[11] Severn Barrage Committee: "Tidal power from the Severn Estuary". HMSO EP46, 1981.General Report.

[*] In 1986, STPG comprised the following companies: Sir Robert McAlpine & Sons Ltd., Balfour Beatty Ltd., GEC Power Engineering Ltd., Northern Engineering Industries plc, Taylor Woodrow Construction Ltd., and Wimpey Major Projects Ltd.

[12] STPG: Severn Tidal Power Group (STPG): Tidal power from the Severn. 1986 "General Report" and detailed "Engineering and Economic Studies".

[13] STPG: Severn Barrage Project: General Report and Detailed Vol I-V, 1989. EP57, HMSO.

- The turbine diameter was reduced to 8.2m to stay within proven experience.
- The generator capacity was reduced to 37.5 MW to suit the reduced turbine size.
- The number of turbines was increased to 192 to maintain the total installed capacity of 7200 MW.
- Mainly by including flood pumping at around high water, the estimate of annual energy output was increased to 14.4 TWh/year.
- The cost was estimated at £5543M at 1984 prices.

The layout of the barrage was broadly similar to that developed in later studies and shown on Figure 2.3(4).

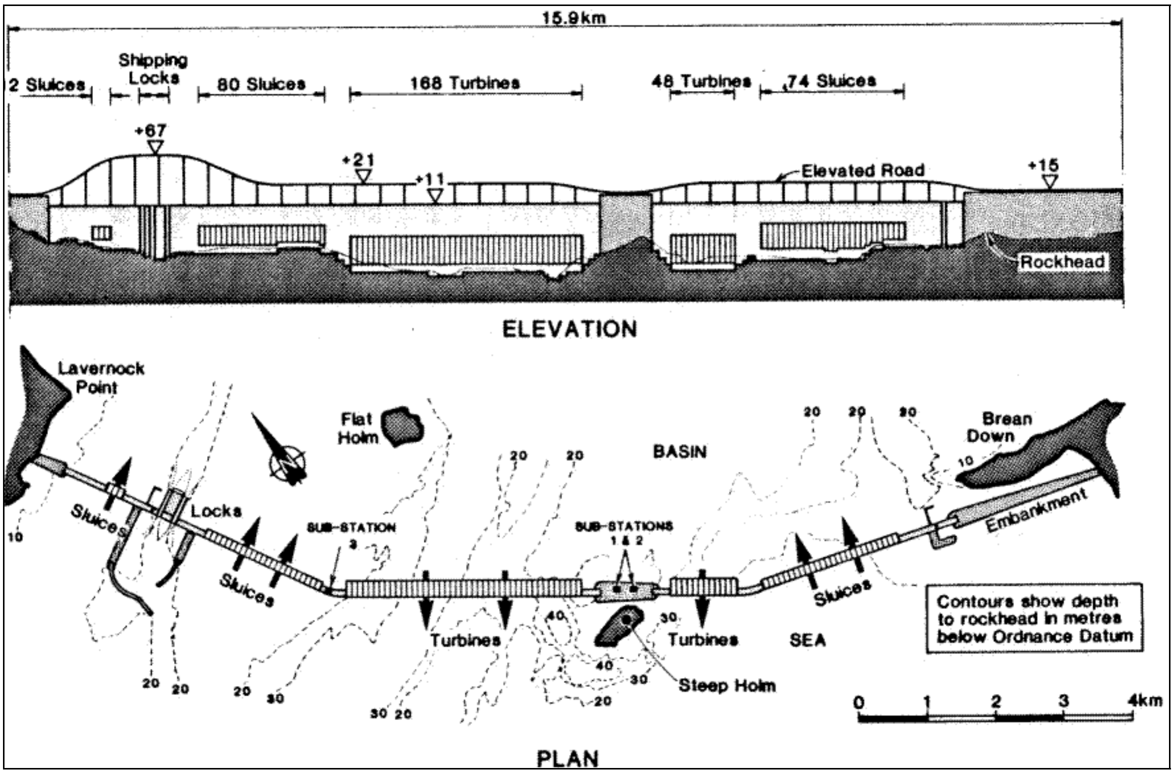


Figure 2.3(4): Layout of Severn Barrage as proposed by STPG

In STPG's second report (1989-90), the recommended features of the barrage are as follows. The layout is shown on Figure 2.3(4).

Operating mode	Ebb generation with flood pumping
No. of turbine generators	216
Diameter of turbine runners	9.0m
Operating speed of turbines	50rpm
Generator capacity	40MW
Total installed capacity	8640MW
No. of sluices, of various sizes	166
Total area of sluice openings	35,000m^2
Ship locks (2 No.)	360m x 50m
Average annual energy output	17TWh
Length of barrage	16.1km

Area of enclosed basin at mean sea level	480km^2
Approx total cost (2006)	£15,066M

In the 1989-90 report, certain aspects were identified as being on the critical path to development. Three of these were the subject of further studies in 1990-92 and reported in 1993[14], as follows:

- Further study of sediments and turbidity in the Severn Estuary, focussing particularly on the Bridgwater Bay area.
- Primary biological productivity and bird populations in the Severn Estuary.
- Barrage energy capture.

The third aspect, energy capture, was investigated by various computer models representing ‘flat-estuary (0-D) and dynamic (1-D and 2-D) conditions, including 0-D and 1-D models with internal optimising routines to maximise the energy generated. This work showed that the gains to be expected from reverse pumping at high tide would be only 2.7-3.2% compared with, for example, about 10% achieved at La Rance. Even these lower figures are subject to further evaluation taking into account the values of the energy used during pumping and later, while generating. The main reason for the low gain appears to be that, soon after high water, the water in the basin starts to ebb and raise the water level immediately behind the barrage. This increases the head against which the turbines have to pump, and prevents the pumped water from propagating up the estuary. This is not the case at La Rance, where the tides in the relatively short basin are much less dynamic.

Figures 2.3(5) and 2.3(6) show the envelopes of high and low water along the estuary. The former shows a mean spring tide and a mean neap tide. The latter shows a mean spring tide with a 1m rise in sea level. These illustrate the dynamic character of the tides in the Severn estuary.

The overall annual energy output of the barrage in a year of average tides was assessed as 17TWh.

In 2002, the STPG published a report[15] setting out the case for a study to reappraise the Severn barrage in the light of developments since the 1989-90 report. The main aspects supporting this case are:

- Reductions in the cost of capital. The long construction period for the Cardiff-Weston barrage results in financing costs being a major item.
- Following Kyoto, the development of a market value for savings in greenhouse gases.
- The potential impact of climate change on sea levels and the ability of the barrage to protect the low-lying parts of the estuary.
- The government’s policy to encourage the generation of energy from renewable resources.
- The government’s policy to reduce greenhouse gas emissions, particularly CO_2.
- The barrage would add to the diversity of supplies and reduce reliance on imported fuels.
- The tides are a highly predictable source. As a result, although the barrage’s output would be intermittent, the barrage would allow a net reduction of 1100MW in the overall mix of gas-fired and coal-fired thermal plant i.e. this would represent its firm capacity credit in the overall generating system.
- Tidal power is a proven and reliable technology, as demonstrated by the Rance barrage over the last 40 years.

The report concludes with a list of subject areas recommended for further study to bring knowledge about the Cardiff-Weston barrage up to date:

1. The benefits of varying the start times of generation.
2. The feasibility of adding a low-head pumped storage capability.
3. The issue of grid reinforcement and the contribution of the barrage to firm power.

---

[14] STPG: Severn Barrage Project: Further Environmental and Energy Capture Studies, ETSU TID 4099, 1993

[15] STPG: The Severn Barrage – Definition study for a new appraisal of the Project; ETSU T/09/00212/REP, 2002.

4. The role of the barrage in flood protection and the prevention of coastal erosion.
5. Statutory conservation aspects.
6. Navigation aspects.
7. An evaluation of the existing and possible new ports; the provision of large locks in the barrage, and the associated dredging requirements.

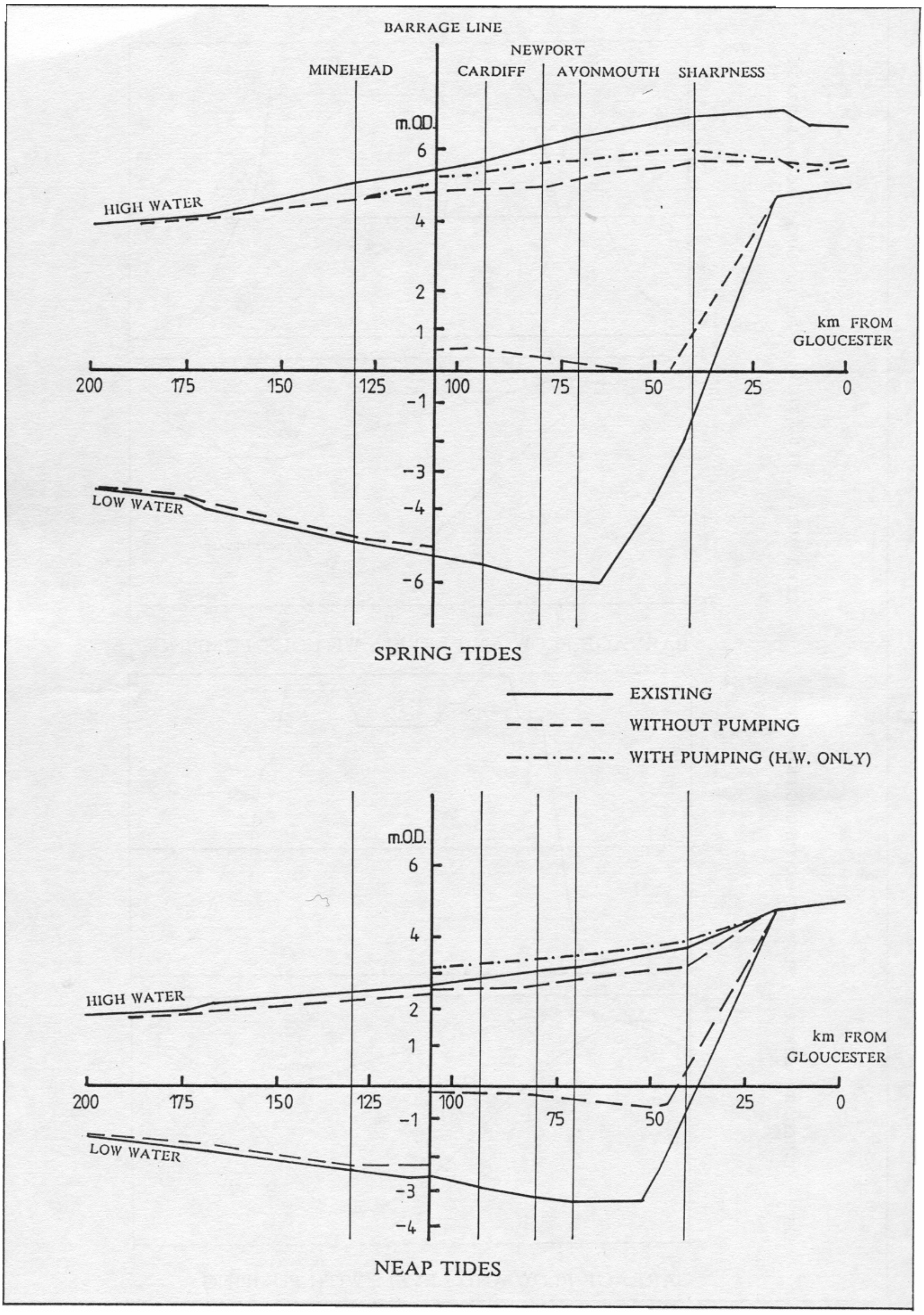


Figure 2.3(5): Cardiff – Weston barrage: envelopes of high and low water levels

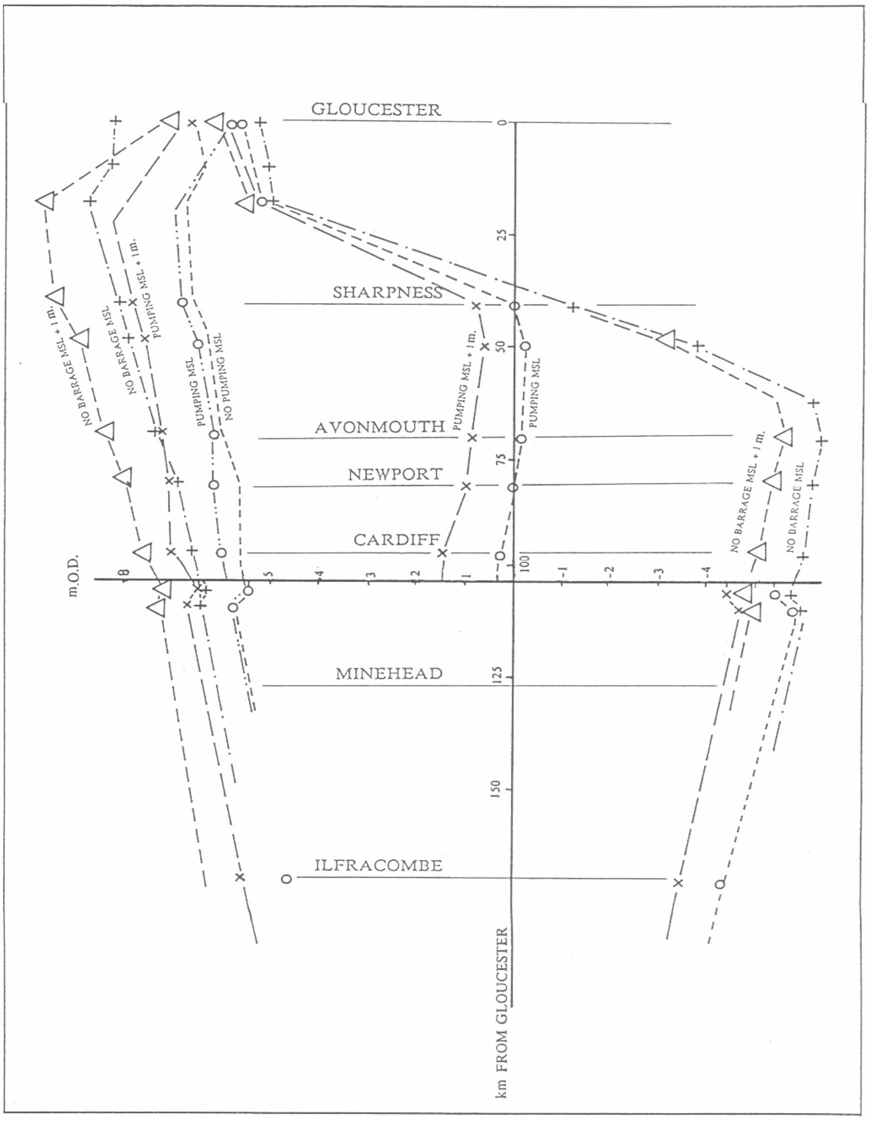


Figure 2.3(6): Cardiff – Weston barrage: envelope of spring tide water levels with 1m rise in sea level

8. The cost-benefit of road and rail links on the barrage.
9. A new cost estimate and construction programme, taking into account the results of the above studies
10. A new cost-benefit analysis, taking into account the social and economic benefits of the barrage.
11. An assessment of how the barrage meets the aims of sustainable development in accordance with the Sustainable Development Scheme of the National Assembly for Wales.
12. A risk assessment of construction and operation.

The first item has been the subject of some study which showed that the start time of generation, relative to the time of high water, can be varied significantly without incurring a severe penalty in terms of reduction of overall energy generated. Optimisation of barrage operation on the basis of the overall value of energy, rather than the amount of energy, would be a logical approach but requires the prediction of the long-term value of energy in a free market.

The second item was studied in some detail in the Bondi Committee studies, and this type of scheme is discussed later.

2.4 TWO-BASIN EBB AND FLOOD GENERATION SCHEME

- A two-basin scheme based on the Cardiff-Weston barrage was developed and evaluated during the Bondi Committee studies, primarily as an alternative to the Outer barrage.

The second basin would be located along the English shore of the outer estuary, with its landfall at Warren Point, close to Minehead (Figure 2.4(1)). The turbines in this basin would be operated in flood-generation mode, so the combined output of the two basins would result in four periods of generation each day. As there would be no increase in the maximum output of the first stage, there would be no need for further strengthening of the grid system and the contribution of the two basins to the firm power of the overall generating system would be enhanced.

A summary comparison of the Outer barrage and the Cardiff-Weston two-basin scheme is presented in Section 2.3.1 above.

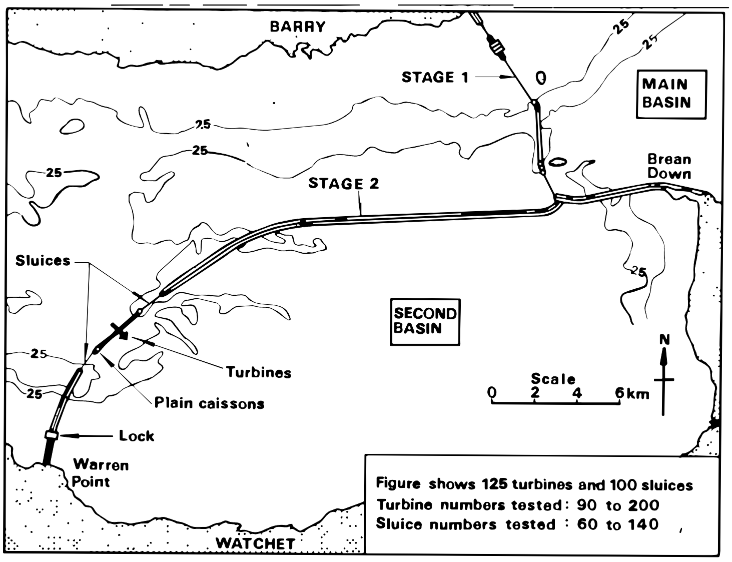


Figure 2.4(1): Two-basin ebb and flood scheme: plan

The second basin, costing £3618M or 85% of the cost of the first stage (at 1979 prices), produces only a net 5.2TWh/year extra energy. Also, as for the Hooker scheme discussed in Section 2.4 above, the long length of embankment results in the second stage being far less economic than the first stage. However, the overall performance of the staged scheme is comparable with that of the outer barrage and the energy potential of the estuary would be more or less fully developed. Any decision to build the second stage can be taken after, and separately from, a decision to build the Cardiff-Weston barrage.

There are at present no proposals to develop the two-stage scheme further.

2.5 TWO-BASIN PUMPED STORAGE SCHEME

This concept was originally proposed by Dr T Shaw when at Bristol University. By having two basins, each with turbines capable of generating in one direction and pumping in the other, a steady power output could be produced during each day, with power for pumping being imported each night. This concept (and possible variations in its mode of operation) was studied during the Bondi Committee studies. Figures 2.5(1) and 2.5(2) show the arrangement developed during those studies and one method of operation.

The studies led to the following conclusions:

1. The second basin is best considered as a low-head pumped storage scheme with an operating efficiency of about 100%, rather than an energy-producing scheme, and

therefore should be compared with other storage options available, in particular high-head pumped storage such as at Dinorwig and underground pumped storage.

2. The introduction of (predictable) tidal power into the UK electricity supply system does not imply the need for storage unless there is a very high proportion of nuclear plant in the system.
3. Economic analysis of two-basin pumped tidal storage schemes showed that about 50GWh/day for 12 hours generation could be available over the full spring-neap tidal cycle at a cost (1980 prices) of about £1900/kW, compared with a cost of about £970-1130/kW for high head pumped storage.
4. Overall, two-basin schemes are not a cost-effective way of developing the Severn Estuary as an energy resource.

Notwithstanding the Bondi Committee's findings, STPG's 2002 proposal for a new appraisal of the project included the study of 1.5 to 2GW of low-head pumped storage either constructed integral to the barrage or possibly added at a later date.

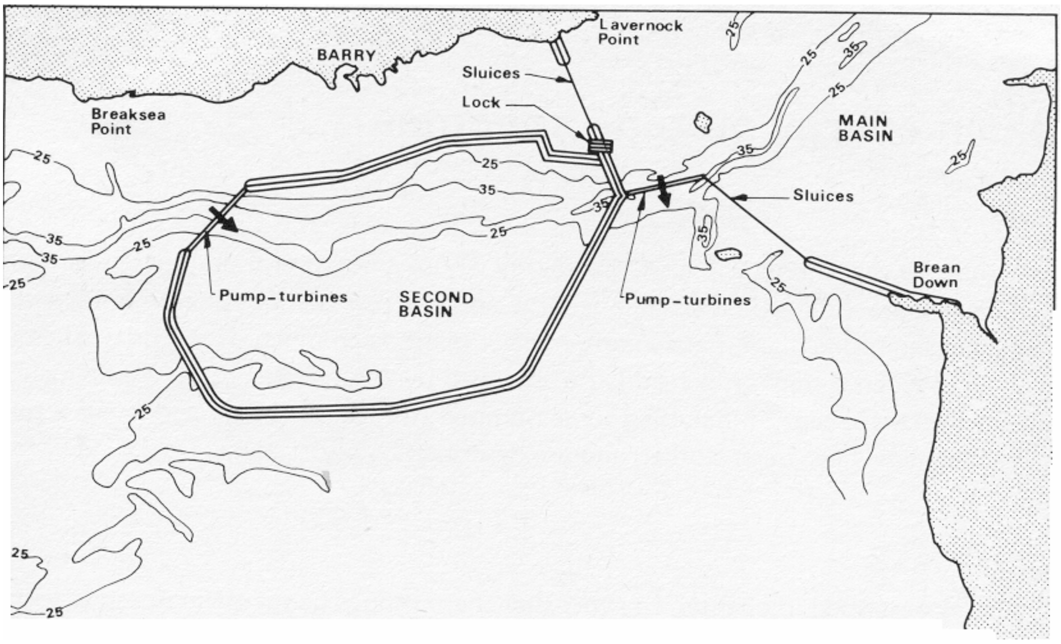


Figure 2.5(1): Plan of two-basin energy storage scheme

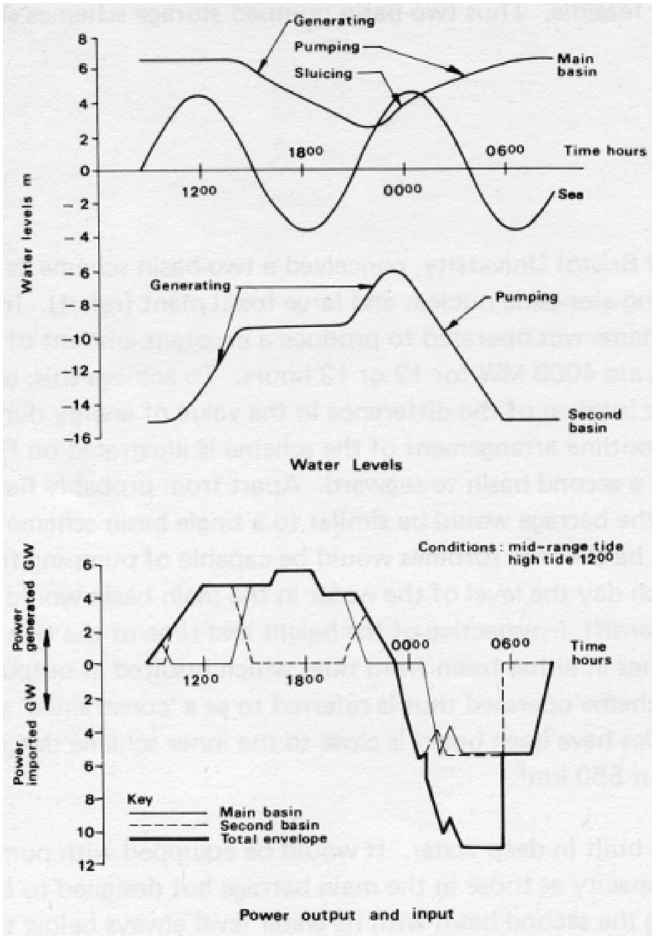


Figure 2.5(2): Example of operation of two-basin energy storage scheme

2.6 SEVERN BARRAGE – CONTINUOUS POWER GENERATION

A two-basin scheme has been proposed by R Dawson of Dawson Construction Plant Ltd, arranged to generate continuous power. The general layout is shown on Figure 2.6(1). AS described in Section 2.1.1 above, the main basin water level is kept above mean tide level, while the water level in the second basin is kept below mean tide level. This results in a difference of water level across the turbines at all times, allowing continuous power generation in one direction of flow.

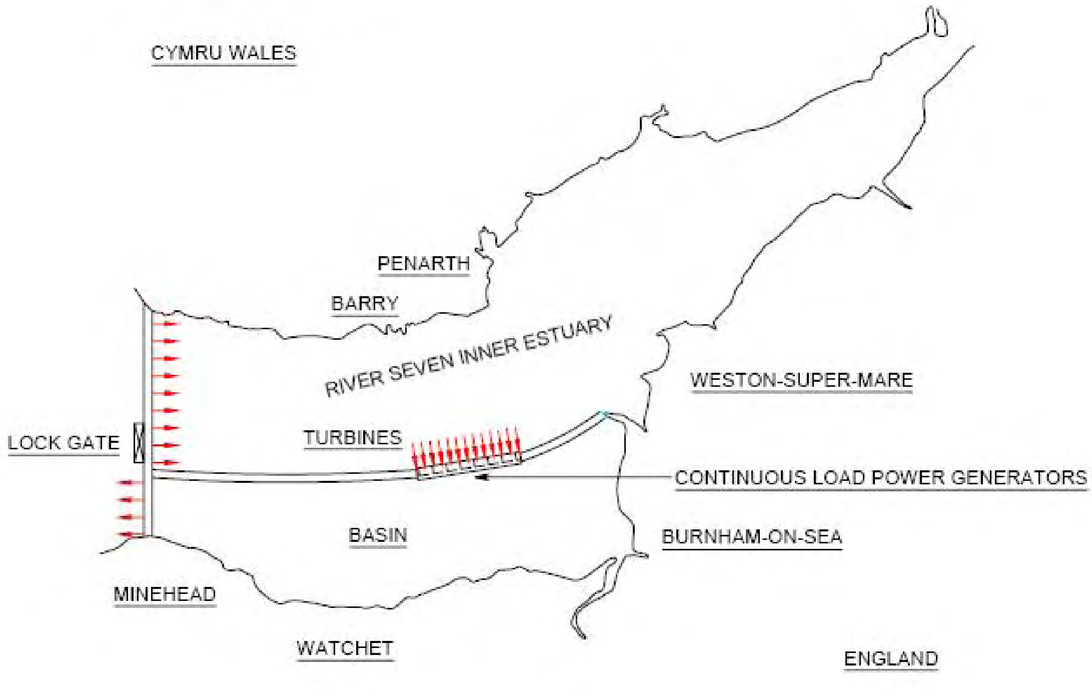


Figure 2.6(1): Dawson continuous power generation scheme[16]

The claimed continuous power output of the scheme is 3,500MW. Over a year, this would total 30.7TWh or 180% of the output of the Cardiff-Weston barrage. Without much more evidence, it is not possible to judge the value of this scheme. One reason why the claimed power output could be optimistic is that, during the Bondi studies, an ebb generation barrage at a similar location was found to reduce the tidal range outside the barrage by about 20%. Also, schemes with long embankments were found to suffer from higher unit costs of energy due to the high cost of the embankments, as described earlier.

2.7 SEVERN LAKE CONCEPT

The recently-formed Severn Lake Co. Ltd has proposed a version of the Severn barrage, the overall layout of which is shown on Figure 2.7(1). The aim is to construct a barrage about 1km wide, with the following features:

[16] Dawson Construction Plant Ltd: The "Dawson Plan" for sustainable, continuous tidal power generation, 2006

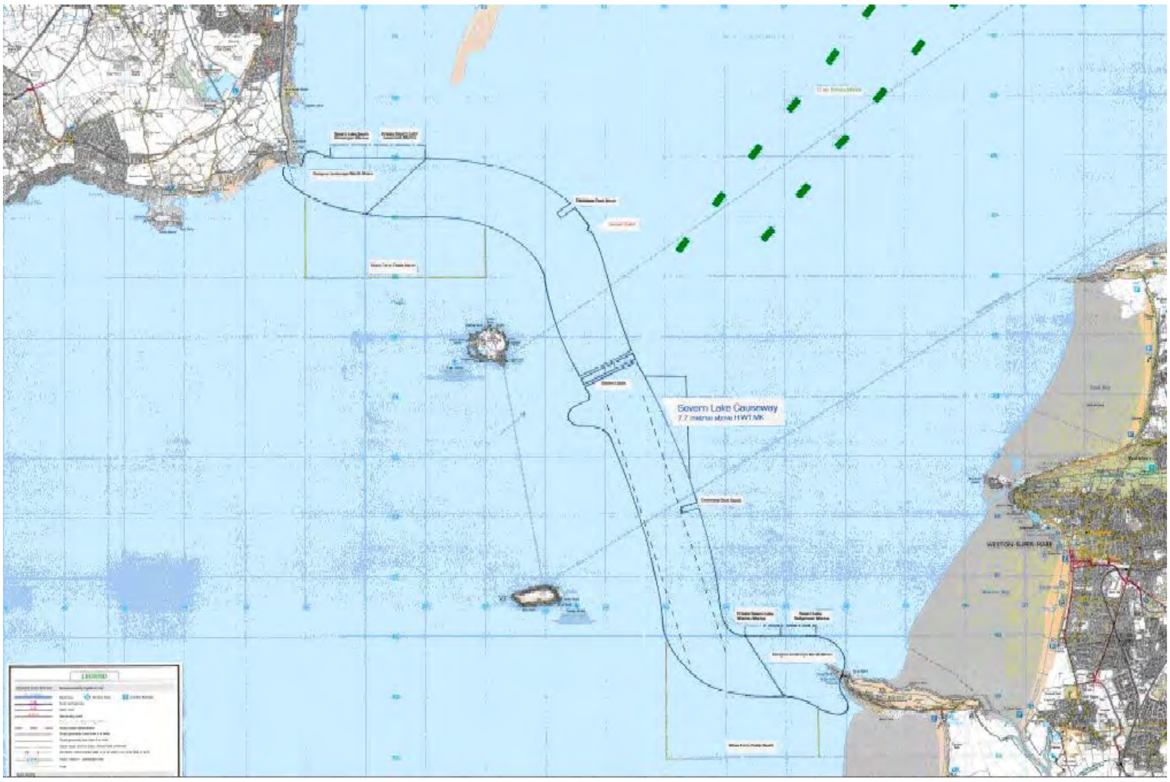


Figure 2.7(1): Layout of Severn Lake barrage

- 200 hydro turbines “two directional one way”
- Two wave farms on the western side.
- Central concrete-encased, robotically controlled land fill cellars.
- Autonomous power and water services.
- Two lock gate shipping channels.
- Four marinas.
- One lifeboat station.
- Twelve islands on the central eastern shipping channel.

As this proposal appears to be at a preliminary outline stage of development, not enough evidence is available on which to base a judgement as to its feasibility.

2.8 SCHEMES SELECTED FOR MORE DETAILED ASSESSMENT

Studies have shown consistently that tidal power barrage schemes requiring long lengths of embankment result in significantly higher unit costs of energy than equivalent schemes where the length of embankment is kept to a minimum. This conclusion applies to the Hooker two-basin scheme and to the Cardiff-Weston scheme where a second basin is included, either as a flood generation scheme or as a pumped-storage scheme. It can also be expected to apply to the Dawson continuous power scheme, although for this scheme and the Severn Lake scheme there is not enough evidence yet available on which to assess their feasibility.

Of the schemes discussed above, two main schemes remain as the most likely to generate electricity at an acceptable cost:

- The English Stones barrage (the Shoots barrage, Figure 2.2(6)) as presently being proposed by Parsons Brinckerhoff, and
- The Cardiff-Weston barrage, Figure 2.3(4), as developed by the Severn Tidal Power Group.

These two schemes are considered the most prominent and well-studied proposals for a Severn barrage, and have been selected for further consideration within this study. They are also provide two distinctive examples of potential projects in terms of a range of factors including scale, power output, and potential impacts. The following sections of this report consider a range of issues including technology, costs and power output, life cycle carbon emissions, environmental and regional impacts in relation to these schemes.

3 PRACTICAL EXPERIENCE WITH TIDAL POWER BARRAGES

3.1 INTRODUCTION

There are two large-scale tidal barrages in operation at present:

- The 240MW Rance barrage, near St Malo on the Brittany coast, France, and
- The 20MW Annapolis Royal tidal power plant, on an inlet to the Bay of Fundy in Nova Scotia, Canada.

A number of small-scale (<5MW) tidal power plants have been built over the last 40 years in China. A small pilot plant with a capacity of 400kW was floated into position in the early 1960s at Kislaya Guba, near Mezen on the White Sea.

These projects, and their relevance to this study, are discussed below.

In South Korea, work is under way to install a 260MW tidal power plant in an existing embankment which separates Sihwa Lake from the sea. The turbines will generate with the flow of water from the sea into the basin[17]. This project is not yet at a stage where the experience is relevant to this report.

3.2 LA RANCE BARRAGE

3.2.1 General description

The Rance barrage was commissioned in 1966 after a six-year construction period. It was conceived at a time of uncertainty in France concerning the future sources of power and was therefore intended partly as a prototype for a much larger scheme to seaward.

The Rance barrage[18] includes the following main features:

- A basin area of 22km^2 and a barrage length of 750m.
- An equinoctial spring tide range of 13.5m. This compares with the Severn Estuary at Avonmouth where equinoctal tides can exceed 14m.
- 24 bulb turbines in a concrete powerhouse. Each turbine is of Kaplan type, double regulated, with a runner diameter of 5.35m, capable of generating or pumping in each direction of flow. Each direct-driven generator, enclosed in a dry, pressurised steel bulb, is rated at 10MW at 3.5kV and at a speed of 93.75rpm.
- Six gated 'sluices', equipped with vertical-lift gates, to supplement the flow through the turbines when appropriate.
- A ship lock, with lifting road bridge.
- A short length of embankment linking the powerhouse and the sluice gate structure.
- A public road crossing of the estuary.
- A net annual energy output of about 540GWh, after deducting 64GWh used for pumping.

Before work started on the structure of the Rance barrage, two sets of upstream and downstream cofferdams were first built, to allow the area between to be dewatered and the structure built in the dry. One set enclosed the sluice gate structure, the other the powerhouse and embankment, with an extension for the ship lock. Each cofferdam comprised linked steel sheet piling to form connected vertical cylinders which were filled with sand. Building the cofferdams in the strong tidal currents presented its own challenges.

The sluice gate structure was completed after about two years, allowing its cofferdams to be removed and the basin partly connected to the sea again. The closure of the estuary behind the barrage for two years, followed by restricted opening to flows, resulted in the water becoming brackish and the loss of marine life. This process was then reversed when the main cofferdams

---

[17] Renewable Energy Access: *Sihwa Lake Tidal Power Plant*; May 2005.

[18] La Usine Maramotrice, Alexandre Pigeard.

were removed and the barrage commissioned. Apart from adding to the cost of the barrage, the use of similar cofferdams would not be acceptable now on environmental grounds.

Figure 3.2(1)[19] shows two modes of operation of the Rance barrage. The upper part shows two-way operation, with the turbines generating during both the flood tide and the ebb tide. In addition, during the second night, the turbines were operated as pumps, first to lower the water level in the basin prior to flood generation, then again at the following high water to increase the volume in the basin.

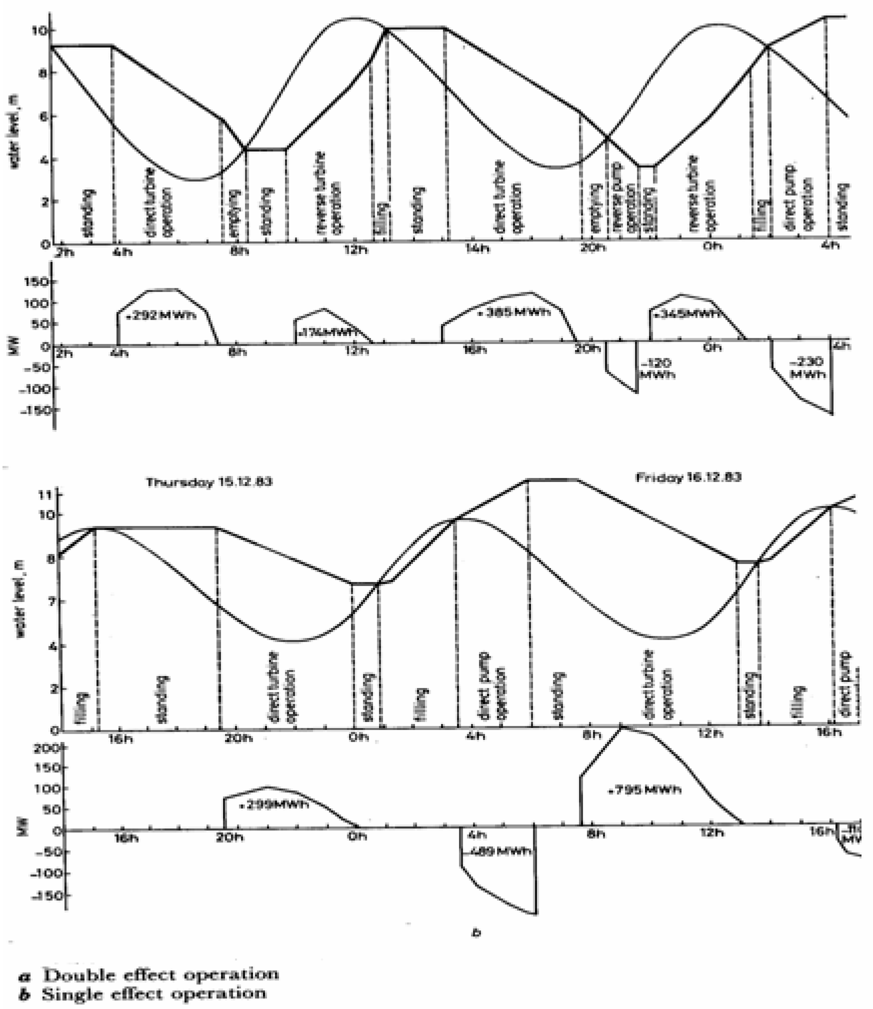


Figure 3.2(1): Operating cycles at La Rance

The lower part of Figure 3.2(1)shows ebb-generation only, with no reverse pumping at the first high water, then significant pumping after the second high water to raise the basin level by about 2m. It is noteworthy that the net output during the two tides is about 300GWh, but the pumping for the second tide took place in the early hours when, probably, power from nuclear plant was available, and the extra energy generated later was of higher value. Overall, in 1996, the turbines were operated in ebb-generation mode about 72% of the available time, in reverse, flood-generation mode about 6%, and as reverse pumps about 22%.

By its 30th anniversary in 1996, the Rance turbine-generators had operated for a total of 160,000hrs, producing electricity at a unit cost of about 18.5 centimes/kWh compared with EDF's

[19] Menint l: *The new design of bulb turbine units based on the experience fron the Rance tidal station and on-the-river bulb units.* Proc. 3rd International Symposium on Wave, Tidal, OTEC and Small scale Hydro Energy. BHRA, 1986.

overall average cost of 20 centimes/kWh. The only significant problem reported was with the fixings of the generator stators, which failed under the high torques of direct-on-line starting. These were repaired without great difficulty.

3.2.2 Relevance to study

The relevance of the Rance barrage to the UK's interest in tidal barrages lies in the following:

- The successful demonstration of tidal power generation over a period of 40 years.
- The confirmation of the long life of good quality reinforced concrete in a marine environment.
- The successful demonstration of bulb turbines as a reliable and long-lived type of turbine-generators.
- More recently, some confirmation that one-way, ebb-generation operation is preferable to two-way generation, as has been found to be the case in UK studies.

3.3 ANNAPOLIS ROYAL

3.3.1 General description

The Annapolis Royal tidal power plant has a single, 7.6m runner diameter Straflo turbine and generator. The 'Straflo', short for 'Straight-flow' turbine, so called because the generator rotor is mounted on the tips of the runner blades, leaving the water passage relatively free of the obstruction otherwise presented by a generator bulb. The generator stator is located outside the rotor, and a key component is the seal between the rotor and the fixed structure, which has to exclude water reliably from the generator space.

Until 1984, nearly 100 Straflo turbines had been used for run-of-river schemes in diameters up to 3.7m. Then the 20MW Annapolis Royal machine was commissioned. This has fixed runner blades, as having adjustable blades presents difficulties with the fixity of the rotor between its seals. The power house was built in-situ, in an island alongside an existing tide-control sluice. As a result, the tidal range is relatively small.

After commissioning, problems were encountered with the rotor seals, due to excessive silt in the water used to pressurise the seals. This was cured by providing filtered water. Otherwise, high reliability has been reported.

One unexpected adverse environmental effect has been the finding of decapitated fish which have passed through the turbine. This has been ascribed to the turbine running at relatively low efficiency, causing swirling flow around the runner blades and the turbine bearing supports downstream[20].

3.3.2 Relevance to study

The Straflo turbine is favoured by Parson Brinckerhoff for the Shoots barrage, so the success of the Annapolis Royal machine is of direct relevance. This machine provides engineering, operational and environmental experience. The turbines for the Shoots barrage are not intended to be used for reverse pumping, as this requires the runner blade angle to be adjustable, and this would be difficult and unproven technology.

The more compact arrangement of the Straflo design compared with the bulb turbine should lead to economies in the design of the turbine caissons, and resulting savings in costs.

[20] Delory, R P: *The Annapolis Tidal Generating Station.* Proc. 3rd International Symposium on Wave, Tidal, OTEC and Small Scale Hydro Energy. BHRA, 1986.

3.4 EXPERIENCE IN CHINA

3.4.1 General description

A number of small tidal power plants have been built in China over the last 40 years. The largest is the Jiangxia plant, located in Zhejiang province[21]. The plant was built in the dry on the left bank, behind cofferdams, and operates in two-way generation mode. The first 500kW bulb unit was commissioned in 1984 followed by four more, larger, units to give a total capacity of 3.2MW. The plant generates 6GWh of electricity a year.

3.4.2 Relevance to study

The experience in China has all been at small scale, with power plants built in situ. As a result, there is little relevance to proposed schemes in the UK.

3.5 EXPERIENCE IN RUSSIA

3.5.1 General description

The 400kW tidal power plant installed at Kislaya Guba in the early 1960s[22] was based on a concrete caisson housing the turbine-generator and equipped with a sluice gate. Therefore it was a complete tidal power plant successfully floated into position. The turbine has a runner diameter of 3.8m and drives the generator through a step-up gearbox.

3.5.2 Relevance to study

Apart from demonstrating the feasibility of floating a complete tidal power plant into position (in a relatively small tidal range of about 3m), this plant has little relevance to the UK work.

[21] Wilmington Media, 2004.

[22] Bernstein, L: *Tidal energy for electric power plants*: Israel Program for Scientific Translations, Jerusalem, pp 208-344. 1965.

4 TECHNOLOGY

4.1 DESIGN AND METHODS OF CONSTRUCTION

4.1.1 Introduction

As described in Section 3, the Rance barrage was constructed in the dry between two sets of cofferdams. This approach would not be appropriate for either the Cardiff-Weston barrage or the Shoots barrage, for two main reasons:

- At La Rance, the cofferdams accounted for about 30% of the total cost of the barrage[23].
- A cofferdam which enclosed only the turbines and sluices would obstruct over half the width of the estuary and leave only the shallower parts open to flow. As a result, the current velocities in the remaining gaps would be greatly increased, and these would redistribute widely the existing sediments. Navigation would be adversely affected, while the time needed to build and remove the cofferdams would increase overall construction time and cost.

Therefore there remain two feasible methods of constructing the main parts of the barrage – the powerhouse, sluices and ship lock(s):

1. The first would be to build a temporary embankment of dredged sand contained within sloping walls of precast concrete planks installed in tripod frames, then construct the walls of the structure from the top of the embankment, using the diaphragm walling technique. This method, originally proposed by consultants Rendel, Palmer & Tritton[24], was considered by the Severn Tidal Power Group and found not to offer an overall advantage in time and cost.
2. The second, and generally accepted method, would be to build the structures in suitable work-yards in the dry, float them to the site and carefully sink them into position. The first use of such structures, ‘caissons’, in any numbers was for the Mulberry harbour works for the D-Day landings. The concept has been well proven since, for example in the massive concrete structures installed for extracting oil from under the North Sea, although there has been little experience of placing caissons in high tidal ranges.

The rest of this section is based on the caisson method.

Reinforced concrete is the preferred construction material for the caissons for the Cardiff-Weston barrage and for the turbine and sluice caissons for the Shoots barrage. However, studies by the Steel Construction Institute[25] and others have shown that these structures could be built in fabricated steel, suitably protected and, after final placing, filled with concrete or sand as necessary for stability and strength. This option is considered by PB to be preferred for the ship lock for the Shoots barrage, the lock being built as a single caisson. The feasibility of the use of steel for caissons depends very much on the relative costs of the raw materials. The recent steep rises in steel costs presently weigh against this option.

4.1.2 Caissons for turbines

Cardiff-Weston barrage

The design, method of construction, towing and placing into position of the caissons for the turbine-generators for the Cardiff-Weston scheme have been the subject of considerable study

[23] Cotillon J: *La Rance: 6 years of operating a tidal power plant in France.* Water Power, 1974.

[24] Rendel, Palmer & Tritton for Dept. of Energy: *Sand embankments and diaphragm walling for tidal power barrage construction.* March 1988.

[25] E.G. Gilfillan *et al*: *Steel caissons for tidal barrages.* Tidal Power, Thomas Telford, 1987.

since the start of the second Severn Barrage Committee studies [26,27,28]. The present proposed arrangement is shown as a cutaway view in Figure 4.1(1).

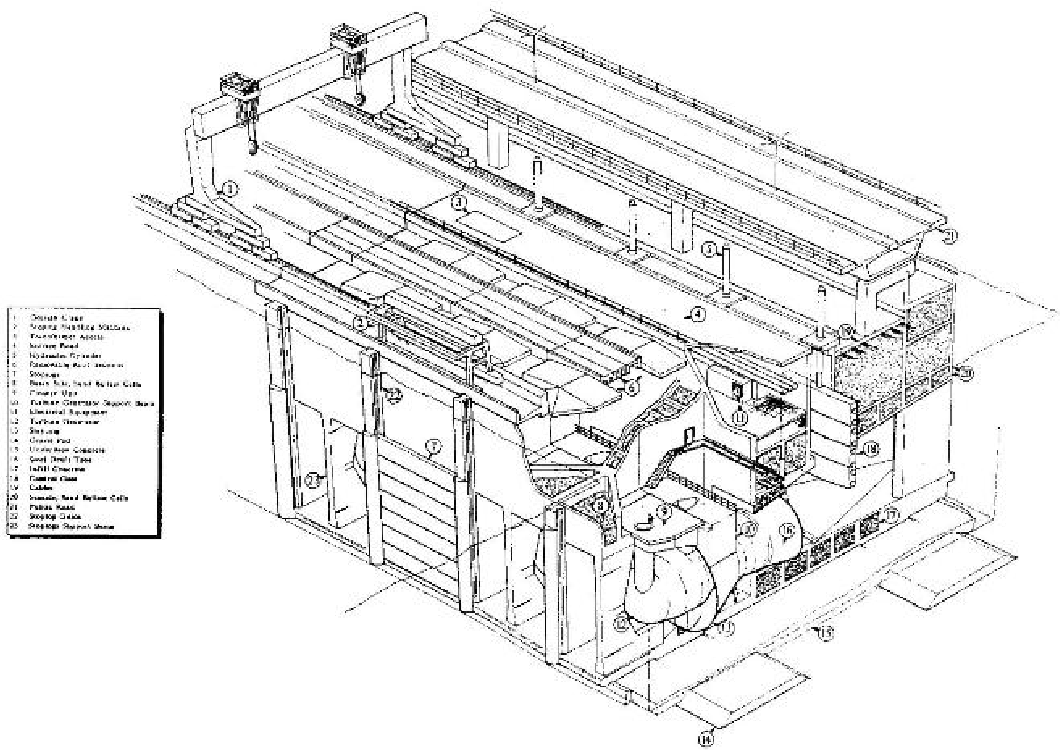


Figure 4.1(1): Cutaway view of turbine caisson

The main features of this design are as follows:

- Each caisson would house four bulb turbines with a runner diameter of 9.0m. Earlier studies preferred a three-turbine arrangement, but four turbines showed overall economy and improved stability when one turbine water passage has to be dewatered for maintenance.
- Each water passage can be closed off by inserting stoplogs from the deck. This facility allows the whole of the water passage to be accessible for inspection and maintenance. Similarly, stoplogs or 'limpet' gates would be installed in all four water passages at the time of floating the caisson into position.
- The overall structure is cellular, to provide good stiffness, strength and lightness. After installation, most of the cells would be filled with concrete (mainly the lower cells) or sand, in order to increase the stability of the caisson and to provide added mass in the event of ship collision.
- A 350t capacity goliath crane, spanning a service road and the access openings above the turbine-generators, would provide the lifting capacity required for maintenance of the mechanical and electrical equipment.
- An elevated dual-carriageway road on pillars, of box section, would provide a public road crossing of the estuary and the route for the power cables.

---

[26] Sir Robert McAlpine & Sons: *Severn tidal power feasibility study. Further report on caissons and other civil engineering.* Sept 1980, STP 55.

[27] Taywood Engineering Ltd: *Severn tidal power study Stage 2: Report on the design, construction and placing of caissons.* Nov. 1980. STP80.

[28] STPG: *Tidal power from the Severn.* 1986, and *Severn Barrage Project, Detailed Report.* 1989.

The principal dimensions of a typical turbine caisson would be:

- Dimensions 79.5m along barrage x 77.4m x 40m height (excluding public road).
- Float-out weight 126,000t approx. Final weight 270,000 t (excluding public road).
- Level of underside of installed caisson – 28.65m OD. Axis level of turbines –17m OD.
- Total number of turbine caissons: 54.

For the construction and placing of the turbine caissons, STPG propose that these are built in several construction yards located around the UK or possibly including Europe. Building would take place in a dry dock and would be completed alongside a quay after the dry dock had been flooded and the part-complete caisson floated out. Then each caisson would be towed to the site by large tugs, set down near the barrage, attached via two winch pontoons to a number of mooring lines, refloated and carefully winched into final position.

Figure 4.1(2) shows the sequence of operations for a caisson at the barrage.

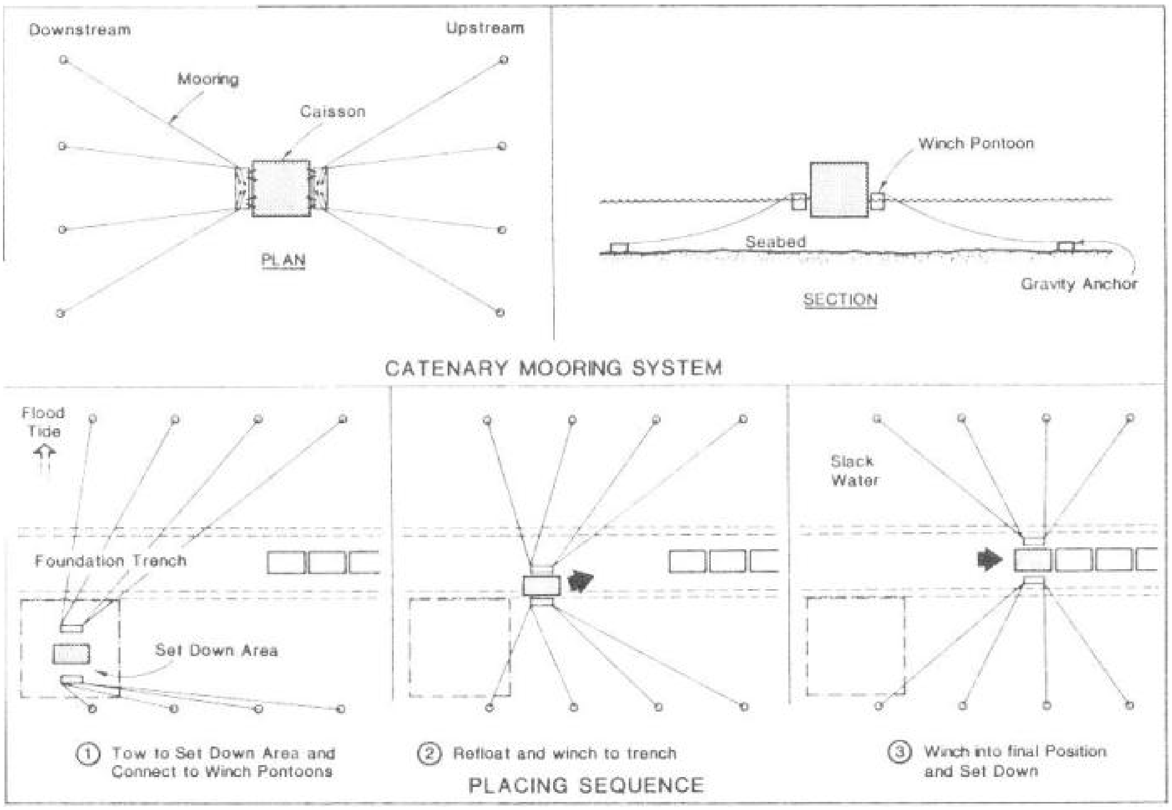


Figure 4.1(2): Cardiff-Weston caisson placing sequence

STPG envisage one caisson being placed each month at a number of construction faces. This would be during neap tides, when tidal currents are at their minimum. As there are two sets of neap tides each month, this would provide 100% standby in terms of available tides.

After being sunk into its final position, finishing work on each caisson would include:

- Grouting up the spaces between the underside of the caisson and the prepared foundation.
- Sealing the gap between each caisson and its neighbours.
- Filling the appropriate cells in the structure with concrete or sand.
- Completing in-situ concrete, including the public road bridge.
- Completing the installation of remaining M&E equipment.

The Shoots barrage turbine caissons

The design of the turbine caissons for the Shoots barrage is based on the use of the ‘Straflo’ or rim-generator turbine design with a 7.6m diameter runner, with two turbines to each caisson. Figure 4.1(3) shows a cutaway view of the design proposed.

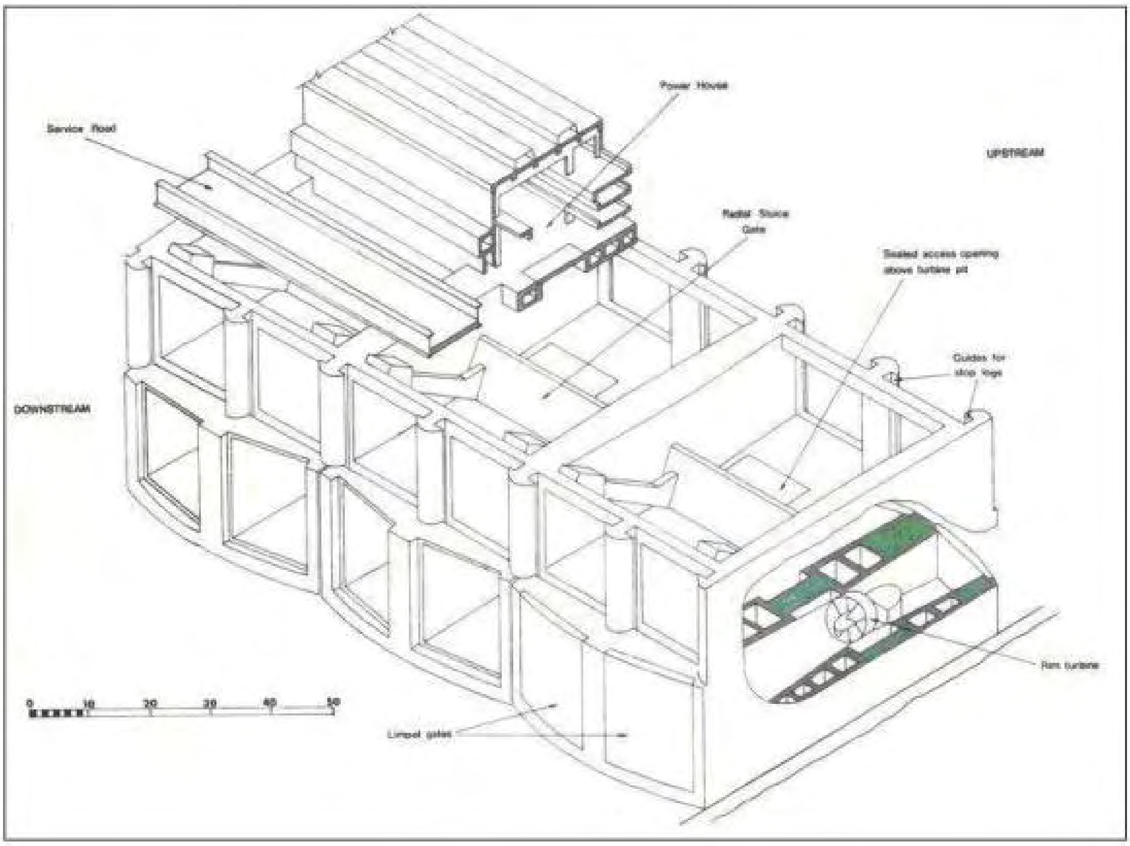


Figure 4.1(3): Isometric view of turbine + sluice caisson for The Shoots

The axis level of the turbines is –16mOD. In addition, above each pair of turbines, there is a sluice 32m wide with its invert at -3m OD. This is, relatively, much higher than the equivalent level for the Cardiff-Weston barrage, where the sluice gates are fully submerged. PB have selected this level partly because it allows the sluice to be located above the turbine, and partly to help minimise the amount of silt carried into the basin. On either side of the locks, the adjacent caissons do not have sluices, as these caissons include assembly areas.

Above the sluice water passage, on the basin side of the caisson, is a continuous building housing a travelling crane to service the turbines, turbine ancillary equipment and electrical equipment.

PB have based the cost estimate for the Shoots barrage on the use of concrete caissons. However, they point out that the caissons could be made from steel, which would permit the use of existing construction facilities in different parts of the country. If concrete is to be the construction material, the greater draft of the caissons compared with steel caissons would require a purpose-built construction yard. PB state that one proposal is to establish a caisson dock at Northwick Deep[*] to provide the depth and temporary anchorage facilities required.

PB considers that the caisson construction yard would have residual value as a port, capable of handling ships up to 25,000 dwt. The ship lock has been sized for the same capacity.

[*] Channel near Aust on the Severn (between the old and new Severn crossings)

4.1.3 Caissons for sluices

Cardiff-Weston barrage

The construction of the caissons to house the sluices would follow the same general principles as described above for the turbine caissons, and they would be built in the same workyards.

The principal dimensions of the sluice caissons are:

- Dimensions: length (along barrage) 89.5m, width 46.5m to 52.5m, depending on height, and height 24m to 34m, depending on foundation level (-14m to –24mOD).
- Float-out weight 58,800t to 83,300t.
- Final weight 84,000t to 126,000t, excluding the elevated road structure.
- Gates 16m wide x 9m to 17.5m high.
- Total number of caissons: 46.

The gates are of counterbalanced radial type, recessed into the roof and sides of the water passage when fully open. The water passage is symmetrical, with rounded entrances to minimise head losses. Figure 4.1(4) shows an isometric view of a sluice caisson.

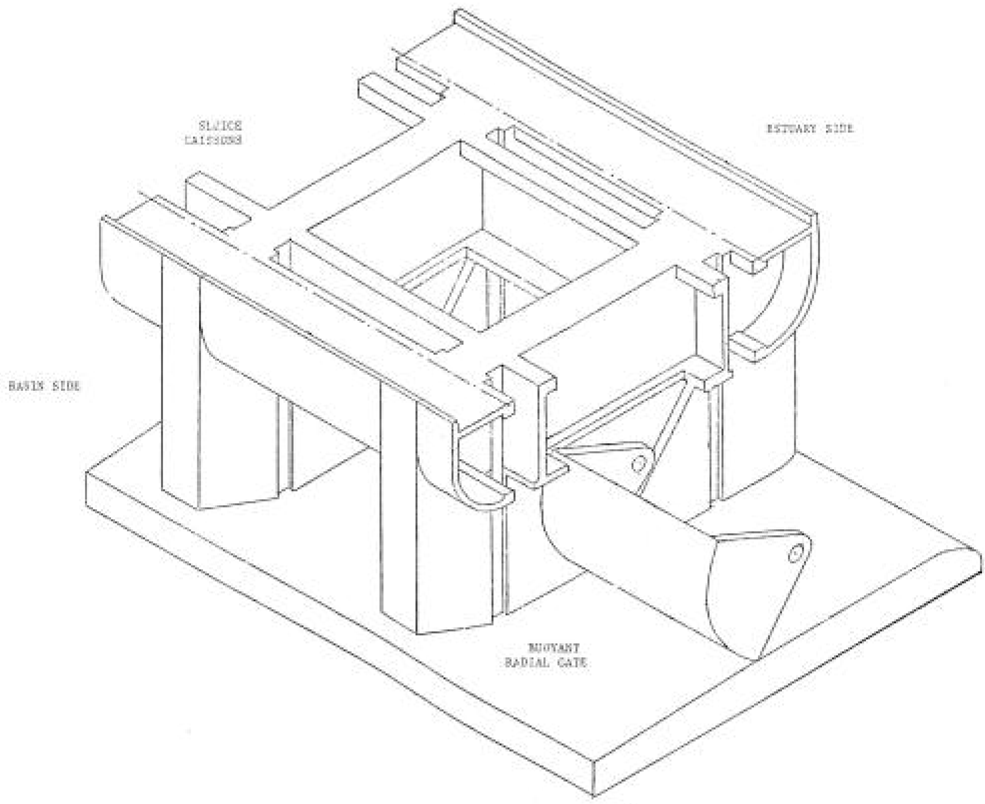


Figure 4.1(4): Isometric view of sluice caisson for Cardiff-Weston barrage

As with the turbine caissons, the walls and floors are of cellular construction and, after final placing, the cells would be filled with sand or concrete to achieve the required stability and strength.

The Shoots barrage sluices

As mentioned above, the arrangement proposed for the turbine caissons for the Shoots barrage includes sluices above each pair of turbines except for two caissons adjacent to the ship locks. This arrangement provides 13 sluices, each with a counterweighted radial gate 30m wide. An additional four sluices are in caissons without turbines. These would be constructed in the same manner as the turbine/sluice caissons. Finally, a further eight sluices would be built in shallow water beside the deep-water channel. These would require concrete to be placed under water as well as above water, and PB have allowed a higher unit cost for the former.

Figure 4.1(5) shows a cross section of the sluice design proposed for the Shoots.

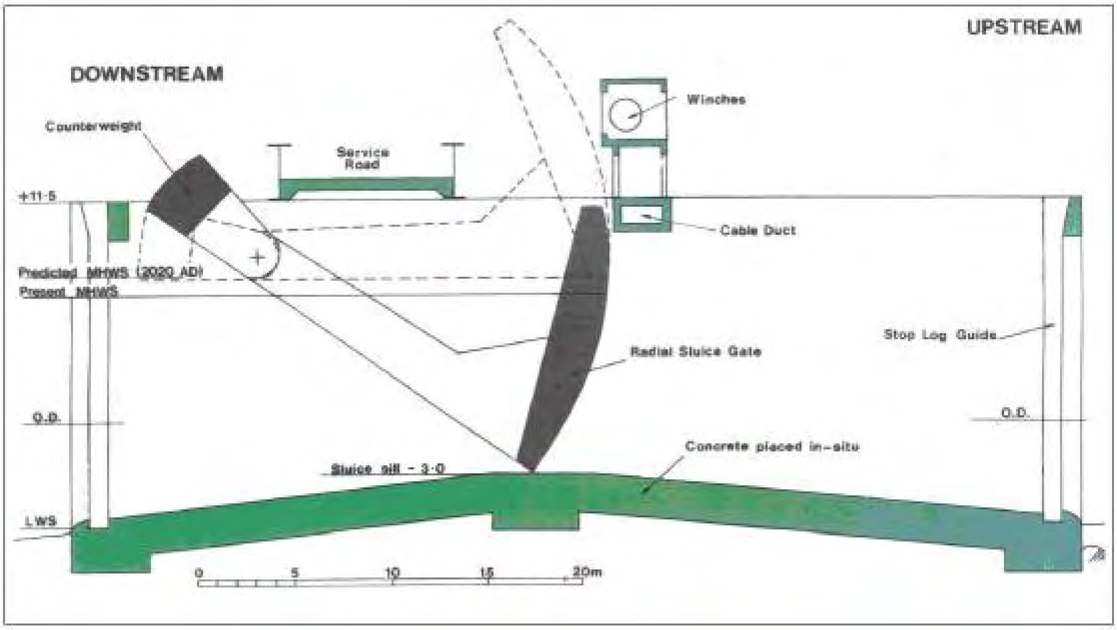


Figure 4.1(5): Section of sluice caisson for The Shoots

4.1.4 Plain caissons

Cardiff-Weston barrage

Plain caissons are proposed for the deeper parts of the barrage not occupied by turbine caissons, sluice caissons or ship locks. They have no openings for flow, so are relatively simple box structures with internal partitions to provide the necessary rigidity. Towing and placing would follow the same method described for turbine caissons above. After final placement, the cells would be filled with sand to provide the required stability.

STPG plan two types of plain caisson – 'standard' and 'wide', each in various sizes to suit the seabed topography. The principal dimensions are:

	Standard	Wide
Length (along barrage) (m)	89.5	89.5
Width (m)	44.9	62.5
Height (m)	20-38.5	20-38.5
Concrete volume (1000 cu m)	15.5-24.2	21.2-32.9
Sand ballast volume (100 cu m)	27.9-93.2	39.1-130.6

Figure 4.1(6) shows plans and sections of a Standard plain caisson.

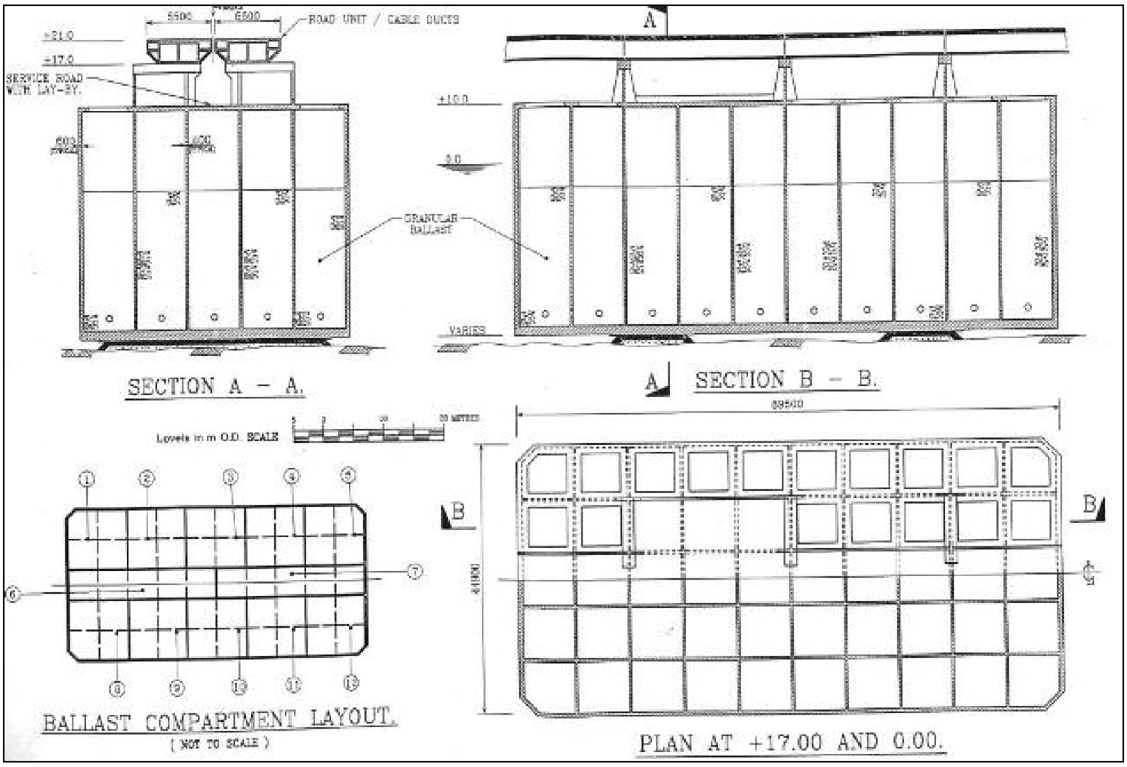


Figure 4.1(6): Standard plain caisson

The Shoots barrage plain caissons

PB propose only two plain caissons, one each side of the ship lock. Their size(s) are not yet defined. It can be expected that they would be built and placed using the same methods proposed for turbine/sluice caissons.

4.1.5 Ship locks

Cardiff-Weston barrage

Two large ship locks and a small-craft lock are planned. The ship locks are presently sized for Panamax* vessels (70,000 dwt) and would be located in an existing deep-water channel about 2km from the Welsh coast. On the seaward side, large breakwaters would provide sheltered conditions for entry to the locks. Figure 4.1(7) shows the general layout, and Figure 4.1(8) shows details of one of the caissons with lock gates.

* Panamax = the largest ship that can negotiate the Panama canal.

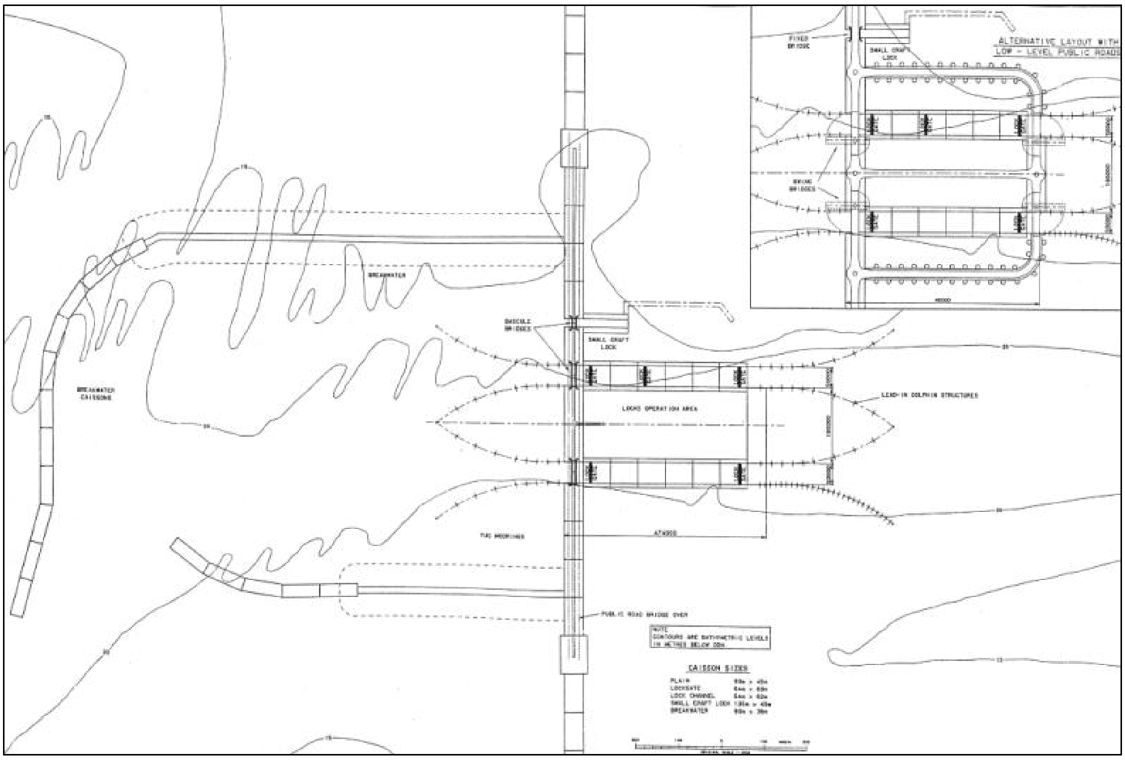


Figure 4.1(7): General arrangement of ship locks

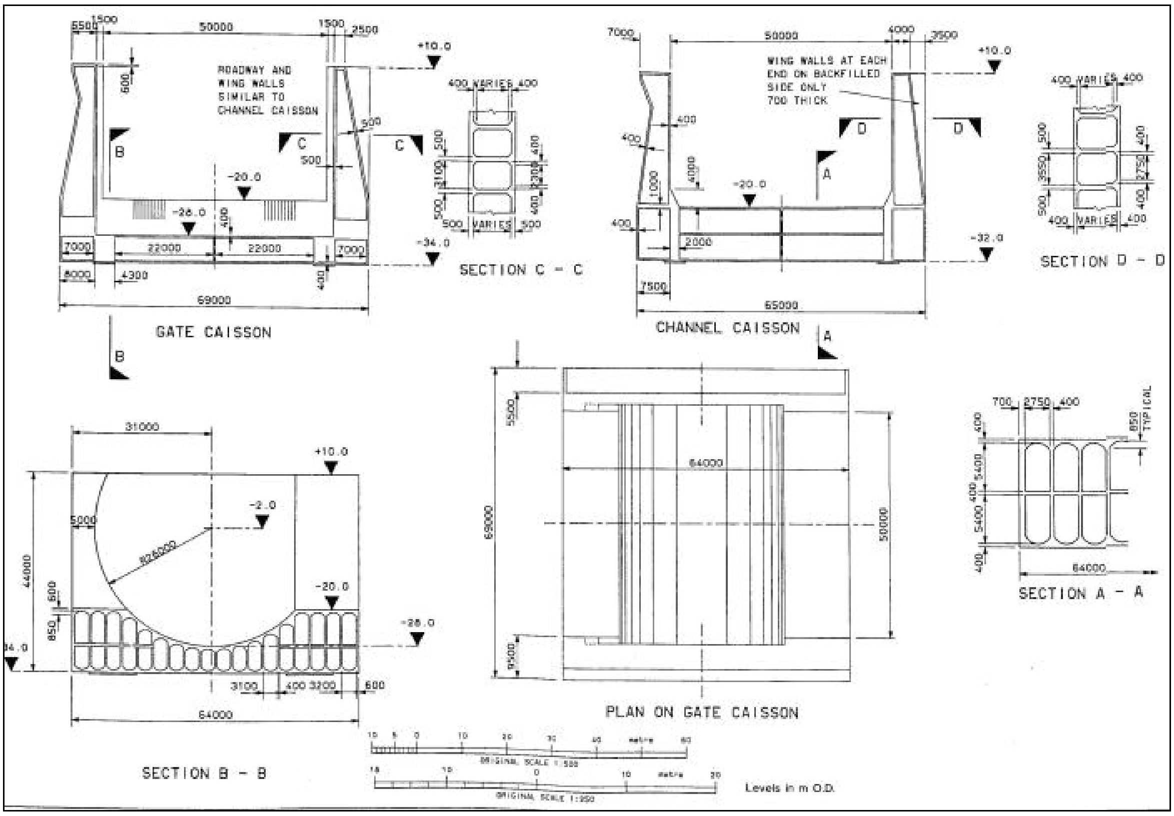


Figure 4.1(8): Typical lock caisson for gate

The approach channel would require some dredging to provide a channel base at -21 mOD on the seaward side and -16mOD on the landward side. The difference allows for the increased depth of water available in the basin, but it may be necessary to have the same depth in the channel in the basin for the time when ships have to divert through the locks while turbine caissons are being built in the deep water channel. At this time, the basin and sea levels would be the same.

The two ship locks proposed would be built using twelve caissons, each U-shaped in section. Two types of caisson would be required – for the main lock section, and for the sections with lock gates. Figure 4.1(8) shows the arrangement of a caisson for gates. In addition, a small craft lock is proposed, located towards the English coast. The principal dimensions of the caissons are as follows:

	Main lock: Gate section	Main lock: Plain section	Small-craft lock
Number required	5	7	2
Length (along lock) (m)	64	64	about 105
Width (m)	69	64	about 46
Height (m)	44	42	about 28
Structural concrete (cu m)	26.800	21,400	approx. 22,200
Weight at float-out (t)	64,000	51,500	approx. 53,000

The method of construction and installation is similar to that planned for the turbine and sluice caissons.

The Shoots barrage lock

A single navigation lock is proposed for the Shoots barrage, 225m long between outer gates, with duplicate inner gates for operational security, and 37.5m wide. It is designed to handle ships up to 25,000 dwt. Figure 4.1(9) shows the general arrangement.

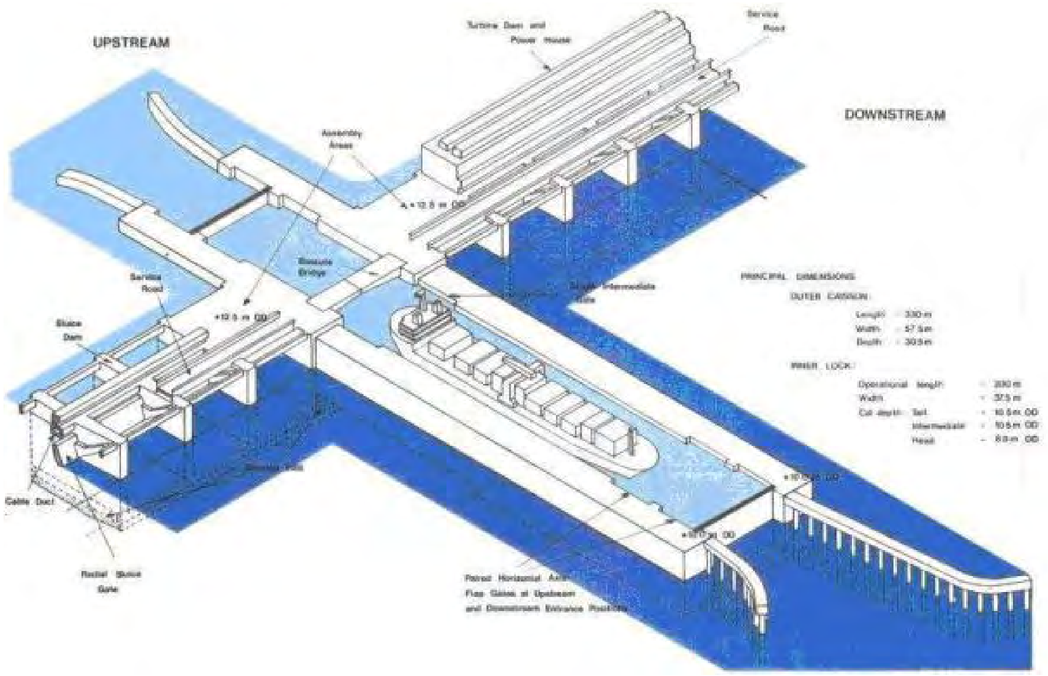


Figure 4.1(9): Ship lock for The Shoots

For the construction method, PB presently favour a single steel caisson, fully fitted out and ready to operate, built in a shipyard and floated into position and sunk onto prepared foundations.

4.1.6 Embankments

Cardiff-Weston barrage

Embankments are required to connect the concrete structures forming the main part of the barrage to the shores. In addition, a short length of embankment is planned for the part of the barrage behind the island of Steep Holm. The transition between embankment and plain caissons is determined on cost grounds, as the cost of an embankment rises steeply with increasing depth.

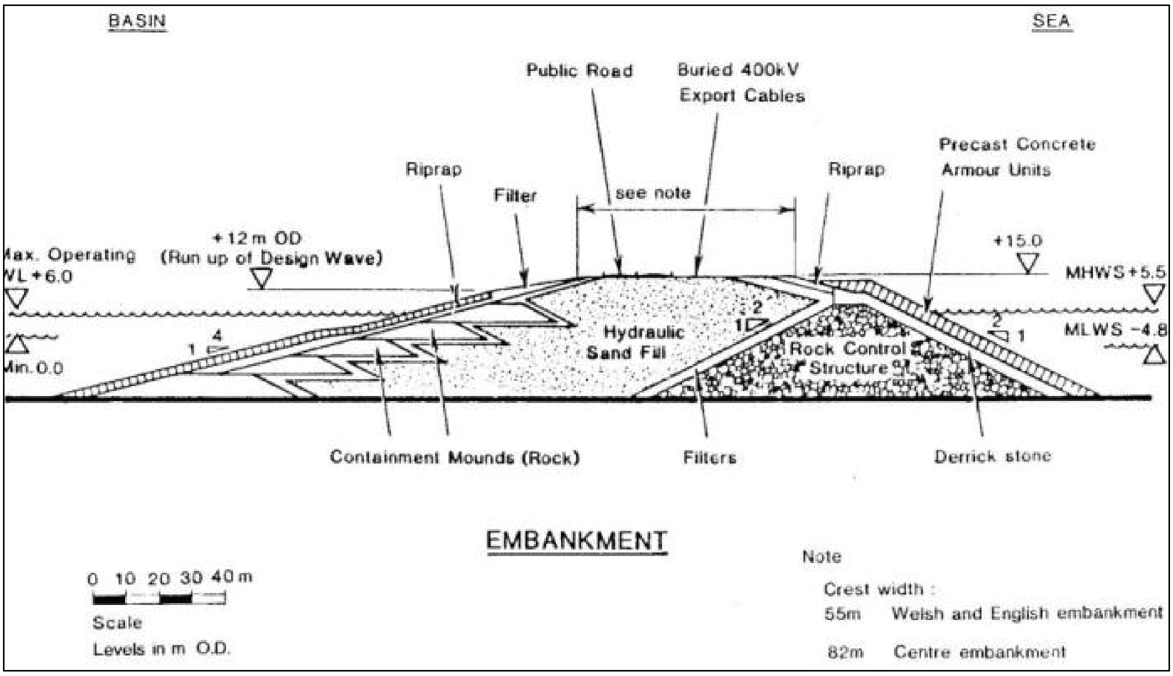


Figure 4.1(10): Section of embankment for Cardiff-Weston barrage

Figure 4.1(10) shows a typical cross section for the Cardiff-Weston embankment design. The main features of this design include:

- An initial mound of rock fill on the seaward face, to gain control over the tidal flows and protect subsequent work on the basin side. The rock size required at any place will depend on the maximum current to be expected across the part-complete embankment.
- A core of hydraulically placed sandfill, protected from currents and small waves on the basin side by successive containment mounds of quarry waste or other cheap fill of suitable size particles (a 'Christmas tree').
- Filter layers between materials of different sizes, to prevent migration of finer materials into coarser materials.
- Armour layers to provide permanent protection against wave attack.
- A wide crest to accommodate the road and the main power cables.

The design on Figure 4.1(10) shows the initial rock mound with slopes of 1V:2H. This is suitable for a hard seabed or where the seabed material is sand or gravel. On the English side, the embankment would have to cross deep soft sediments and a flatter slope may be required to prevent slip failures.

Figure 4.1(11) shows the planned sequence of construction and is largely self-explanatory. As much of the fill materials as safely possible would be placed by sea-going plant – side-dump or bottom-dump barges, floating dredgers and so forth. The overall sequence of construction would be planned to minimise the extent that the part-complete embankment would be exposed to attack by currents and waves.

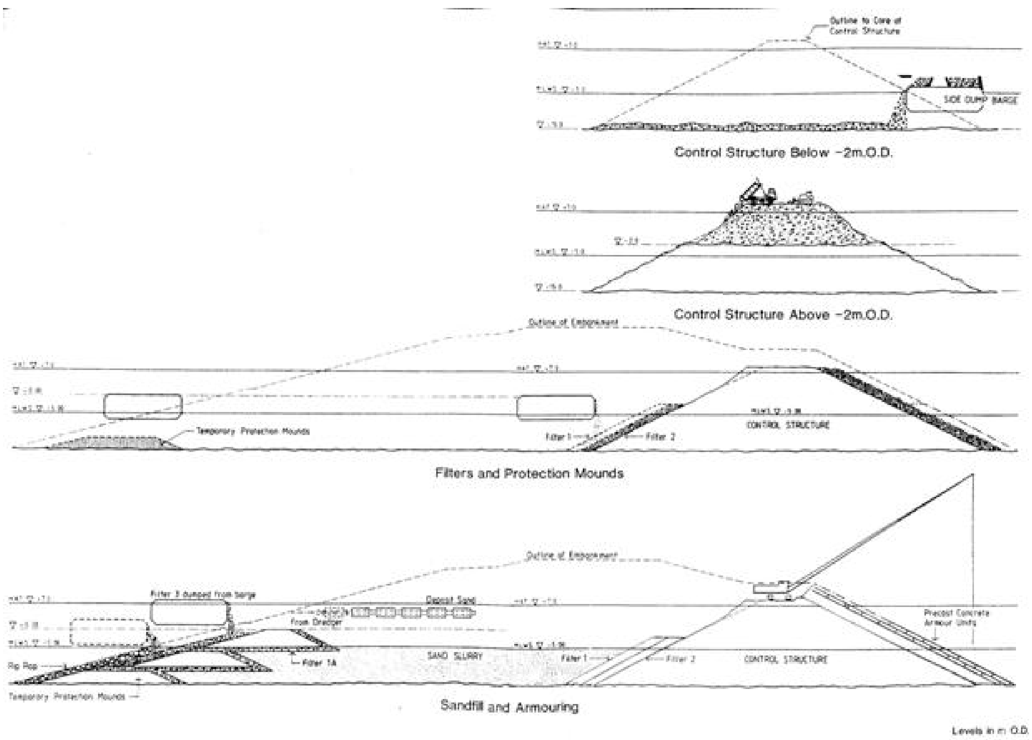


Figure 4.1 (11): Sequence of construction of embankment

The Shoots embankments

The embankment for the Shoots barrage would be constructed outside the deep-water channel, on the shoulders of the estuary, and would therefore present less of a problem than the embankment for the Cardiff-Weston barrage. PB plan the embankment to be constructed in 3m lifts, with the outside faces protected by mounds of rockfill of adequate size to resist the maximum current flow at the time. Between the protection mounds would be a core of dredged sand fill, with suitable filter(s) between the sand and the protection mounds. The seaward slope would be protected by a layer of perhaps 2t armouring, the basin slope with smaller material. This permanent slope armouring would be added as construction progressed, again to minimise the amount of part-completed embankment exposed to current and wave attack.

4.1.7 Mechanical & electrical plant

Cardiff-Weston barrage

The standard type of turbine for low-head hydro applications is of propeller type, with horizontal axis. Upstream of the runner there is a ring of guide vanes (the ‘distributor’) which imparts a swirl in the water flowing towards the runner, enabling the runner blades to ‘fly’ through the flow in similar fashion to an aeroplane wing, thus generating lift to rotate the runner. This is far more efficient than the flow simply impinging on an angled blade. Either, both or neither the distributor vanes and runner blades can be adjustable for angle. If both are adjustable – double-regulated - this achieves the best overall efficiency and this type is termed a Kaplan turbine. If the distributor blades are fixed-angle, this type is the ‘Kapeller’. If both are fixed, which is rare, then the turbine is unregulated.

The flow through turbines with adjustable guide vanes can be controlled by opening and closing the distributor vanes, which are engineered to provide a satisfactory seal when fully closed. If the distributor is fixed, the flow during starting and stopping is normally controlled by a vertical-lift gate downstream, as the runner blades cannot provide the required seal. The Kaplan turbine operates at high efficiencies over a wider range of heads and flows than either of the single-regulated types. The benefit of this has to be traded against its higher capital and maintenance cost.

The horizontal-axis turbine offers the advantage over vertical-axis machines that the geometry of the water passage is relatively very simple and, by avoiding turning the flow round corners, minimised head losses, thus helping to maximise the overall efficiency of the installation.

For large-capacity bulb turbines, the runner is connected directly to the generator rotor which is housed upstream in a pressurised steel bulb. The stator is mounted on the bulb. Cooling is normally by air, the pressurised atmosphere aiding cooling efficiency. For smaller machines, it is feasible to include a step-up gearbox between the runner and generator, thus enabling the generator/bulb diameter to be reduced.

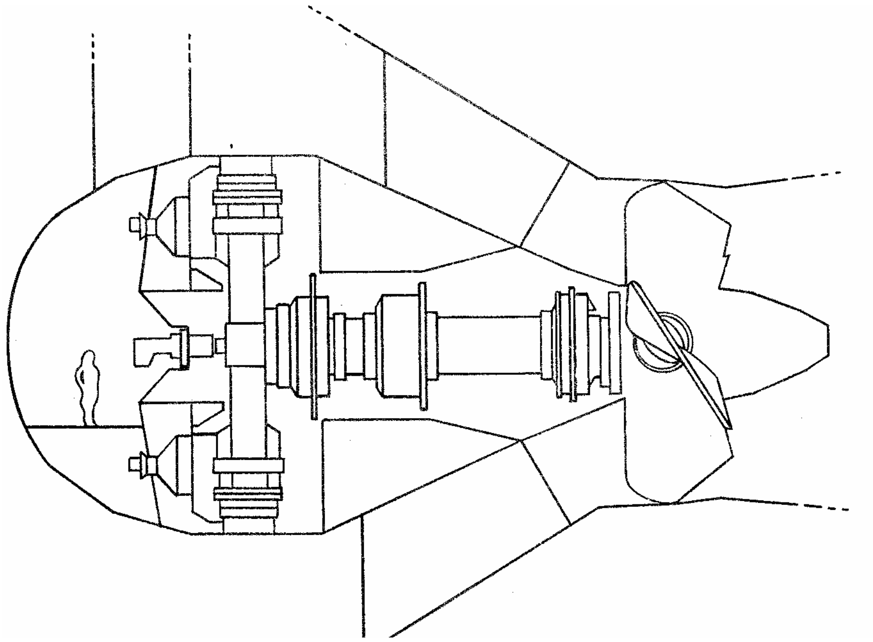


Figure 4.1(12): Bulb Turbine Layout

The type of turbine-generator preferred by STPG for the Cardiff-Weston barrage is the Kapeller, with four variable-angle runner blades and fixed distributor (Figure 4.1(12)). The main features are as follows:

Number of installed machines:	216
Number of machines in each control group	24
Machine type:	Kapeller
Runner diameter	9.0m
Speed	50 rpm
Generator rating	40MW @ 0.9 power factor
Generator terminal voltage	8.6kV
Total installed capacity	8,640MW
Transmission links to shore	400kV

The runner diameter of 9.0m is considered to be a reasonable extrapolation of experience to date.

The number of turbines required and the difficulty of assembling such numbers quickly in a marine environment have led STPG to the conclusion that the turbines and generators would be constructed as complete units in suitable on-shore fabrication and assembly facilities. Assembly in caissons before float-out would extend the construction programme unacceptably. Instead, when required, they would be transported two at a time on a special barge to the site and off-loaded into position by a suitable heavy-lift barge crane. The weight of each unit would be around 2000t, well within the capacity of existing cranes.

The electrical systems, control systems and transmission links proposed are generally based on proven technology and are described in detail in STPG's reports.

The Shoots barrage

The electrical and mechanical equipment design for the Shoots barrage is at a preliminary stage of development compared with the Cardiff-Weston barrage. PB have preferred to adopt the 'Straflo' design of turbine-generator. This has the generator rotor mounted on the tips of the runner blades, with the stator outside. The runner diameter proposed is 7.6m, the same as the prototype machine at Annapolis Royal, off the Bay of Fundy, commissioned in 1984. The generator capacity would be 35MW, greater than the Annapolis' 20MW, this smaller capacity being due to the smaller tidal range at the site. Apart from a total of 30 machines, giving an overall capacity of 1,050MW, further details are not available as yet.

Four aspects of the experience gained at Annapolis Royal are relevant:

- The fixed runner, variable distributor arrangement is not suitable for reverse pumping at high tide. This method of operation is therefore not proposed for the Shoots.
- Two sets of seals are required between the sides of the generator rotor and the structure. One is a 'hydrostatic' seal, used when the turbine is operating, and for which a small gap is maintained by filtered water introduced under pressure. The excess water is collected in suitable shrouding. The second seal is an inflatable seal, used when the turbine is stationary. The filter plant for the hydrostatic seal had to be uprated to cope with the suspended sediments and marine organisms encountered. The inflatable seal was damaged as a result of prolonged use during a strike. Both problems were sorted and the machine has achieved high availability since.
- Some of the fish passing through the turbine have been found to have been decapitated. This may be caused by the bearing support vanes downstream of the runner. When the turbine is operating at less than maximum efficiency, the water leaving the runner is still swirling, so that fish are approaching the vanes at an angle. The arrangement developed during the Severn Barrage Committee studies had the runner shaft cantilevered from the upstream support, so avoiding the downstream support vanes.
- The turbine and generator were transported to the site as only three main assemblies on a barge – runner/rotor, distributor, and stator.

4.1.8 Construction programme

Cardiff-Weston barrage

STPG consider that the Cardiff-Weston barrage could be built in 7, 6 or even 5 years, depending on the number of workyards provided for the construction of the caissons, and on the sizes of ship locks required. The repetitive nature of the construction, coupled with the use of prefabricated caissons for the main structures, is conducive to flexibility in programming, as work can progress at a number of advancing faces at a time. The key element is the ship locks. Not only are they very large but they have to be ready to allow ships through before the present shipping lane starts to be obstructed by the installation of turbine caissons. About four years are required to build and commission the ship locks and their breakwaters.

After the ship locks, the next item on the critical path is the installation and commissioning of the turbines, which would require significant resources of highly skilled labour. However, the barrage would not be commissioned with all turbines ready – better overall economy would be achieved with around 60% of the turbines ready to generate when the barrage is commissioned.

The Shoots barrage

PB consider that the Shoots barrage could be constructed ready for commissioning in about four years, with the fabrication of the 21 caissons being completed in two years, and all caissons in position after three years. Closure of the barrage would be achieved by raising the embankments above high tide level while keeping the turbine and sluice openings clear to minimise flows over the part-complete embankments.

4.2 EMBEDDED CARBON

4.2.1 Introduction

A full carbon life cycle analysis of either barrage option would include an analysis of the CO_2 released during construction, operation and maintenance, and decommissioning phases of each project. As renewable energy projects have low fossil CO_2 emissions during their operational phase (compared to fossil fuel projects), this analysis has focused on the CO_2 emissions during the construction phase of the two Severn Barrage options. Further analysis could include emissions during the operational phase, but these are expected to be low compared with those in the construction phase. Emissions during the decommissioning phase are highly uncertain given the long life of the barrage and in any case are likely to be very low in comparison to the other phases, as well as less relevant being after 2100.

The CO_2 emissions during construction of such projects are mainly associated with the sourcing and manufacture of the materials required (known as embedded or embodied CO_2). However, there would be CO_2 emissions from installation activities (e.g. haulage of materials to site, vessel movements on site, personnel activities etc.). These have not been assessed, but in general are considered to be of a similar magnitude to the manufacturing emissions.

It should be noted that the CO_2 emissions associated with the construction and decommissioning phases of fossil fuel projects are normally ignored in their assessment, since the fossil fuel element of the operational phase (as calculated by standard emissions factors) is always far more significant. It should also be noted that the sourcing activities required for the fossil fuel (extraction, processing and transport) are not normally included in such standard emissions factors, and previous work has shown that these additional emissions are significant and of the order of 10-20% of the standard emissions factors[29].

A carbon life cycle analysis for the barrage options produces a value for $kgCO_2/kWh$. This can be used to compare the projects to other energy producing installations, bearing in mind the caveats noted above around items included in this analysis, and items not included in other fossil fuel analyses.

4.2.2 Data for embedded carbon

The data that have been used to calculate the embedded carbon have been cross-checked with a number of sources, and in general it has been found to be a good match with other sources. The embodied CO_2 values for materials have been taken from the "Inventory of Carbon and Energy" document from the University of Bath[30].

As the quantity of energy produced from the barrage and the design life is 120 years, the amount of carbon dioxide produced per kWh of energy is low, and subsequently a low carbon payback period is also expected. Therefore the absolute accuracy of these figures is not considered essential

---

[29] "Balance of Energy and Greenhouse Gas Emissions Throughout the Life Cycle of Natural Gas and Heating Oil as Fuel for Domestic Heating", RDC, Feb. 2005 and "Carbon Energy Balances for a Range of Biofuel Options", DTI Report B/B6/00784, 2003.

[30] Hammond, G and Jones, C *"Inventory of carbon & Energy (ICE)"* Version 1.5 Beta. Department of Mechanical Engineering, University of Bath, 2006.

as there is between one and two orders of magnitude between the lifecycle emissions of the barrage options and those, for example of a Combined Cycle Gas Turbine plant.

The following sections provide the breakdown for the embedded carbon in the Cardiff-Weston barrage and the Shoots barrage.

Cardiff-Weston embodied carbon

Table 4.2(1): Cardiff-Weston Embedded CO_2

Cardiff-Weston		
	Quantity (tonnes)	tonnes CO_2
CAISSONS		
Concrete		
Cement	2,900,000	2,378,000
Fine Aggregate	5,000,000	26,500
Coarse Aggregate	9,200,000	73,600
Rebar	900,000	1,548,000
EMBANKMENTS & FOUNDATIONS		
Rock	16,300,000	342,300
Sandfill	29,100,000	154,230
Roadworks	400,000	56,000
Fabricated Steel	200,000	364,000
TOTAL CO_2 (tCO_2)		4,942,630
Total Energy production over lifetime (TWh)		2,040
CO_2 emissions gCO2/kWh		**2.42**

n.b Quantities taken from STPG 1989 report[28]

The Shoots embodied carbon

Table 4.2(2): English Stones Embedded CO_2

English Stones		
	Quantity (m^3)	CO_2
CAISSONS		
Rock dredging for foundations	720,900	38,074
Rockfill mattress/foundations	46,970	2,481
Turbine/sluice caissons concrete (pre-cast)	171,240	88,360
Sluice caissons concrete (pre-cast)	38,660	19,949
Ship lock concrete	94,135	48,574
Grout (assumed motar)	61,563	35,301
Sand ballast	504,921	4,683
Concrete placed under water	116,952	60,347
Concrete placed between tides	104,698	54,024
EMBANKMENTS		
Rockfill	2,020,000	106,686
Sand fill	2,210,000	20,498
Armouring - seaward (assumed rock)	369,600	19,520
Armouring - basin side (assumed rock)	201,600	10,648
Filter membrane (assuming rock density)	667,800	13,436
TOTAL CO_2 (tCO_2)		522,581
Total Energy production over lifetime (TWh)		330
CO_2 emissions gCO2/kWh		**1.58**

4.2.3 Energy payback for structure installation

The energy payback associated with the Severn Barrage can be calculated in relation to the amount of CO_2 that would otherwise be produced from using the energy that comes from the electricity grid (Option A represents a general mix of energy sources) or electricity generated from combined cycle gas turbines (CCGT). Based on this the CO_2 payback period is shown in the Table 4.2(3) below.

Table 4.2(1): CO_2 Payback Period

	Cardiff Weston	English Stones	units
Average Annual Energy	17.00	2.75	TWh/year
CO_2 emissions	2.42	1.58	gCO2/KWh
CO_2 saved (assuming grid supply uses 430gCO2/KWh)	427.58	428.42	gCO2/KWh (saved)
CO^2 Payback (A)	**8.16**	**5.32**	**months**
CO_2 saved (assuming CCGT generated electricity 329gCO2/KWh)	326.58	327.42	gCO2/KWh (saved)
CO^2 Payback (B)	**10.68**	**6.96**	**months**

4.3 POWER OUTPUTS AND CARBON SAVINGS

4.3.1 Cardiff-Weston barrage power outputs

Summary of studies

The power and energy outputs from the Cardiff-Weston barrage have been the subject of detailed study, initially as part of the Severn Barrage Committee studies[31] and subsequently by the Severn Tidal Power Group[32] [33] [34]. Early work relied on so-called ‘flat-estuary’ computer simulations, where no account was taken of the hydrodynamics of the tidal flows in the estuary seaward of the barrage or in the enclosed basin. As studies progressed, more sophisticated computer models were developed or became available. These computer models are described below.

Method of operation applying La Rance experience to the Severn

The 240MW Rance barrage, described in Section 3, is well known for being capable of generating with the flow from basin to sea (ebb generation) and from sea to basin (flood generation). The turbines can also be used as pumps to increase the volume of water in the basin at around high tide (flood pumping) or to reduce the basin volume at low tide (ebb pumping). Initially, the last of these options – ebb pumping, was used for only about 1% of the time and has been discontinued. The barrage is now operated mainly in ebb generation mode with flood pumping, and in two-way mode – ebb generation and flood generation – as illustrated in Figure 3.1(1).

With this experience available, early studies (Ref. 1) compared the different modes of operation using flat-estuary simulations and came to the following main conclusions:

- For a given number of turbines and with adequate sluice area, two-way generation results in less energy then ebb generation.

---

[31] Severn Barrage Committee: *Tidal Power from the Severn Estuary*. EP46, 1981.

[32] STPG: *Tidal power from the Severn,* 1986.

[33] STPG: *Severn Barrage Project: Detailed Report*, EP57, STPG, 1989.

[34] STPG: *Severn Barrage Project: Further environmental and energy capture studies,* ETSU TID 4099, 1993.

- For installations with the same energy output, energy from two-way generation is about 10% more expensive than from ebb generation.
- Flood generation suffers from the smaller basin volume due to the slope of the seabed. The permanent large reduction in high tide level in the basin would not be acceptable to shipping interests.
- Ebb generation with flood pumping at high water on every tide produces about 10% more net energy than ebb generation alone. This is the case at La Rance.

Subsequent studies have therefore concentrated on ebb generation, with or without flood pumping.

Computer models for power and energy estimates: 0-D models

With the area/depth relationship of the basin defined, and with algorithms defining the operation (flow, head, power) of the turbines and sluices (head, flow), a simple spreadsheet model can be set up which divides the tide into short timesteps, tracks the flows and water levels on each side of the barrage and thus calculates the power and energy produced. For the calculation of power and energy, the operation of the turbines has to be defined using algorithms relating power to flow, head and turbine efficiency. Such a model can be useful for comparing similar schemes, e.g. the same barrage but with different numbers of turbines, and for evaluating smaller schemes where the basin length is short and the dynamics of the tide are not significant. Such models are referred to as 0-D models. For reasonable accuracy, the input tides' shape and range should be modified in the light of results from 1-D or 2-D models.

More sophisticated versions can include internal optimising routines in which, for example, the full curves of turbine efficiencies/flows/heads are available, and operation can be simulated over a number of tides, such as a spring-neap cycle.

1-D models

In this type of model, the estuary is divided into a series of slices, starting out to sea where the natural tidal range can be expected to be unchanged by the barrage.

1-D models are based on the simplifying assumption that the flow along the estuary across each slice is uniform and parallel to the estuary centreline – there is no lateral or vertical flow. In spite of this limitation, a 1-D model can accurately simulate the propagation of the tides along the estuary. Typically, such a model would be tuned, by adjusting bed friction factors, to represent one tide accurately for height and phase, then verified by running it for a different tide.

For the 1-D model widely used for the Cardiff-Weston barrage and also for the STPG studies of the Shoots barrage, the model limit was at Ilfracombe. This was the most westerly location in the estuary where the 1-D model assumption that the dominant flows are approximately parallel to the estuary centreline is still reasonable. Further west the estuary widens dramatically and starts being influenced by flows in the Irish Sea. Subsequent studies with more extensive 2-D models showed that the tide range at Ilfracombe is likely to be reduced by the presence of the Cardiff-Weston tidal power barrage by 2-3%. Tests for STPG English Stones barrage showed that high tide levels at Portbury (near Avonmouth) were hardly changed, though the effect on low levels extends to near Cleveden.

For simulation of the operation of the tidal power barrage in a 1-D model, special algorithms need to be included, as in the 0-D model, to represent the relationship between available head and flow for sluices and turbines and the relationship between head, flow, turbine efficiency and turbine power output. These relationships are often the same as those used in the 0-D model though the conditions tested were selected by both SBC and STPG from the wide range of conditions tested in the 0-D model as run times are significantly longer. Testing barrage operation over a complete spring neap cycle remains practical in a 1-D model, and was used extensively for both SBC and STPG studies of the Cardiff-Weston and the Shoots barrages.

For the later studies by STPG of the Cardiff-Weston barrage, a 1-D model with an internal energy optimising routine was developed, using the turbine and pump performance charts which define turbine / pump power output / input as a function of head and flow over the full range of operating conditions as described above for the 0-D model. However, this was a very time consuming process so a very limited number of runs were completed.

A 1-D model approach was used by the SBC to investigate how estuary flows would change and velocities increase as a tidal power was progressively constructed across the Severn estuary. Such studies provide much valuable information on how the estuary would respond to barrage construction and an indication of the velocities as caissons are placed and embankments are raised, without providing the detail of local flow velocities that would be required for construction planning or for management of navigation thorough a partially complete barrage.

2-D models

This type of model represents the estuary as a grid of squares, the size of the grid being varied to suit the shape of the estuary. Water can enter or leave a grid across any face of each square, so transverse currents are represented. This is important near the barrage, where concentrated flows from turbines or sluices have to spread out across the estuary. This is also important for a realistic simulation of flows west of Ilfracombe where the dominant flows are no longer parallel to an assumed estuary centreline. The very large scale of the Severn estuary requires progressively smaller grid sizes as the estuary narrows to maintain an adequate representation of the details of the channels. In the STPG model developed by WRc grid sizes range from 4500m in the outer section west of Ilfracombe to 500m in the estuary east of Minehead with an inset area with a 167m grid in the area around the barrage.

The flow across each grid square is assumed to be constant with depth – vertical currents are not represented. To prove and verify such models, appropriate data on currents strengths and directions are needed in addition to good simultaneous tidal data for both sides of the estuary.

In a 2-D model it is also necessary to include algorithms defining the flow through the sluices and turbines as a function of the head across the barrage and the relationship between turbine / pump flows and heads and power output / input. In practice the computational demands of these routines at each cell where sluices or turbines are present, combined with the very large number of model cells has limited the use of 2-D models to a few key tests to confirm the results from the 1-D and 0-D models.

One key output from the 2-D models used for both the SBC and later for STPG has been to assess the reduction in tidal range at the boundary of the 1-D model as this has a direct effect on the annual energy output of the barrage.

The 2-D model developed for STPG was used to examine how velocities are likely to change as a barrage is progressively constructed across the estuary.

The long runs times associated with using a detailed 2-D model of the estuary and its approaches, with the added complexity of a tidal power barrage has meant that both SBC and STPG only carried out a limited number of tests in this model. The algorithms representing turbine performance in particular were often simplified, and the STPG runs in particular were limited to single tides spring or neap tides.

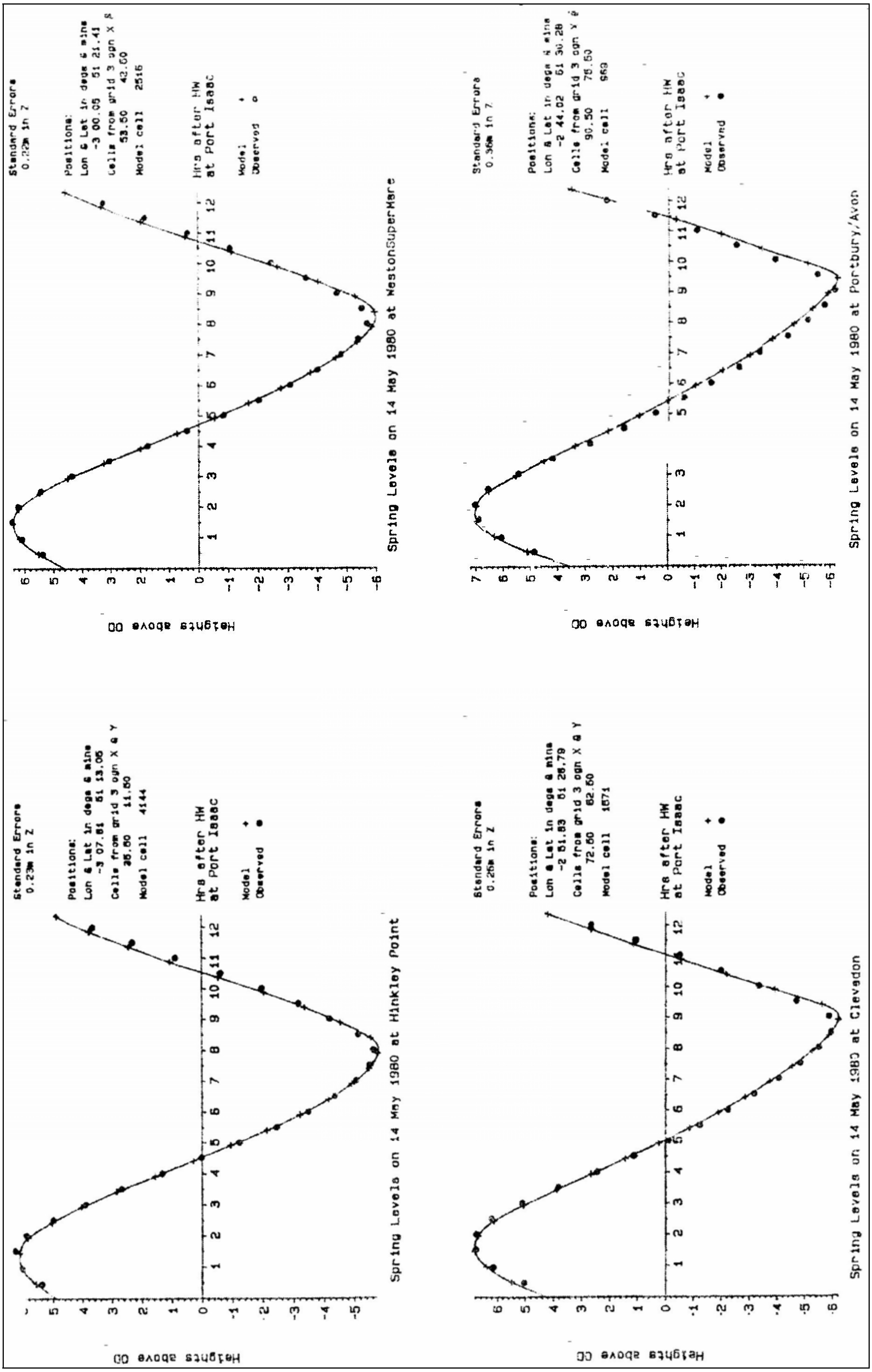


Figure 4.3(1): Typical measured and model tide curves – WRC 2-D model

Figure 4.3(1) presents a sample of four tide measured tide curves and compares them with the curves represented in the WRC 2-D model[35]. The excellent agreement between the two, both amplitude and phase, is clear. These graphs show the characteristic tide shape in the Severn estuary, with the flood (rising) tides being shorter and rising more rapidly than ebb (falling) tides. In the outer estuary west of Ilfracombe, tide shapes are approximately sinusoidal, but as the tide propagates into the estuary it becomes progressively more distorted as it passes the Cardiff-Weston site and then the Shoots. The distortion is greatest on a spring tide and least on a neap tide. A short flood and long ebb is a common feature of the upper reaches of long estuaries with a high tidal range and is due to the effects of bed friction on the propagation of the tidal wave.

4.3.2 Cardiff-Weston barrage power outputs

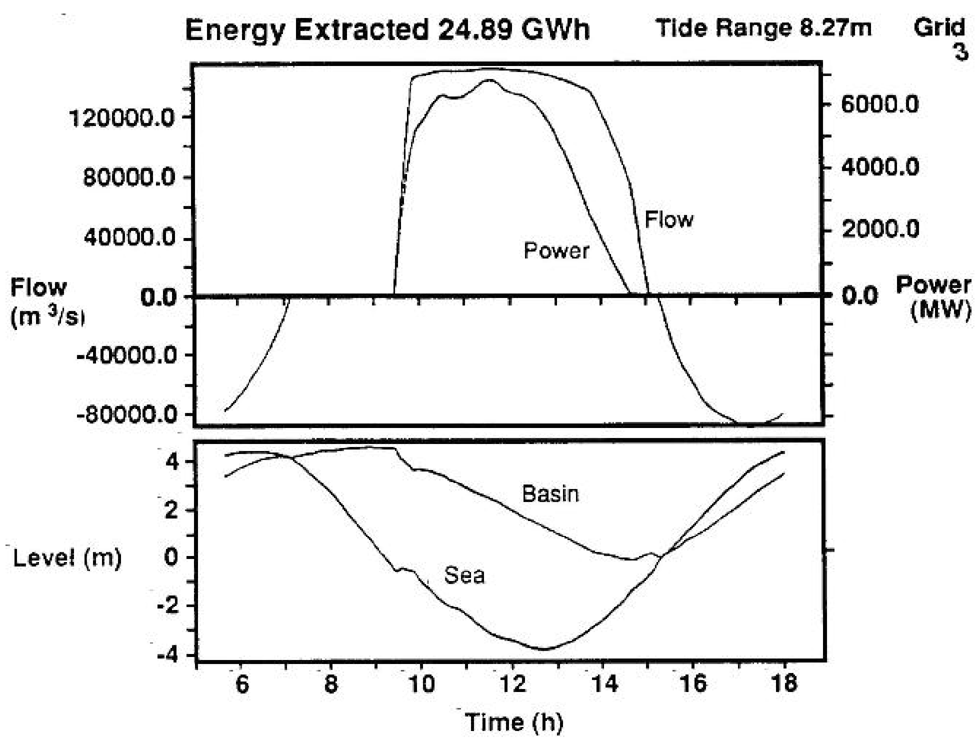


Figure 4.3(2): Results from 2-D model for nominal mid-range tide at Cardiff-Weston barrage

Figure 4.3(2) shows an example of results from a dynamic model, in this case the 2-D model developed for STPG by the Water Research Centre. The following points arise:

- After high tide, the water level in the basin rises, due to the ebbing of the water in the basin towards the barrage, reaching a level higher than the previous high tide level.. In a 0-D model, the basin level would be constant over this period and below high tide level.
- At the start of generation, there is a sharp fall in basin level and a noticeable rise in sea level outside the barrage. These are caused by the large flows through the turbines.
- At the end of generation, the basin level shows a small rise, due to the turbines shutting down and flow piling up behind the barrage.
- Towards the end of generation, the power output drops more quickly than the flow, due to the head across the turbines reducing quickly.

---

[35] Water Research Centre for STPG: *2-D Plan hydrodynamic modelling of the Bristol Channel and Severn Estuary with and without barrage.* 1989

These results are typical for 1-D and 2-D dynamic computer models.

Choice of tidal histogram

To estimate the average annual energy output for a barrage, a year of average tides must be selected. The principal long-term lunar cycle has a period of 18.6 years and the annual energy output can vary by about ±7% over this period. 1974 was a year of near-average tides and was selected as the base year for the Severn Barrage Committee studies. More recent studies have been based on the same years. Figure 4.3(3) shows the resulting histogram for tides at Ilfracombe.

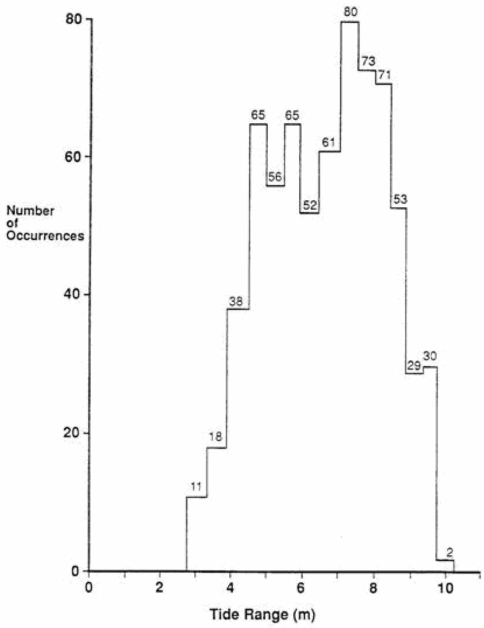


Figure 4.3(3): Ilfracombe tidal range histogram for 1974

Results of computer models

A great deal of study has been carried out by different organisations into the performance of the Cardiff-Weston scheme. STPG [36] have reported the most recent and in-depth studies.

Figure 4.3(4) below compares ebb generation only and ebb generation plus flood pumping for neap, mean and spring tides. This shows that, unlike at La Rance, there is little to be gained by flood pumping. Although best-fit straight lines are shown, inspection shows that there is least to be gained during neap and spring tides, more during mean tides.

[36] STPG: *Severn Barrage Project: Further environmental and energy capture studies*, ETSU TID 4099, 1993.

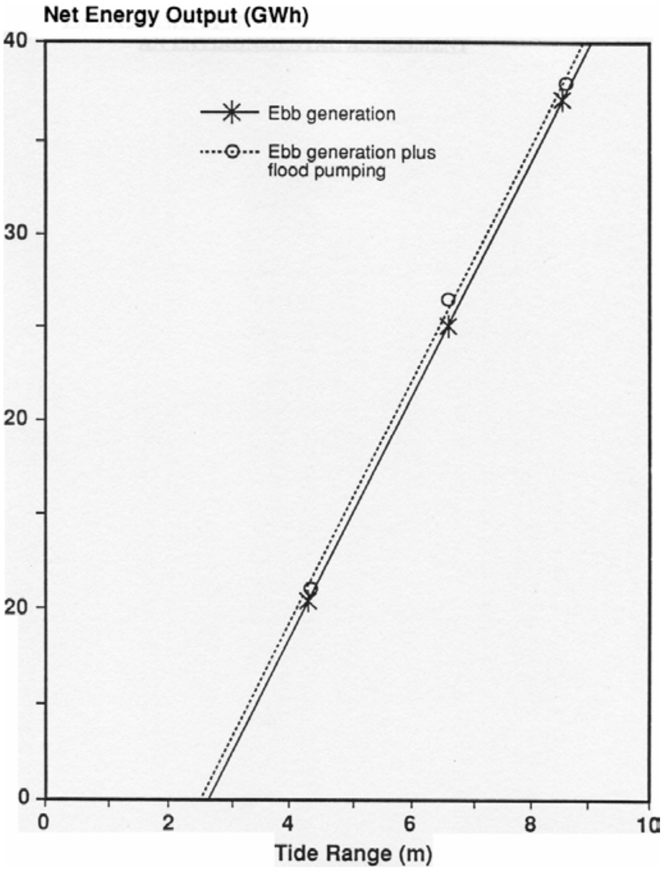


Figure 4.3(4): Results from 2-D model: net energy sent out *vs* tidal range at Ilfracombe, ebb generation and ebb generation + flood pumping

Conclusions from energy modelling of Cardiff-Weston barrage

Table 4.3(1) summarises the results from the 0-D, 1-D and 2-D models used in STPG's latest study. These results lead to the following conclusions:

- 0-D models with sinusoidal tides show that 10-11% net energy gain can result from flood pumping. This is broadly the picture for the Rance barrage, where the estuary is too small for significant dynamic effects.
- The 0-D model with non-sinusoidal tides (as is the case at both the Cardiff-Weston and Shoots barrage sites) shows a net gain due to flood pumping of 5%, confirming that the non-sinusoidal tides at the barrage are less suitable for flood pumping.
- The 1-D and 2-D models give very similar results for the gain due to flood pumping, only 3.2% and 2.7% respectively.
- The results for the two dynamic models, 1-D and 2-D, agree to within 2.9% and 4.6% for the ebb-generation and ebb-generation plus flood pumping cases respectively.
- The 1-D and 2-D models are likely to be more accurate than the 0-D models, and so the average annual energy output for the Cardiff-Weston barrage, with flood pumping, can be expected to be close to 17TWh, the figure assumed by STPG.

Table 4.3(1): Annual energy output predictions by computer models

Model	Net annual energy sent out		Net gain from flood pumping
	Ebb generation (TWh)	Ebb generation plus flood pumping (TWh)	(%)
2-D	16.15	16.95	2.7
1-D	15.70	16.21	3.2
0-D(Algorithmic model with histogram of sinusoidal tides)	16.62	18.49	11.2
0-D (optimising model with 29-tide series and non-sinusoidal tides)	15.62	16.44	5.2
0-D (Optimising model with 29-tide series and sinusoidal tides)	16.17	17.83	10.3

4.3.3 The Shoots barrage energy output

Method of operation

PB propose to use Straflo turbines for the Shoots barrage. At the diameter required, 7.6m, the prototype machine at Annapolis Royal has fixed-angle runner blades. This prevents the machine being used for flood pumping. Providing moveable runner blades presents difficulties with the sealing of the gap between the generator rotor and the fixed structure. Therefore, ebb generation only is proposed for the Shoots barrage.

Annual energy output

The annual energy output of the Shoots barrage has been assessed by two organisations:

- Binnie & Partners (now Black & Veatch) for STPG as part of the 1986 studies[37], using the same 1-D computer model of the estuary that was used at the time for the Cardiff-Weston barrage.
- Professor E M Wilson of Salford University who used a 0-D optimising model previously developed for early studies of the Cardiff-Weston barrage. Studies were carried out both for STPG as an input to their 1986 report on the English Stones scheme, and then in 1989 as input to studies by PB’s predecessors. During the STPG studies, simple asymmetrical tides were included, as sinusoidal tides would not be representative of the conditions at site.

The two studies assessed the energy output of two different turbine and sluice arrangements, so are not directly comparable. The results were as follows:

[37] Binnie & Partners for STPG: *Dynamic modelling of an English Stones tidal power barrage.* 1986.

Table 4.3(2): Comparison of predicted energy outputs for English Stones/The Shoots

	English Stones	The Shoots
	STPG arrangement (bulb turbines and submerged sluices). Ebb generation plus flood pumping	PB arrangement (Straflo turbines and open sluices). Ebb generation
Turbine diameter (m)	7.5	7.6
Number of turbines	36	30
Generator capacity (MW)	27	35
Total capacity (MW)	972	1050
Sluice opening size	12m x 11m	32m x 6m at +3mOD
Number of sluices	44	42
Area of sluices at +3mOD water level (m^2)	5808	7560
Annual energy output (TWh)	2.7	2.9, reduced to 2.75 to allow for storm closures, transmission losses etc

The STPG result includes an allowance of 7% for the net gain from flood pumping. Although the basin behind the Shoots barrage is much smaller than that for the Cardiff-Weston barrage, there are still dynamic effects which would reduce the net gain from pumping. This is evident from Figure 4.3(5) which, although appearing to have been smoothed, shows the basin level rising after high water in a manner similar to that found for the Cardiff-Weston barrage. This effect, among others, reduces the net gain from flood pumping from about 10% to about 3% for the Cardiff-Weston barrage. Therefore the 7% allowance may be somewhat optimistic.

The Shoots barrage line is to seaward of the line studied by STPG, so the basin area is larger, although basin areas are not quoted in the relevant reports. Therefore the PB estimate of energy output, 2.75TWh/year, appears to be reasonable.

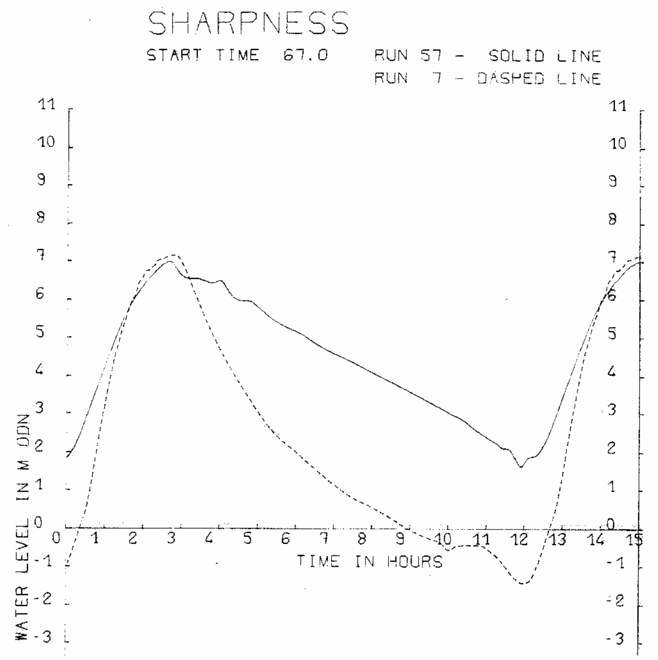


Figure 4.3(5): Spring Tide Curve

4.3.4 Carbon savings

The present standard value of carbon savings for electricity generated by non-thermal plant is 0.43kgCO_2/kWh. On this basis, the annual and nominal lifetime carbon savings (expressed as CO_2) for the two barrages are shown on Table 4.3(3).

Table 4.3(3): Annual and lifetime carbon savings

	Annual energy (TWh)	Annual CO_2 saving (Mt)	Lifetime CO_2 saving (Mt)
Cardiff-Weston barrage	17	7.3	877
The Shoots barrage	2.75	1.18	142

SDC have requested that the standard value of carbon savings for electricity generated by CCGT, which is 0.329kgCO_2/kWh, is included. On this basis, the annual and nominal lifetime carbon savings (expressed as CO_2) for the two barrages are shown on Table 4.3(3a).

Table 4.3(3a): Annual and lifetime carbon savings

	Annual energy (TWh)	Annual CO_2 saving (Mt)	Lifetime CO_2 saving (Mt)
Cardiff-Weston barrage	17	5.6	671
The Shoots barrage	2.75	0.9	108

4.4 IMPLICATIONS OF CLIMATE CHANGE

4.4.1 Introduction

For tidal power barrages, there are three principal implications of climate change:

- Rising sea levels, affecting the design and operation of a barrage.
- Increased frequency of storms, resulting in a more severe wave climate and more frequent surge tides and/or large river floods.
- Increasing temperatures, affecting the ecology of the estuary.

Each is discussed briefly below. However, the last significant work on the feasibility of the Cardiff-Weston barrage dates back to 1993, while that on the Shoots barrage dates back to 1990. At the time, STPG considered a nominal 1m rise in sea level when studying the operation of the Cardiff-Weston barrage and the resulting water levels in the enclosed basin[38]. Apart from this, the studies pre-dated the present concerns about rising temperatures, changes in weather patterns and ecological changes. Therefore, for this evidence-based review of Severn barrage options, there is little information on which to base assessments of the effects of climate change on a post-barrage estuary.

4.4.2 Rising sea levels

The latest DEFRA[39] guidance on rising sea levels for the southwest of England and Wales is as follows:

- An increase in mean sea level of 3.5mm/year from 2005 to 2025.
- 8mm/year from 2025 to 2055.
- 11.5mm/year from 2055 to 2085
- 14.5mm/year from 2085 to 2115.

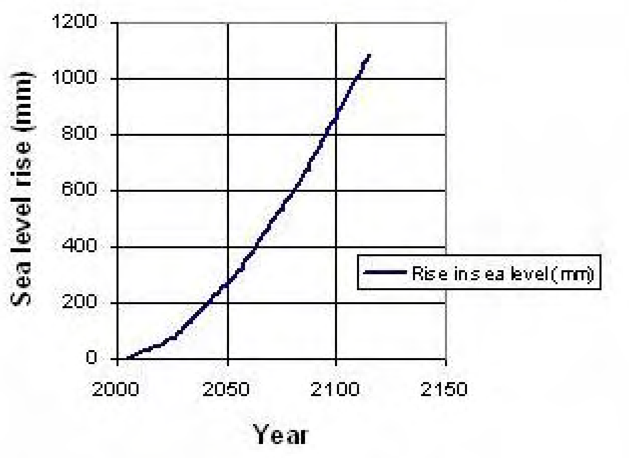


Figure 4.4(1): DEFRA guidance on sea level rise

The resulting cumulative curve is shown on Figure 4.4(1). This shows that, over the next century or so, a rise of about 1m can be expected. The latest IPCC report[40] predicts a range of rises in sea levels, depending on the underlying assumptions and the resulting temperature changes. This range is 0.18m to 0.59m rise at 2090-2099 relative to the level during 1980-1999. Any significant rise in sea level would affect the design of a tidal power barrage and perhaps its operation. Perhaps more importantly, the benefit of a barrage in controlling water levels in the enclosed basin to prevent flooding would increase in importance over a barrage's nominal 100+ years life.

The main structural elements of the Cardiff-Weston barrage and the Shoots barrage, namely the caissons for the turbines, sluices and ship locks, are already designed for water depths of 30m or

---

[38] STPG: *Severn Barrage Project.* 1989, Vol. I, Section 2.

[39] Department of Environment, Food and Rural Affairs: *Flood & Coastal Defence Appraisal Guidance – FCDPAG93: Economic Appraisal,* Oct 2006.

[40] Intergovernmental Panel on Climate Change: *Climate Change 2007: The Physical Science Basis;* February 2007.

more. Therefore modifying the design to accommodate say a 1.2m rise in sea level will have a modest impact on costs. In addition,, the caissons could be designed so that the water retention level could be raised in the future, e.g. by adding a concrete parapet along the seaward face, thus postponing most of the expenditure on this aspect. Similarly, the embankments could be designed at the outset for a higher sea level or left with their crest levels unchanged but their crest widths increased to allow subsequent raising along the seaward side.

Overall, the effect of allowing for rising sea levels on the design of the Cardiff-Weston and Shoots barrages can be expected to be a small increase in cost.

4.4.3 More stormy weather

This aspect has not yet been studied to any extent in the context of tidal power barrages. The IPCC report predicts that intense tropical cyclone activity is likely to increase. Possible increased frequency of surge tides, associated with low atmospheric pressure and strong westerly winds, would require more frequent operation of the barrage to exclude high water levels from the basin and thus prevent flooding around the enclosed basin. For such events, operation of the barrage gates could have to be timed carefully to minimise the extent of any reflected tidal wave on the seaward side. Such operation would have a minor effect on overall annual energy output.

Increased wave activity could adversely affect sea defences and foreshore sediments both inside and outside the barrage. The barrage would prevent waves generated on the seaward side, including swell waves, penetrating into the basin area. Otherwise, uncertainty about morphological changes that may be caused by the barrage prevents any confident forecast of overall effects of the barrage on sea defences.

4.4.4 Increased temperatures and ecology of the estuary

A global increase in temperatures can be expected to result in changes to the ecology of the estuary, but these would take place with or without a Severn barrage. For example, recent surveys have shown that, possibly as a result of milder winters, wading birds have been leaving the Severn estuary in favour of the cooler east coast estuaries[41].

4.4.5 Conclusion

In general, a Severn barrage would help mitigate the effects of climate change, while allowing for such changes in the design of the barrage should have little effect on its cost or life.

4.5 MAINTENANCE

4.5.1 Introduction

The operation of a tidal barrage will be concerned with the control of the turbines and generators and gates associated with power generation and the passage of shipping through the lock(s). This will require a dedicated team of shift-workers, although the trend for hydro projects is towards remote supervision and control.

The maintenance of a tidal power barrage falls into three main categories:

- Maintenance and repair of the ‘working’ structures, comprising reinforced concrete caissons.
- Maintenance and repair of the ‘non-working’ elements, such as the embankments, access roads and so forth.
- Maintenance, repair and occasional replacement of the electrical and mechanical equipment: turbine-generators, switchgear, transmission links, gates and gate operating equipment.

[41] RSPB The Severn Estuary – its Nature Conservation Value and Regulatory Protection. 2006

In addition, recurring costs would be incurred that are not maintenance as such – licence fees, rates etc. This section considers the results of studies to date by STPG and PB of the costs of operation and maintenance of the Cardiff-Weston barrage and the Shoots barrage.

4.5.2 Experience at La Rance barrage

The Rance barrage, commissioned in 1966, has operated continuously since that date. There were some initial problems with the fixings of the generator stators due to starting the turbines as pumps direct-on-line. After these were corrected, there has been little in the way of major repairs. Recently, a programme of overhauling the turbines and generators has been in progress but, by working on only a few machines at a time, the effect on total energy output has been minimal[42].

The reinforced concrete structures have required negligible maintenance, giving strong support to the view that reinforced concrete, properly designed, built and with its reinforcing steel cathodically protected, is a very durable material in marine conditions.

4.5.3 Cardiff-Weston barrage

The annual costs of operation and maintenance of the Cardiff-Weston barrage as estimated in 1989 are summarised as follows:[43]

	1988 prices	2006 prices
Operation & maintenance (£M/year)	40	66
Off-barrage costs (£M/year)	30	49.5
Plant replacement costs (£M/30 years)	90	148.5

With a total capital cost (2006) of about £15000M, the first two items, totalling £115.5M/year, represent 0.77% of capital cost. The plant replacement costs equate to 3.7% of the 1988 cost of plant of £2417M, implying overhaul rather than replacement, as has been the case at La Rance.

4.5.4 The Shoots barrage

PB have estimated operation and maintenance costs as follows, at 2006 prices:

Normal operations:	£16.5M/year, plus 25% contingency for worst case.
Business rates	£4.4M/year
Insurance	£3.6M/year
Total	£24.5M/year

The total represents about 1.7% of the capital cost – higher than the STPG figure – but there is no allowance for plant ‘replacement’.

4.5.5 Previous studies

Based on experience with large hydro projects, which normally require little maintenance, earlier work, e.g. during the Severn Barrage Committee studies, allowed operation and maintenance costs

[42] http://membres.lycos.fr/chezalex/projects/rance/

[43] Carr, JG: The economics of *the Severn Barrage.* Proc. Conference on developments in tidal energy, ICE, 1989, Paper 18.

equal to 0.66%/year of the capital cost. The STPG allowance is in line with this, but the PB allowance is significantly higher.

4.6 LIFE CYCLE AND DECOMMISSIONING

4.6.1 Experience to date

The most relevant experience to date as regards the life cycle of a tidal power barrage and its generating plant has been gained at La Rance barrage. After 40 years' continuous operation, the structure is in good condition, while the turbines are being overhauled in turn, as described above.

Elsewhere, there are many examples of structures built of reinforced concrete which, given good quality design and construction, have survived well after many decades in a marine environment. One relevant example is the 6000t Phoenix caissons built for construction of the Mulberry harbour for the D-Day landings in WW2. Although many were refloated and reused in the repair of breached sea defences in the Netherlands, there are examples to be seen which are still structurally sound after more than 60 years although they were designed for a life of only a few years.

4.6.2 Life cycle of structure

In the report of the Severn Barrage Committee[44], the Severn barrage was assumed to have a working life of 120 years. In the economic analyses, the effects of discounting over this period of time reduces the present value of the benefits of a barrage almost to zero, so the economics of a tidal power barrage are not sensitive to this variable. This figure was not selected on the basis of detailed research but as a reasonable multiplier of the life cycle of the plant and equipment, discussed below.

The Severn Tidal Power Group (STPG) selected 120 years as a base case for the life of the structure but also tested sensitivity of the discounted unit cost of energy to life cycles of 30, 60 and 240 years[45]. Using test discount rates of 5% up to 15% showed there was little difference with barrage life cycles of 60 to 240 years. Differences were more marked with a test discount rate of 2%, as follows:

[44] Severn Barrage Committee: *Tidal power from the Severn Estuary*. Energy Paper 46, 1981.

[45] Carr J.G., *The economics of the Severn barrage.* Paper 18 in proc. Conference on Developments in Tidal Energy, ICE, 1989.

Table 4.6(1): Effects of life cycle variation on unit cost of energy from barrage (p/kWh) (1988 prices)

Discount rate:	2%	5%	8%	10%	15%
Operating life:					
30 years	3.59	5.13	7.15	8.19	14.05
60 years	2.27	3.89	6.11	7.90	13.51
120 years	1.81	3.65	6.01	7.85	13.51
240 years	1.68	3.64	6.01	7.85	13.51

The results above lead to the conclusion that the structure of a Severn barrage should have a very long life, the precise length of which does not have to be defined, as large differences in assumed life have little effect on the unit cost of energy.

4.6.3 Life cycle of plant and equipment

For the economic evaluation of the various barrage options studied by the Severn Barrage Committee, it was assumed that the plant and equipment would all be replaced every 40 years, giving three sets of plant in the life of the schemes.

The Severn Tidal Power Group (STPG) selected instead to allow for a major overhaul of the plant and equipment every 30 years. This is in line with experience at La Rance.

The allowances included in the cost estimates for operation and maintenance should be fully adequate to cover normal maintenance on the plant and equipment. As noted above, shutting down a few turbines at any time would have minimal effect on the overall energy output from a tidal power barrage. If such closures can be restricted to periods of neap tides, there will be no loss of energy as optimum energy output would be achieved with fewer than all the turbines operating.

4.6.4 Decommissioning

To date, there have been no detailed studies of the method and cost of decommissioning a tidal power barrage. The Rance barrage, which provides an important road crossing of the Rance estuary in addition to its energy generation role, is being maintained in full working order and there are no plans for it to be decommissioned in the foreseeable future.

In the case of a Severn barrage, whether at the Shoots or on the Cardiff-Weston line, decommissioning would result in the following benefits ceasing to be available:

- The predictable generation of renewable energy, with associated savings in carbon emissions from fossil fuel plants.
- The protection of the hinterland around the basin from flooding due to exceptionally high tides coupled with rising sea levels and/or large river flows.
- The recreational benefits of a less extreme tidal environment in the enclosed basin.
- If added to a barrage, the loss of any public road crossing (Cardiff-Weston) or rail crossing (Cardiff-Weston and The Shoots).

Clearly, the economics of decommissioning would have to take the values of the above benefits as well as the cost of decommissioning.

No attempt has yet been made to evaluate the cost of decommissioning a tidal power barrage. Such evaluation would have to take into account the following aspects:

- The electrical and mechanical plant including the gates could be extracted reasonably easily and taken away for recycling of their materials.

- In-situ demolition of a part-demolished barrage in the resulting concentrated tidal currents, without causing adverse environmental effects, cannot be considered feasible with present technology.
- The caissons would have to be refloated and towed elsewhere for breaking up. Techniques would have to be developed to re-float the various concrete caissons, which would have been fixed together with grouted joints, have been grouted to their foundations, and have had their lower internal cells filled with concrete and sand.
- Having refloated each caisson, it could be towed to deep water and sunk to form artificial reefs. Otherwise, it would have to be towed to a suitable workyard to be broken up. The resulting concrete, steel reinforcement and other materials could perhaps be recycled but this could involve considerable transport.
- Most of the embankment materials should be recoverable but would have little residual value, so also may be disposed of in deep water.
- Restoring the estuary to its pre-barrage condition, including its mobile sediment deposits, is unlikely to be feasible at acceptable cost.

As an order of magnitude estimate only, the cost of decommissioning could be similar to the cost of construction. However, this excludes the restoration of the estuary to its pre-barrage condition.

4.7 Compatibility of Barrage and Non-Barrage Options

4.7.1 Cardiff-Weston and The Shoots barrages

If The Shoots barrage were to be built, it could be followed in due course by the construction of the Cardiff-Weston barrage in order to develop a larger proportion of the tidal resource in the estuary. The Cardiff-Weston barrage would reduce the tidal range within its basin to about half its natural valve. This would result in the output of The Shoots barrage reducing significantly, perhaps by around 75%. The effect of The Shoots barrage on the output of a Cardiff-Weston barrage would depend on the residual method of operation of the former, and this would need further study.

4.7.2 Tidal lagoons

Tidal lagoons, for example as proposed by Tidal Electric Ltd, are designed to be founded on a seabed level between 0mCD and –5mCD[*]. Figure 4.7(1) shows the –10mOD contour, approximately equivalent to the –5mCD contour. This shows that the areas suitable for tidal lagoons would be Bridgwater Bay and English Grounds on the south side, and Cardiff Grounds and Welsh Grounds on the north side.

[*] CD = Chart datum – the datum for Admiralty charts and approximately the level of the lowest astronomical tide (LAT). In the Severn estuary, 0mCD is equivalent to about –6mOD.

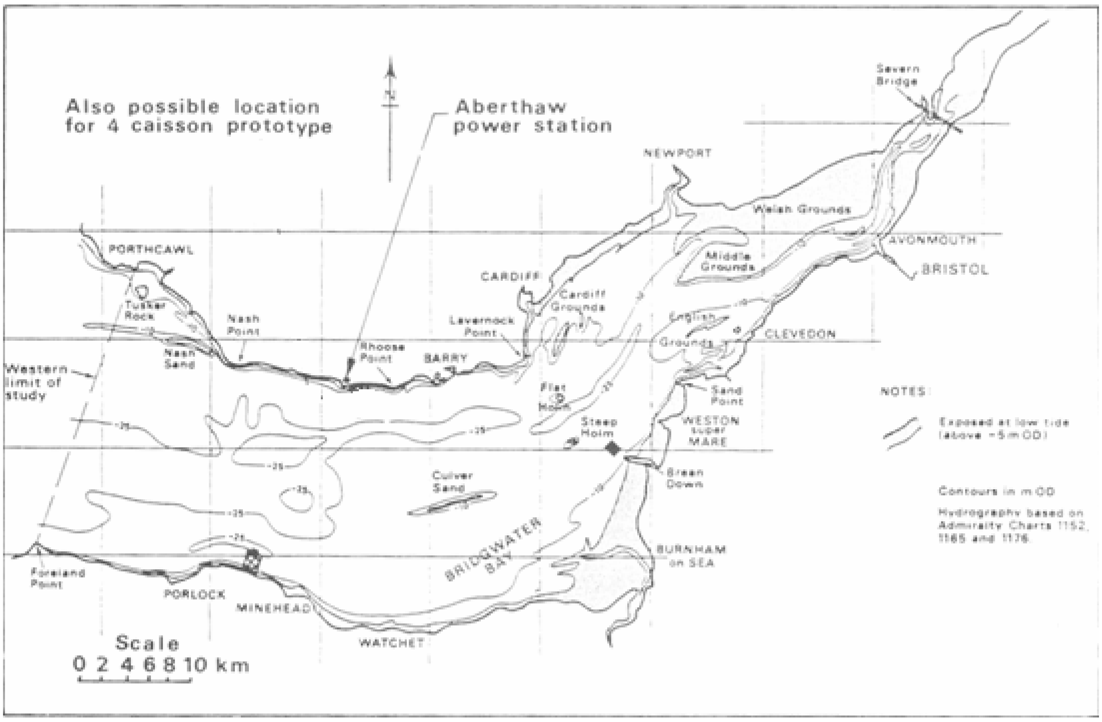


Figure 4.7(1): Bathymetry showing shallow areas

Since, behind a tidal power barrage, the tidal range would be about half the present tidal range, any tidal lagoon here would have its energy output reduced to about 25% of its normal value, as energy output is approximately proportional to the square of the tidal range. Therefore development of a Cardiff-Weston barrage would preclude the development of tidal lagoons inside the enclosed basin but would leave Bridgwater Bay available. The approximately 10% reduction in tidal range forecast on the seaward side of the Cardiff-Weston barrage would reduce the output of a tidal lagoon scheme in Bridgwater Bay by about 20%, adversely affecting its economics.

A barrage at The Shoots would enclose a basin that lacks space for tidal lagoons of any useful size, bearing in mind that a lagoon which obstructs a significant proportion of the estuary width would increase tidal currents in the remaining gap. This would be expected to result in the widespread redistribution of nearby existing sediment deposits. With a barrage at The Shoots, the four areas of shallow water identified above would remain available, with a relatively small reduction in tidal range expected (about 8% at the barrage, reducing with distance to seaward). The comment about obstruction of the estuary would apply to any large lagoons in these areas, suggesting that Bridgwater Bay could be the only feasible site as regards sediment stability.

To summarise:

- Tidal lagoons located within the basin of a tidal power barrage would have their energy output reduced by about 75%.
- Although four large areas of shallow water exist in the Severn estuary which could be suitable for tidal lagoons, any tidal lagoons which obstruct tidal flows in the remaining width of the estuary can be expected to cause significant redistribution of existing sediment deposits nearby.
- Of the four large areas apparently suitable for tidal lagoons, only Bridgwater Bay could remain as a viable option for a large tidal lagoon, and a Cardiff-Weston barrage would reduce its output by about 20% compared with pre-barrage tides.

4.7.3 Tidal current devices

The situation with tidal current devices with regard to tidal power barrages has similarities with that for tidal lagoons discussed above. Within the enclosed basin of a barrage, except for the vicinity of the barrage turbines and sluices, tidal currents would be substantially reduced, typically by 50% or more[*]. As the energy output of a tidal current device is proportional to the cube of the current velocity, this reduction would render tidal current devices uneconomic. In addition, as much of the Severn estuary outside the deep water channels has large deposits of erodible sediments, these would present more of an engineering challenge as a foundation for tidal current devices than a hard seabed. The deep water channels are used by shipping and so could not be developed for tidal current power.

Outside a barrage, there would be a reduction in tidal range, estimated at about 10% immediately to seaward of the Cardiff-Weston barrage and similarly 8% at the Shoots, both figures reducing progressively with distance to seaward. In the case of the Cardiff-Weston barrage, a reduction of about 3% in tidal range at Ilfracombe has been estimated from 2-D modelling. Assuming as a first approximation that the percentage reduction in current velocities would be the same as the reduction in tidal range, the effects of these reductions on the performance of any existing tidal current devices would be a reduction in energy output ranging from 33% for devices near the Cardiff-Weston barrage to 9% for devices near Ilfracombe. With relatively few areas of shallow water near shore, the Bristol Channel, rather than the Severn Estuary, would seem preferable for tidal current devices, as farms of devices should be more readily sited near the shore, thus reducing cabling costs while also being clear of shipping routes.

For devices to be installed after a tidal barrage became operational, the effect on their economics would be less pronounced than the reduction in current strengths, as their designs would be optimised for the changed tidal conditions.

Should the Bristol Channel be heavily developed for tidal current power, the extraction of energy by the devices could be expected to reduce the tidal range slightly. This would have a corresponding effect on the performance of a tidal power barrage to landward.

To summarise:

- Tidal current devices, existing or planned, would not be viable within the basin of a tidal power barrage, due to the large reductions in tidal currents.
- A tidal power barrage would reduce the tidal range, and hence tidal current velocities, on its seaward side. The extent of the reduction, about 10% for the Cardiff-Weston barrage, would reduce progressively with distance downstream. The effect on a tidal current device would be a reduction in energy output of about 33%, reducing seawards.
- Conditions in the Bristol Channel should remain suitable for tidal current devices.

[*] For example, see Report No CO 2187-M: *2-D Hydrodynamic modelling of the Bristol Channel and Severn Estuary without and with barrage* by Water Research Centre to STPG, 1989, Figures 38 and 40 for comparison of spring tide velocities with and without a barrage.

5 ECONOMICS AND GRID IMPLICATIONS

5.1 COSTS OF CONSTRUCTION

5.1.1 Introduction

For the two schemes selected for analysis, the Cardiff-Weston barrage and the Shoots barrage, detailed estimates of costs were last prepared in 1988 and 1990 respectively. To allow the economics of the two schemes to be assessed at the present time, the costs have to be updated. In addition, the unit rates for the principal items also need to be compared to check that the bases of the estimates for the two schemes are similar. Alternative estimates of the updated costs for the Shoots barrage have been prepared by PB, using the All New Construction Output Price Index (COPI) and Power Sector inflation plus a contingency. The associated multipliers are 1.44 and 1.54 respectively.

Other price escalation indices published by the UK Government[46] include:

- Plant price index (PPI)
- Infrastructure
- Private industrial
- Civil Engineering.

The following sections consider which index or indices should be used to update tidal barrage prices, and the resulting costs.

5.1.2 Escalation indices

Table 5.1(1) compares the five indices listed above for the middle of each year, concentrating on the period 1985-2005. The last detailed estimate of the cost of the Cardiff-Weston barrage was prepared at April 1988 prices. Similarly, the cost estimate for the Shoots barrage is based on an estimate prepared in 1990. For each of these indices except PPI, the base year is mid 1995, with the index set at 100.

Table 5.1(1): Price escalation indices, 1985-2006

Year	PPI	Infrastructure	Private Industrial	All New Construction	Civil Engineering
1985	74	84	84	77	74
1986	78	83	85	81	86
1987	82.5	85	87	84	87
1988	88	95	95	94	97
1989	95	105	106	105	109
1990	100	105	108	108	110
1991	105.5	98	97	101	103
1992	110.5	87	88	92	91
1993	116.5	82	90	89	85

[46] Dept. of Trade & Industry: *Public Sector Construction Works: Quarterly Building Price & Cost Indices.*

1994	121	87	92	92	88
1995	125.5	100	100	100	100
1996	128.5	104	99	103	106
1997	131	105	102	105	106
1998	132.5	107	107	110	109
1999	133	107	111	115	109
2000	134	111	112	120	112
2001	135	115	114	124	118
2002	137	119	117	128	121
2003	141	120	119	133	123
2004	145	122	118	143	126
2005	149	134	120	150	139
2006	152	143	122	155	147

Figure 5.1(1) presents the same information in graphical form. It shows that, between 1988-90 and 2006, with the exception of the Private Industrial Index, the other four indices have increased by similar amounts.

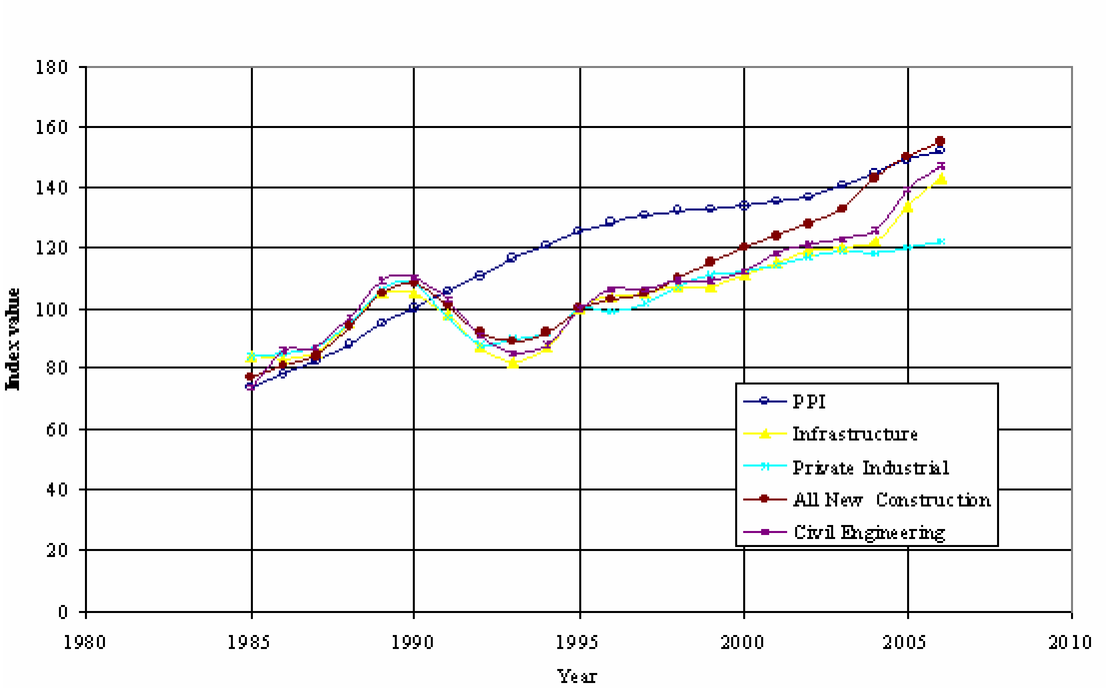


Figure 5.1(1): Comparison of indices

The resulting choices of multipliers for the two barrage costs are therefore as follows:

Table 5.1(2): Escalation over relevant periods

	PPI	Infrastructure	Private Industrial	All New Construction	Civil Engineering

Cardiff-Weston 1988-Q2 2006	1.73**	1.51	1.28	1.65	1.52
Shoots 1990-Q2 2006	1.52**	1.36	1.13	1.44	1.34
Average annual rise 1988-2006 (%)	3.2	2.3	1.4	2.8	2.3

Note: **PPI data for end 2005.

5.1.3 Choice of index

For the Shoots barrage, PB have used two factors, the All New Construction Output Price Index (COPI), with a factor of 1.44, and an annual inflation rate of 2% plus 12.5% contingency. The former falls in the range of 1.52, 1.36 and 1.34 for the PPI, Infrastructure and Civil Engineering indices. The latter results in a factor of 1.54, higher than the other indices, and appears to be pessimistic. The COPI factor of 1.44 has therefore been left unchanged.

For the Cardiff-Weston barrage, the index to be applied to the turbine-generators and other M&E equipment would appear to be the Plant Price Index (PPI). However, this factor is large at 1.73. There is evidence from recent large hydro projects that, in the case of such a large number of large turbines and generators, manufacture of the major parts – runners, distributors, generator shafts etc., would be distributed among those countries with suitable heavy engineering facilities and low labour rates, with assembly in the UK. Examples are Brazil and South Korea, with China developing suitable skills and industry. This approach would effectively result in a lower escalation factor for such equipment. However, to be consistent between the two schemes, the COPI figure of 1.65 has been applied. This lies between the figures for Civil Engineering and PPI.

5.1.4 Updated costs

The updated costs for the Cardiff-Weston barrage, calculated as described above, and the comparable costs for the Shoots barrage, are shown in Table 5.3. The re-ordering of the items for the Shoots barrage has resulted in changes in the amounts for the overall items of management and contingency, and the overall total cost, now shown as £1493.8M compared with PB's figure of £1498.8M. The difference is less than 0.4%.

The updated cost for the Cardiff-Weston barrage is £15,066M.

It is acknowledged that the process of updating costs over a long period using escalation indices is not precise. If a full resource-based costing were to be carried out now, the results could readily differ significantly from the escalated costs. However, STPG also sconsider that there has been a relative reduction in the amount of labour required, as the result of improvements in methods and efficiency, of perhaps 10% or 20%[47].

[47] STPG: *The Severn barrage – Definition study for a new appraisal of the project.* ETSU T/09/00212/REF. 2002

Table 5.1(3) (A):

THE SHOOTS BARRAGE - CONSTRUCTION COST ESTIMATE (Q2 2006)

Description	Quantity	Unit	Rate (£)	Total (£)	Sub-totals
Studies		Sum	7,200,000	7,200,000	
Planning + environmental costs		Sum	28,800,000	28,800,000	
Drainage + sea defence		Sum	28,800,000	28,800,000	
Other compensatory works		Sum	50,400,000	50,400,000	115,200,000
Caisson construction yard(s)		Sum	64,800,000	64,800,000	
CAISSONS					
Sand dredging for foundations etc					
Rock dredging for foundations	720,900	cu m	72	51,904,800	
Rockfill mattress/foundations	46,970	cu m	21.6	1,014,552	
Turbine/sluice caissons concrete	171,240	cu m	504	86,304,960	
Sluice caissons concrete	38,660	cu m	504	19,484,640	
Ship lock concrete	94,135	cu m	504	47,444,040	
Plain caissons	2	No	3,600,000	7,200,000	
Grout fill under/between caissons	61,563	cu m	144	8,865,072	
Caisson installation	36	month	720,000	25,920,000	
Concrete ballast	0				
Sand ballast	504,921	cu m	17.3	8,725,035	
Concrete placed under water	116,952	cu m	576	67,364,352	
Concrete placed between tides	104,698	cu m	504	52,767,792	441,795,243
EMBANKMENTS					
Rockfill	2,020,000	cu m	14.4	29,088,000	
Sand fill	2,210,000	cu m	8.6	19,094,400	
Armouring - seaward	369,600	cu m	64.8	23,950,080	
Armouring - basin side	201,600	cu m	28.8	5,806,080	
Filter membrane	667,800	sq m	7.2	4,808,160	
Roads	4.06	km	1,800,000	7,308,000	90,054,720
GATES					
Lock gates	3	No.	2,880,000	8,640,000	
Sluice gates	42	No.	1,728,000	72,576,000	
Limpet gates	4	No.	576,000	2,304,000	
Stoplog gates	4	No.	432,000	1,728,000	85,248,000
OTHER CIVIL WORKS					
Road over structures	1.64	km	8,640,000	14,169,600	
Other road/bridge works		Sum	7,200,000	7,200,000	
Powerhouse building + gantries	78,400	cu m	288	22,579,200	43,948,800
					776,246,763
M&E EQUIPMENT					
Turbine-generators	1,050,000	kW	247	259,200,000	
Other M&E equipment	1,050,000	kW	103	108,000,000	
Transmission & control - on barrage	1,050,000	kW	71	74,880,000	
Transmission & control - off barrage	1,050,000	kW	27	28,800,000	470,880,000
Substations					
MANAGEMENT					
Design + supervision of civil works			7.00%	*67,577,002*	54,337,273
Design + supervision of M&E works			4.00%	*27,122,688*	18,835,200
CONTINGENCY ALLOWANCES					
Civil Engineering			15.00%	*100,561,014*	124,587,605
Mechanical & Electrical			10.00%	*47,088,000*	48,971,520
TOTALS				*1,489,475,467*	1,493,858,362

Note: Figures in italics are as PB data. Adjacent figures are recalculated.
Differences are due to sequence of percentage additions.
PB total is £1498.8M

Table 5.1(3) (B):

CARDIFF-WESTON BARRAGE: CONSTRUCTION COST ESTIMATE (Q2 2006)

Description	Quantity	Unit	Rate (£)	Total (£)
Feasibility, environmental studies, planning + parliamentary costs		Sum		313,500,000
Drainage, effluent discharge, port works etc		Sum		181,500,000
Caisson construction yard(s)		Sum		559,000,000
CAISSONS				
Sand dredging for foundations etc	10,800,000	cu m	3.4	)
Rock dredging for foundations:	7,200,000	cu m		)
Dredge only		cu m	35.5	)
Drill + blast		cu m	62.7	627,000,000
Foundations for caissons		Sum		622,000,000
Turbine caissons concrete	2,610,000	cu m	617.0	1,610,370,000
Other costs for turbine caissons		Sum		174,630,000
Sluice caissons concrete	1,301,100	cu m	413.5	538,000,000
Ship lock concrete	328,200	cu m	411.0	134,890,200
Breakwater concrete + rock		Sum		141,109,800
Plain caissons		Sum		446,000,000
Caisson installation		Sum		244,000,000
EMBANKMENTS				
Rockfill for control structure below -2mOD		cu m	52.6	)
Ditto above -2mOD		cu m	35.6	)
Filters below -2mOD		cu m	39.1	)
Ditto above -2mOD		cu m	25.9	)
Protection mounds below -2mOD		cu m	39.1	)
Ditto above -2mOD		cu m	25.9	)
Sand fill		cu m	5.0	)
Rip rap armouring below -2mOD		cu m	54.3	)
Ditto above -2mOD		cu m	43.1	)
Concrete 'dolosse' armour units		sq m	217.1	630,000,000
Roads (excluding public road)		Sum		233,000,000
GATES		Sum		957,000,000
OTHER CIVIL WORKS				
Public road over structures + high level bridge		£M	226.1	Not included
M&E EQUIPMENT				
Turbine-generators	8,640,000	kW	462	3,993,000,000
Transmission & control - on barrage	8,640,000	kW	73	627,000,000
Transmission & reinforcement - off barrage*	8,640,000	kW	162	1,403,000,000
Substations etc.		Sum		107,000,000
Management, engineering + supervision				470,250,000
Contingencies allowance (15% of civil works)				1,054,000,000
TOTAL				15,066,250,000

Note: * Excluding extra cost of underground cables

5.1.5 Comparison of unit costs

There are two key items which require comparison if the costs for the two barrages are to be compared on a like-for-like basis: reinforced concrete and turbine-generators. Each is discussed below:

Reinforced concrete

The cost of supply of concrete represents a small proportion of the 'all-in' unit cost for reinforced concrete. The latter has to include formwork, which may be complex, reinforcement, scaffolding, cranes, minor built-in parts, curing and so forth. PB have used an (updated) unit cost of £504/m^3 for the Shoots structures constructed in the dry, and £576/m^3 for structural concrete placed underwater. STPG's updated rates are £617/m^3 for the turbine caissons and about £412/m^3 for the simpler sluice caissons and the caissons for the ship locks. The average of STPG's turbine and sluice caisson concrete costs is £515/m^3, which is acceptably close to PB's figure of £504/m^3.

Turbine-generators

The updated unit cost of the STPG turbine-generators is shown on Table 5.1(3) as £462/kW including associated control and other equipment. This figure is arrived at using an escalation factor of 1.65 instead of the possibly more relevant PPI figure of 1.73. The PB estimates split this item into the turbine-generators and 'Other M&E equipment', the updated unit costs being £247 and £103/kW respectively, after escalating with a factor of 1.44. Together these total £350/kW. However, the two sets of prices are for different types of turbine-generator. The STPG machine is a single-regulated bulb turbine, with fixed distributor and variable runner blade angle, whereas the PB machine is a single-regulated Straflo turbine with variable distributor and fixed runner blade angle. The former would be capable of reverse pumping, unlike the Straflo machine, and is designed to be pre-assembled in suitable manufacturing works, transported to the barrage and lowered into position as a complete unit including the steel cover to seal the water passage above the turbine. This approach, intended to help reduce the overall construction time by minimising work at the barrage, can be expected to result in some increase in unit cost. On the other hand, the large difference in numbers of machines required would help reduce the STPG costs.

On balance, the PB combined figure seems low, and a unit cost of about £400/kW, instead of £350/kW, would appear to be preferable when comparing the two schemes. This cost is still significantly lower than that for the Severn barrage, and allows for the simpler machine.

The effect of the recommended change to the Shoots unit rates for turbine-generators is to increase the overall estimated cost for the Shoots barrage from £1494M to £1554M including management and contingencies. This is slightly less than PB's upper estimate of £1615M, based on inflation of 2%/year and added contingency allowance of 12.5%.

Other items

Other items for which the unit rates merit comparison include:

- Rock for embankments and for anti-scour foundations. The STPG prices range from £25.9/m^3 to £54.3/m^3. PB's prices range from £14.4/m^3 to £64.8/m^3. The first PB figure appears to be low.
- Dredging in rock for foundations. The STPG prices are £35.5/m^3 and £62.7/m^3 for dredging only and for prior drilling and blasting. The PB single figure is £72/m^3. Since the STPG total quantity of rock dredging is an order of magnitude greater than PB's quantity, these are reasonably close.

5.1.6 Conclusions

The main conclusions from this process of updating and comparing costs are:

The total costs of the Cardiff-Weston barrage and the Shoots barrage are now about £15,000M and £1,500M respectively.

The above totals, relying on the choice of escalation factors and being based on escalation over a 16+ years interval, could easily be inaccurate by 10-15% and both schemes would benefit from a proper present-day resource-based estimate.

The unit costs for concrete and rock dredging used for the two estimates are comparable. The unit cost of turbine-generators for the Shoots barrage appears to be somewhat low, as is the unit cost of rock fill for the embankments. However, the effect on overall cost is not great.

5.2 POWER GENERATION, PEAK OUTPUT AND VARIABILITY

While there is some flexibility in the timing of power output from tidal barrages (Shaw & Watson, 2003)[48], astronomical tide patterns exert a strong influence over the pattern of power generation that can be delivered by barrage systems. Two tidal patterns, semi-diurnal tides and the spring-neap tide cycle, have the greatest effect over power generation magnitude and timing. Other, longer period patterns will also influence tidal patterns and hence power production[49], however, their influence is relatively minor compared to the semi-diurnal and spring-neap tide cycles.

Semi-diurnal tides are the familiar rise and fall of the sea surface, with a full cycle of two high and two low tides occurring every 24 hours and 50 minutes. For ebb-flow barrage operation, this tidal pattern results in the opportunity to generate electricity following each of the two high tides occurring within the 24 hour and 50 minute cycle.

The spring-neap tide cycle is a 29.5 day cycle that affects the tidal range occurring each day, with two peaks in daily tidal range (spring tide conditions) and two minimums in daily tidal range (neap tide conditions) occurring during each cycle. While the spring-neap tide cycle does not affect the timing of semi-diurnal tides, it has a strong influence over the magnitude of the tide range experienced at different times during the spring-neap tide cycle (Figure 5.2(1)).

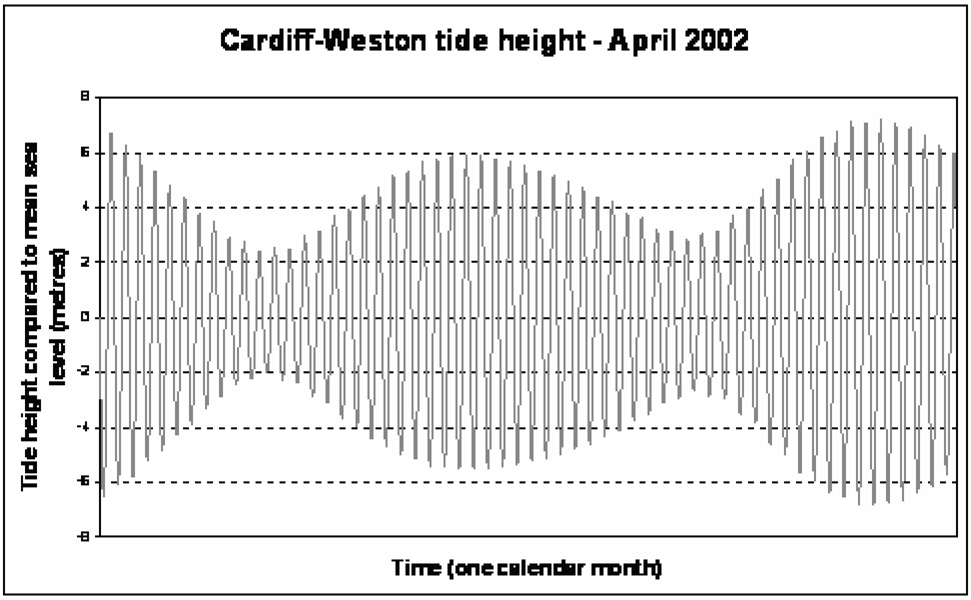


Figure 5.2(1): – Variation in tide height at the Cardiff-Weston barrage location, Severn Estuary.

[48] Shaw, T.L. & Watson, M.J. "Flexible power generation from the tides". Engineering Sustainability, 156, Issue ES2, pp119-123, 2003.

[49] Severn Barrage Committee: *Tidal Power from the Severn Estuary*. EP46, 1981

An ebb-flow barrage design will generate electricity in the period following high tide, with power generation typically commencing between 2.5 and 4 hours after high tide. This delay allows the sea surface height outside the barrage to fall, and when there is a sufficient difference between sea surface height inside and outside the barrage; water commences flowing through the turbines in the barrage to generate electricity. Two examples of power production arising from ebb-generation are shown in Figure 5.2(2).

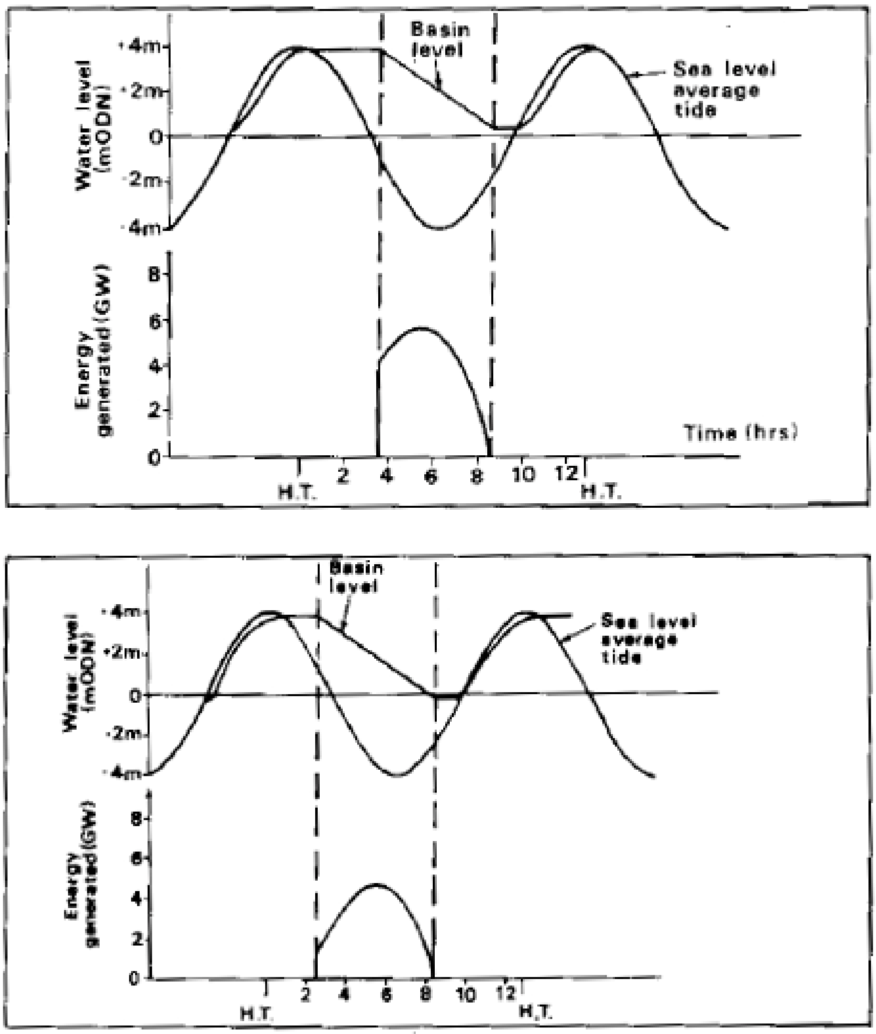


Figure 5.2(2): – Power output pattern of the Cardiff-Weston barrage under normal (top) and earlier (bottom) generation start time in relation to the tide cycle. Source: HMSO (1981b)[50]

[50] Severn Barrage Committee: *Tidal Power from the Severn Estuary*. EP46, 1981 Volume II "Analysis, reports, studies and evaluations"

5.2.1 Relationship between electricity demand and barrage production*

With electricity demand patterns operating on a 24 hour basis, the longer semi-diurnal tidal cycle results in periods of electricity production from a barrage advancing approximately 50 minutes in each successive day in relation to electricity demand. Over a seven day period, the period of generation will advance by approximately 6 hours; over this same seven day period, daily energy production can significantly alter due to the spring-neap tide cycle. The result is a complex relationship between tidal power and electricity demand. The example in Figure 5.2(3) shows significant electricity generation from the barrage in the first week, with generation contributing mostly during the middle of the day and overnight, and with very little impact on peak electricity demand. By the second week, the timing of generation has advanced such that barrage-generated electricity is being delivered during peak demand periods. However, while the timing of production is better at targeting peak demand, the influence of lower daily tidal ranges due to neap tides limits total energy production during each tidal cycle. Alteration to the timing of generation of the barrage (not shown in Figure 5.2(3)) may allow peak electricity demand to be better targeted, but it would not alter the spring-neap cycle of varying energy availability over the two-week period.

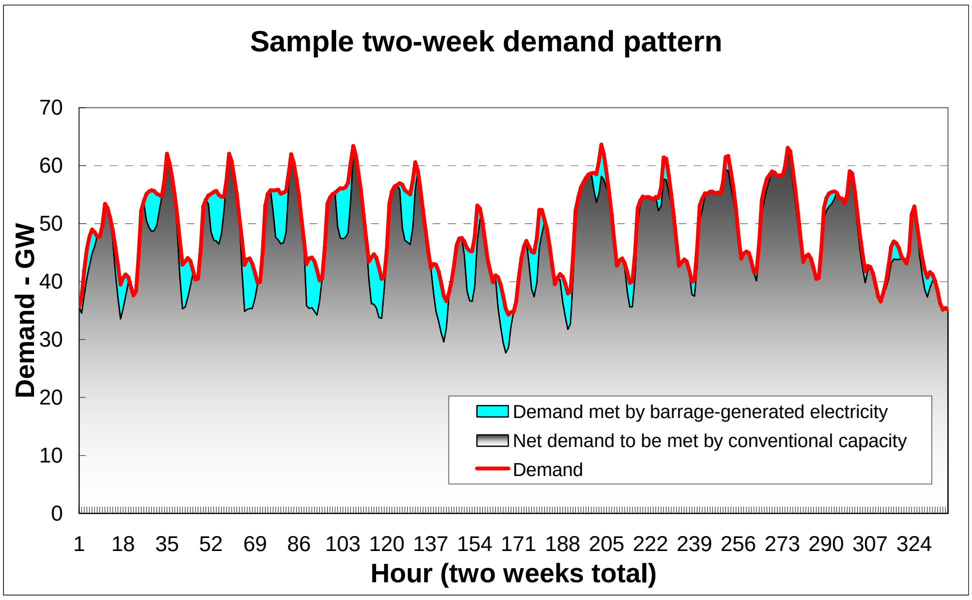


Figure 5.2(3): – Sample electricity demand and contribution from the Cardiff-Weston Barrage over a two-week period during winter 2002.

During spring tide conditions at the Cardiff-Weston barrage, high tides tend to occur around 8am and 8pm, with high tides during neap conditions tending to occur at around 3am and 3pm (Figure 5.2(4)). A very similar pattern of high tide timing is apparent at the Shoots barrage; however, the timing of high tides generally lags that of the Cardiff-Weston barrage by around one hour.

* The results presented in this section are for a UK electricity network with a peak demand of 70GW, and an annual energy demand of around 400TWh. Barrage output data is based on the six-month period of January to June 2002.

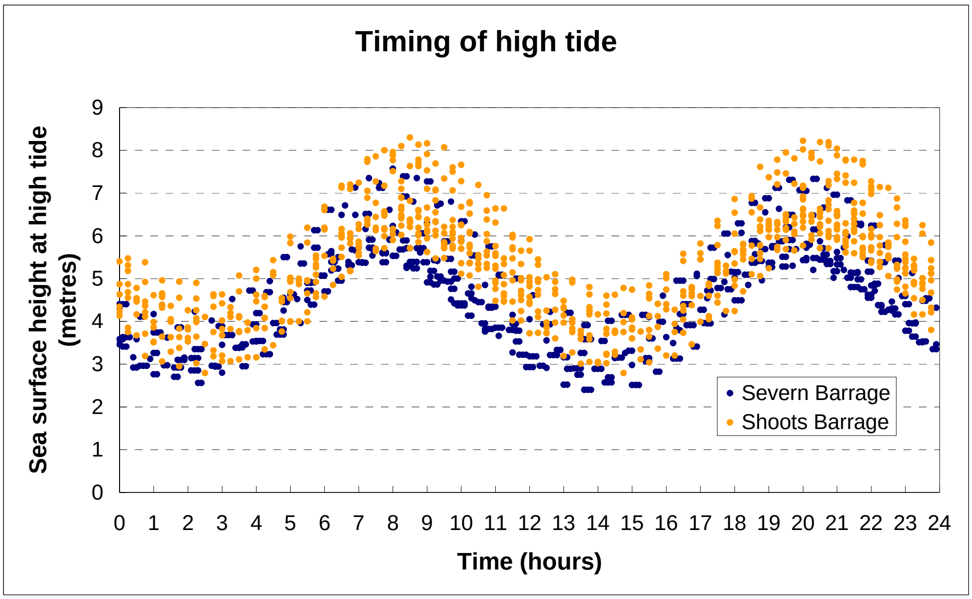


Figure 5.2(4): – Timing of high tide for the Cardiff-Weston barrage and Shoots barrage, January to July 2002.

This timing of high tides has implications for the relationship between electricity generation by barrage schemes and electricity demand patterns. With power production commencing between two and four hours after high tide, periods of high power output from the Cardiff-Weston barrage would tend to coincide with elevated demand during the day (around 10am to 4pm) and again during low demand hours (10pm to 4am). The timing of spring tide power production at the Shoots barrage would be similar, with high generation periods tending to occur between 11am and 5pm, and again between 11pm and 5am. However, the out-of-phase relationship between tides (operating on a 24 hour and 50 minute cycle) and electricity demand (operating on a 24 hour cycle) means that, over the long term, the timing of electricity generation from both the Cardiff-Weston and Shoots barrages will change in relation to electricity demand. This changing relationship in the timing of generation is accompanied by changes tidal range (from spring tide conditions to neap tide conditions), and therefore the magnitude of generation.

On average, greater electricity production will occur in the early afternoon (centred around 1pm to 3pm) and in the very early hours of the morning (centred around 1am to 3am), with minimum production occurring at around 7pm to 9pm in the evening, and again between around 7am and 9am in the morning (Figure 5.2(5)).

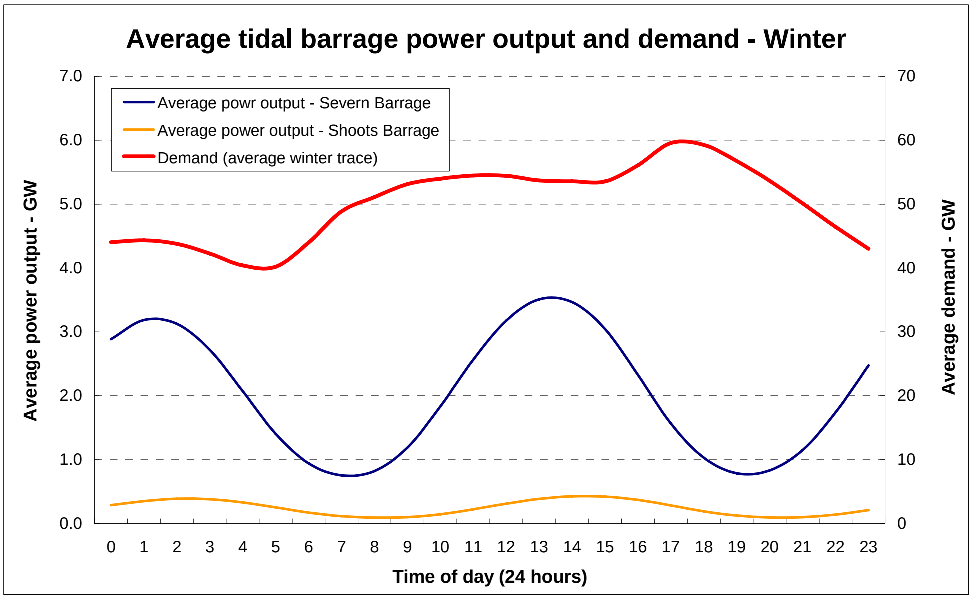


Figure 5.2(5): Average hourly power output from the Cardiff-Weston and Shoots barrages over 24 hours. Average hourly electricity demand is shown for comparison. Data is from January and February 2002.

Given the distribution of power output in Figure 5.2(5), it is apparent that barrage schemes would deliver at less than their long-term average power output during periods of peak electricity demand. Average power output during the peak electricity demand period (5pm to 7pm) would be around 37% of the maximum hourly average for the Cardiff-Weston barrage, and around 55% of the maximum hourly average for the Shoots barrage. The higher average contribution of the Shoots barrage to peak electricity demand, results from high tide at the Shoots barrage occurring around one hour later than at the Cardiff-Weston barrage, and therefore one hour closer to the peak demand period.

The relationship between energy production and demand presented in Figure 5.2(5) is highly averaged. Actual barrage generation across a single 24 hour time period would not be smooth, but would show a sequence of periods of generation and periods of no generation. Examples of actual generation over a 24 hour period during spring and neap tide conditions are shown in Figures 5.2(6) and 5.2(8) for the Cardiff-Weston barrage, and Figures 5.2(7) and 5.2(9) for the Shoots barrage. The timing of generation is essentially inverted between spring and neap conditions, with maximum generation occurring during the day and overnight in spring tide conditions (Figure 5.2(6) and 5.2(7)), while it occurs during morning and evening during neap tide conditions (Figure 5.2(8) and 5.2(9)).

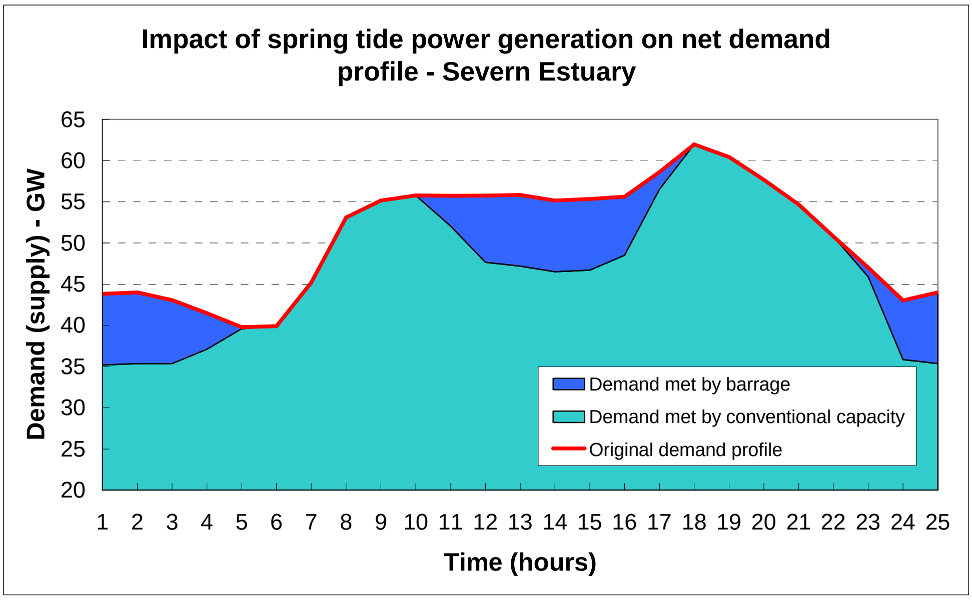


Figure 5.2(6): Example of Cardiff-Weston barrage power production and its relationship to electricity demand, during spring tides

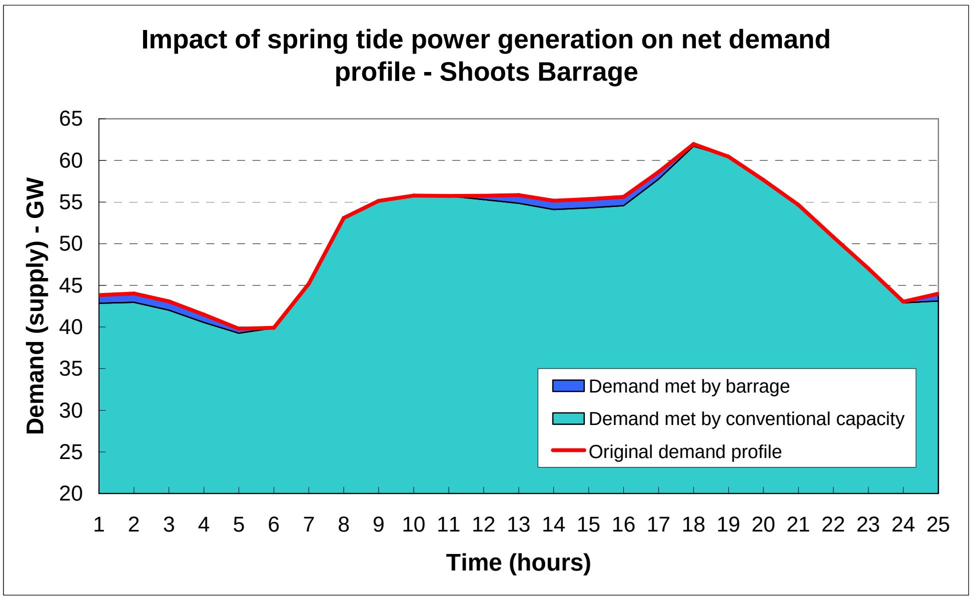


Figure 5.2(7): Example of Shoots barrage power production and its relationship to electricity demand, during spring tides

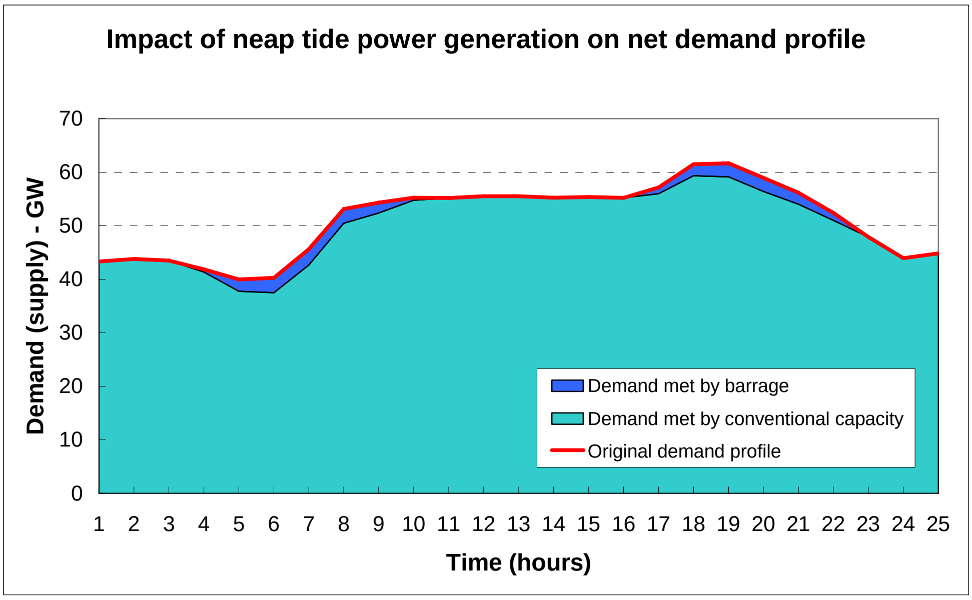


Figure 5.2(8): Example of Cardiff-Weston barrage power production and its relationship to electricity demand, during neap tides

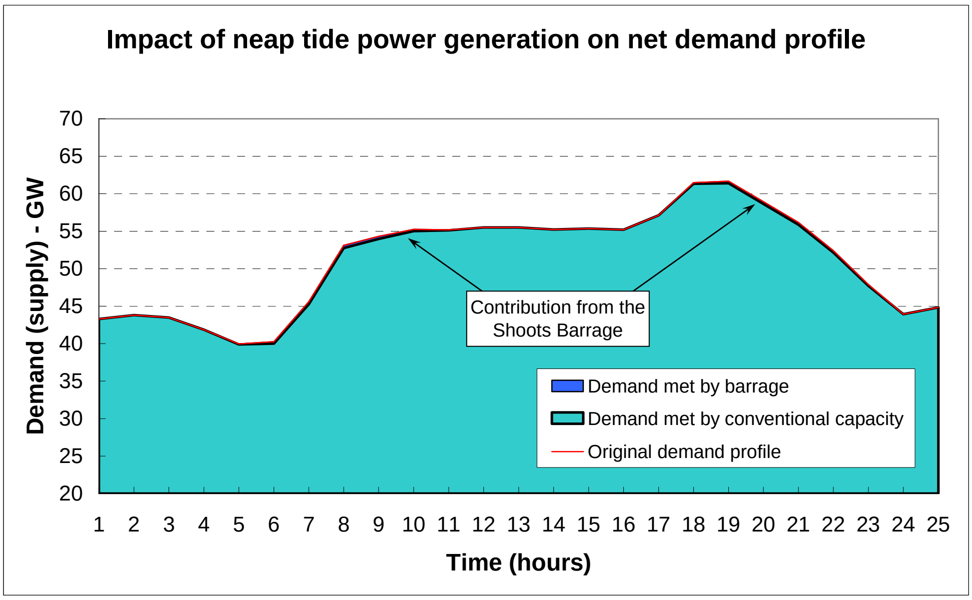


Figure 5.2(9): Example of Shoots barrage power production and its relationship to electricity demand, during neap tides

5.2.2 Power production and variability

The depiction of power output from the Cardiff-Weston and Shoots barrages shown in the previous section demonstrates that electricity generation from either the barrage would not be continuous, with significant periods of non-generation during the flood tide. The power output duration curve (Figure 5.2(10)) for the Cardiff-Weston barrage shows that some level of electricity generation would be expected for 40-45% of hours, with the barrage generating no electricity at other times. During electricity generation hours, power output will vary from 0% to 100% of the rated output of the barrage. Overall, the barrage would have a capacity factor of approximately 22.5%.

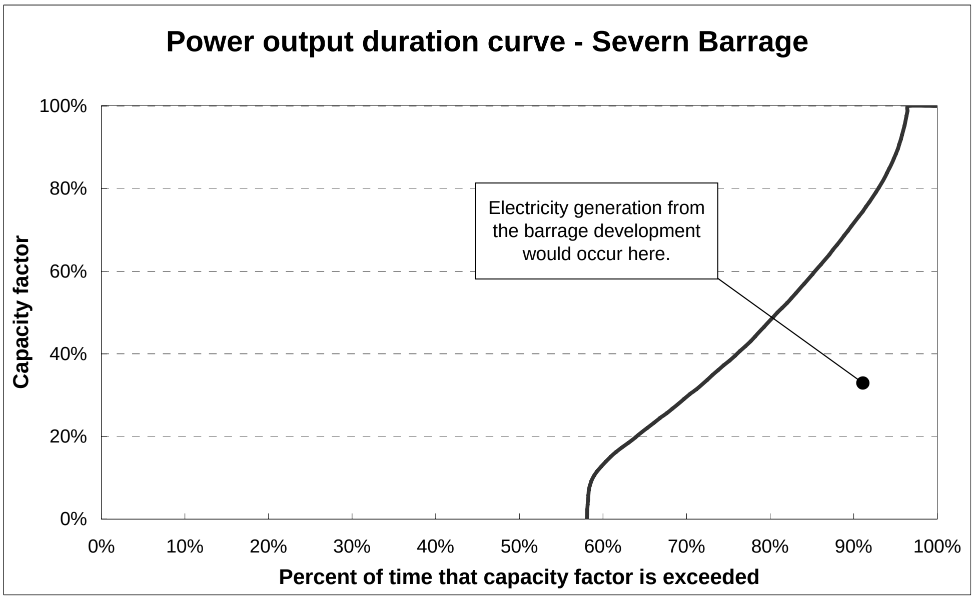


Figure 5.2(10): Power output curve showing the percent of time a given capacity factor is exceeded.

With barrage electricity generation tending to be lower during peak demand periods and higher during low demand periods (on average), the impact that the Cardiff-Weston barrage would have on the existing demand duration curve is more apparent at lower rather than higher demand levels (Figure 5.2(11)). During the one year of tidal power modelled for Figure 5.2(11), the impact of the barrage was found to be greatest during lower demand hours; the barrage would result in the minimum electricity demand met by conventional capacity dropping from 25GW to 19GW, a reduction of 6GW: by comparison, peak electricity demand would drop from 70GW to 68GW (a reduction of 2GW). This relationship will vary from year to year due to changes in demand patterns and changes in the temporal availability of the tidal resource.

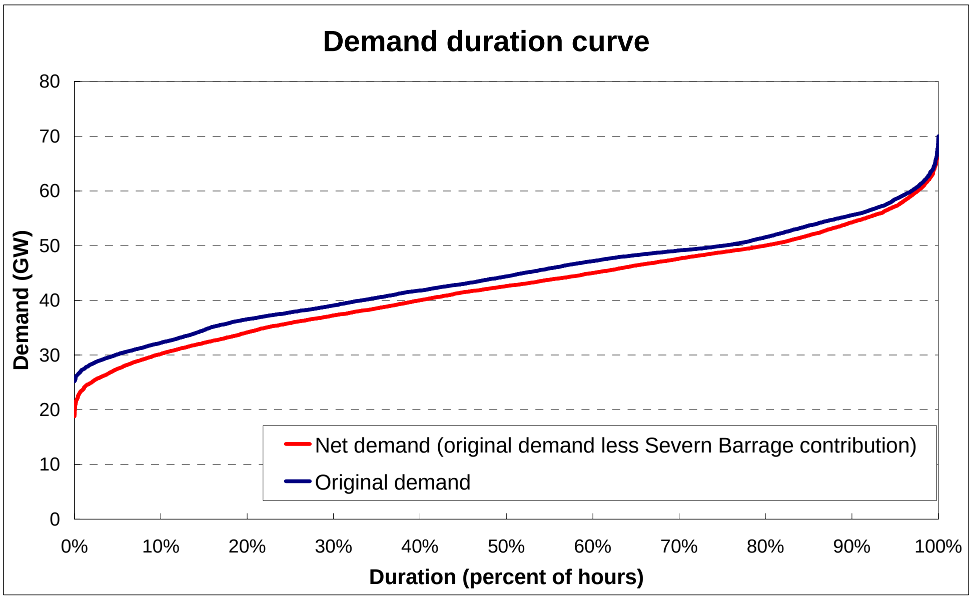


Figure 5.2(11): Load duration curve, showing the impact of barrage power generation on the load duration curve.

Tidal barrage projects on the Severn estuary would provide a variable, but highly predictable, electricity supply to the grid. Due to the out-of-phase relationship between patterns of power availability and patterns of electricity demand, normal operation would result in periods of both smoothing of existing demand patterns (for example, where barrage power generation increases as demand increases) and exacerbating existing demand rates of change (for example, where barrage power production increases as demand is falling). Flexible operation of the barrage, such as advancing or delaying the onset of power generation, could be used to lessen the impact of barrage variability on the network. This mode of operation would typically result in decreased energy production from the barrage, so the decision to modify the production profile of the barrage would ultimately be an economic one, where higher value (or reduced costs) outweigh revenue foregone through lower energy production. Overall, a barrage would result in the need for increased load following capability from other generators, as it would increase the variability of the demand pattern to be followed by conventional generators. This increased load following capability could be provided from existing conventional capacity reserves without the need for additional conventional capacity to be built – at the same time, a small reduction in total conventional generating capacity would be expected in response to the operation of the Cardiff-Weston barrage.

The impact of the normal pattern of power production on the magnitude and frequency of hourly rates of demand change to be met by conventional generation is shown in Figure 5.2(12). The impact of the electricity supply from the barrage being incorporated into the electricity network is to reduce the number of hours that experience small changes in demand, cause a small increase in hours that experience a moderate level of demand change, and increase the extreme hour-to-hour fluctuations in demand that would need to be accommodated by conventional capacity (particularly the incidence of high increases in demand).

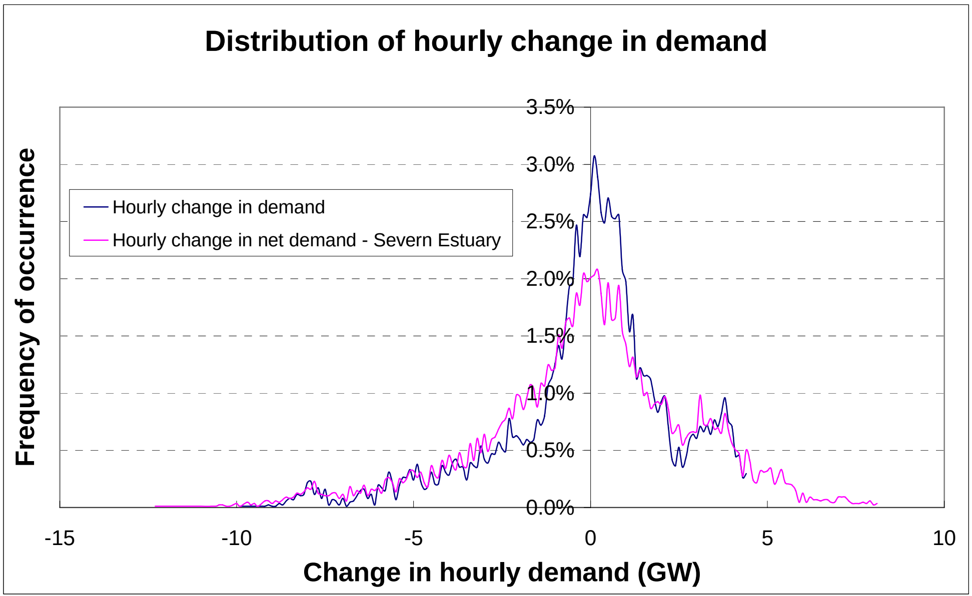


Figure 5.2(12): – Comparison of hourly change in demand and net demand.

At the barrage, change in power output is dictated by changes in head height and operational decisions. For the normal operation of the barrage, change in output was considered on a six minute basis (Figure 5.2(13)). Seventy-two percent of all six-minute periods showed no change from one to the next, while change between successive six-minute periods was equal to 5% or less of installed capacity 98% of the time. There are a small number of periods when very large changes in output were modelled to occur, however in practice these would not occur. For example, commencement of operation of the barrage would be on a staged basis, thus even in conditions where rated output could be achieved from the commencement of operation it is highly likely that power output would increase over a half or one-hour period. This mode of operation would limit increases in power production at the six-minute level to around 11-22% of installed capacity, and a similar ramping down procedure would limit decreases in power output to a similar magnitude.

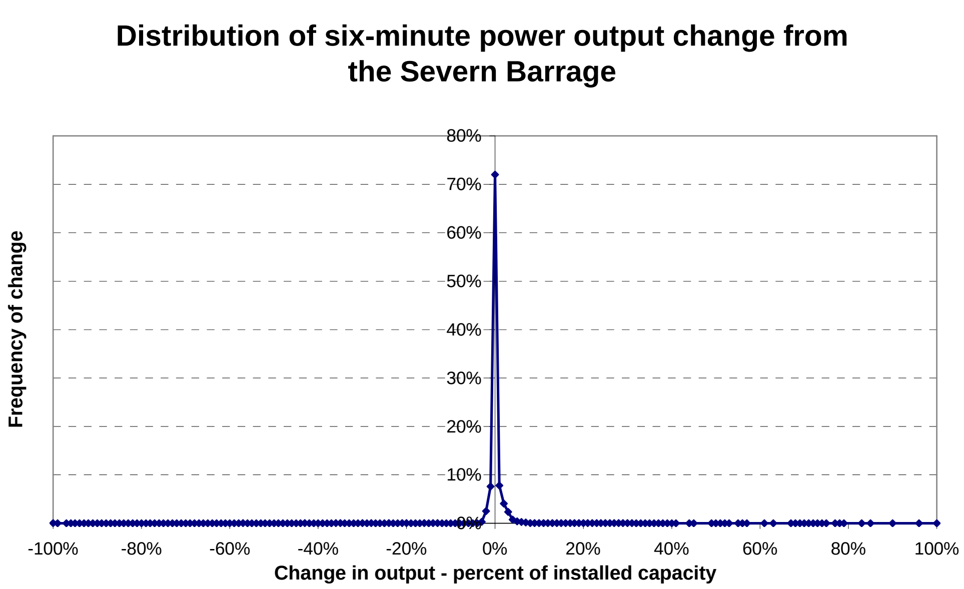


Figure 5.2(13): Change in barrage power output at six-minute resolution

5.3 GRID CONNECTION AND STRENGTHENING

5.3.1 Electrical network overview

The GB electricity network comprises electrical circuits, switchgear and transforming stations, operating at voltages from 400,000 volts (400kV) down to 230 volts, the latter for domestic use. The circuits for connection of a Severn barrage generation project are likely to be operated at the higher transmission voltages of 400kV and 275kV due to their projected capacities and connections desired and hence distribution connections (132kV and below) have been ignored.

The GB electricity network is operated and maintained by several interconnecting parties, National Grid Electricity Transmission (NGET) which operates the transmission network from 400kV to 275kV in England (400kV to 132kV in Scotland) and 14 Distribution Network Operators (DNO's) who are responsible for the operation of their systems from 132kV and below in England and from voltages less than 132kV in Scotland.

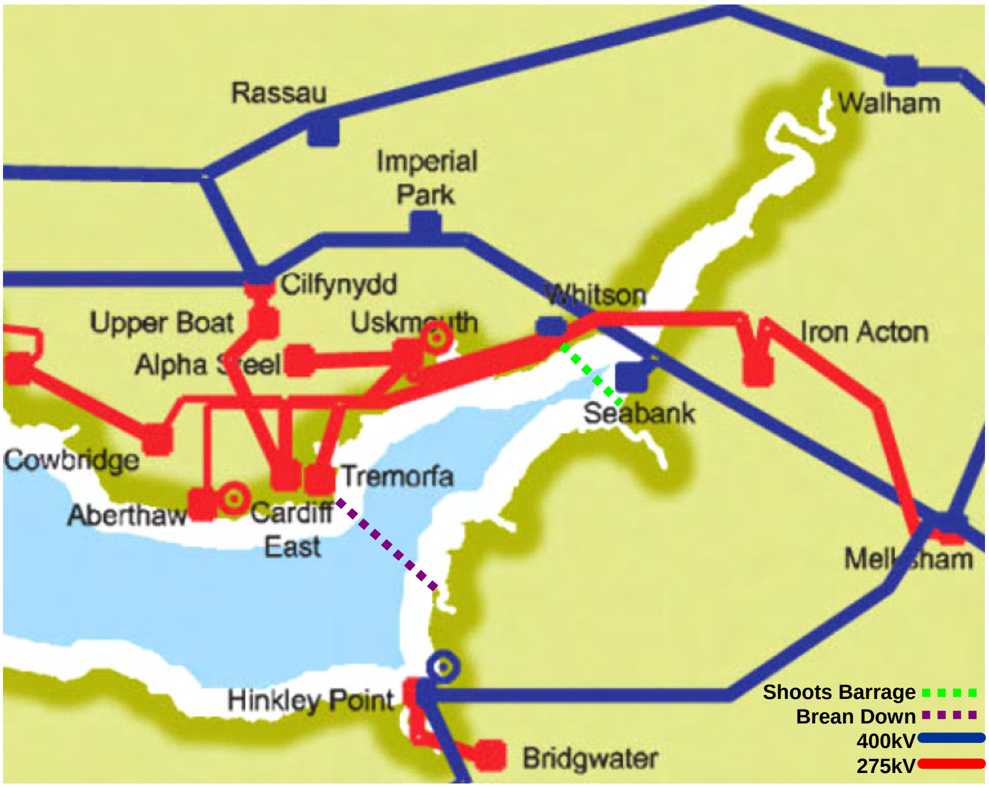


Figure 5.3(1): NGET Network near proposed sites

The transmission network relevant to the proposed Severn barrage generation scheme consists of 400kV and 275kV infrastructure (See Figure 5.3(1)) owned and operated by NGET with the closest sections of network to the land fall points proposed in the following locations:-

Shoots scheme 1050MW proposal:-

North Shore: With the landing point near the end of the M4 motorway the closest section of network is approximately 1km away and consists of the 275kV circuit from Whitson to Iron Acton, additionally the Whitson 400/275kV substation is approximately 10km to the west.

South Shore: With the landing point at English Stones the closest section of network is approximately 5km to the north east and consists of a the 400kV substation at Seabank.

Cardiff-Weston scheme 8640MW proposal:-

North Shore: With a landing point at Lavender Point the closest section of network is approximately 10km away and consists of the 275kV network at Tremorfa and Cardiff West Substations.

South Shore: With a landing point at Brean Down the closest section of network is approximately 20km south and consists of a 400kV double circuit from Hinkley Point to Melksham. There is also some 132kV and 33kV infrastructure close to the south; however, this is seen as insufficiently rated to take even 1% of the proposed capacity.

Based upon this data the approximate capacity available for the connection of the two proposed generation projects at and around these locations was investigated.

5.3.2 Connection capacity overview

NGET already perform network capacity studies as part of their annual Seven Year Statement (SYS) works in order to define the level of capacity that may be available within each of their 17 capacity study zones. This broad brush approach does highlight areas where capacity may be available for generation and in relation to the Severn barrage scheme the areas of concern lie within Capacity Zones 17 and 13 (See Figure 5.3(2)). These areas are defined as having up to 3.5GW of connection capacity available in total in the current SYS.

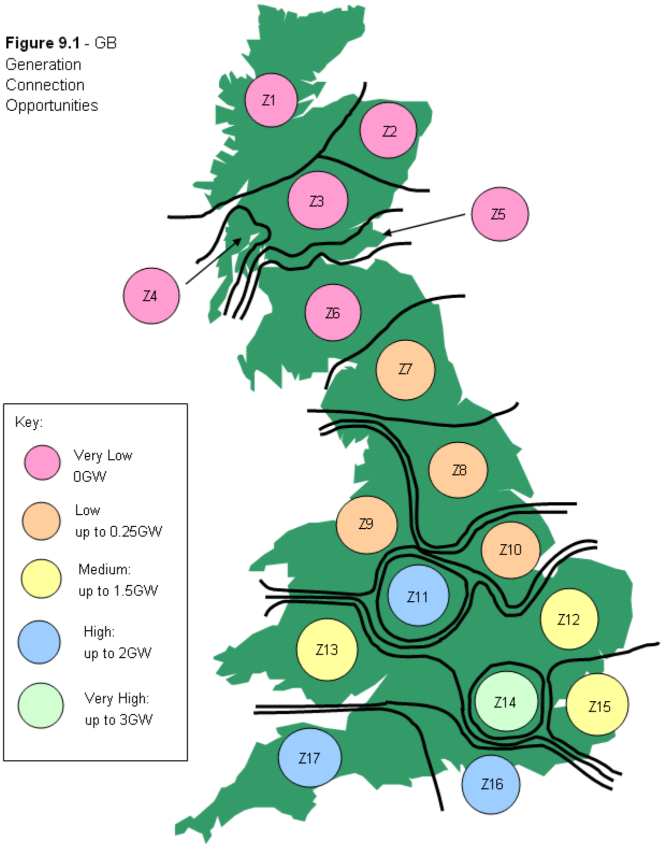


Figure 5.3(2): NGET Capacity Study Zones

A key factor to consider when using the SYS is that the data used to compile these studies is gathered before a specific 'Data Freeze' date in December, well before the issue date for the SYS in May the next year. Therefore, even at the time of publishing, these studies do not reflect upgrades or generation connections that have been implemented / accepted after the data freeze date. Quarterly updates are provided subsequent to the issue of the SYS to give a brief summary of the key changes since the main statement was produced and these have been used to compile a more accurate picture of the current network and proposed generation background. This work was performed for the Severn barrage scheme to give a review of the areas in general before specific connections are suggested.

In order to update the existing capacity zone data, new information and quarterly update data was used along with specific study assumptions which were made as to how generation would connect to the network and as to the assumed generation backgrounds in the area. All of this was done to produce a picture of the network post 2010 when the Severn barrage scheme would be looking to connect at the earliest.

Study assumptions

In order to review the capacity zones, specific assumptions regarding how generation could be connected to the network were required. These assumptions are outlined as follows:-

- System power flows can be altered to utilise the maximum available summer circuit carrying capacity of a transmission line

- Sufficient voltage reinforcement can be provided to maintain the system voltage to within statutory limits
- System stability will not be affected when transferring maximum power across the zone boundaries
- The worst case double circuit (N-2) outage is assumed to be the limiting factor, in accordance with NGET's security standard and will affect the highest rated conductors on the boundary of a capacity zone as a worst case.

Additional to this, when connections are considered in more detail, they must be assessed with reference to the GB Security and Quality of Supply Standards (SQSS). The GB SQSS is a set of criteria and methodologies that the GB transmission licensee (NGET) must use in the planning and operation of the GB transmission system. These criteria and methodologies determine the need for services provided to the GB transmission licensee, e.g. reactive power, as well as transmission equipment.

In relation to this Severn barrage development, two factors will affect the connection of generation and in what manner it may be connected, 'Normal infeed loss risk' and 'Infrequent infeed loss risk'. These are defined as follows:-

<u>Normal Infeed Loss Risk</u>**:** This is the level of risk of the loss of power which is covered over for the loss of a single transmission circuit or busbar. This is set at 1000MW and is to avoid a frequency deviation of greater than 0.5Hz in the long term due to a permanent outage such as a cable failure. In reference to the Severn Barrage this would mean that no more than 1000MW could be connected on a single generation circuit.

<u>Infrequent Infeed Loss Risk:</u> This is the level of risk of the loss of power which is covered over the loss of up to two circuits, both on the same double circuit line, in normal operation or the loss of one circuit at the same time as a planned outage within the transmission system. This is set at 1320MW and is to avoid a frequency deviation of greater than ±0.5Hz for more than 60 seconds. In reference to the Severn Barrage this would mean that generation above 1320MW would need to be connected by at least 3 transmission circuits to account for an N-2 event.

Assumed background

The alterations to the generation background coming from the quarterly update information and additional public domain sources mean that the following modifications were made to the existing SYS background for the period post 2010:

Capacity Zone 13

- System alteration:

  The 400kV network in the area of Pembroke is to be re-configured with all four 400kV circuits from Pembroke turned in to Swansea north 400kV substation before continuing to either (circuits 1-3) Cilfynydd and (circuit 4) Walham.

- Generation Connected:

  Pembroke CCGT generation stages 1 and 2 totalling 4GW will be connected at Pembroke

  Uskmouth CCGT generation will be connected totalling 1.21GW of generation connected at Uskmouth

- Generation Disconnected:

  Great Gabbard 500MW wind farm was shown in the SYS to be connecting in Zone 13 as oppose to Zone 12 where it is actually contracted to connect.

Capacity Zone 17

- System Alterations:

  None

- Generation Connected:

  Langage stage 1 and 2 CCGT generation will be connected totalling 1250MW of generation

- Generation Disconnected:

  Hinkley Point B Nuclear AGR generation will be disconnected for decommissioning

5.3.3 Transmission charging

The underlying rationale behind Transmission Network Use of System (TNUoS) charges is that "*efficient economic signals are provided to users when services are priced to reflect the incremental costs of supplying them*". This means that charges should reflect the impact that users of the transmission network at different locations would have on NGET's costs if they were to increase or decrease their use of the transmission network. These costs are primarily defined as the investment costs in the transmission network, the maintenance costs of the transmission network, and the cost of operating a system capable of providing a secure bulk supply of energy.

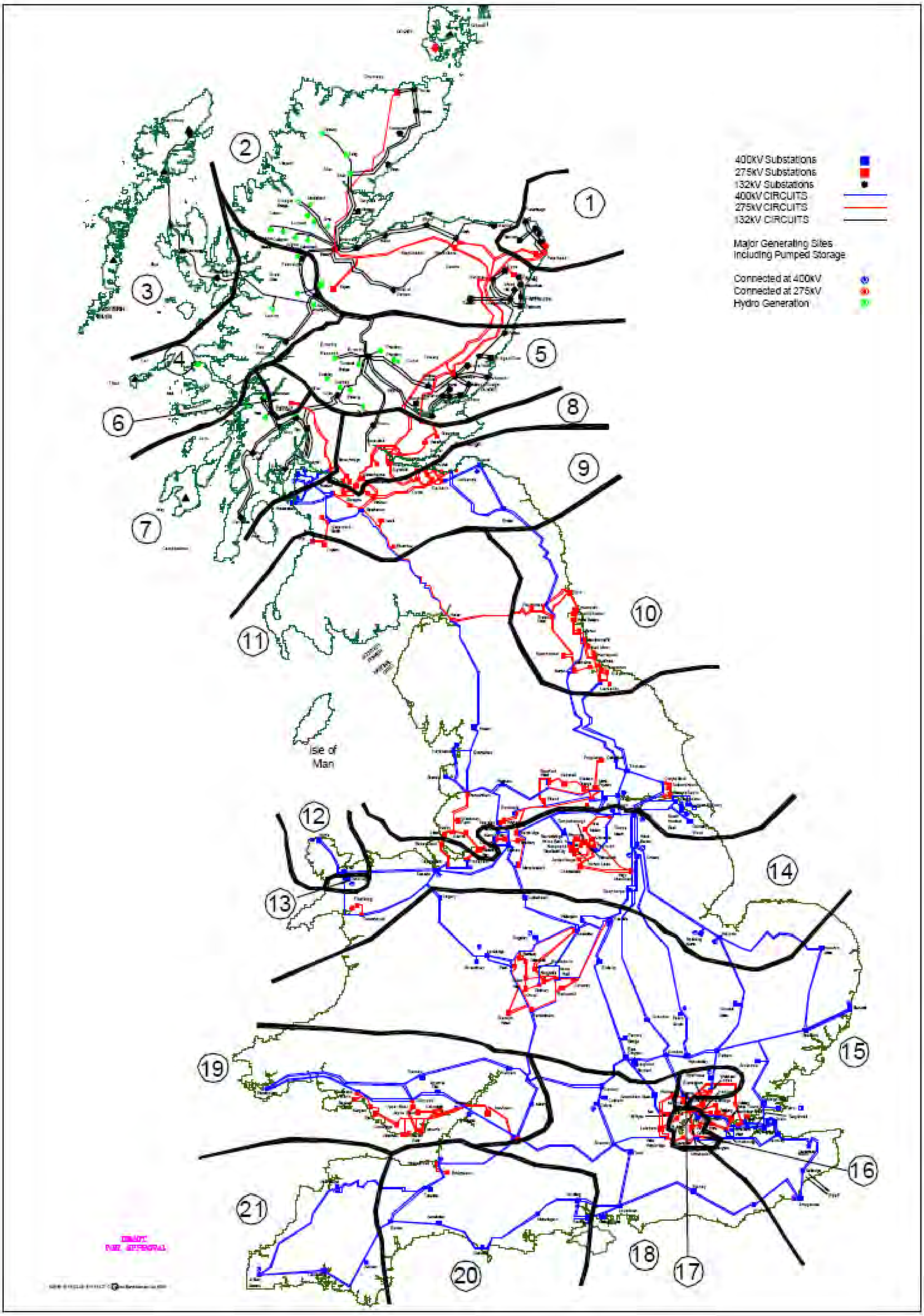


Figure 5.3(3): 2005/06 TNUoS Zones

The boundaries of the TNUoS charging zones (see Figure 5.3.(3)) are reviewed at the start of every five yearly price control period in order to provide stability for the market, while the TNUoS charges within the zones are recalculated every year (see Table 5.3.(1)).

Table 5.3(1): Zonal TNUoS Charges 2005/06

Generation Charging Zone	Zone Name	GB Zonal Tariff (pound/kW)
1	Peterhead	18.393741
2	North Scotland	20.519472
3	Skye	13.297995
4	Western Highland	18.621394
5	Central Highlands	15.412503
6	Cruachan	13.521386
7	Argyll	13.521386
8	Stirlingshire	13.06524
9	South Scotland	12.140893
10	North East England	8.885489
11	Humber Lancashire & SW Scotland	5.61385
12	Anglesey	6.28357
13	Dinorwig	8.938682
14	South Yorks & North Wales	3.835629
15	Midlands & South East	1.219345
16	Central London	-5.495111
17	North London	0.362093
18	Oxon & South Coast	-0.513619
19	South Wales & Gloucester	-2.736627
20	Wessex	-5.065004
21	Peninsula	-9.145693

The factors which affect the level of TNUoS charges from year to year include the forecast level of peak demand on the system, the Transmission Price Control formula (including the effect of any under/over recovery from the previous year), the costs of transmission lines and cables, changes in the transmission network and changes in the pattern of generation capacity and demand, (i.e. the number of new connections at a particular node). Hence where the amount of generation at a particular node is high and the network emanating from that node is relatively weak, the TNUoS charges will also be high. Charging Zone 13 in north Wales around the Dinorwig node demonstrates this effect with a relatively high tariff. If we compare this to the zones in question for the Severn barrage scheme (Charging Zones 19 and 20) which currently benefit from a negative TNUoS charging tariff where NGET pays the generator for using the transmission network to serve the relatively high load in the south more locally. This may be of benefit to the Severn Barrage project as it will effectively increase the return on generated KW's However, given that the Severn barrage scheme could potentially reverse the net power flows in the capacity zones considered the projected rebate figures may be reduced from those shown in Table 5.3(1) above in order to signal that the zone is reaching its capacity. This will be an important factor for consideration when assessing the level of revenue generated by a barrage.

5.3.4 Connection capacity review

Based upon the assumptions made and the background data used a high level rework of the SYS capacity zones 13 and 17 was made. This states the maximum capacity available within the entire capacity zone should all of the boundary export capacity be used although it does not account for interaction between zones.

Capacity Zone 13

Capacity zone 13 is, in the current NGET SYS a net exporter of power, and this is due to the increased level of generation development in the area in the form of Pembroke CCGT and Uskmouth CCGT generators all connecting into this zone from 2006 onwards. This means that, whilst there is still some capacity for connection in this zone, a portion of the export capacity is already utilised. This may not prevent the connection of further capacity, although it may necessitate reinforcements in the wider transmission system to accommodate the generation.

Table 5.3(2): Capacity zone 13 results

Capacity Zone 13			
	2010/11	**2011/12**	**2012/13**
Existing Effective Generation	9467	10795	10795
Existing Demand	5647	5761	5829
Existing Planned Transfer	3820	5034	4966
Updated Effective Generation	8481	9811	9727
Updated Demand	5647	5761	5829
Updated Planned Transfer	2851	4085	3923
Zone Capacity under N-2 Summer Rating	9140	9140	9140
Zone Export Capacity under N-2 Summer Rating	**6289**	**5055**	**5217**
Note: Negative figures denote import to the zone whilst positive figures denote export from the zone All figures in MW			

Capacity Zone 17

Capacity zone 17 is currently a net importer of power, as can be seen from the existing SYS data and it is set to remain this way to the extent of the current SYS in 2012/13 with a planned transfer of approximately 1GW into the zone to serve existing load. Additionally, due to current problems with the Hinkley point B nuclear plant, and according to British Energy[51], this nuclear facility is due for decommissioning in 2011. This was not accounted for in the current SYS or quarterly updates and therefore this leaves Capacity Zone 17 with an even larger net import of approximately 2GW of power.

If more than 2GW were to be connected it would change the zone to a net exporter, whilst this may not prevent the connection of capacity in excess of 2GW it may necessitate reinforcements in the wider transmission system and would also reduce the level of negative TNUoS charges that are currently seen in this area.

[51] British Energy http://www.british-energy.com

Table 5.3(3): Capacity zone 17 results

Capacity Zone 17			
	2010/11	**2011/12**	**2012/13**
Existing Effective Generation	2000	1937	1994
Existing Demand	3117	3152	3186
Existing Planned Transfer	-1113	-1208	-1192
Updated Effective Generation	2200	1154	1154
Updated Demand	3117	3152	3186
Updated Planned Transfer	-917	-1998	-2032
Zone Capacity under N-2 Summer Rating	3500	3500	3500
Zone Export Capacity under N-2 Summer Rating	**4417**	**5498**	**5532**

Note: Negative figures denote import to the zone whilst positive figures denote export from the zone
All figures in MW

Connection capacity review conclusions

Capacity Zone 13 is already an exporting zone, and an increase in the export from this zone by the connection of additional generation over and above the national grid stated figure of 1.5GW may have knock on effects in other areas of the transmission network and force reinforcements on a large scale. Therefore, whilst there is notionally the potential to connect a further 5GW of generation to utilize all export capacity from the zone there is unlikely to be a single connection location with potential for a connection of this level.

Capacity Zone 17 is contrast in an importing zone and therefore a preference for the smaller generation schemes around 1GW as this would simply service existing load within the zone. In addition, the possibility that Hinkley B nuclear facility may be decommissioned in 2011 could free up additional connection capacity. However, another impact of the connection generation into Zone 17 would be that, due to the reduction in demand or reversal of net power flows to exporting, the TNUOS charging structure for the area (Charging Zone 20) may be altered so that the current effective TNUOS rebate (in the form of a negative TNUOS charge of £5.065/kW) would either be reduced or reversed. This may affect the overall economics of the project, however, it would not be possible at this stage to accurately define the change in charge as this would be dependent upon the generation background at the time of connection.

5.3.5 High Level connection proposals

Given the results of the Capacity Zone review, specific connection locations were investigated at a high level to ascertain indicative connection capacities for the existing network based upon circuit ratings and the adapted SYS power flows. On both the north and south of the Severn Estuary only the 400kV system appears to have sufficient capacity to accommodate the proposed levels of generation as the 275kV network near the landing point for the Cardiff-Weston proposal is currently close to existing rated levels and the 132kV network on the south of the estuary would not be capable of accommodating even 5% of the Cardiff-Weston proposed generation.

Therefore 400kV connections on both the north and south of the bay were identified proximate to the landing points of both of the proposed barrages and are stated below:-

- Connection to Whitson/Imperial Park - Melksham 400kV double circuit
- Connection to Seabank / Cilfynydd - Melksham 400kV double circuit
- Connection to Hinkley Point – Melksham 400kV double circuit

- Connection to Cilfynydd – Whitson Tee / Imperial Park 400kV double circuit

These connections are based upon the existing and planned network up to 2010 and therefore do not include ?transmission system reinforcements. Further detailed study would be required to ascertain if deeper transmission system reinforcements are required.

All of these proposed connections have circuit ratings in the order of 1000-2000MVA each. This means that, even neglecting existing power flows, a 400kV double circuit connection would only have capacity for less than half of the Cardiff-Weston project capacity. Therefore in order to enable connection of close to the maximum capacity of the Cardiff-Weston project it is likely that two connections to the 400kV network will be required on the north and south of the estuary. With reference to the SQSS this would therefore require at least two sets of two circuits from the barrage, one set to the north of the estuary and one set to the south, both connecting into a 400kV double circuit. If a capacity close to the proposed maximum were to be connected, the connection would need to be made via a more complicated mesh transmission substation, in order to mitigate the infrequent infeed loss risk, rather than a tee connection. A high level representation of this connection is shown in figure 5.3(4) below

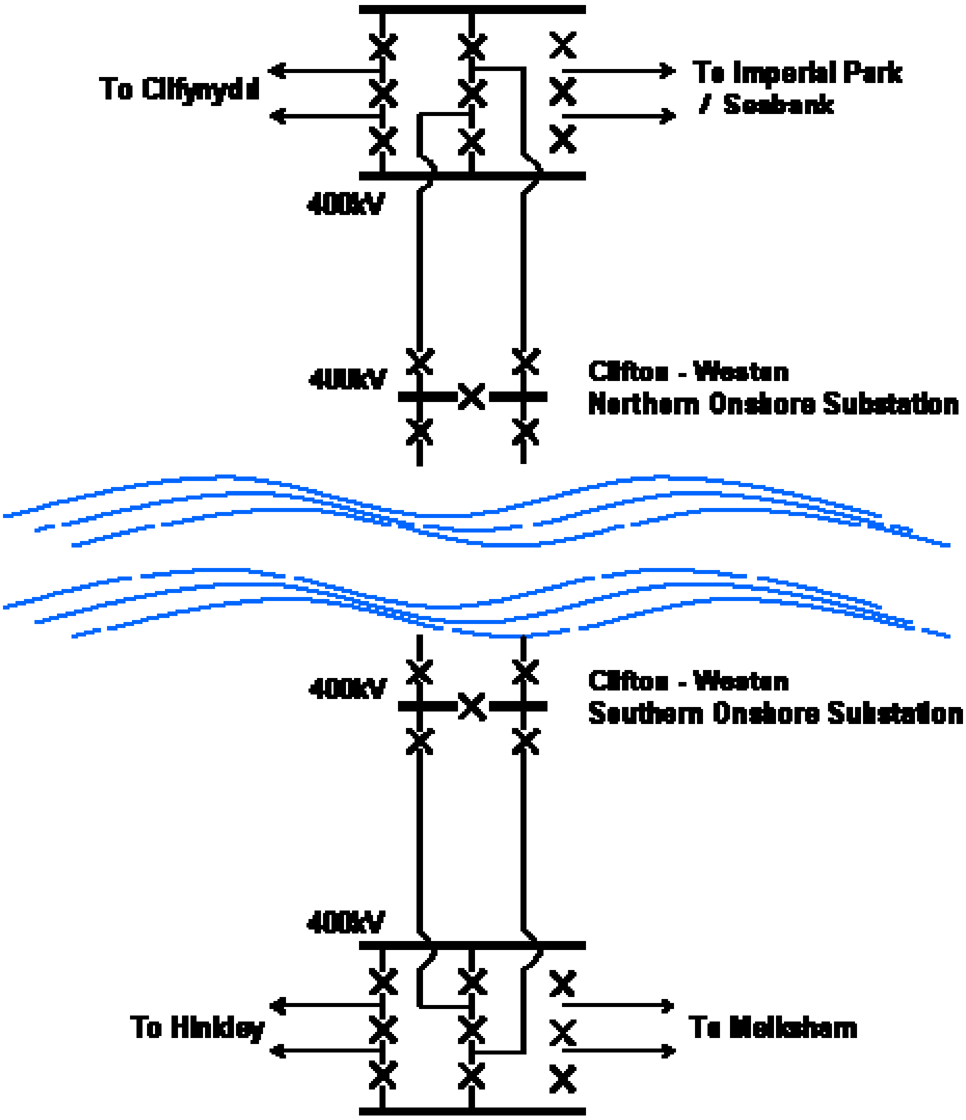


Figure 5.3(4): Indicative Connection for Cardiff Weston Barrage

For the Shoots scheme, all of the proposed connection options seem to have adequate capacity to accommodate the proposed level of generation in one connection. Of the connections shown, a connection into the Hinkley Point – Melksham 400kV double circuit may be most preferable due to the Capacity Zones existing high demand along with the potential to replace the connection capacity currently held by Hinkley Point B if it were to be decommissioned in 2011. With reference to the SQSS this connection could be enabled by looping into a double circuit and, splitting the generation between the two circuits, with two 400kV cables from the connection point to the Barrage. As the Shoots barrage only has a proposed capacity of 1050MW a connection can be made by splitting the capacity between two 400kV circuits and since the capacity on each line would be lower than that required for Normal infeed loss risk this would be suitable. A high level representation of this connection is shown in figure 5.3(5) below.

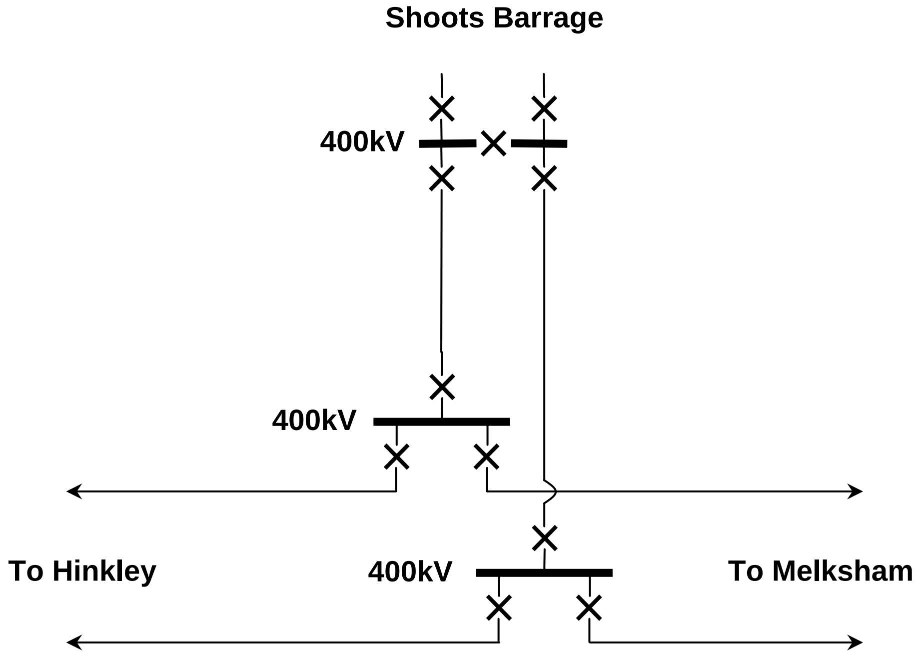


Figure 5.3(5): Indicative Connection for Shoots Barrage

It must be noted that all connections will require further detailed network studies to ascertain how the connection of any significant level of generation will affect the power flows and other equipment in the network.

5.3.6 Grid strengthening possibilities

As was echoed by the Severn barrage definition study[52] and NGET it is not possible to accurately identify what grid strengthening may be required in the future with or without the connection of the Severn Barrage project. There may be generators currently in the connection offer process and projected reinforcements that are currently just in the feasibility stage and therefore not in the public domain. As has been seen in more recent times there is a lot that can happen to the network in a relatively short period, with the current uncertainty over the future of nuclear generation within the GB energy mix, future capacity beyond NGETs current plans is very uncertain.

However, within the existing and planned network NGET has invested heavily in reactive compensation devices (switched capacitors[*], static var compensators[**] etc) over the years and whilst the Severn Barrage generation may effect this existing plant there may be potential for the

[52] Sir Robert McAlpine Ltd on behalf of the Severn Tidal Power Group: “The Severn Barrage – Definition Study for a new appraisal of the Project – main report” 2002

[*] Switched Capacitors are used to provide additional reactive power to the transmission system and support the voltage at particular busbars

[**] Static Var Compensators or SVC’s typically comprise a bank of individually switched capacitors in conjunction with a thyristor controlled reactor. The reactor control thyristor is modulated to provide a continually variable reactive power (VAr) injection (or absorption).

use of similar devices such as quadrature boosters[***] and other plant to divert the power generated toward the French interconnecter and thereby reduce our power import from Europe.

5.3.7 Grid connection conclusions

Results show that the current planned network should have enough capacity for a barrage proposal of the size of the Shoots scheme without requiring significant network reinforcements. It would be possible to connect the Cardiff-Weston barrage with a capacity close to the specification, however this level of generation would have a significant effect on the wider transmission system and would require detailed study work to ascertain exactly how the network would respond to the connection. A connection of this type also would most likely require a split connection sharing capacity between the transmission network on the north and south sides of the estuary. Additionally, network modifications may be required to channel the majority of the generated energy to service the loads currently supplied by the French interconnector. However, this would not be beneficial from a carbon perspective because French nuclear power is low CO_2 so would the climate change benefits of tidal barrage would be decreased.

5.4 CONSTRUCTION PROGRAMME

A disadvantage of tidal power barrages is that their long construction periods attract large charges for interest during construction (IDC). Projects would not normally be required to pay back this interest before first power has commenced and so the interest is accumulated over the period of construction. Based on the capital costs of the barrage proposals (Section 5.1) and the construction term, the following table highlights the total costs of these interest payments and their value in terms of a unit cost, for a range of representative interest rates. A linear distribution of capital spend is assumed over the construction term and the interest is paid back over the 120 year lifetime of the projects. This time period is much greater than for other power projects and it is likely that the project would be financed over a much shorter time period. However, in order to provide a like-for-like comparison with other technology options for the Severn, the project is assumed to be financed over its lifetime.

Table 5.4(1): Interest Rate Costs for the Proposed Barrage Schemes (2006 values)

Scheme	**£m (p/kWh) - real**	2.0%	3.0%	4.0%	5.0%	6.0%
Shoots	Low case	£75 (0.06)	£113 (0.13)	£152 (0.22)	£193 (0.35)	£233 (0.51)
4 year construction term	Mid case	£84 (0.07)	£127 (0.14)	£172 (0.25)	£217 (0.39)	£263 (0.57)
	High case	£93 (0.07)	£142 (0.16)	£191 (0.28)	£241 (0.44)	£292 (0.64)
Cardiff-Weston	5 year programme	£842 (0.11)	£1,280 (0.23)	£1,730 (0.41)	£2,191 (0.65)	£2,665 (0.94)
	7 year programme	£1,138 (0.15)	£1,742 (0.32)	£2,370 (0.56)	£3,024 (0.89)	£3,704 (1.31)

[***] Quadrature boosters, also known as phase shifting transformers, are used to control the flow of power in the transmission system and to protect certain sections of network that would otherwise see power flowing in excess of their rated capability.

For the Shoots scheme the interest charges ranges from £75m to £292m, which represent an increase in the charging rate of 0.06p/kWh and 0.64p/kWh respectively over the 120 year project life. The Cardiff-Weston scheme is greater ranging from £842m to £2,665m for the 5 year construction programme and £1,138 to £3,707 for the 7 year construction programme. It is assumed that the capital costs for both the 5 and 7 year Cardiff-Weston scheme are the same and so the difference in costs is as a result of the differing construction periods.

Whilst the increase in unit charges, as a result of the interest charged over the construction term, may not appear excessive in terms of the overall unit costs of the scheme they can represent a significant component, depending on the interest rate charged. To put these numbers into context, the value that the schemes could obtain as a result of exemption from the climate change levy (CCL) may be up to 0.43p/kWh, which is the equivalent CCL charge, although this number is set to rise in line with inflation from April 2007.

The debt rate offered by the lender will, in part, depend on the lenders view of the risk of the project. The different rates above show the relative effect on the projects costs and required charging rate over the projects lifetime. Also, as with other energy projects, it is likely that the project will be re-financed after the construction period to obtain a more favourable financing package (i.e. a lower debt rate and higher gearing).

5.5 UNIT COSTS OF ENERGY

This study is one of several investigating the opportunities for developing the Severn resource. A range of technologies are being investigated including barrage and non-barrage schemes. In order to provide a direct comparison between schemes unit costs have been calculated by converting their present costs to equivalent annual costs (EAC).

The unit costs have been based on the overall capital and operating costs of the schemes – including interest charges over the construction term, but does not include costs associated with the additional infrastructure required such as transmission upgrades or costs of decommissioning the barrage schemes. In terms of transmission costs, generators connecting to the transmission system are only required to pay very shallow connection charges. This means that transmission system reinforcement costs that result from new connections are recovered through use of system charges. Therefore, where reference is made to “off barrage” transmission costs, these have been excluded from the capital costs of the scheme. It may, however, result in an increased use of system charge and therefore operational costs (and hence higher unit costs), but these cost are “shared” by all users of the system and is therefore unlikely to be a significant component of the operational cost of a barrage scheme. The unit costs presented show the delivered electricity price, based upon a range of project discount rates and estimated electricity output from the barrage schemes.

Shoots tidal barrage

The most recent report for the Shoots tidal barrage is the updated financial assessment undertaken by Parsons Brinckerhoff (PB) in November 2006[53]. Their analysis was based on their assessments of the Hooker Barrage pre-feasibility report undertaken in 1990. The PB report represents the most up to date analysis of the Shoots scheme and so forms the basis of our review on the unit costs. The capital and operational costs of the scheme are presented in section 5.1. The capital spend, over the 4 year construction period, was assumed to have a linear cost distribution[*].

[53] Parsons Brinckerhoff, 2006. The Severn Estuary; Shoots Tidal Barrage. Updated Financial Assessment. November 2006.

[*] It has not been possible to derive the exact unit costs in the PB report for the 5% and 7.5% discount rates, based on the data and assumptions presented in the report. However, the results obtained from our analysis are of a similar order of magnitude.

The average annual energy yield at the generator terminals was determined to be 2.9 TWh. However, this was reduced to take into account the effect of transmission losses and the availability of the generators, to 2.75TWh. This is further discussed in section 4.3.

The following table shows the unit costs of the Shoots scheme (in money of the day – i.e. 2006), for discount rates of 3.5%, 8%, 10% and 15% respectively over a 120 year period lifetime of the scheme. The rate of 3.5% has been included at the request of the SDC to reflect the social discount rate used by HM Treasury, with the other rates offering more commercial returns.

Table 5.5(1): Estimated Unit Costs of Energy for the Shoots Barrage Proposal

Sensitivity Tests (p/kWh)(Real)	3.50%	8%	10%	15%
Low case	2.96	6.08	7.69	12.36
Mid case	3.29	6.8	8.62	13.87
High Case	3.62	7.52	9.54	15.38

Whilst the analysis undertaken by PB provides the most up to date review of unit costs, these are subject to significant uncertainty. The actual design and requirements of a barrage scheme will affect the overall capital and operational costs and determine the delivered unit costs of the scheme.

Cardiff-Weston scheme

There have been a number of different studies undertaken on the Cardiff-Weston scheme. The most recent in 2002[47] re-evaluated the STPG studies of 1989 and updated the costs of the scheme using escalation indices to the original estimates as well as applying an adjustment to the indexation to take account of technical improvements. It did not, however, take into account improvements in construction methods and productivity since 1988. This report provides the most up-to-date analysis of the Cardiff-Weston scheme and so forms the basis of our review on the unit costs.

The annual operating and maintenance costs for the barrage comprised of staff costs, spares, materials and sub-contracted items[54]. However, unlike the PB study for the Shoots scheme, it does not include any costs for business rates or insurance. These therefore have not been included in our analysis of the Cardiff-Weston scheme. Given the size of the scheme these components are unlikely to be a significant component of the overall operational costs.

The STPG 2002 Definition Report presents its values in 2001 money. The updated figures (i.e. 2006 values) are presented in section 5.1.

The assessment of the increase in capital and operating costs are given for a 5 year and 7 year construction programme, which is considered to be as upper and lower limits. For the purpose of this analysis it is assumed that the capital costs are the same for both the 5 and 7 year construction programme, with the only difference being the interest payment costs during construction. It is assumed that the scheme will provide 17 TWh per annum and is also expected to have a lifetime of some 120 years. In the STPG 2002 Definition Report this period was used to derive a unit cost for the scheme but sensitivities were also undertaken to include 40, 70 and 100 years.

The following table shows the unit costs of the Cardiff-Weston scheme (in money of the day – i.e. 2006), for discount rates of 3.5%, 8%, 10% and 15% respectively.

[54] STPG, The Severn Barrage Project: General Report, EP57, 1989

The total costs of the scheme, based on figures from the STPG 2002 Definition Report, is £13.7bn (not including off barrage transmission costs) in money of the day (i.e. 2006). The capital spend is assumed to be linear over the 5 year and 7 year construction period.

Table 5.5(2): Estimated Unit Costs of Energy for the Cardiff-Weston Barrage Proposal

Sensitivity Tests (p/kWh)	3.50%	8%	10%	15%
5 year programme	3.56	8.54	11.18	19.1
7 year programme	3.68	9.24	12.37	22.31

As with the analysis for the Shoots scheme, the costs of the Cardiff-Weston scheme is subject to significant uncertainty.

5.5.1 Comparison of unit costs

From the review of previous studies, it is shown that the smaller Shoots barrage provides a lower cost per unit output than the Cardiff-Weston scheme. The magnitude of this difference, however, will vary depending on the sensitivity analysed. If we consider a 10% project return and a 5 year construction programme for the Cardiff-Weston scheme then the difference will be around 1.64-3.49p/kWh (or ~£45.1m-£100m per annum) depending on the sensitivity of the Shoots scheme (low, mid, high).

In our analysis of unit costs no provision has been made for costs associated with any major overhaul of the barrage schemes – this is consistent with the unit cost analysis presented in both the PB and STPG 2002 Definition Reports. Section 4.5 presents the anticipated *overhaul* costs of the Cardiff-Weston scheme as £148.5m (2006 values) every 30 years, although no figure is available for the Shoots Barrage. These additional costs would increase the unit costs of the schemes, the magnitude of which would depend on how it is financed and the resultant fall in output during maintenance. It would be expected, however, that the Shoots proposal would still provide a lower delivered electricity price.

Also, in deriving the unit costs it has been assumed that the debt will be serviced over the 120 year lifetime of the barrage schemes. In reality, however, private investors are unlikely to take such a long term view and would require a much shorter period, which would increase the unit costs of the barrage schemes. The table below shows the units costs of the barrage schemes with a more realistic repayment period of 40 years (i.e. total project return over 40 years). The figures in brackets show the percentage increase compared to the 120 year period.

Table 5.5(3): Unit Costs of Energy for the Barrage Proposals (40 year period)

Sensitivity Tests (p/kWh) (Real)	3.50%	8%	10%	15%
Shoots Mid case	4.03 (22%)	7.08 (4%)	8.79 (2%)	13.92 (0.4%)
Cardiff-Weston 5 year programme	4.57 (28%)	8.93 (5%)	11.43 (2%)	19.15 (0.3%)
Cardiff-Weston 7 year programme	4.72 (28%)	9.67 (5%)	12.64 (2%)	22.39 (0.4%)

Relying on a unit cost to recover the capital and operational costs of the project has significant risk. Whilst the figures presented in the previous tables represent the required unit costs of the scheme based on different project returns, the actual unit costs achievable will be dependent upon the value of the electricity in the market place and any "green" benefits that will be attributable to the production. Therefore, in order to reflect the profitability or viability of the scheme an understanding of future electricity market prices and "green" benefits will be required.

The following figure presents a range of different generation sources and their fully built up costs (including financing costs) compared to the two barrage schemes.

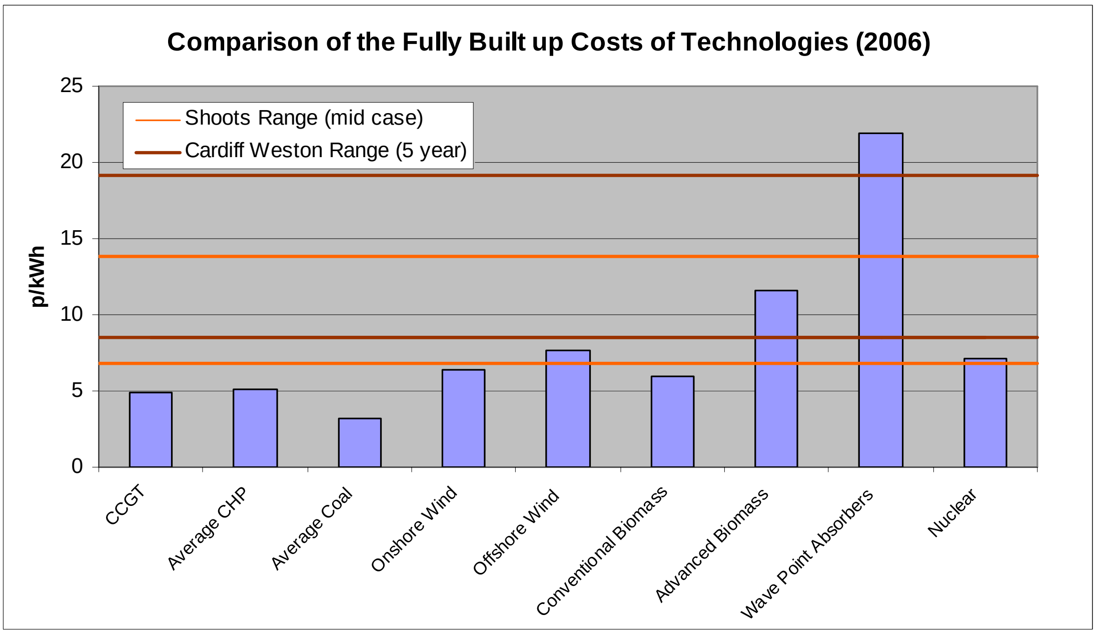


Figure 5.5(1): Comparison of the Fully Built up Costs of Technologies (2006)

Source of other generation costs: IPA Energy + Water Consulting, December 2006, DTI[55].

The above figure presents a range of project returns (8%-15%) for the two barrage proposals. The expected project returns (or weighted average cost of capital – WACC) for the other technologies represents IPA's assessment of credible project returns, which varies between 8.5% and 17% depending on the maturity and type of technology, over the expected technology lifetime.

From this snapshot of the built up costs of other generation sources, it can be seen that the cost of the barrage proposals are greater than conventional and established renewable energy technologies. The current costs of offshore wind (which are likely to fall in the near future as more experience is gained) are, however, a similar order of magnitude as the lower end unit costs of the Shoots scheme.

As with offshore wind and other renewable energy technologies the barrage proposals are likely to be eligible for both renewable obligation certificates (ROCs) and in full (LECs). This will increase the value of the output above that of conventional generation sources. However, both schemes are extremely large in terms of renewable and conventional generators and if eligible for ROCs would have a significant impact on the renewables market. The Cardiff-Weston scheme would deliver almost the 2005/06 target (5.5% of total GB electricity sales) on its own. Whilst the barrage proposals would contribute significantly to the Government's renewable targets, this may be at the expense of other marginal renewable energy technologies such as advanced biomass and wave devices as well as other renewable technologies. An assessment is therefore required to determine the overall effect of the barrage proposals on the renewables market and in particular its

[55] Department of Trade and Industry. Nuclear Costs.
http://www.dti.gov.uk/energy/review/Financial%20Models/page32771.html

contribution to the Government’s renewable energy targets. From the review of the literature no such study has been undertaken.

A different approach for the Severn Barrage scheme, which is highlighted in an SDC discussion paper* could be for the barrage scheme to fall outside of the Renewable Obligation mechanism. The use of long term low carbon electricity contracts (which would have the aim of further – in addition to existing mechanisms - reducing the UK’s dependence on fossil derived fuels), would essentially operate as a feed-in tariff scheme with generators bidding in to supply specified quantities of output. The scheme would be mutually exclusive of the Renewables Obligation and generators would only be eligible for one scheme. However, having two different types of support mechanisms in the UK for renewables is likely to provide conflicting signals to investors and project developers. An alternative solution may be to increase the target of the Renewables Obligation to take into account a Severn Barrage scheme. We would, however, recommend that a further study is undertaken to investigate the different options for supporting a Severn barrage scheme both within the renewables obligation and outside.

In terms of the wider power market the STPG 2002 Definition Report, whilst recognising that the market has changed considerably since previous studies, highlights a range of impacts of the Barrage on the market. These are summarised below and discussed (italics) in terms of both the Cardiff-Weston and Shoots scheme:

Entry of barrage power to the electricity market could lead to its distortion. Therefore, because of the large size of the barrage output (8.6GW for the Cardiff-Weston scheme) it may be necessary to ring-fence barrage electricity.

For the smaller Shoots scheme, this may not be such an issue. Clearly, the larger Cardiff-Weston scheme is likely to affect the overall dynamics of the electricity market, but no mechanism for ring fencing its output has been proposed.

Because of the impact barrage power could have on the electricity market, the timing of its entry into this market may need to be linked to the planned closure of those elements of existing generation capacity which it would replace.

Whilst it is likely to take a number of years before consent is achieved for a barrage scheme, an understanding of the expected generation mix over the medium term would be required. For example, a number of coal powered stations are likely to close by 2016 as a result of the Large Combustion Plant Directive and the UK’s nuclear fleet will also be diminishing in the medium term. Counter to this there is likely to be significant other renewable build, further gas generation and the possibility of new nuclear build.

Effect on carbon markets

The emissions savings from the barrage proposals arise from the fact that it would displace electricity generated by other sources. However, the magnitude of these savings depends on a number of factors such as transmission losses associated with the project, generators being displaced and the emissions associated with generation required to be maintained on standby in case of unexpected reduction in the output from the barrage.

In addition to the manufacture of the barrage components and its construction, which will require significant amounts of concrete, are activities that produce greenhouse gas emissions. It will therefore be important to understand the whole life cycle emissions of the schemes as discussed in section 4.

* SDC Discussion Paper, Unlocking the power sector: Proposal for long-term low-carbon electricity contracts, December 2006.

As carbon credits under the EU ETS are only allocated to the "carbon producing" industries, such as coal power stations, the barrage schemes would not directly participate in and benefit from the carbon markets. Rather, the effect of the barrage scheme is likely to benefit UK plc as a whole – by reducing the emissions reductions that UK plc will have to meet. However, the barrage schemes would benefit indirectly from the carbon price, in that it would increase the overall electricity market price of electricity.

It has also been postulated that any carbon savings as a result of new-build, low carbon generation capacity (such as nuclear or a barrage) could be auctioned off with the gains being apportioned to the project[56]. Any share of the gains could be realised on refinancing the project after construction.

The following table shows the anticipated carbon savings for both of the barrage proposals and the equivalent financial amount based on a range of carbon prices including €17/tCO2, as used in the PB power report. The carbon savings are calculated based on DTI Emission factors (coal fired generation – 0.3171tCO2/MWh, gas fired generation – 0.1852tCO2/MWh[57]).

Table 5.5(4): Carbon Offset from the Barrage Proposals

	CO_2 Saving (mt per annum)	**Financial Equivalent (~£m per annum)*@ €10/tCO_2**	**Financial Equivalent (~£m per annum)*@ €17/tCO_2**	**Financial Equivalent (~£m per annum)*@ €20/tCO_2**	**Financial Equivalent (~£m per annum)*@ €30/tCO_2**
Shoots (coal replacement)	0.871	£5.8	£9.8	£11.5	£17.3
Shoots (gas replacement)	0.51	£3.4	£5.7	£6.7	£10.1
Cardiff-Weston (coal replacement)	5.5	£35.6	£60.5	£71.2	£106.7
Cardiff-Weston (gas replacement)	3.15	£20.8	£35.3	£41.6	£62.3

*in order to derive a Carbon saving value the CO2 savings is multiplied by (12/44)

To put these figures into context, for Phase II of the EU ETS (2008-2012) the UK has been cleared to emit 246.2mt[58] of CO2 per annum, which is broadly equivalent to 67mt of carbon per annum. Considering the Cardiff-Weston scheme and assuming a carbon saving relating to coal replacement, this barrage scheme would therefore represent around 2.26% of the total national allocation plan for Phase II of the EU ETS. If considering existing large electricity producers only, which have an allocation of around 99mt of CO2, assuming a carbon saving relating to coal replacement for the Cardiff-Weston scheme this would represent approximately 5.4% of their total allocation for Phase II of the EU ETS.

The carbon market price is determined by a range of different variables such as the availability and use of carbon project credits (e.g. Clean Development Mechanism (CDM) and Joint Implementation (JI) credits), the allocation of carbon credits to different industries by governments and the reduction targets. The actual magnitude of the effect of the barrage proposals on the carbon markets has not been quantified in any of the reviewed reports. However, in terms of the barrage

[56] Sustainable Development Commission, The role of Nuclear power in a low carbon economy: Paper 4; The Economics of Nuclear Power, March 2006.

[57] Department of Trade and Industry http://www.dti.gov.uk/files/file33302.xls Accessed February 2007.

[58] Commission Decision of 29 November 2006 concerning the national allocation plan for the allocation of greenhouse gas emission allowances notified by United Kingdom in accordance with Directive 2003/87/EC of the European Parliament and of the Council.

proposals this is unlikely to be a critical point to determine whether or not the barrage scheme should go ahead. It may, however, be of value to Government and traders operating in the market.

Decommissioning

As highlighted in section 4.6 there have been no detailed studies of the method and cost of decommissioning a tidal power barrage. Whether or not the barrage scheme will require decommissioning at some point in the future is dependent on a number of factors. However, when considering the economics of the scheme, this eventuality should be taken into account.

In order to understand decommissioning we must therefore look to other sectors where decommissioning forms a key component of the overall costs. The most obvious analogy is the Nuclear sector, whilst clearly having different complexities, the process of funding decommissioning is likely to be similar. The following summarises these (The economics of Nuclear Power, SDC, March 2006), which may have relevance to a tidal barrage scheme. However, as discussed in section 4.6 it may be better not to decommission a barrage scheme.

While decommissioning costs are highly uncertain and could be substantial, financing these over the lifetime of a new plant at even a low rate of assumed fund accumulation would make such costs potentially quite small.

There are many ways in which funding could be put in place for decommissioning costs, including the possibility that substantial funds could be required at the start of the project – in other words an addition to capital cost. However, common practice for privately-owned nuclear plants is to require plant owners to cover back end costs by setting up a segregated trust fund (to guarantee availability of money when required) and then to allow the fund to accumulate by annual contributions for at least the expected plant lifetime.

As an illustration, if we assume an annual interest of 5% and an assumed decommissioning cost of £15 billion (real) for both the Cardiff-Weston barrage and £1.5billion (real) for the Shoots barrage then:

Table 5.5(5): Illustration of Decommissioning Funds

	Unit Rate Required (p/kWh) – 40 year fund accumulation	**Unit Rate Required (p/kWh) – 80 year fund accumulation**	**Unit Rate Required (p/kWh) – 120 year fund accumulation**
The Shoots Barrage	3.18	2.78	2.74
Cardiff-Weston	5.14	4.5	4.42

The costs presented above would be additional to the unit rates presented previously in Section 5.5. It can therefore be seen that a significant additional unit cost would be required if the barrages were decommissioned.

5.6 FINANCING

A number of studies including the STPG tripartite studies in 1986[59], STPG's financial studies proposal of 1993 and the STPG 2002 Definition Report have investigated the financing of the

[59] STPG, 1986. Tidal Power from the Severn. Engineering and economic studies – The Cardiff-Weston Scheme and English Stones scheme. The Severn Tidal Power Group.

barrage schemes. However, since the publication of the former two reports there have been major changes in the financial system in general, and project financing in particular. These relate to the economic context in which projects are financed, the approach of banks and other lenders to assessing risks and making lending decisions, and finally to the way that project financing is constructed and optimised. This section therefore reviews the analysis presented in the STPG 2002 Definition Report. The key highlights are as follows:

- Where infrastructure concessions are concerned, it is now customary that there has to be an open competition to decide which private-sector entity (usually, but not necessarily, a consortium of companies) should be granted the right to exploit that concession.
- The most likely route to financing the barrage proposals is through a non-recourse project finance basis.

  Another approach could be through corporate finance (i.e. on the balance sheet). However, for a barrage project of the scale discussed, corporate finance is unlikely to be suitable.
- The service price tendered by each bidder will depend entirely on the key project variables as perceived by the bidder and its lenders (capital costs, operating costs, usage, reliability, taxation) and the financial parameters of the funders.
- The key financial parameters are:

· the target return on equity;

· the servicing cost of the debt, ie the annuity rate, itself a function of:

  - the interest rate, and
  - the maturity of the debt

· the cover ratio required by the lenders

- "Typical terms" offered by lenders may not reflect the particular situation of the Severn Barrage – e.g. project duration, predictable output, no fluctuating "fuel price". Providing the construction risk can be adequately addressed, terms may be better than those offered for other power projects.
- The STPG 2002 Definition Report also investigated the sensitivity of the unit costs on two financing parameters: maturity of investment and cover ratios. Whilst the previous section 5.5 (unit costs of energy) highlighted the unit costs based on the total project returns of the scheme, in practice there are likely to be a variety of lenders to the scheme requiring different returns.
- In financing projects of this type, bank debt will be generally cheaper than equity – reflecting its relative security and risk – and therefore the use of debt will allow the project company to "gear up" the returns to equity – allowing projects to go ahead that would otherwise not be economic.
- In practice, the potential debt/equity ratio (gearing) that can be supported by a project impacts the cost of borrowing (the margin over base rates) but there are limits to the level of debt bankers are prepared to accept in a non-recourse structure and this is determined by an assessment of the technical risk being taken by the project (that is whether the development uses proven technology and what warranties are available), the "quality" of the offtakers (e.g. electricity suppliers), the perceived political and regulatory risk in the project (that is how stable the market is seen as) and other factors. The gearing, presented in the STPG 2002 Definition Report, is in excess of 90% for all of the options for the Cardiff-Weston scheme, which represent a very high gearing.
- It would therefore be recommended that as part of its dissemination activities the SDC involve the financing community to ascertain their appetite for such a large project and

determine whether a project of the scale of the Cardiff-Weston scheme could be financed by the private sector.

Delivery Options

The STPG 2002 Definition Report also discusses the ability of the project to be financed. Key points of note are shown in the bullets with a discussion on these in italics below:

- A debt requirement in the region of £13.7 billion (2006 values for Cardiff-Weston scheme excluding off transmission costs) represents approximately twice the entire amount of UK sterling project bonds issued to date. The Eurotunnel project (which cost in the region of £10 billion to construct) required a syndicate of over 200 banks to provide the necessary finance.

- The Project risk would lie entirely in its construction.

However, it may also be difficult to secure a long term offtake agreement for the scheme's output. This is a risk to all power generation projects, and so if the marginal cost of electricity (plus green benefits) falls below that of the unit cost of the barrage scheme there may be a risk that the debt may not be able to be serviced. An understanding of the medium to long term electricity market price will be required to give confidence to both project developers and investors that the project will be commercially viable unless Government intervention of some kind is forthcoming.

- A proper risk assessment for the project, to quantify as far as is possible the major risks and their possible effects on construction time and cost, needs to be undertaken.

- It is possible to envisage the Severn Barrage Project being financed by the private sector, subject to the Government policy instruments necessary to achieve the long-term security of supply contracts and with capital grants to recognise the value of the non-energy benefits.

This raises a key question of what or if any further policy instruments will be put in place for the benefit of a particular energy project. Under the current energy policy, it is down to the "market" to determine what and when new electricity generation capacity is built. Any intervention by the Government may reduce the confidence of investors to invest in other forms of power generation as there would be no guarantee of further Government intervention. However, given the scale of a barrage scheme it may be difficult to secure long term power offtake agreements to satisfy the investor community and so some form of Government intervention may be required.

In terms of capital grants these have already been used for supporting the development of technologies such as offshore wind and wave technologies and so the market is familiar with this kind of intervention. However, the level of capital grants available to the scheme could be significant given the size of the potential non-energy benefits. An analysis would therefore be required to determine the level of capital grants required (if any) and the cost/benefit relative to other technologies/projects.

Other less direct financial support could include government guarantees of some bond or bank financing. Whilst this would reduce the costs of capital, some of the risk of the project would be transferred to taxpayers[56].

The Government would need to be a key part in the development and promotion of the project. A Public Private Partnership (PPP) is considered to be a suitable approach for developing the project. The Government would need to accept a larger degree of risk in the Project at its early stages, until the risk of its implementation is reduced. Thereafter the private sector would be prepared to take more of the risk.

However, given the DTI's recent Energy Review[60] and the Government's position on new nuclear build: "It would be for the private sector to initiate, fund, construct and operate new nuclear plants and cover the costs of decommissioning and their full share of long term waste management costs"[61], any direct financial support for other energy projects such as the barrage schemes may not be forthcoming.

Some form of Government support may be required for the larger Cardiff-Weston scheme. However, the Shoots barrage at around 1GW, whilst large in terms of an individual power project, is not significantly so in terms of other generating capacity in the UK. For example, there are a number of coal-fired power stations of the order of 2GW and Drax, the UK's largest power station is some 4GW in capacity, although these were all built by the then Central Electricity Generating Board (CEGB). Therefore, there may be sufficient private sector appetite for the Shoots scheme thereby avoiding Government intervention.

[60] The Energy Challenge, 11th July 2006.

[61] BBC News Website "Nuclear power plants get go ahead
http://news.bbc.co.uk/1/hi/uk_politics/5166426.stm Accessed February 2007

6 ENVIRONMENTAL IMPACTS AND POLICY FRAMEWORK

6.1.1 Introduction

This chapter describes the main features of marine environmental legislation and policies relevant to the consideration of any barrage proposal and summarises existing baseline information on the marine environment of the Severn Estuary. The potential environmental impacts of two possible barrage options (the Cardiff-Weston scheme and The Shoots scheme) are evaluated for each component of the marine environment based on existing information. The implications of these possible impacts is then evaluated in the context of existing legislation and policies, with particular reference to the requirements of the Conservation (Natural Habitats & c.) Regulations 1994 (the 'Habitats Regulations'). Where appropriate recommendations are made for additional studies.

The main environmental components evaluated in this chapter comprise:

- Water levels, currents and waves
- Sediment regime
- Morphology
- Water quality
- Ecology – specifically, the various estuarine habitats, plankton and marine algae, fish, birds and mammals
- Archaeology
- Visual assessment

Contact has been made with the following organisations to obtain relevant information:

- Natural England
- Countryside Council for Wales
- Environment Agency
- Royal Society for the Protection of Birds
- National Trust
- English Heritage
- Cadw
- Royal Commission on the Ancient and Historical Monuments of Wales

The assessment has focused on the main marine impacts directly associated with construction, operation and decommissioning of either barrage option. Depending on the proposed construction materials for the barrage there is also the potential for additional marine impacts, for example, if marine-won aggregate was used as the main construction material.

There is also potential for significant issues to arise in relation to the terrestrial environment depending on the nature of any final barrage proposal, but these have not been considered here. Similarly the potential environmental impacts associated with the extraction, production, distribution and use of all of the materials required for the construction of a barrage have not been reviewed.

A number of the component assessments draw on recent work undertaken for the Environment Agency to develop a coastal habitat management plan (CHaMP) to ensure that the management of flood defences in the Severn complies with the requirements of the Habitats Regulations[62]. In particular, the Severn CHaMP considers the implications of sea level rise and climate change over the period up to 2105 and therefore contains important baseline information about the morphological evolution of the estuary in the absence of a barrage proposal.

This section:

- identifies the main environmental policies and legislation relevant to the consideration of any barrage proposal
- describes the main features and requirements of such legislation

[62] ABPmer, 2006. Severn Estuary ChaMP Morphological assessments

- identifies key legal issues from an environmental perspective for any barrage proposal.

The assessment focuses on the legal issues from a marine physical/biological perspective. Information on the impacts to other marine uses is provided in Chapter 7.

6.2 RELEVANT ENVIRONMENTAL LEGISLATION

6.2.1 Environmental policies and legislation

A wide range of environmental policies and legislation are relevant to the consideration of any barrage in the Severn estuary. The focus of this section is on specifically marine legislation and policies, although it is recognised that there will be an important interaction with the land use planning controls for any land based development associated with a barrage scheme and at the barrage landfall locations.

The next decade is likely to see significant further development of policies for the marine environment. It is probable that a Marine Bill will be enacted in the next few years that will introduce a new planning framework for the marine area (Marine Spatial Planning) together with a range of other developments, for example, enhanced provisions for marine nature conservation (including a network of Marine Protected Areas), and the establishment of a Marine Management Organisation. If current proposals for marine planning are implemented, a number of statutory regional marine plans containing policies for the sustainable development of the marine environment, supported by a national marine planning policy statement, would need to be prepared. Any barrage proposal would need to be brought forward and approved within this overarching planning context. It is not possible to be prescriptive about these requirements at this stage, pending the enactment of the legislation and the related marine policy and planning framework. New policy and legal provisions under a Marine Act may have a significant bearing on how a barrage proposal might need to be taken forward.

Because of the scale and nature of the development, it is probable that either barrage option would need to be promoted through an Act of Parliament. Such an Act could incorporate the requirements of certain national environmental legislation, for example, the Water Resources Act 1991 and Food & Environment Protection Act 1985 such that separate consent under these Acts might not be required. However, the proposal would still be likely to require separate regulatory approval in relation to the requirements of European directives such as the EC Birds Directive (79/409/EEC), EC Habitats Directive (92/43/EC) and EC Environmental Impact Assessment Directive (85/337/EEC), for example. Normally, the main consenting provisions of such development proposals would provide for a Public Inquiry to be held if there were significant objections to a development. For the purposes of this review, notwithstanding that some regulatory decisions may be subsumed within approvals granted under an Act of Parliament, it has been assumed that the requirements of existing legislation would still apply to a barrage scheme, albeit that regulatory approval might be provided by a different mechanism under an Act of Parliament. Box 1 identifies the main requirements.

Box 1: Main Environmental Legislation Relevant to the Severn Barrage Proposal

EC Birds Directive (79/409/EEC) and **EC Habitats Directive (92/43/EC)** as implemented through the Conservation (Natural Habitats & c.) Regulations 1994 (as amended) - in relation to potential impacts on internationally designated nature conservation sites (Special Protection Areas designated under the Birds Directive, Special Areas of Conservation designated under the Habitats Directive and, as a matter of Government policy, Ramsar sites designated under the Ramsar Convention)

EC Water Framework Directive (2000/60/EC) as implemented by the Water Environment (Water Framework Directive) (England and Wales) Regulations 2003 (the Water Framework Regulations) – in relation to potential impacts of the development on Water Framework Directive objectives

EC Strategic Environmental Assessment Directive (2001/42/EC) as implemented by Environmental Assessment of Plans and Programmes Regulations 2004. It is anticipated that any proposal to take forward either Severn Barrage option would need to be considered in the wider context of UK/national energy policies and programmes, which would be subject to the requirements of the SEA Directive (on the basis that it is unlikely that such a large project could be successfully promoted in the absence of a robust supporting strategic context).

EC Environmental Impact Assessment Directive (85/337/EEC) as amended by 97/11/EC) as implemented through sectoral EIA Regulations. Any development application for a barrage would need to be supported by a detailed environmental impact assessment (the Electricity Works (Environmental Impact Assessment) (England and Wales) Regulations 2000 are likely to be the most relevant Regulations for environmental impact assessment for a barrage proposal)

Wildlife & Countryside Act 1981 (as amended by the Countryside & Rights of Way Act 2000) – in relation to potential impacts on nationally designated nature conservation sites

Food & Environment Protection Act 1985 - in relation to the environmental impact of construction works or the disposal of dredged material below mean high water mark of spring tides (MHWS))

Water Resources Act 1991- in relation to any requirement for consented discharges and approval of works affecting flood defences

6.2.2 Conservation (Natural Habitats & c.) Regulations 1994 (as amended) (the Habitats Regulations)

The Habitats Regulations transpose the requirements of the EC Birds Directive and EC Habitats Directive into GB law.

Projects or plans affecting areas in or near sites designated as Special Protection Areas under the Birds Directive or Special Areas of Conservation under the Habitats Directive (collectively known as European Sites) are subject to the requirements of Article 6 of the Habitats Directive which are transposed into GB law through Regulations 48 to 53 of the Habitats Regulations. Either barrage option would be likely to significantly affect one or more European Sites and thus be subject to the requirements of the Regulations. The main provisions of these regulations are as follows:

Before granting consent for a project:

- There must be an assessment by the competent authority* as to whether a plan or project is likely to have a significant effect on a European Site (reg. 48(1)) whether alone or in combination with other plans or projects.

- If there is likely to be a significant effect, the competent authority must carry out an appropriate assessment (reg. 48(1)).

- The appropriate assessment must consider the implications for the European Site in view of that site's conservation objectives (reg. 48(1)).

- In the light of the conclusions of the assessment, the competent authority shall agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the European Site (reg. 48(5))

- If it cannot be ascertained that the project will not adversely affect the integrity of the European Site, the authority must then consider whether there are any alternative solutions (reg. 49(1)).

- If there are no alternative solutions and notwithstanding a negative assessment of the implications for the site consent or authorisation etc may be granted for the project but only "for *imperative reasons* of *overriding public interest*" (IROPI)(reg. 49(1)).

- Such imperative reasons may be of a social or economic nature (reg. 49(1)), unless the site hosts priority habitats or priority species listed on annexes to the Habitats Directive. In the latter case, the reasons are more constrained.

- If the competent authority is satisfied that there are imperative reasons etc., notwithstanding a negative assessment of the implications for a European Site, the Secretary of State is under a duty to secure that all necessary compensatory measures are taken to ensure that the overall coherence of Natura 2000* is protected (reg. 53).

The regulations impose a highly structured assessment process on projects and plans proposed in designated sites, and transparent adherence to these requirements is key in working to secure the support of stakeholders.

As a matter of policy, the Government has chosen to apply the procedures in respect of Ramsar sites and potential SPAs (pSPAs), even though these are not European sites as a matter of law. Paragraph 6 of ODPM Circular 06/2005 indicates that the Habitats Regulations do not apply as a matter of law or as a matter of policy to proposed SACs (pSACs). However, the guidance advises that 'planning authorities should take note of this potential designation in their consideration of any planning applications that may affect the site'.

A range of guidance is available at national and European level in relation to the requirements of the Directives and Regulations. The key documents include:

- Planning Policy Statement 9 (PPS9): Biodiversity and Geological Conservation containing policies for England. Equivalent policies for Wales are contained in TAN 5: Nature Conservation and Planning.

---

* For the purposes of a barrage proposal, any statutory body that was required to give formal approval to an aspect of the scheme would be a competent authority and would need to take account of the requirements of the Habitats Regulations prior to granting any approval.

* Natura 2000 is the network of Special Protection Areas and Special Areas of Conservation across the EU.

- ODPM Circular 06/2005: Biodiversity and Geological Conservation – Statutory Obligations and their Impact within the Planning System
- Managing Natura 2000 Sites (MN2000) – The Provisions of Article 6 of the 'Habitats Directive' 92/43/EEC (guidance prepared by the European Commission, 2000)
- Assessment of plans and projects significantly affecting Natura 2000 sites: Methodological guidance on the provisions of Article 6(3) and (4) of the Habitats Directive 92/43/EEC (guidance prepared by the European Commission, 2001)

In early 2007, the European Commission published further clarification on the interpretation of Article 6(4) of the Habitats Directive 92/43/EEC[63]. This generally amplifies existing guidance.

Further insight is also available from certain recent planning decisions, for example, the Dibden Bay decision (2004) [64].

The documents include useful advice on the interpretation of the particular requirements of Article 6 of the Habitats Directive, for example:

- assessment of significance of impacts in relation to a site's conservation objectives;
- scope of assessment required in relation to the consideration of alternatives;
- determination of imperative reasons of over-riding public interest (IROPI); and
- scope of compensatory measures that may be required to secure the overall coherence of the Natura 2000 network.

Specific guidance relating to the consideration of alternatives, IROPI, compensatory measures and the coherence of Natura 2000 is presented below as these matters are likely to be particularly relevant to the consideration of a barrage proposal.

Alternative solutions

If it cannot be ascertained that a project or plan will not adversely effect the integrity of the European Site, the competent authority must then consider whether there are any alternative solutions (reg. 49(1)).

Paragraph 24 of ODPM Circular 06/2005 states:

> 'If there are alternative solutions that would have no (or a lesser) effect on the site's integrity then consent cannot be granted in accordance with the Habitats Regulations; permission must be refused or the appeal dismissed. .... In assessing alternative solutions the decision taker should consider whether there are or are likely to be suitable and available sites (or routes in the case of linear projects) which are alternatives for the proposed development, or different, practicable approaches which would have a lesser impact.'

Guidance on alternatives in section 5.3.1 of MN2000 indicates that:

> 'They could involve alternative locations (routes in the case of linear developments), different scales or designs of development, or alternative processes. The zero option should be considered too.'

---

[63] Guidance doc on Article 6(4) of the Habitats Directive: Clarification of the concepts of: Alternativve Solutions, Imperative Reasons of Over-riding Public Interest, Compensatory Measures, Overall Coherence, Opinion of the Commission, European Commission, January 2007.

[64] http://www.dft.gov.uk/stellent/groups/dft_shipping/documents/page/dft_shipping_028330-03.hcsp#TopOfPage

The guidance goes on to state:

> 'In conformity with the principle of subsidiarity, it rests with the competent national authorities to make the necessary comparisons between these alternative solutions. It should be stressed that the reference parameters for such comparisons deal with aspects concerning the conservation and the maintenance of the integrity of the site and of its ecological functions. In this phase, therefore, other assessment criteria, such as economic criteria, cannot be seen as overruling ecological criteria.'

The guidance contained in EC (2001) further states that:

> 'The examination of alternative solutions requires, therefore, that the conservation objectives and status of the Natura 2000 site will outweigh any consideration of costs, delays or other aspects of an alternative solution. The competent authority should not, therefore, limit its consideration of alternative solutions to those suggested by the project or plan proponents. It is the Member State's responsibility to consider alternative solutions which could be located even in different regions/countries.'

In relation to the Dibden Bay decision, the Secretary of State similarly noted (paragraph 51 of the Decision Letter) that

> "the consideration of alternatives for projects which would have a significant impact upon a site designated in accordance with the Habitats Regulations must necessarily range more widely [than those alternatives that would meet the specific needs of the project promoter]".

The Decision letter indicated that the public interest need that would be met by the Dibden Bay proposal was the need for additional long-term container capacity in the South-East of England and therefore other schemes that could contribute to meeting this need therefore needed to be taken into account.

Imperative reasons of overriding public interest

If there are no alternative solutions, the competent authority should consider whether there are imperative reasons of overriding public interest to justify the grant of permission despite a potentially negative effect on site integrity. Different tests apply depending on whether the site hosts a priority natural habitat type or species.

If a site does not host a priority natural habitat type or species, permission can be granted if the proposed development has to be carried out for imperative reasons of overriding public interest, including those of an economic or social nature. Such reasons would need to be sufficient to override the harm to the ecological importance of the designation[*].

If the site hosts a priority habitat or species, the only considerations which can justify the grant of permission are:

- those which relate to human health, public safety or beneficial consequences of primary importance to the environment; or
- other imperative reasons of overriding public interest agreed by the European Commission (Regulation 49(2).

MN2000 (EC, 2000) provides a number of clarifications on the interpretation of these requirements (section 5.3.2):

- only public interests, promoted either by public or private bodies, can be balanced against the conservation aims of the directive – thus, projects that lie entirely in the interests of companies or individuals would not be considered to be covered;
- the public interest must be overriding. Thus, not every kind of public interest is likely to be sufficient;

[*] Priority habitats and species are indicated by an asterisk in Appendices I and II of the Habitats Directive.

- it is suggested that the public interest can only be overriding if it is a long-term interest; short-term economic interests or other interests which would only yield short-term benefits for society would not appear to be sufficient to outweigh the long-term conservation interests protected by the directive

Securing compensation measures to ensure the overall coherence of Natura 2000

In the absence of alternatives and where the competent authority determines that a project should proceed on the grounds of IROPI, compensatory measures must be taken to ensure the overall coherence of Natura 2000 is protected (Regulation 53 of Habitats Regulations). Such measures might typically involve the creation of new or the enhancement of existing habitats to replace the functions that are affected by a particular development.

Compensatory measures

There is relatively little guidance on the nature of compensatory measures. MN2000 indicates that (section 5.4.2) compensatory measures *sensu stricto* have to ensure the maintenance of the contribution of a site to the conservation at favourable status of one or several natural habitats '*within the biogeographical region concerned'*. It indicates that appropriate measures could include new habitat creation or 'work to improve the biological value of an area (to be designated) or of an SPA (designated) so that the carrying capacity or the food potential are increased by a quantity corresponding to the loss on the site affected by the project'. It further indicates that in terms of the Habitats Directive, the compensation could similarly consist of the re-creation of a comparable habitat, the biological improvement of a substandard habitat or *even the addition to Natura 2000 of an existing site the proposal of which under the directive had not been deemed essential at the time of drawing up the biogeographical list'*.

Paragraph 30 of ODPM Circular 06/2005 states that:

> '..where new habitats are created as compensatory measures, the newly created habitats should be in place in time to provide fully the ecological functions that they are intended to compensate for'.

There are also specific requirements in relation to Ramsar sites. Paragraph 31 of ODPM Circular 06/2005 states that:

> 'Article 4(2) of the Ramsar Convention requires Contracting Parties that delete sites or restrict site boundaries to provide compensatory measures for the loss of conservation interests. The convention refers to creating additional nature reserves for waterfowl and for the protection, either in the same area or elsewhere, of an adequate portion of the original type of habitat. Compensatory measures should provide, as a minimum, no net loss to the overall value of the national Ramsar site series either by way of quality or area'.

Ensuring the overall coherence of the Natura 2000 network

There is some guidance at European level on the requirement to ensure the overall coherence of the Natura 2000 network.

MN2000 states that:

> 'In order to ensure the overall coherence of Natura 2000, the compensatory measures proposed for a project should address, in comparable proportions, the habitats and species negatively affected; concern the same biogeographical region in the same Member State; and provide functions comparable to those which had justified the selection criteria of the original site'.

EC (2001) provides similar guidance to MN2000 but also indicates that the compensatory provision should 'be in as close proximity as possible to the habitat that has been adversely affected by the project or plan'.

6.2.3 Water Environment (Water Framework Directive) (England & Wales) Regulations 2003 (The Water Framework Regulations)

The Water Framework Regulations implement the requirements of the EC Water Framework Directive (2000/60/EC) in England and Wales.

The Water Framework Directive (WFD) establishes a framework for the management and protection of Europe's water resources. It applies to all surface waters out to 1 nautical mile (nm) seaward of the baseline for territorial waters and to groundwaters. For management purposes surface and groundwaters are divided into a number of discrete units termed 'water bodies'. The WFD has two key objectives for all water bodies:

- To prevent deterioration of the status of all surface water and groundwater bodies; and
- To protect, enhance and restore all bodies of surface and groundwater with the aim of achieving good ecological and chemical status in all surface water and 'good chemical and quantitative status in groundwaters by 2015.

Where new developments may compromise the achievement of the Directive's objectives, the provisions of Article 4(7) apply (see text box below). Either barrage option is considered likely, based on available information, to compromise achievement of these objectives in one or more water bodies.

> WFD Article 4(7)
>
> Member States will not be in breach of this Directive when:
>
> -failure to achieve good groundwater status, good ecological status or, where relevant, good ecological potential or to prevent deterioration in the status of a body of surface water or groundwater is the result of new modifications to the physical characteristics of a surface water body or alterations to the level of bodies of groundwater, or
>
> -failure to prevent deterioration from high status to good status of a body of surface water is the result of new sustainable human development activities
>
> and all the following conditions are met:
>
> (a) all practicable steps are taken to mitigate the adverse impact on the status of the body of water;
>
> (b) the reasons for those modifications or alterations are specifically set out and explained in the river basin management plan required under Article 13 and the objectives are reviewed every six years;
>
> (c) the reasons for those modifications or alterations are of overriding public interest and/or the benefits to the environment and to society of achieving the objectives set out in paragraph 1 are outweighed by the benefits of the new modifications or alterations to human health, to the maintenance of human safety or to sustainable development, and
>
> (d) the beneficial objectives served by those modifications or alterations of the water body cannot for reasons of technical feasibility or disproportionate cost be achieved by other means, which are a significantly better environmental option.

The tests in Article 4(7) have some parallels with the tests for projects or plans under the Habitats Directive, although there are also some important differences.

The WFD Strategic Co-ordination Group[**] has recently approved guidance on how the requirements of Article 4(7) are to be interpreted and applied (EC, 2006)[65]. This guidance includes interpretation of:

- The requirement to take 'all practicable steps'
- 'overriding public interest'
- the weighing of benefits associated with the environmental objectives, against the benefits from the proposed modification or sustainable human use; and
- consideration of alternative means of providing the benefits offered by the modification or sustainable human use.

These tests would be relevant to the consideration of a barrage proposal and are considered in more detail below.

All practicable steps

The test in Article 4(7)(a) requires the competent authority to ensure that all practicable steps are taken to mitigate the adverse impact on the status of the water body.

It is also important to note that Article 4(7)(a) requires only mitigation and not compensatory measures. The guidance offers the following distinction:

- Mitigation measures are those measures which aim to minimise or even cancel the adverse impact on the status of the body of water; and
- Compensatory measures are those measures which aim to compensate in another body of water the "net negative effects" of a project and its associated mitigation measures.

The guidance indicates that the notion of "steps" should be interpreted as relating to a wide range of measures in all phases of development, including maintenance and operating conditions, facilities' design, restoration and creation of habitats. The guidance further indicates that "all practicable steps", in analogy with the term "practicable" used in other legislation, should be taken to indicate that the mitigation measures should be technically feasible, do not lead to disproportionate costs, and are compatible with the new modification or sustainable human development activity.

Overriding public interest

The test in the first part of Article 4(7)(c) requires that the competent authority satisfy itself that the reasons for the proposed modifications or alterations are of overriding public interest.

The guidance draws specific parallels with the provisions of the Habitats Directive and EC guidance (EC, 2001) in considering how overriding public interest should be interpreted.

It indicates that it is reasonable to consider that the reasons of overriding public interest refer to situations where plans or projects envisaged prove to be indispensable within the framework of:

- Actions or policies aiming to protect fundamental value for citizen's lives (health, safety, environment);
- Fundamental policies for the State and the society;

[**] The Strategic Co-ordination Group comprises the Water Directors (senior Civil Servants) from each Member State with responsibilities for taking forward the practical implementation of the Directive.

[65] EC, 2006. Guidance Ref

- Carrying out activities of an economic or social nature, fulfilling specific obligations of public services.

Furthermore, it also indicates that public participation will contribute considerably in determining overriding public interest.

Weighing benefits

The test in the second part of Article 4(7)(c) requires that the competent authority consider whether the benefits to the environment and to society of achieving the objectives set out in paragraph 1 are outweighed by the benefits of the new modifications or alterations to human health, to the maintenance of human safety or to sustainable development.

The guidance recommends that an analysis of the costs and the benefits of the project adapted to the needs of the Directive is necessary to enable a judgement to be made on whether the benefits to the environment and to society of preventing deterioration of status or restoring a water body to good status are outweighed by the benefits of the new modifications or alterations to human health, to the maintenance of human safety or to sustainable development. The guidance indicates that it should not be necessary to monetise or even quantify all costs and benefits to make such a judgement. The appropriate mix of qualitative, quantitative and, in some cases, monetised information should depend on what is necessary to reach a judgement and what is proportionate and feasible to collect.

Alternative means

The test in Article 4(7)(d) requires the competent authority to consider whether the beneficial objectives served by the proposed modifications or alterations of the water body cannot for reasons of technical feasibility or disproportionate cost be achieved by other means, which are a significantly better environmental option.

The guidance indicates that alternative solutions could involve alternative locations, different scales or designs of development, or alternative processes and that alternatives should be assessed in the early stages of development and at the appropriate geographical level (EU, National, River Basin District) against a clear view of the beneficial objectives provided by the modification.

The guidance also refers to the consideration of alternatives under the EIA Directive (85/337/EEC) as a source of help in assessing different alternatives, notwithstanding that the scope of these considerations is dissimilar. For example, under the EIA Directive the requirement to consider alternatives is generally interpreted as a consideration of alternatives available to the promoter (see Dibden Bay decision), whereas under the Habitats Directive, the competent authority's consideration of alternatives can be considerably broader.

6.2.4 Strategic Environmental Assessment

European Directive 2001/42/EC (the SEA Directive) "on the assessment of the effects of certain plans and programmes on the environment" requires a formal environmental assessment of certain plans and programmes which are likely to have significant effects on the environment. While individual projects are not subject to the requirements of the Directive, the scale and nature of any barrage proposal would be such that it is difficult to envisage how such a project might be successfully promoted without a very strong supporting strategic context. Given the debate surrounding possible barrage schemes and the very major issues relating to alternatives under the Habitats Directive, a formal Strategic Environmental Assessment (SEA) of UK high level energy policy in accordance with the requirements of the SEA Directive (2001/42/EC) is likely to be necessary before a specific barrage option could be promoted through the planning system.

Under the Directive, authorities which prepare and/or adopt such a plan or programme must prepare a report on its likely significant environmental effects and those of reasonable alternatives, consult environmental authorities and the public, and take the report and the results of the consultation into account during the preparation process and before the plan or programme is adopted. They must also make information available on the plan or programme as adopted and how the environmental assessment was taken into account. The SEA Directive is transposed into UK law by the Environmental Assessment of Plans and Programmes Regulations 2004.

Environmental assessment is usually mandatory for plans and programmes:

- which are prepared for agriculture, forestry, fisheries, energy, industry, transport, waste management, water management, telecommunications, tourism, town and country planning, or land use **and** which set the framework for future development consent for projects listed in Annexes I and II to the Environmental Impact Assessment (EIA) Directive (85/337/EEC as amended by 97/11/EC); and

- requiring assessment under Article 6 or 7 of the Habitats Directive (92/43/EEC).

Outside this core scope, environmental assessment is required for any plans and programmes which set the framework for development consent of projects (not limited to those listed in the EIA Directive) and which are determined by screening to be likely to have significant environmental effects.

The UK has prepared guidance on the implementation of SEA[66] which would be relevant to the consideration of a barrage proposal. This includes guidance on:

- the level of detail required;
- consultation requirements;
- consideration of alternatives; and
- decision making.

These aspects are considered in turn below.

Level of detail

Section 2.2 of the Guidance states that:

> 'An SEA need not be done in any more detail, or using any more resources than is useful for its purpose. The Directive requires consideration of the significant environmental effects of the plan or programme, and of reasonable alternatives that take into account the objectives and the geographical scope of the plan or programme'.

Consultation requirements

The Directive requires that authorities which, because of their responsibilities, are likely to be concerned by the effects of implementing the plan or programme, must be consulted on the scope and level of detail of the information to be included in the Environmental Report (termed Consultation Bodies in the UK Regulations). In the UK, the Consultation Bodies include Natural England/Countryside Council for Wales and the Environment Agency/Environment Agency Wales. The public and the Consultation Bodies must be consulted on the draft plan or programme and the Environmental Report. The Directive requires that responses to consultation are to be taken into account during the preparation of the plan or programme and before its adoption or submission to a legislative procedure. The authority must also take account of any legal obligations or guidelines, in addition to those of the Directive, which are relevant to the plan or programme for which it is responsible.

Consideration of alternatives

The Directive requires that reasonable alternatives should be considered alongside the proposed plan or programme. The guidance indicates that such options should include a 'do nothing' option, but also consider options such as obviation of demand, for example, improving energy efficiency rather than increasing electricity generating capacity.

---

[66] ODPM, 2005. A Practical Guide to the Strategic Environmental Assessment Directive.

The guidance recognises that the options considered need to be appropriate to a particular stage or level of plan, for example, for some responsible authorities, demand reduction measures may be outside their powers. A wider range of alternatives will be available at a regional level than at a local level, and decisions made at the higher level will close off some alternatives. Nevertheless, 'up the hierarchy' thinking could suggest a wider, and more sustainable, range of alternatives than previously considered.

Stakeholders may usefully be involved in the generation and assessment of both strategic and more detailed alternatives through consultation.

Decision making

The Directive requires the information on the Environmental Report and the responses to consultation to be taken into account during the preparation of the plan or programme and before the final decision is taken to adopt it. Responsible authorities must produce a summary of how they have taken these findings into account, and how environmental considerations have been integrated into the plan or programme, with enough information to make clear any changes made or alternatives rejected.

6.2.5 Environmental Impact Assessment

Directive 85/337/EEC on 'The assessment of the effects of certain public and private projects on the environment', came into effect in July 1988 and was amended by Directive 97/11/EC. Recently, it has been further amended by the Public Participation Directive (2003/35/EC) to take account of requirements for improved public participation and consultation in decision making. The effect of the Directive is to require environmental impact assessment to be carried out, before development consent is granted, for certain types of major project which are judged likely to have significant environmental effects. A barrage proposal would require an environmental impact assessment in accordance with the provisions of the Directive.

Environmental impact assessment (EIA) is an important procedure for ensuring that the likely effects of new development on the environment are fully understood and taken into account before the development is allowed to go ahead.

EIA in the UK has been implemented on a sectoral basis. The Electricity Works (Environmental Impact Assessment) (England and Wales) Regulations 2000 implement the requirements of the Directive for electricity generation projects, although the requirements of these regulations may be subsumed within any specific Barrage Act.

The EIA Directive applies to the assessment of environmental effects from public and private projects which are likely to have a significant effect on the environment. Annexes I and II of the EIA Directive list the projects which should or may be subject to an environmental impact assessment before consent is given for such a project to proceed. Where an EIA is required, the direct and indirect effects of a project on the following factors must be identified (following amendments made under Council Directive (97/11/EC[67]):

- human beings, fauna and flora;
- soil, water, air, climate and the landscape;
- material assets and the cultural heritage; and
- the interaction between these factors.

Guidance on the application of EIA is available from:

- ODPM 2000. Environmental Impact Assessment – A Guide to Procedures
- ODPM Circular 02/99: Environmental Impact Assessment (currently in revision)

[67] Council Directive 97/11/EC, Official Journal L 073, 14/03/1997, p.5. http://ec.europa.eu/environment/eia/full-legal-text/9711.htm

The guidance includes advice on the consideration of alternatives, consultation arrangements and decision making, which are briefly discussed below.

Consideration of alternatives

The Directive and implementing regulations do not expressly require a developer to study alternatives. However, the nature of certain developments and their location may make the consideration of alternative sites a material consideration. In such cases, the Environmental Statement (ES) must record this consideration of alternative sites. More generally, consideration of alternatives (including alternative sites, choice of process, and the phasing of construction) is widely regarded as good practice, and resulting in a more robust application for planning permission. Ideally, EIA should start at the stage of site and process selection, so that the environmental merits of practicable alternatives can be properly considered. Where this is undertaken, the main alternatives considered must be outlined in the ES. The Dibden Bay decision has clarified that the range of alternatives for consideration should relate to those alternatives that were available to the project promoter.

Consultation

The Regulations give a particular role in environmental impact assessment to those public bodies with statutory environmental responsibilities that must be consulted by the planning authority before a Schedule 1 or a Schedule 2 planning application is determined. Such public bodies include the conservation agencies and the Environment Agency.

Decision making

In determining an application, the authority is required to have regard to the environmental statement as well as to other material considerations.

6.2.6 Wildlife & Countryside Act 1981

The Wildlife & Countryside Act 1981 (as amended by the Countryside & Rights of Way Act 2000) provides for the protection of important national wildlife in Great Britain. This includes the notification of sites of special interest (SSSIs), protection of such sites against damage and protection of endangered species.

Through the Act, there is an important general duty on a range of authorities exercising functions which are likely to affect SSSI. This general and overarching duty requires an authority to take reasonable steps, consistent with the proper exercise of the authority's functions, to further the conservation and enhancement of the features for which sites are of special interest (section 28G(2) of Wildlife & Countryside Act (as amended). It applies whenever an authority is exercising its functions, including when it has powers to take action, and applies at every stage from the formulation of plans to the carrying out of operations and the making of decisions. The duty applies to Ministers, Government Departments and any other public body (section 28G(3)).

Under section 28I of the Act, where a decision-making authority is granting permission for other parties to carry out operations likely to damage the special interest features of a SSSI, they must notify the relevant conservation agency (Natural England in England, Countryside Council for Wales in Wales) before reaching their decision (section 28I(2)). The authority must then allow 28 days before deciding whether to grant its consent unless the conservation authority has responded sooner (section 28I(4)). The authority must take account of any advice from the conservation agency, including advice on attaching conditions to a consent (section 28I(5)). If the authority decides that it will issue a permission against the conservation agency's advice, it must notify the conservation agency of the permission, the terms on which it is proposed to grant it and how, if at all, it has taken the conservation agency's advice into account. It must then allow a further period of 21 days before the operation can commence (section 28I(6)). This allows the conservation agency to consider any further action, such as, in exceptional circumstances, legal action challenging the validity of the permission.

These provisions ensure that the conservation agencies are able to provide full advice and information about the effects of an operation or authorisation on an SSSI and any steps that might mitigate them. This will enable the decision taker to make an informed decision about whether, and how, to go ahead with an operation or to grant an authorisation and, if so, on what terms.

Section 9 prohibits the intentional killing, injuring or taking, the possession and the trade in wild animals listed on Schedule 5. This includes species such as dolphins, porpoises, whales, otters, allis shad and twaite shad which might be encountered in the Severn Estuary. In addition, places used for shelter and protection are safeguarded against intentional damage, destruction and obstruction and animals protected under the relevant part of Section 9 must not intentionally be disturbed whilst occupying those places.

6.2.7 Food and Environment Protection Act 1985

The Secretary of State for Environment, Food and Rural Affairs (and in Wales, the Welsh Assembly Government) has a statutory duty to control the deposit of articles or materials in the sea / tidal waters; the primary objectives being to protect the marine ecosystem and human health, and minimising interference and nuisance to others. This duty is exercised through powers conferred by the Food and Environment Protection Act Part II (FEPA) FEPA requires that a licence be obtained from the licensing authority to deposit any articles or substances in the sea or under the seabed. A barrage would be subject to the requirements of FEPA but these requirements may be subsumed within any Barrage Act.

The statutory controls exercised under the Food and Environment Protection Act 1985 (FEPA) regulate the deposit or placement of articles or materials in the sea or tidal waters for use in construction or similar works.

The Act requires the licensing authority, in deciding whether to issue a licence, to have regard to the need to:

- protect the marine environment and the living resources which it supports and human health;
- prevent interference with legitimate use of the sea;
- minimise any nuisance or noise arising from the disposal of waste; and
- to consider other matters as the authority considers relevant.

The controls exercised by the Act apply to the deposit or placement of articles and materials that it is proposed to use during construction. In this context, the primary environmental considerations are the potential hydrological effects; interference with other marine activities; the possibility of turbidity and drift of fine materials to smother seabed flora and fauna, and adverse implications for designated conservation areas.

The controls apply equally to all waste materials which are disposed at sea (principally dredged materials) where, in addition to the environmental factors above, consideration may focus particularly on the potential risk to fish and other marine life from contaminants and burial of benthic communities.

6.2.8 Water Resources Act 1991

Part III of the Water Resources Act 1991, *inter alia*, seeks to protect controlled waters from pollution from point sources discharges through a system of licensing and control. Any discharges arising from the construction or operation of the barrage with the potential to cause pollution of controlled waters would require licensing under the Act. Such discharges might arise from, for example, pumping out of water from within coffer dams, or discharge of contaminated surface water run-off during scheme operation.

Furthermore, because of the nature and scale of possible barrage options, and the potential for very significant changes to the flow regime in the Severn and tributary estuaries, the Habitats Directive is likely to require a review of existing discharge consents to these waters (under the Water Resources Act) to ensure that the environmental risks associated with these discharges continue to be minimised in relation to the objectives of the designated sites.

Part IV of the Water Resources Act contains provisions for the approval of schemes affecting flood defences to be approved by the relevant Flood Defence Committee.

6.3 ENVIRONMENTAL DESIGNATIONS

The Severn Estuary area is recognised through a number of international, national and local designations including (see Figures 6.2(1) and 6.2(2)):

- Special Protection Area (SPA);
- Ramsar Site;
- Special Areas of Conservation (SAC) and a possible SAC (pSAC);
- Sites of Special Scientific Interest (SSSIs);
- National Nature Reserves (NNRs);
- Local Nature Reserves (LNRs);
- Sites of Importance for Nature Conservation (SINCs);
- European Marine Site.

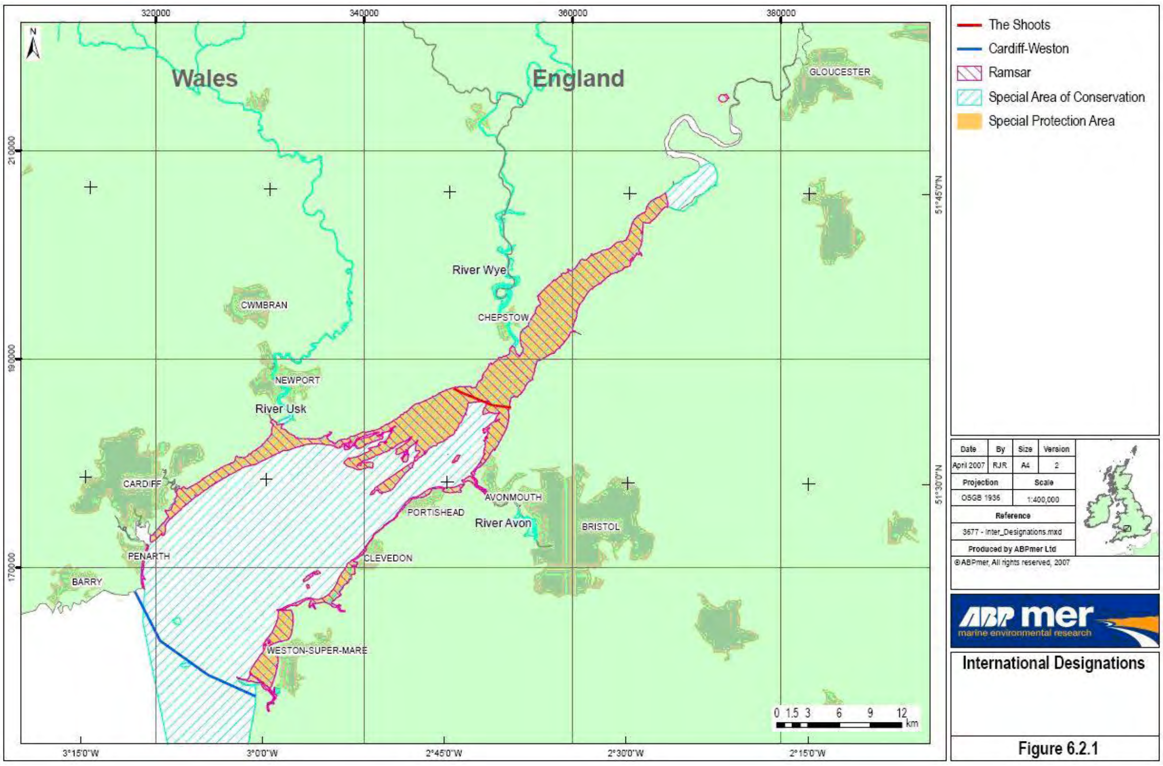


Figure 6.2(1): International designations

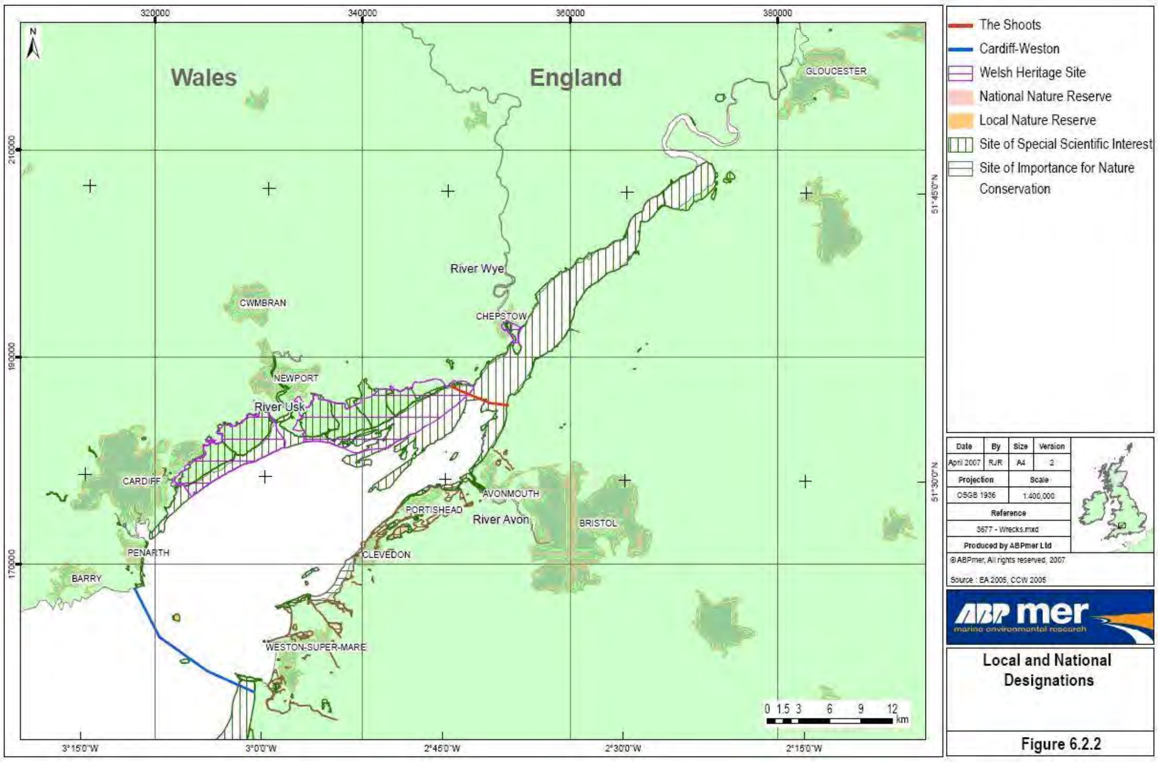


Figure 6.2(2): National designations

6.3.1 The Severn Estuary SPA

The EC Birds Directive (79/409/EEC) requires all member states to identify areas to be given special protection for the rare or vulnerable species listed in Annex 1 of the Directive (Article 4.1), for regularly occurring migratory species (Article 4.2) and for the protection of wetlands, especially wetlands of international importance. These areas are known as Special Protection Areas (SPAs).

The Severn Estuary SPA was classified in 1995 and has an overall size of approximately 24,663 ha. Information on populations of bird species using the Severn Estuary European Marine Site at the time the Severn Estuary SPA was classified is presented in Table 6.2(1).

The Severn Estuary SPA qualifies under Article 4.1 of the EU Birds Directive by supporting internationally important populations of regularly occurring Annex I species.

It also qualifies under Article 4.2 of the EU Birds Directive in that it supports:

- Internationally important populations of regularly occurring migratory species; and
- An internationally important assemblage of waterfowl.

Table 6.2(1): Information on populations of bird species using the Severn Estuary European marine site at the time the Severn Estuary SPA was classified.

A - Internationally important populations of regularly occurring Annex 1 species

Species	Population	(5 yr peak mean :1988/9 to 1992/3)
Bewick's swan Cygnus columbianus bewickii	289 birds	4.1% Great Britain 1.7% North West Europe

B - Internationally important populations of regularly occurring migratory bird species

Species	Population (5 yr peak mean: 1988/9 to 1992/3)	
Shelduck *Tadorna tadorna*	2,892 birds	1.2% North West Europe
Dunlin *Calidris alpina alpina*	41,683	2.9% East Atlantic flyway
Redshank *Tringa totanus*	2,013	1.3% East Atlantic flyway
European white-fronted goose *Anser albifrons Albifrons*	3,002	1.0% North West Europe

An internationally important assemblage of waterfowl

Importance	Population (5 yr peak mean: 1988/9 to 1992/3)
The Severn Estuary supports over 20,000 wintering waterfowl.	68,026 individual birds comprising 17,502 wildfowl and 50,524 waders

Nationally important bird populations within internationally important assemblage of waterfowl

Species	Population (5 yr peak mean: 1988/9 to 1992/3)	
Wigeon *Anas penelope*	3,977 birds	1.6% Great Britain
Teal *Anas crecca*	1,998	2.0% Great Britain
Pintail *Anas acuta*	523	2.1% Great Britain
Pochard *Aythya ferina*	1,686	3.8% Great Britain
Tufted duck *Aythya fuligula*	913	1.5% Great Britain
Ringed plover *Charadrius hiaticula*	227	1.0% Great Britain
Grey plover *Pluvialis squatarola*	781	3.7% Great Britain
Curlew *Numenius arquata*	3,096	3.4% Great Britain
Whimbrel *Numenius phaeopus*	246	4.9% Great Britain
Spotted redshank *Tringa erythropus*	3	1.5% Great Britain

Sub-features of the SPA, which support these bird species, include:

- Intertidal mudflats and sandflats;
- Saltmarsh; and
- Shingle and rocky shore.

The site also supports a number of terrestrial features:

- Internationally important populations of regularly occurring migratory species, Gadwall *Anas streprea;*
- Wet grazing marsh is a supporting habitat.

6.3.2 Severn Estuary pSAC

The EC Habitats Directive (92/43/EEC) requires the establishment of a network of important high quality conservation sites that will make a significant contribution to conserving the 169 habitat types and 623 species identified in Annexes I and II of the Habitats Directive. The listed habitat types and species are those considered to be most in need of conservation at a European level with the overall aim of the Directive being the conservation of biodiversity.

The Severn Estuary has been recommended as a pSAC because it contains habitat types and species that are threatened within a European context. The following list contains the European Interest features for which the site has been proposed:

- *Alosa alosa* - allis shad.
- *Alosa fallax* - twaite shad.
- Atlantic saltmeadows (*Glauco-Puccinellietalia maritimae*) - encompasses salt marsh vegetation containing perennial flowering plants that are regularly inundated by the sea.
- Estuaries - semi enclosed bodies of water which have a free connection with the open sea and within which the seawater is measurably diluted by freshwater from the surrounding land.
- *Lampetra fluviatilis* - River lamprey.
- Mudflats and sandflats not covered by seawater at low tide - these are mud and sand sediments that are exposed at low tide but submerged at high tide.
- *Petromyzon marinus* - sea lamprey.
- Reefs - areas of rock or biological concretions formed by various invertebrate species.
- Sandbanks which are slightly covered by sea water all the time

6.3.3 Severn Estuary Ramsar Site

Under the 1972 Ramsar Convention on Wetlands of International Importance, it is a requirement of signatory states to protect wetland sites of international importance, including those that are important waterfowl habitats. The Severn Estuary Ramsar Site has an overall area of approximately 24,663 ha. The Severn Estuary qualifies as a Ramsar Site through meeting a number of the qualifying criteria (Appendix A) as outlined below:

- Criterion 1 - due to its immense tidal range.
- Criterion 3 - due to itsunusual estuarine communities, reduced diversity and high productivity.
- Criterion 4 - as it is particularly important for the run of migratory fish between the sea and rivers via the estuary.
- Criterion 5 - bird assemblages of international importance.
- Criterion 6 - bird species/ populations occurring at levels of international importance. (Qualifying species at time of designation: tundra swan (*Cygnus columbianus bewickii*), greater white fronted goose (*Anser albifrons*), common shelduck (*Tadorna tadorna*), gadwall (*Anas strepera strepera*), dunlin (*Calidris alpina alapina*) and common redshank (*Tringa tetanus tetanus*).
- Criterion 8 – the fish population of the whole estuarine and river system is one of the most diverse in Britain with over 110 species recorded.

6.3.4 European Marine Site

SACs and SPAs are defined as European Sites in the Conservation (Natural Habitats &c.) Regulations 1994. Where the European Site lies below highest astronomical tide, i.e. land covered (continuously or intermittently) by tidal waters, or any part of the sea, in or adjacent to Great Britain, up to the seaward limit of territorial waters, it is described as a European Marine Site. The designated SPA described previously therefore forms part of the Severn Estuary European Marine Site.

Interim advice for the Severn Estuary European Marine Site has been produced under Regulation 33(2) of the Conservation (Natural Habitats &c.) Regulations 1994 (English Nature and the Countryside Council for Wales, 2005). The Advice outlines the conservation objectives for the European Marine Site and advises relevant authorities as to any operations which may cause deterioration of natural habitats or the habitats and species, or disturbance of species for which the site has been designated.

6.3.5 River Usk SAC

The Usk is a medium-sized catchment in south Wales, which flows eastwards along the Brecon Beacons, meandering through Monmouthshire to the tidal waters of the Severn Estuary. Annex I habitats present as a qualifying feature, but not a primary reason for selection of this site include:

- Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation

Annex II species that are a primary reason for selection of this site include:

- *Petromyzon marinus* – sea lamprey
- *Lampetra planeri* – brook lamprey
- *Lampetra fluviatilis* – river lamprey
- *Alosa fallax* – twaite shad
- *Salmo salar* – atlantic salmon
- *Cottus gobio* – bullhead
- *Lutra lutra* - Otter

Annex II species present as a qualifying feature, but not a primary reason for site selection and include:

- *Alosa alosa* - allis shad

6.3.6 River Wye SAC

The Wye, on the border of England and Wales, is a large river with a geologically mixed catchment, including shales and sandstones. There is a clear transition between the upland reaches, with characteristic bryophyte-dominated vegetation, and the lower reaches, with extensive *Ranunculus* beds. The River Wye SAC extends into the tidal waters of the Severn Estuary.

Annex I habitats that are a primary reason for selection of this site include:

- Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation

Annex I habitats present as a qualifying feature, but not a primary reason for selection of this site include:

- Transition mires and quaking bogs

The Annex II species that are a primary reason for the selection of this site include:

- *Austropotamobius pallipes* – white clawed crayfish.
- *Petromyzon marinus* – sea lamprey
- *Lampetra planeri* – brook lamprey
- *Lampetra fluviatilis* – river lamprey
- *Alosa fallax* – twaite shad
- *Salmo salar* – atlantic salmon

Annex II species present as a qualifying feature, but not a primary reason for site selection include:

- *Alosa alsoa* - allis shad

6.3.7 National and local designations

There are a large number of additional nature conservation designations that occur within and adjacent to the Severn Estuary. Tables 6.2(2) and 6.2(3) present an overview of the sites which intersect with the coastline and could therefore be impacted by a barrage scheme. The sites have been designated for a range of geological and biological interests and those SSSIs that form component parts of the Severn Estuary SPA are highlighted in Table 6.2(2). Many of the sites within this area are contiguous including terrestrial, riverine and estuarine habitats and species. In addition to the statutory and non-statutory designations, there are a host of other sites with non-statutory local designations that apply to sites around the estuary[68].

Table 6.2(2): Summary of SSSIs within or adjacent to the Severn Estuary

Site Name	Grid Reference	Area (ha)	Key Interests
Robins Wood Hill Quarry	SO8314	1.9	Robin's Wood Hill Quarry provides the best inland section of Lower Jurassic, Middle Lias strata in Britain; a complete section of the Upper Pliensbachian Stage is present.
Garden Cliff	SO7112	5.2	Complete local succession of the Rhaetian, from the Tea Green Maria to the base of the Lower Lias.
Upper Severn Estuary*	SO7106	1,457.5	International conservation importance. Uppermost part of the Severn Estuary and its marginal saltmarsh and pastureland. A wide range of estuarine habitats, outstanding ornithological significance. Regularly supports more than 10,000 wintering wildfowl. Amongst these are internationally significant numbers of Bewick' swans *Cygnus columbianus.*
Purton Passage	SO6804	4.7	Important locality for studies of vertebrate palaeontology. Rocks of Upper Ludlow (Silurian) age exposed on the foreshore at Tites Point include bone beds which have been described as the most productive bone beds of their age. Primitive fish remains which include thelodont denticles and acanthodian fragments are diverse and abundant.
Lydney Cliff	SO6501	8.6	Contains exposures in the topmost Raglan Marls. Two important fish beds also occur here, amongst several fish bearing horizons in a sequence of Upper Silurian-Lower Devonian strata. One of the fish beds contains species of cephalaspids and cyathaspids together with bivalves molluscs.
Pennsylvania Fields Sedbury	ST5492	26.7	The brackish pastureland is dominated by a mixture of species including mud rush *Juncus gerardii*, grasses such as meadow barley *Hordeum secalinum,* red fescue *Festuca rubra*, marsh foxtail *Alopecurus geniculatus* and large amounts of the nationally rare bulbous foxtail *Alopecurus bulbosus*. Scattered throughout the site are a variety of saltmarsh plants.
Aust Cliff	ST5689	8.3	Conglomeratic unit contains rich fish faunas, marine reptiles and the dinosaur *Avalonia.* most productive locality in Britain for Triassic insects: famous for its Rhaetic bone bed.
Portishead Pier To Black Nore	ST4476	70.2	Portishead Pier -section of alluvial sandstones is the best exposure of Upper Carboniferous rocks in the Avonmouth Coalfield.Portishead Point - geological structures formed during the Variscan mountain building episode. Portishead - exposures of the Devonian sequence

[68] English Nature and the Countryside Council for Wales, 2005. English Nature & the Countryside Council for Wales' advice for the Severn Estuary Special Protection Area given under Regulation 33(2) of the Conservation (Natural Habitats &c.) Regulations 1994.

Site Name	Grid Reference	Area (ha)	Key Interests
			south of the Bristol Channel.
Walton Common	ST4273	26.6	Complex mosaic of grassland, scrub and woodland, and is of high botanical and entomological interest. The site is one of only two known locations in Britain for the nationally rare moss *Cheilothela chloropus*.
Clevedon Shore	ST4071	0.4	A mineralised fault, trending east-west adjacent to the pier, forms a small cliff feature in Dolomitic Conglomerate bounding the north side of Clevedon Beach.
Middle Hope	ST3366	93.8	Middle Hope supports a calcareous grassland community with a restricted British distribution. Additional interest lies in the occurrence of a plant species considered to be endangered in Britain. The geological interest of the site is great as Middle Hope affords some fine carbonate exposures and features of fundamental importance for geological demonstration.
Spring Cove Cliffs	ST3062	2.0	Spring Cove Cliffs are of geological importance because of the stratigraphic and igneous features which are displayed.
Steep Holm*	ST2260	26.0	260 recorded species, which includes several rarities, is of particular interest because of the long period (400 years) for which records are available.
Bridgwater Bay*	ST2849	5,618.2	Succession of habitats ranging through extensive intertidal mudflats, saltmarsh, shingle beach and grazing marsh intersected by a complex network of freshwater and brackish ditches. It supports internationally and nationally important numbers of over-wintering and passage migrant waders and waterfowl. Largest Common Cord-grass *Spartina anglica* swards in the Severn Estuary. Nationally scarce species include the aquatic snail *Cyraulus laevis*, the Hairy Dragonfly *Brachytron pratense* and a ladybird *Coccidula scutellata*.
Brean Down	ST2858	66.2	Outstanding examples of calcareous grassland, supports plant communities which are very local in Britain and is a locality for several rare plants and insects. Beds of Devensian age contain abundant remains of horse, reindeer, lemmings and other mammals in an excellent state of preservation.
Uphill Cliff	ST3158	19.5	Somerset Hair Grass *Koeleria vallesiana*, and Honewort *Trinia glauca* which are largely confined to the Somerset/Avon borders, and Goldilocks *Aster linosyris* of which there are now only 8 colonies in Britain.
Berrow Dunes	ST2952	200.7	Supports one of the most diverse floras in Somerset. 272 species of flowering plant have been recorded. 2 are nationally rare, while at least 10 have a restricted distribution in Britain. A rich invertebrate fauna with 3 nationally rare species and 21 notable species occurs, and the area is locally important for breeding and wintering birds. The dune system is of geomorphological interest.
Flat Holm*	ST2264	35.3	One of the few British stations for the rare wild leek and another plant of restricted distribution in Britain, bird's-foot clover, is also found here. notable breeding colony of lesser black-backed gulls and to a lesser extent herring gulls.
Gwent Levels - Magor And Undy	ST4385	605.2	A total of 43 nationally rare and notable invertebrate species such as the soldier fly *Stratiomys furcata*, the snail killing fly *Pherbellia brunnipes* and the water beetle *Haliplus mucronatus*. Also supports a number of rare and notable aquatic plant species including the

Site Name	Grid Reference	Area (ha)	Key Interests
			pondweed *Potamogeton trichoides* and *P berchtoldii* and the narrow-leaved water plantain.
Gwent Levels - Nash And Goldcliff	ST3584	981.3	Particular botanical interest as it is the only area in Wales for the least duckweed. There is also an interesting community where two species of hornwort grow together. The invertebrate interest is also high, as rare and notable species such as *Odontomyia ornata*, *Oplodontha viridula* and *Hydaticus transversalis* are present.
Gwent Levels - Redwick And Llandevenny	ST4185	969.6	Supports rich assemblages of invertebrates including *Chalcis sispes* a parasite of the Stratiomys fly larvae, the beetle *Scirtes orbicularis* and the drone fly *Pharhelophilus consimilis:* nationally rare plant species including the rare *Myriophyllum verticillatum.*
Gwent Levels - Rumney And Peterstone	ST2579	1,042.5	Nationally rare brackish water-crowfoot and several regional rarities including the pondweeds *Potamogeton obtusifolius* and *Potamogeton berchtoldii*.
Gwent Levels - St. Brides	ST2882	1,351.3	Thread-leaved water-crowfoot and small pondweed, relict meadow plant species such as the regionally notable grass vetchling and common meadow-rue, rich invertebrate communities with a number of nationally notable and notable marshland species, e.g. the true fly *Chrysogaster macquarti* and the beetle *Hydaticus transversalis*.
Gwent Levels - Whitson	ST3884	954.9	Particular importance for its large number of nationally rare and notable invertebrate species. Also important for its botanical interest as it contains the nationally rare hairlike pondweed and is the only location in Gwent for the tussock sedge. Arrowhead also grows in abundance in several main reens in this area.
Penarth Coast*	ST1868	54.3	Rich calcareous grassland and cliff-top scrub which supports a number of plant species of limited occurrence and distribution in the former counties of Mid and South Glamorgan, including dyer's greenweed, butterfly orchid, bee orchid and adder's tongue.
River Usk (Lower Usk)/Afon Wysg (Wysg Isaf)	ST3286	209.8	Rare example of a large lowland river which has not been subject to significant modification by man. Common knapweed, meadowsweet, comfrey, common otter are widespread along the length of the river; wide range of riverside breeding birds such as sand martin and kingfisher nesting in eroding earth cliffs.
River Wye (Lower Wye) Afon Gwy (Gwy Isaf)	ST5492	64.5	Rare example of a large western eutrophic river which has not been subject to many significant modifications from human activities. The river is of special interest for three main aquatic plant community types – rivers on sandstone, mudstone and hard limestone; clay rivers; and lowland rivers with minimal gradient, as well as for certain flowering plants and bryophytes.
Severn Estuary*	ST 480830	14,938	Intertidal zone of mudflats, sand banks, rocky platforms and saltmarsh is one of the largest and most important in Britain. internationally important populations of waterfowl; invertebrate populations of considerable interest; and large populations of migratory fish, including the nationally rare and endangered Allis shad. The estuary has a diverse geological setting and a wide range of geomorphological features, especially sediment deposits.
Taf/Ely Estuary	ST1873	167.4	Special interest for its saltmarsh vegetation, which is associated with extensive areas of intertidal mud, sand and the river channel. The site is also of special interest for two species of migratory fish.

Site Name	Grid Reference	Area (ha)	Key Interests
Sully Island*	ST 167670	11.5	In geological terms this site demonstrates the regionally significant unconformity between Carboniferous and Triassic rocks, as well as a range of sediments, facilitating study of the lake facies and palaeoenvironments prevalent in late Triassic times. An important site for birds.

Table 6.2(3): Summary of NNRs, LNRs, SINCs and other designations within or adjacent to the Severn Estuary

Site Name	Grid Reference	Area (ha)	Key Interests
Flat Holm Local Nature Reserve (LNR)	ST2264	11.19	Herring gulls, the lesser black back gull and the greater black back gull. A special range of maritime grass species which withstand high levels of salt grows here. Slow worms can be found under rocks and logs and are commonly mistaken for snakes! A wide collection of meadow plants such as the wild leek.
Bridgwater Bay National Nature Reserves (NNR)	ST2647	2283.07	Important bird population with approximately 190 species recorded on the reserve.
The Gwent Levels Welsh Heritage Site	ST2780	10557	Although they are an important wetland resource in their own right, archaeologically the area contains a variety of landscapes of different dates.
Lower Wye Valley Welsh Heritage Site	ST5492	250	
Gwent Levels Historic Landscape			The Outstanding Historic Landscape of Gwent Levels comprises three discrete and extensive areas of alluvial wetlands and intertidal mudflats situated on the north side of the Severn Estuary represent the largest and most significant example in Wales of a 'hand-crafted' landscape.
Newport Wetland Reserve	ST3583	438	Newport Wetlands Reserve was created in response to the loss of mudflats at Cardiff Bay and opened in 2000. It is now home to a wide range of animals and plants.

6.4 WATER LEVELS, CURRENTS AND WAVES

6.4.1 Water levels

The high tidal range is a defining characteristic of the Severn Estuary and is the feature that draws interest in a barrage. The tide moves into the estuary from the Bristol Channel as a progressive tidal wave with a fairly symmetrical sinusoidal shape. As the tide moves upstream it amplifies in range due to the funnel shape of the estuary, reaching a maximum at Beachley (12.3m on mean spring tides). Further upstream the estuary shallows rapidly leading to increased tidal asymmetry due to shallow water effects. Eventually this steepening leads to the formation of a tidal bore from around Minsterworth during periods of high spring tides.

A further feature of the tide relates to periods around low waters. Upstream of White House (Oldbury Power Station), low water levels on neap tides fall to marginally lower levels (0.1m on average) than on spring tides. This is due to the longer times required to drain the larger volumes of water on a spring tide, meaning that the system has not fully drained before the next flood tide commences.

Implications of a barrage

Figure 6.3(1) illustrates predicted changes in water surface profiles at times of high and low water resulting from the Cardiff-Weston.

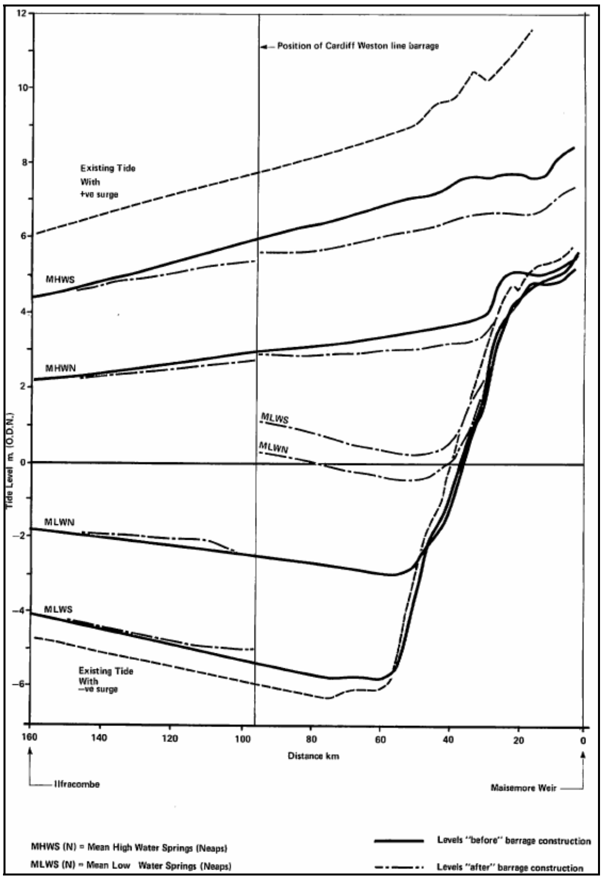


Figure 6.3(1): Envelope of high and low waters resulting from the Cardiff-Weston barrage[59]

On the basis of these predictions, the following comments are offered:

Upstream

- Low tide levels in the basin would only fall to about present mean sea level (except where constrained by local high bed levels)
- The mean water level in the basin would be raised by some 2.5m to 3m
- Low water neaps would drop lower than low water springs, by around 1m
- High waters would also be reduced and by as much as 1m on spring tides, this would have a critical impact on navigation upstream to Sharpness
- The net effect is over a 50% reduction in tidal range (springs reduced from around 11.5 to 4.5m and neaps from 5.5 to 2.5m).

Downstream

- An apparent reduction in high water spring and neap, an effect which is evident for over 50km downstream of the barrage, declining from a 1m reduction closest to the barrage
- An equivalent raising in low water levels

Figures 6.3(2) illustrates the predicted modification to water levels resulting from The Shoots barrage.

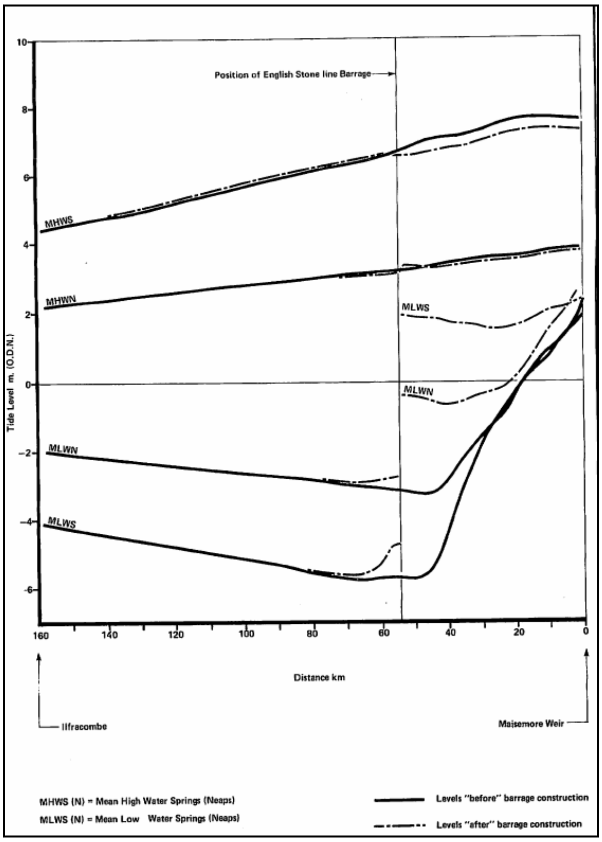


Figure 6.3(2): Envelope of high and low waters resulting from The Shoots barrage[59]

Upstream

- Low tide levels on neaps would fall to just below mean sea level
- Low tide levels on springs would fall substantially less than on neaps
- Around the 20km chainage downstream from Maismore Weir the low water levels on springs and neaps would not drop as far.
- High water springs would reduce by a small amount (around 0.5m)
- High waters on neaps are only marginally affected
- The net effect is around a 50% reduction in tidal range (springs reduced from around 12.5 to 4.5m and neaps from 6.5 to 3.5m).

Downstream

- A very slight reduction in high water spring and neap
- An equivalent raising in low water levels which is more prominent close to the barrage

La Rance

A typical two-week period of operation of La Rance barrage is shown in Figure 6.3(3).

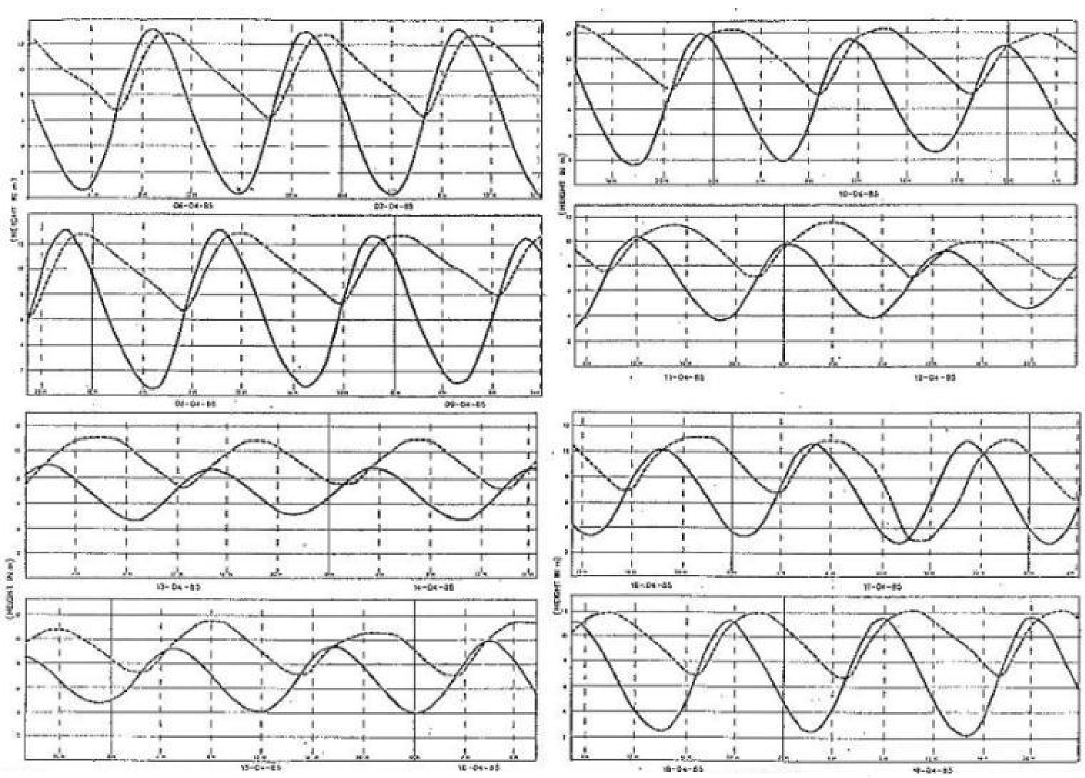


Figure 6.3(3): Representative tide and estuary water level curves at La Rance

Pumping occurs on almost all tides, more on neaps and mid-range tides but with little or none on springs.

It is not appropriate to draw too close a comparison with the case of the Severn Estuary due to the pumping arrangements. However, it is clear that spring tide ranges are reduced by around 50%.

6.4.2 Currents

The large and rapid rise and fall of the tide leads to very strong currents through the main body of the estuary. These strong currents maintain deep channels and high loads of suspended sediment. Flows also increase in strength where they are forced through constrained narrows (e.g. The Shoots). Where the tide becomes asymmetric then a dominance is established between ebb and flood currents. In the Severn, the flood tide becomes dominant in strength over the ebb, but the period of the ebb tide becomes more prolonged. This effect increases further into the estuary and influences the sediment regime.

These currents appear to be the primary mechanism for sorting seabed materials such that channels contain gravels and rocky patches, and intertidal margins have muddy deposits. Within the centre of the estuary there is also a large body of sand known as Middle Ground, extending to Welsh Ground.

Conceptually, the currents produced by the incoming tide travel up the estuary until opposing fluvial flow creates an area of slack flow. The position and time of slack flows changes with each tide. As the current is slowed and halts altogether, deposition of both incoming and fluvial sediment can be expected. he presence of tidal asymmetry results in a division of sediment transport between mud and sand.

For the Severn, marine sands are pushed up the estuary during the fast flowing flood tide where it deposits at the point where slack water is reached. The slower flowing ebb is unable to remobilise all the material for a seaward return. In this way, there tends to be “tidal pumping” of sand up the estuary. The direction of net transport of sands has been confirmed by sediment trends analysis undertaken as part of the original STPG field investigations.

Muds, on the other hand, appear to remain in suspension for most tides, and tend to be introduced to the estuary from fluvial sources.

Implications of a barrage

The consequence of a reduced tidal range is to reduce the currents. In the vicinity of the barrages the water which is allowed to pass into the basin over sluices and pass out through turbines will be focussed into areas leading to locally faster flows. Early modelling approaches are limited in resolving all these effects as they did not fully represent the barrage structures and were based on 2-dimensional depth-average predictions.

6.4.3 Waves

The wave climate in the Severn Estuary is considered to be wind-generated in the main, with exposure to Atlantic swell wave limited by the change in orientation of the estuary around Flat Holm and Steep Holm. Sand Bay and Weston Bay are the limit of Atlantic facing beaches exposed to swell waves.

The wave conditions in the estuary are linked to the tide in that at high water wave fetches can extend over long distances, whereas at low water the inter-tidal banks dramatically reduce fetches.

Implications of barrage

The issue of waves is mostly relevant to the Cardiff-Weston scheme. With water levels in the basin retained above present mid-tide the fetch conditions in the estuary will remain fairly constant as the exposure of banks around low water will no occur. The overall fetch will be slightly reduced for winds blowing from the south-west.

As a consequence, the opportunity for wind-wave growth increases, but the height of the waves may be limited by a reduced fetch from the south-west. Overall, the risk of wave energy dissipating on the margins of the estuary around the revised position of high waters will increase. This concentration of wave energy could be detrimental to soft shorelines.

6.5 SEDIMENT REGIME

6.5.1 Sediment types

The range of sediments present through the Severn Estuary includes both organic and inorganic materials. The components and origins for this material are[69]:

- Clay - part of the geological succession of the Severn Estuary area, in particular of Flandrian age, dating from 2000 to 3000 B.P. This material is becoming extensively exposed in the inter-tidal area due to rising sea level over the last 1000 years. Dense, compact, slowly eroding and largely, if not totally, uncolonised by animals.
- Mud - recent material, brought in by rivers, especially following heavy rainfall, result of land erosion, rich in organics, very mobile, encouraged to flocculate by salinity. Ecologically productive when allowed to consolidate over periods of weeks, prone to erosion in shallow water from storms.
- Sand - generally moving up-stream through the estuary, especially during prevailing westerly storms, readily mobilized, moving intermittently on ebb and flood tides as bedload, but frequently transported in suspension in areas of high flow.

[69] STPG, 1989. The Severn Barrage Project. Detailed report Vol I “Tidal Hydrodynamics, Sediments, Water Quality, Land Drainage and Sea Defences.” Chapter 3 Sediments

- Shingle - occurs in very specific locations, e.g. west of Barry and in the Caldicot area up-estuary of Newport, probably of glacial origin, essentially stable.
- Rock - exposed for much of the Inner Bristol Channel and in places through the Severn Estuary (e.g. The Shoots). Occasionally overlain by thin layers of mobile sands in transport.

These sediment types appear to be highly fractionated with distinct populations of muds around the main rivers and margins of the estuary, contrasting to coarser sands and gravels located mainly in mid-estuary (Figure 6.4(1)).

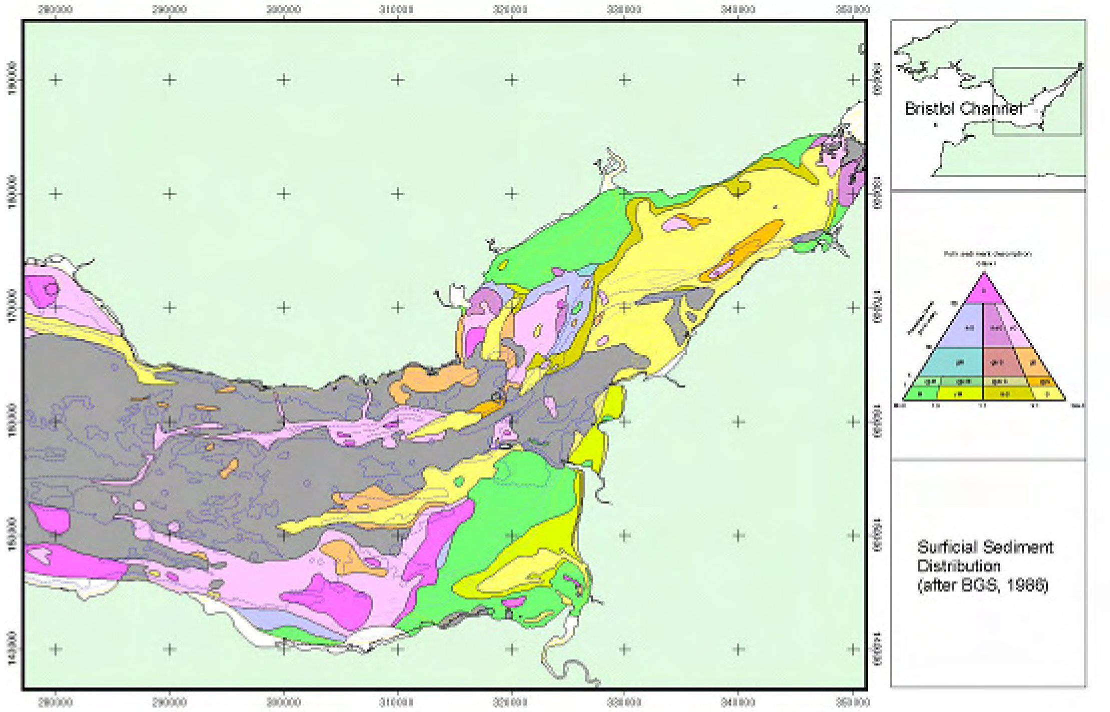


Figure 6.4(1): Seabed sediments[70]

6.5.2 Sediment sources

Sediment sources can be considered as inputs of new sediment to the estuary. These are important to the sustainability of sedimentary features in the area.

Fluvial sediment supply

The major contemporary source for new sediments entering the system corresponds to silt input from the many rivers. A first order estimate suggests that the annual sediment load into the Severn is 1M tonnes/yr[69].

Cliff erosion

It is recognised that some fine sediment is contributed by limestone and shale cliff recession, on the margins of the Bristol Channel and Severn Estuary[71]. Gifford (1998)[72] estimates a total sediment input into the estuary of 0.3M tonnes/yr, with 0.2M tonnes/yr of mud, 0.05M tonnes/yr of sand and 0.05M tonnes/yr of gravel.

---

[70] BGS, 1986. Bristol Channel - Sheet 51ºN - 04ºW. Sea Bed Sediments and Quaternary Geology. 1:250 000 Series. NERC

[71] Allen J.R.L., 1990. The Severn Estuary in southwest Britain: its retreat under marine transgression, and fine-sediment regime. Sedimentary Geology, 66: 13-28.

[72] Gifford & Partners, GeoData Institute, ABP Research and Consultancy, Peter Fraenkel Maritime and Adams Hendry, 1998. Severn Estuary Shoreline Management Plan.

Saltmarsh erosion (horizontal)
STPG (1989) report that around the Severn Estuary marsh erosion represents a very small proportion of the total annual cohesive sediment supply into the estuary (approximately 0.1M tonnes/yr). However, saltmarsh edge has retreated by around 1m/yr, corresponding to a 2 to 3km recession since Roman times[71].

Mudflat erosion
The predominant long-term trend in mudflat behaviour is characterised by erosion. Evans (1982)[73] suggests that inter-tidal erosion supplies around 2.5M tonnes of sediments each year.

Seabed
The seabed has been extensively reworked over the long-term from a bedload parting zone in the inner Bristol Channel to provide an input of coarse sediments. This source is now effectively exhausted leaving a large area which extends eastwards to the line of the Cardiff-Weston barrage.

Seaward input
Although the inner Bristol Channel and Severn Estuary enjoy a flood-dominated tidal regime, different field and laboratory work[74] suggests that the contribution of muds which enters the system from seaward to the west is insignificant compared to the total fluvial supply. The sands, however seem largely to have an immediate western origin. Indeed, according to Barrie (1980a[75], 1980b[76]) the estuarine sand gives every evidence of having an ultimate metamorphic source, and probably largely represents ice-introduced material reworked eastward over post-glacial time from the Celtic Sea and Bristol Channel.

6.5.3 Sediment sinks

Sediment sinks act to remove material from the transport process, leading to deposition.

Saltmarsh accretion (vertical)
The saltmarshes of the inter-tidal zone have historically been subject to extensive land claim, thereby reducing their capacity to act as a sink for cohesive sediments. Nonetheless, although landward recession of the marsh edge might be experienced, many features are experiencing vertical accretion of the marsh surface[77].

Mudflat accretion
In some areas mudflats are perceived to be erosional (see the “Source”, section above), and in other parts of the estuary the mudflat areas are accretional. The mudflats in Bridgwater Bay, Peterstone Flats, and Newport Deep are characterised by an accretion rate between 1 and 2M tonnes/yr. An explanation of the variability of the mudflat behaviour may be related to the river flows. Indeed, the mixing of fresh water and coastal water encourages local deposition in some inter-tidal areas, whereas in the central regions of the estuary the tidal flows generally are so strong as to prevent significant deposition[72].

---

[73] Evans, C.D.R. 1982. The geology and surficial sediments of the Inner Bristol Channel and Severn Estuary. In: Severn Barrage (Proceedings of a symposium organised by the Institution of Civil Engineers, London 8-9 October 1981. Thomas Telford, London. 35-42.

[74] Allen, J.R.L., 1991. Fine sediment and its sources, Severn Estuary and inner Bristol Channel, southwest Britain. Sediment. Geol. 75, 57–65.

[75] Barrie, J.V., 1980a. Heavy mineral distribution in bottom sediments of the Bristol Channel, U.K. Estuarine Coastal Mar. Sci., 11: 369-381.

[76] Barrie, J.V., 1980b. Mineralogy of non-cohesive sedimentary deposits. In: M.B. Collins and others (Editors), Industrialised Embayments and their Environmental Problems. Pergamon Press, Oxford, pp. 249-257.

[77] ABPmer, 2006. Severn Estuary ChaMP Morphological Assessments Part F: Sediment budget analysis, R1260f.

Sub-tidal deposition

On the basis of geophysical surveys, a conservative estimate of settled mud in Bridgwater Bay is 270M tonnes for the sub-tidal area[78]. According to Parker and Kirby (1982)[79] the settled mud population in Bridgwater Bay alone is equivalent to of the order of 200 yrs of river input. This point highlights the importance of the future behaviour of this area, which is likely to have significant implications on the sediment budget.

Sandbanks

Major sand deposits exist within the main body of the estuary as sandbanks and sandflats and adjacent to the main channel. The sand here is normally well-sorted material and has the interest of the marine aggregate industry as a resource for supplying the construction industry. The sandbank features are collectively known as English Grounds and Welsh Grounds.

6.5.4 Material in suspension

For muds, there is generally a high load of material maintained in suspension which is carried over long distances as it advects between ebb and flood phases of the tide. This material has a long residence time with relatively little loss from the system. The natural sink area for this material would be the extensive flood plains which lie behind flood defences (e.g. Somerset and Gwent Levels). Suspended sediment concentrations within the estuary are very large and increase upstream to peak around Sharpness on spring tides (Figure 6.4(2)).

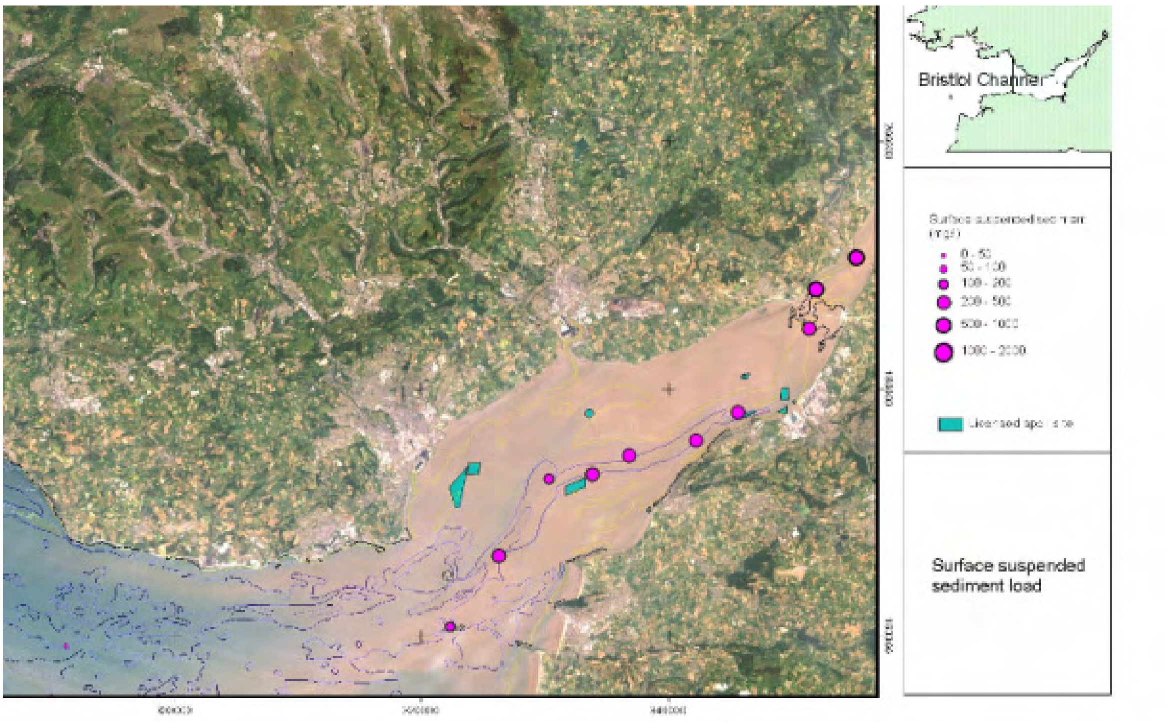


Figure 6.4(2): Suspended sediment load[80]

[78] Collins M.B., 1987. Sediment Transport in the Bristol Channel: A review. Proceedings of the Geologists Association.

[79] Parker, W.R. and Kirby R, 1982. Sources and transport patterns of sediment in the inner Bristol Channel. The Severn Barrage, Thomas Telford, London, 181-89.

[80] ABPmer, 2004. A Review of the Bristol Channel Sediment Regime. R1161.

The suspended sediment load shows a particularly complex distribution, varying on spatial and temporal scales[81]. During the neap period the lower amount of tidal energy allows some of the sediment load to temporarily settle out to form hyper-concentrated areas of fluid mud in main channels, such as Newport Deep. Kirby (1986)[81] estimated a spring tide suspended sediment load of 30M tonnes within the estuary, reducing to about 3M tonnes during neap tides. Collins (1987)[78] calculated a concentration of 13M tonnes of fine suspended sediment during typical spring tides against 9M tonnes during neaps, in the Inner Bristol channel and Severn Estuary.

The chief spatial feature is a consistent sediment front running down the centre line of the estuary, and in line with the thalweg[82]. This front contains between 9M tonnes (neaps) and 17M tonnes (springs) suspended solids[81]. The more turbid water is located on the southern English side (Figure 6.4(3)).

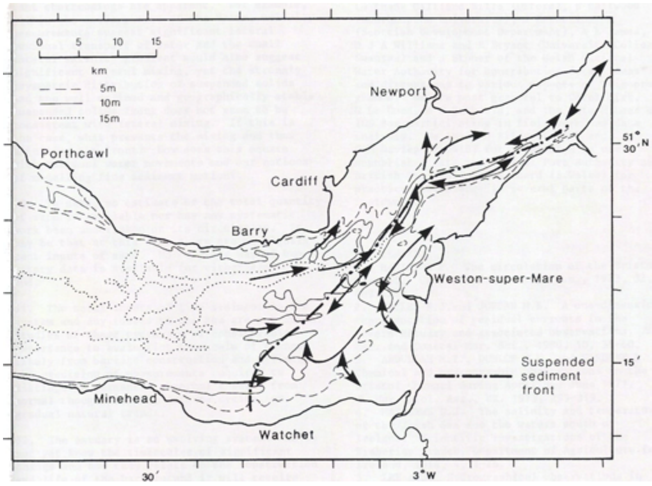


Figure 6.4(3): Schematised circulation of fine sediment [79]

6.5.5 Sediment transport paths

The sediment populations may become transported through the estuary at times when the force exerted by waves and currents (bed shear stress) is sufficiently strong to mobilise the sediment. The occasion when muds and sands become mobile is different leading to different pathways.

Sand transport pathway

It appears that sand is driven by a flood dominated tide, which at times is enhanced by westerly waves, into the Severn Estuary from a bedload parting zone that is fairly coincident in position to the Cardiff-Weston scheme. Along the net easterly sediment pathway the various banks form local recirculation cells and some sand may return westward along the southern sand zone, but there is no firm evidence for this[79].

Mud transport pathway

The general pattern for mud transport is ebb and flood with the tide. Mud deposits in Bridgwater Bay are considered to be fed mainly by sediment loads fluxing along the English side of the estuary. When they reach Bridgwater Bay, the reduced tidal flows enable some of this material to form the mud deposit.

[81] Kirby, R., 1986. Suspended fine cohesive sediment in the Severn Estuary and inner Bristol Channel, U.K. Department of Energy, Energy Technology Support Unit, Rep. ETSU-STP-4042.

[82] Kirby, R., Parker, W.R., 1983. Distribution and behaviour of fine sediment in the Severn Estuary and inner Bristol Channel, U.K. Can. J. Fish. Aquat. Sci 40 (Suppl.), 83-95.

6.5.6 Implications of a barrage

Construction

The construction method for the Cardiff-Weston scheme has been elaborated in order to limit any effect on the overall patterns of water circulation, until the final stage of construction when the turbines and sluices would be set to work. From then, the following impacts are identified[69]:

- Away from the vicinity of the barrage there should not be a huge modification of the coarse sediment regime; and
- Close to the barrage the increase in current speed might tend to erode fine sediments; and would disturb area of soft fine sediment deposits such as the north-western part of Bridgwater Bay.

In addition, some construction activities such as dredging for caissons foundations and shipping channels are expected to affect the sediment regime of the estuary more directly[69]. For example, there may be an increase in the amount of sediment in suspension whilst dredging takes place, although this effect would be relatively short-lived and also small relative to the large amounts of suspended sediment present in the estuary

Barrage operation

Early mathematical modelling suggests that away from the vicinity of the barrage, the tidal force on the seabed (bed shear stress) would be reduced by a factor of about four during flood tides and ten during ebb tides, which leads to the modification of the sediment transport parameters[83], such as:

- A major reduction in sand transport which implies a significant “freezing” of sand patches and veneers development;
- A transport and deposit of mud and sand together, generating mixed substrates (common to estuaries in general); and
- An alteration of the balance of erosion and deposition; with a settlement and consolidation of sediment from the fluid mud phase. Permanent deposition is likely to be observed in deep water area such as Bristol Deep, Newport Deep and the tributary river estuaries[69]. Moreover, the relatively fast flood rise and slow ebb might also contribute to the fine sediment settlement and consolidation.

Close to the scheme, on the contrary, the strong currents circulating through the turbines and sluices would continue to move available sediment (noting the area is already predominantly exposed rock having already been stripped of the majority of mobile sediment) in the direction of the strongest discharge:

- Seaward from the turbines; and
- Up-estuary from the sluices.

Closure would result in the deposition of 85% of presently mobile sediment, mainly in the deeper channels and the suspended sediment concentration will decrease to reach a value commonly observed for other high tide estuaries[83]. The main consequence is that sufficient light would penetrate into the water column creating a viable photic zone, which will allow the development of primary production in the water body.

The currents would be locally strong near the turbines and sluice gates, reducing with distance from the barrage. According to Kirby and Shaw (2005)[83], the only soft sediment zone seaward of

[83] Kirby, R., 2005. Severn Barrage, UK – Environmental reappraisal. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 158, Issue ESI.

the barrage, which it is likely to be affected by the development, is Bridgwater Bay. The supply of mud in this area will be reduced, but the foreshore erosion will be maintained. Even if the current intensity will be lowered, some eroded material will continue to be carried up-estuary past the barrage into the basin.

On the assumption that the mud flat erosion rate inside the basin would reduce, it is expected that the turbidity of the inner Bristol Channel, immediately seaward would decline; this reduction will be further enhanced by generally weaker currents[83].

The Shoots barrage

The Shoots barrage will have the potential to impact on the sediment inputs received from the River Severn and any present exchanges of sediments from the estuary. The initial evaluations of this scheme suggested that the net siltation in the upstream basin would be severe enough to make the project unviable. The recent re-evaluation of this project suggests that design modifications could be able to mitigate any severe siltation effects.

Kirby (1990)[84] estimates sediment infilling of the Shoots barrage, assuming a sediment concentration of 0.05g/l in surface waters and 1g/l in lower waters (Table 6.4(1)). In addition, a distinction is made between the turbines and the sluices input and the following will be considered:

- Sediment inputs through sluices drawing water from upper layers; and
- Turbines drawing water from lower layers of the water column during sluicing mode.

Table 6.4(1) Estimates of sediment infilling of The Shoots barrage[84]

Sediment input	Tonnes/Annum
Input via turbines	9,036,800
Input via sluices	1,807,360
Input via rivers	706,000
Total	11,550,160

According to Kirby (1990)[84], a method for alleviating sedimentation in the English Stones barrage basin would be to not use the turbines in sluicing mode (if possible), and to use sluices sited at high level and located along the barrage to minimize the sediment inflow. On this basis, the potential rate of sedimentation in the basin could reduce from 11.5Mt/yr to 2.5Mt/yr. However, this result is very sensitive to the assumptions regarding the concentrations of suspended sediment in the approaching flow.

It seems that these observations have been taken into account in the Shoots scheme barrage, which is characterised by the following criteria[85]:

- High-level sluice gates; and
- When refilling the basin during flood tide the turbines will be kept closed.

Thus, it is expected that the more sediment-rich lower part of the flow would be excluded from the basin and thus the rate of sedimentation of the basin would be reduced. However to demonstrate the efficiency of this arrangement for excluding sediment from the basin will require significant mathematical modelling, probably in 3D, supported by a programme of appropriate field measurements, to predict with reasonable confidence the vertical and lateral variation in sediment concentrations so that the barrage can be designed to minimise the amount of sediment imported.

[84] Kirby, R., 1990. Shoots barrage, sedimentation report by Dr R Kirby of Ravensrodd Consultants Ltd (originally prepared in 1990 for the Hooker Barrage).

[85] Parsons Brinckerhoff, 2006. Severn Estuary. Shoots Tidal Barrage. Updated Financial Assessment. November 2006.

Kirby suggests several methods for alleviating sedimentation in an English Stones barrage. These are:

- The higher low tide level upstream of the barrage allows some sediment storage before causing adverse effects,
- Rising sea levels with climate change also allow increased sediment storage,
- Timing of refill to be as late in the flood tide as possible,
- Change turbine cycle during sediment laden fluvial floods to prevent sediment settlement in the basin, estimated to persist for 1-3% of the time,
- Consider not operating barrage when estuary sediment concentrations are highest, during highest spring tides or following gales (5 to 15 days per year),
- Consider a silt trap on Welsh grounds to remove sediment from circulation, and
- Dredge sediment from within the basin and deposit seaward of the barrage or on land adjacent to the basin.

Kirby highlights that some of these suggestions are innovative and have not been proved for this type of scheme. This would be relevant to the sediment bypassing, silt trap and dredging proposals.

The change in method and timing of barrage operations and also the closure of the barrage for a few days each year would reduce its annual energy output.

6.6 MORPHOLOGY

In the present context, considerations of morphology relate to large scale-changes in the form of the estuary resulting in quasi-stationary equilibrium in response to natural forces, with such changes observed over contemporary time-scales.

The principal morphological elements of the Severn Estuary are identified as follows[86]:

- Rocky platforms covered with a thin veneer of sediment;
- Major sand deposits and sandbanks in the central regions along the estuary;
- Sub-tidal channels, with gravel and sand deposits or mud deposits;
- Muddy estuaries as tributaries to the Severn Estuary;
- Muddy inter-tidal foreshores with relatively limited saltmarsh development; and
- Some sand beaches and dunes on the English side.

The margins of the estuary are dominated by low-lying "levels" which would be inundated at high water if there were no flood embankments (Figure 6.5(1)). These embankments presently constrain the natural development of the estuary.

[86] ABPmer, 2006. Severn Estuary CHaMP Morphological assessments Part F: Sediment Budget Analysis, R1260f.

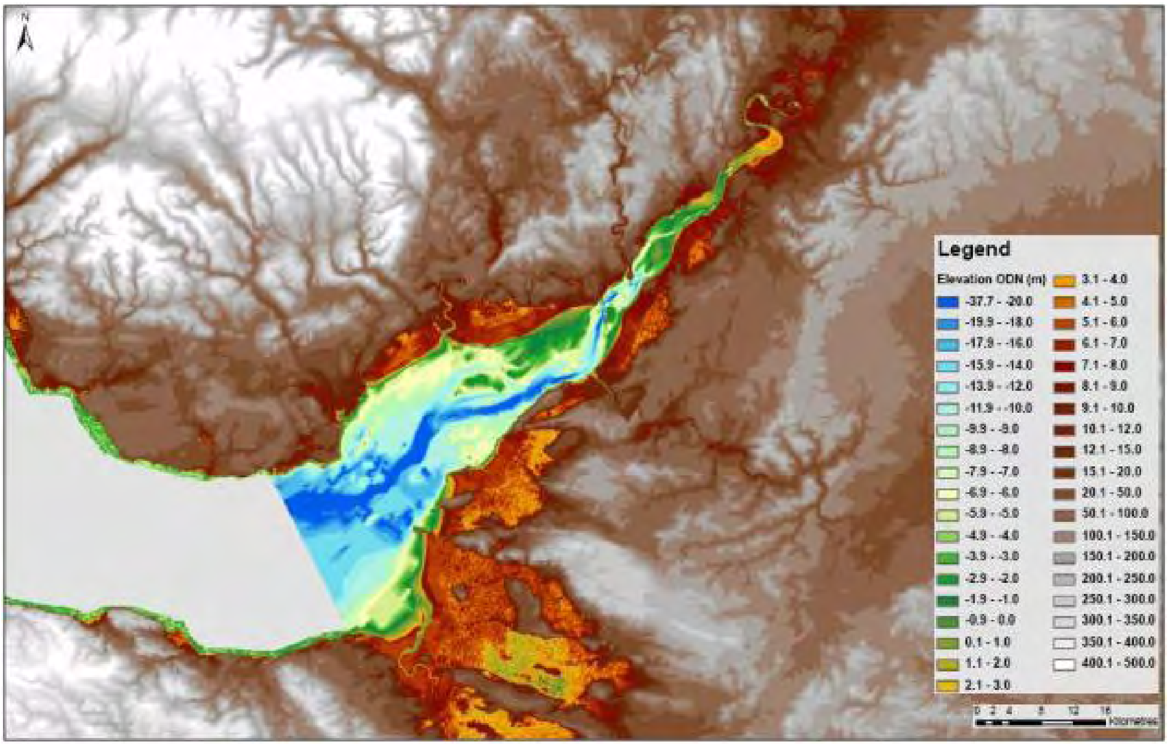


Figure 6.5(1): Areas of low lying land (ABPmer, 2005)

In addition, geological formations (rock bed, islands and headlands) provide a further set of generally non-erodable limits on morphology. Variation of tide, wave and sediment regimes (e.g. supply) provide the main influences which may lead to changes in the form of the estuary between these fixed margins. Along with placement of flood embankments, man's influence in the estuary extends to aggregate dredging, port development, maintenance dredging, impoundment barrages and indirectly upstream in catchments.

One legacy of the estuary's long history with ports and shipping is in the form of navigation charts which date back to 1800's. Modern charts acknowledge the issue of rapidly changing depths across the major sandbanks and intermediate channels, a process that can be as rapid as an ebb and flood phase of one tide in some cases. Any larger scale change of features is a far slower process. However, on decadal timescales, the major sandbanks have shown periods of fragmentation and consolidation[87].

Although not the subject of any concerted study, there is some recent evidence that the position of Cardiff Grounds shifted after the construction of the Cardiff Bay Barrage. Cardiff Grounds, previously one large spit of sand, was observed to have split in two and to have migrated to the south-east and towards Monkstone Lighthouse, leading to the repositioning of the Cardiff Spit buoy.

Future morphological response may occur if increased pressure on the constrained estuary from sea level rise effects requires setback of defences, or if increased storm frequencies drives more sediment into the estuary and modifies the present distribution of sandbanks and sand flats. However, if sea level rise outpaces sediment supply, then the estuary may lose inter-tidal area over time. Consequently, there remains large uncertainty in future morphological response of the Severn Estuary.

[87] Velegrakis, A.F., Houghton, A., Thompson, C., Collins, M.B., 2001. Morphological development and sediment dynamics of the Middle Grounds Bank (Severn Estuary). Technical Report. School of Ocean and Earth Sciences. University of Southampton

6.6.1 Solid geology

The main influences from solid geology exist in the form of headlands, islands and areas of exposed rocky seafloor.

The notable features in the vicinity of the Cardiff-Weston barrage are the carboniferous limestone headland of Brean Down and the mid-estuary islands of Flat Holm and Steep Holm. In between is an area of impoverished rocky seabed.

The Shoots barrage is also linked to a geological constrained reach of the estuary in the area of the bridges. A deep channel known as The Shoots is incised through English Stones.

Sites of geological importance

Much of the geological interest in the coastal area is located in wavecut platforms, and lying between high and low water. As an example, the Lilstock – Blue Anchor exposure is of international importance, being the standard for the base of the Hettangian stage of the Lower Jurassic[88].

6.6.2 Implications of a barrage

As a first comment, there is as yet no detailed study or modelling that has examined the potential scale of morphological changes that may arise as a result of any of barrage options. In addition, the feasibility to conduct such work may be limited by present understanding and the availability of data. However, some high level comment can be offered, with contrast given to other barrage cases. Many of these comments must be taken as postulated views put forward by experts rather than statements of fact. In addition, it is fairly common for the views of several experts to be in contradiction to each other.

Scour

The sluicing and turbine arrangements will funnel flows through the barrage (over sluices on the flood tide and through turbines on the ebb) which will have the potential to scour away any mobile sediments in those areas where the current strengths are greater than at present. These areas will be relatively close to the barrage. H, however, it is to be noted that both barrage options target areas where the seabed is already predominantly exposed rock.

Potential change along foreshore

In general, the existing foreshores are eroding. There are characterised by a concave profile (typical profile of erosional mud shores) and made of an exposed “fossil” Holocene clays and peats beneath a thin mud veneer[83].

Kirby postulates that after the closure of the barrage, the regular overlays of fluid mud will cease and the main source will be the rivers. The settlement of this material on the mudflats and Holocene clays will induce a profile change from low and concave to high and convex.

It is also to be noted from Section 6.3 that with the Cardiff-Weston barrage the water levels in the basin will no longer drop to a level to expose the large areas of inter-tidal sandbanks, and with the retained depths local wind-waves will be active for longer periods at the margins of the estuary

[88] Severn Barrage Committee, 1981: Tidal power from the Severn Estuary. Energy Paper 46.

increasing the potential for erosion. Inundation of active saltmarsh sites by the tide will also become restricted.

In addition, within the main river tributaries the effect of a modified tidal frame will lead to a new regime position of the channels. This is likely to lead to silting up of the channels which will reduce channel widths and depths until a new regime position is reached. This process may place an additional sediment demand in these reaches met by the muddy banks (Figure 6.5(2)).

Figure 6.5(2): Typical mud banks in river tributaries

Potential impact on sites of geological importance

At present, continual coastal erosion prevents any accumulation of debris which would obscure the rock outcrops; in addition, some of the sites are only accessible at low tide. However, it is expected that a decrease in the tidal amplitude would change the erosion pattern and result in some sites being permanently underwater. As an example, the Lilstock-Blue Anchor coastal site, recognized as a site of international importance, would be sensitive to any change of low water level.

Seaward changes

The Cardiff-Weston barrage would limit the flux of fine sediment across Bridgwater Bay, leaving the River Parrett as primary source of new material. With increasing sea levels and reduced sediment supply the inter-tidal area and foreshore in this area may experience increased erosion.

The sand transport patterns seaward of the barrage will modify in reflection to changes in flows and waves. The extent of these effects is unknown at present, however, the comments related to the Cardiff Bay Barrage and Cardiff Grounds demonstrate a potential causal linkage.

Other potential changes

With the absence of any comprehensive study there remains uncertainty how the morphological components of the estuary might respond in areas both upstream and downstream of the barrage, which in turn has important implications for the uncertainty of any predictions made of the impacts on habitats and subsequently an impacts on birds

Logically, the morphology upstream may stabilise if less energy is available to work the seabed and maintain high sediment loads. Also, if local changes in the water circulation resulting from the Cardiff Bay Barrage led to a direct morphological response in the same area, then it might be anticipated that a proportional scale of change may result after completion of either barrage option and in regards to any adjacent mobile sand feature.

This aspect requires further detailed consideration.

6.7 WATER QUALITY

6.7.1 General

The water quality of the Severn Estuary is summarised in two recent reviews[89] [90]. The water quality standards are set by UK legislation, including that derived from International conventions and EC Directives and implemented via UK Regulations. In the future, management and monitoring requirements are likely to be determined by the implementation of the EC Water Framework Directive. The Environment Agency is the primary Government regulatory body responsible for managing and regulating waste and polluting activities. The Environment Agency is responsible for licensing, monitoring and enforcing control over waste and other potentially polluting activities. Local Authorities are responsible for some aspects of the regulation of waste and other potentially polluting activities through planning and environmental health responsibilities.

There is a wide range of discharges direct to the estuary that can affect its quality. These vary from point source discharges of sewage and industrial effluent, to diffuse agricultural run-off, highway drainage and spillage from industrial premises and marine vessels. Contaminants in rivers can also affect the water quality of the Severn Estuary. Major sewage and industrial discharges are presented in Figures 6.6(1) and 6.6(2).

[89] Severn Estuary Partnership, 2001. Strategy for the Severn Estuary.

[90] Marine Biological Association, 2003. The Severn Estuary (possible) Special Area of Conservation Special Protection Area. Characterisation of European Marine Sites. Occasional Publication No. 13.

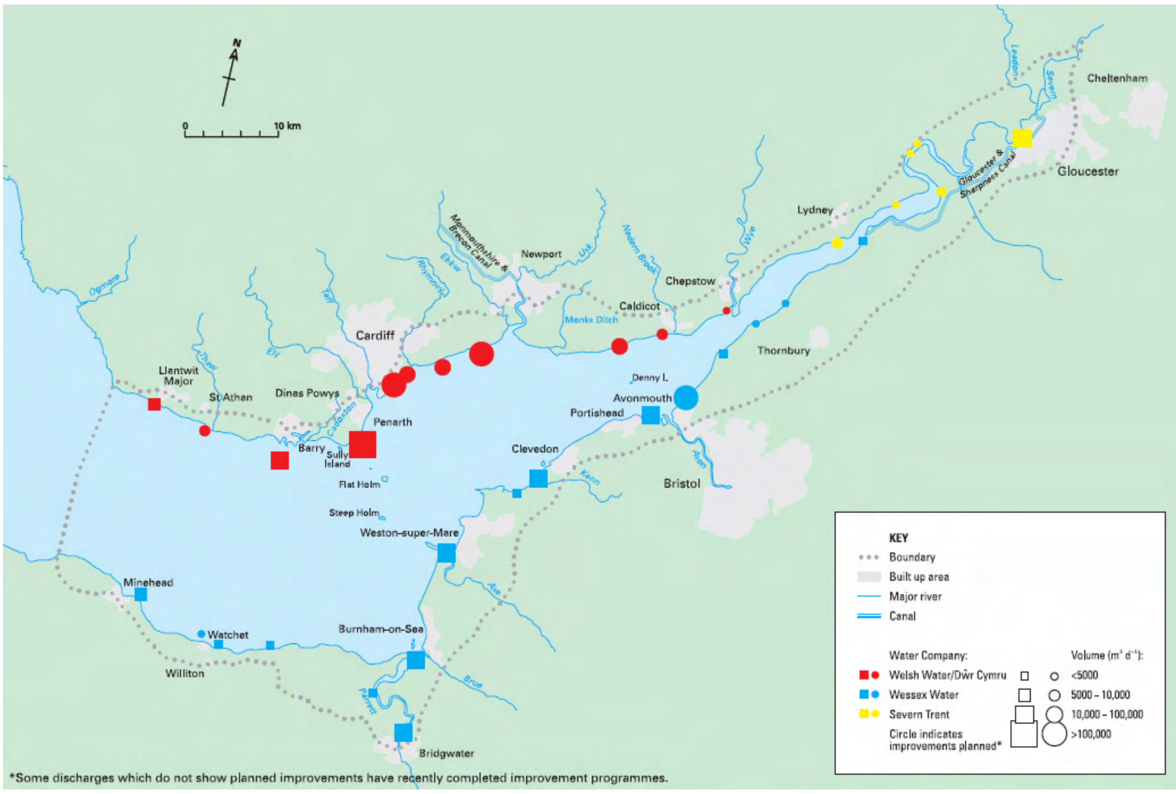


Figure 6.6(1): Major sewage works and planned improvements[89]

Figure 6.6(2): Major industrial discharges[89]

The Environment Agency currently monitors the quality of the estuary to assess compliance with the Environmental Quality Standards (EQS) stipulated by the EC Dangerous Substances Directive. The Environment Agency also monitors designated bathing waters in line with the EC Bathing Water Directive (1976). Estuary water quality and statutory monitoring sites are presented in

Figure 6.6(3). The estuary is classified under the National Water Council classification system mainly as good quality in the upper estuary and fair quality in the middle and lower estuary. Compliance with EQSs under the EC Dangerous Substances Directive is generally good, however, copper levels are close to the EQS at a number of sites and in 1996 and 1998 there were failures for zinc around Avonmouth[89]. Evidence from loadings, concentration data and EQS compliance frequencies indicates continuing improvements in water quality for the major contaminants[90].

Nutrient levels and loadings in the Severn Estuary are considered significant in UK terms. However, high turbidity means that algal productivity is typically low and eutrophication is not seen as a major threat. Intermittent oxygen sags occur in low salinity regions of the Severn and in some of the principal rivers feeding the estuary. These probably originate from the high densities of suspendable solids and associated particulate organic matter, perhaps enhanced by discharge outfalls. Suspended sediment concentrations within the Severn Estuary are recognised as very large and increase upstream to peak around Sharpness on spring tides.

Much of the heavy industry in the estuary area is centred around Avonmouth and between Newport and Barry in south-east Wales. Most of these process facilities are large and are located on the estuary to take advantage of water available for cooling and the high dilution available for large volume trade effluent discharge into the Estuary. The Environment Agency regulates these discharges through authorisations allowing control of the quality of effluent discharged and the standard of treatment provided. Many of these discharges contain organic compounds and heavy metals.

Water companies are responsible for complying with the consented limits for sewage effluent discharges that are set by the Environment Agency. Disposal of sewage and industrial waste at sea has ceased following the Oslo Convention and Paris Commission (OSPAR, 1992). International conventions have been designed to protect the marine environment from dumping of waste at sea by marine vessels, but this is very difficult to police at sea. Port authorities on the estuary have produced and implemented port waste management plans in recent years and these are subject to regular review.

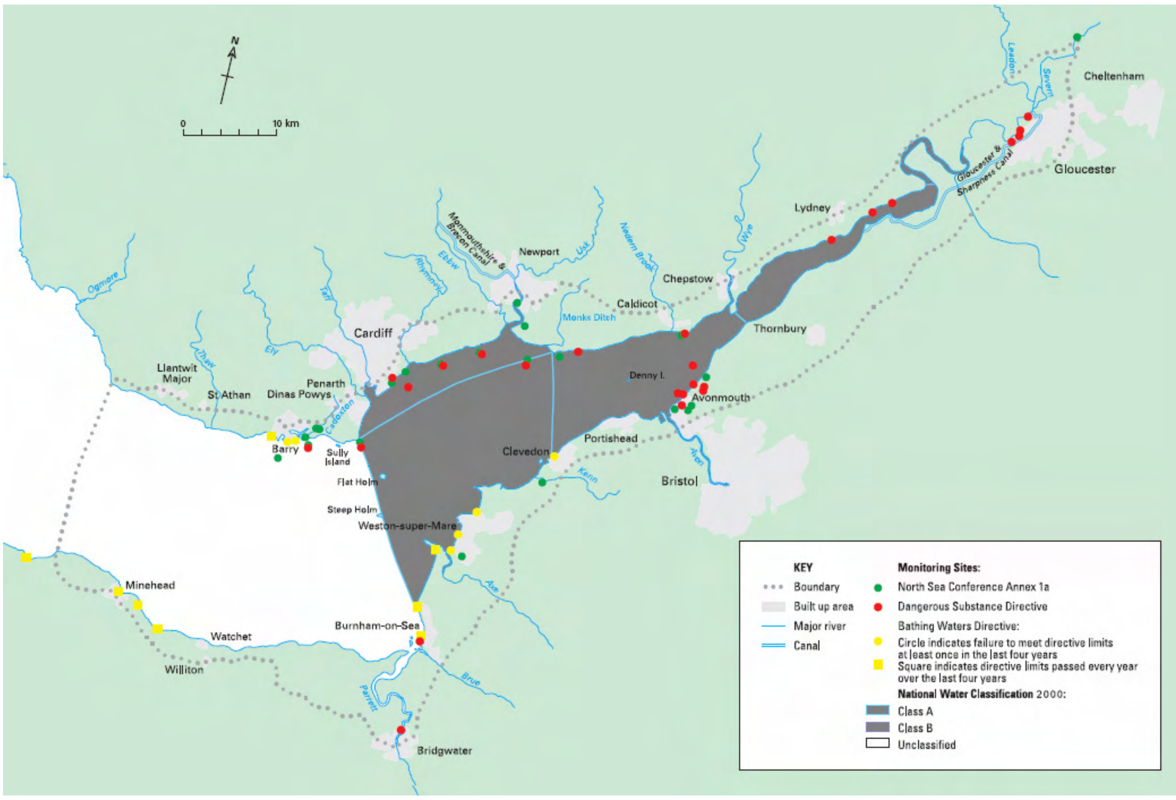


Figure 6.6(3): Estuary water quality and statutory monitoring sites[89]

6.7.2 Future evolution in the absence of a barrage

A full review of current and projected trends in water quality of the Severn Estuary is presented in Marine Biological Association, 2003[90]. Evidence from loadings, concentration data and EQS compliance frequencies do however, suggest continuing improvement in water quality for the major contaminants. The nature of the water quality of the Severn Estuary in the absence of a barrage would be dependent on a number of parameters including:

- Changes in policy and environmental legislation such as the Water Framework Directive;
- The re-mobilisation of sediments and associated contaminants;
- Changes in discharges and sources of contaminants;
- Changes in land use;
- Changes in recreational activities; and
- The influence of climate change.

6.7.3 Implications of a barrage

Changes to the hydrodynamic regime of the estuary have the potential to alter the water quality status of the estuary, particularly landward of the barrage. Similarly changes to the sediment regime could affect water quality through the mobilisation of contaminants, suspended sediment concentrations and associated changes in dissolved oxygen. Assessments, which have been made to date, have been based on limited information, therefore considerable uncertainty remains as to how water quality would change in the presence of a barrage.

Modelling has been undertaken to assess the likely implications of the Cardiff-Weston barrage on the water quality of the Severn Estuary and based on specific discharges and levels of treatment relevant at this time[91] [92]. Constituents studied included salinity, nickel, cadmium, e. coli, BoD, dissolved oxygen and faecal coliform. These studies were based on dispersion characteristics and background concentrations, both of which have the potential to change in the presence of a barrage. These changes would be associated with reduced currents, changes in turbidity, reduced tidal displacements, greater average near-shore water depths, and the strong residual circulations set up because of the spatial distribution and pattern of use of turbines and sluices.

The predicted changes in water quality as a result of the Cardiff-Weston barrage can be summarised as follows:

- The barrage could reduce rates of longitudinal dispersion and the efficiency of absorption of oxygen from the air. Based on a 75% reduction in dispersion and 50% reduction in oxygen transfer (the maximum values considered likely), the freshwater/salt water interface would move seaward by 5 to 30km, depending on river flow.
- The concentrations of conservative pollutants such as nickel and cadmium could at worst double.
- Concentrations of non-conservative pollutants behind the barrage were not predicted to change significantly. Similarly, the number of bacteria near sewage outfalls is predicted not to change significantly.
- The oxygen status was predicted to be largely un-affected by the reduced tidal mixing and the system would tend to be capable of retaining more oxygen because of the associated reduced salinity.
- The suspended sediment concentrations characterising the water column, landward of the barrage are predicted to reduce to those typical of other high tide estuaries.
- It is predicted unlikely that eutrophic conditions would result.

---

[91] Radford, P.J. 1982. The effects of a barrage on water quality. Severn Barrage, Thomas Telford Ltd., London.

[92] STPG, 1989. The Severn Barrage Project. Detailed report Vol I “Tidal Hydrodynamics, Sediments, Water Quality, Land Drainage and Sea Defences.” Chapter 3 Sediments

The limited knowledge as to the behaviour of the sub estuaries suggests that most effects would be qualitatively similar to those in the main estuary[92]. The effect on dissolved oxygen would possibly be more severe in the Usk, the Avon and the Parrett than in the main estuary, although much would depend on the influence of the changed hydraulic regime on the oxygen demand of the mud.

With regard to The Shoots scheme very generalised predictions have been made in the context of the results from the Cardiff-Weston scheme[93]. In summary concentrations of cadmium could potentially reduce landward of a barrage because the main sources are seaward of The Shoots scheme. In contrast concentrations of nickel and other substances entering at the head of the estuary would increase. It was predicted that copper may be the most sensitive metal in this respect. Concentrations of ammonia, BOD and dissolved oxygen are predicted to be relatively less satisfactory than in the basin of the Cardiff-Weston scheme.

Discharge and Abstraction Consents

A barrage could fundamentally change the basis for determining limits for discharges to and abstractions from the estuary and rivers that feed into it, and may require changes to existing authorisations for such activities.

Construction

There is the potential for spillages and pollution incidents during the construction phase of the barrage which could directly impact on the water quality of the estuary. In addition the construction of the barrage will require dredging which will have implications for the water quality of the estuary.

6.7.4 Requirements for additional studies

There would be a requirement for a re-evaluation of the current water quality status of the estuary. This would need to be reviewed in the context of the proposed physical changes within the estuary in the presence of a barrage. The subsequent implications for changes in water quality on the receiving environment also require further investigation. In addition the implications for surrounding land uses based on the requirements for revised discharge and abstraction consents would require a detailed evaluation process. Overall, considerable uncertainly remains as to the predicted impacts of a barrage on the water quality of the Severn Estuary and as such detailed investigations would be required to further define the potential impacts of such a proposal. This would include a requirement for detailed modelling studies to identify the potential impacts of a barrage on water quality under a full range of scenarios.

6.8 ECOLOGY

The ecological appraisal of a possible Severn Barrage contained within this report has been based entirely on existing data and documents that have previously investigated this subject. Where possible the potential consequences of both the Cardiff-Weston and The Shoots schemes have been identified. It should be highlighted that there is considerably more information available regarding the possible environmental effects of the Cardiff-Weston scheme and as such the potential impacts should be reviewed in this context. Where possible, information has also been derived from other relevant proposals and developments to provide an evidence base for any assessments that have been made.

An overview of baseline conditions, potential impacts of a barrage (including where feasible construction, operational and decommissioning), future predictions in the absence of a barrage and

[93] STPG, 1986. Tidal Power from the Severn. Engineering and economic studies – English Stones scheme. The Severn Tidal Power Group.

the requirements for further study are all reported. Future predictions in the absence of a barrage within this section have largely been based on recent studies, in particular the Severn Estuary CHaMP. It is important to highlight that changes in policy, management practices and the continual evolution of this dynamic system will also influence the structure and functioning of all ecological components. The potential impacts of a barrage that have been identified within this review have typically been based on limited information, therefore considerable uncertainty remains as to how the ecology of the Severn Estuary would change in the presence of a barrage. While recommendations for further study have been made it is important to recognise that even after undertaking such work certainty in ecological predictions cannot be assured, particularly given the major and broad scale changes that either barrage option would introduce.

6.8.1 Intertidal mudflats and sandflats

There are extensive areas of intertidal mudflats and sandflats exposed at low water throughout the entire Severn Estuary, the total area of which is estimated at 20,958ha within the Severn Estuary[94] and 2,090ha in Bridgwater Bay[95]. The hydrodynamic and morphological processes operating within the system mean that the intertidal mud and sandflats vary in width, overall size and exposure time throughout the entirety of the estuary. The relative composition of the sand and muddy sediments is also largely determined by the physical processes operating within the system.

The dynamic environment and large tidal range within the system creates a range of physical conditions to which inhabiting organisms are exposed. A number of studies have investigated the fauna and flora of the intertidal mudflats and have attempted to relate this to the physical properties of the estuary[96]-[97]. The dynamic nature of the system means that sediments are mobile and can change in location and nature over a range of timescales. This high level of variability, combined with the physical stresses of an estuarine environment lead to a species poor assemblage of invertebrates, although not necessarily a low biomass.

The mud and sandflats are dominated by polycheate worms, amphipod crustaceans and gastropod molluscs. Species such as the gastropod *Hydrobia ulvae*, the bivalve *Macoma balthica* and the polychaetes *Hediste diversicolor* and *Nephtys hombergii* occur in abundance. In comparing the invertebrate fauna in 1974/75 and 1987[98] it was concluded that in general few changes in the distribution of sediments and fauna had occurred. It has been demonstrated that, in comparison with other estuaries populations, several invertebrate species in the Severn Estuary are dominated by small individuals.

Only above Sharpness does the distribution of species appear to be limited by salinity[97]. Elsewhere the large tidal range, funnelling, strong tidal streams and high suspended sediment concentrations create difficult conditions for the colonisation of benthic species. In general, species composition is determined by differences in sediment type and the level of consolidation[99].

---

[94] English Nature and the Countryside Council for Wales, 2005. English Nature & the Countryside Council for Wales' advice for the Severn Estuary Special Protection Area given under Regulation 33(2) of the Conservation (Natural Habitats &c.) Regulations 1994.

[95] English Nature, 1998. Bridgwater Bay National Nature Reserve. English Nature - Taunton Team.

[96] ETSU, 1989. The prediction of post barrage densities of shorebirds: Volume 4: Birds. Institute of Terrestrial Ecology, ETSU TID 4059.

[97] Boyden, C.R. and Little, C. 1973. Faunal distribution in soft sediments of the Severn Estuary. Estuarine Coastal and Marine Science, 1, 203-223.

[98] Wimpol Ltd, 1988. Intertidal invertebrate distributions in the Severn Estuary. Report to Severn Tidal Power Group No. SBP 36.

[99] Davies, J 1991. Benthic marine ecosytems in Great Britain: a review of current knowledge. Western Channel and Bristol Channel and approaches. MNCR sectors 8 and 9. Nature Conservation Council, CSD Report, No. 1173

A qualitative assessment of the composition and diversity of the benthic macrofauna of the estuaries of the Rivers Wye, Bristol, Avon and Usk[100] concluded that their fauna was similar to that of the soft sediments of the Severn Estuary[101]. However, maximum numbers of some benthic species were higher in the sub-estuaries highlighting them as a potentially important part of the system.

Future evolution in the absence of a barrage

The Severn Estuary CHaMP has provided an indication of the predicted morphological evolution of the estuary assuming that the current flood defences are maintained. The implications of these changes on the designated habitats within the estuary have also been assessed over 20, 50 and 100 year time horizons. A full description of the methods that have been applied within the CHaMP can be found in ABPmer, 2006[102]. The CHaMP has not yet been finalised and as such the predictions reported within this review should be interpreted with a degree of caution.

There is predicted to be a net loss of intertidal mudflats and sandflats between the time period 2005 to 2105. Overall the losses are predicted to be in the region of 2000ha by 2105, which is approximately 9% of the current (2005) extent. During this timeframe losses are unevenly distributed throughout the estuary.

Table 6.7(1): Predicted change in habitat extent as compared to 2005 (Source – provisional results from the Severn Estuary CHaMP).

Total Estuary Change (As compared to 2005)	20 year % loss	50 year % loss	100 year % loss
Intertidal area	7	7	11
Intertidal mudflat and sandflat	6	5	9

Implications of a barrage

An Environmental Impact Assessment would be required for the development that would need to incorporate all aspects of the construction, operation and decommissioning of the proposed barrage. During the construction phase of the barrage there is the potential for direct loss of intertidal habitat. There is also the potential for spillages and pollution incidents during this stage of the development.

Once operational the change in the hydrodynamic parameters within the estuary will lead to an overall reduction in the intertidal area. An estimation of the loss of intertidal area associated with each of the two barrage schemes has been calculated based on the predicted changes in water levels landward of each barrage. The digital elevation model that has been used for these calculations is based on current Lidar and NEXTMAP data and as such assumes no morphological evolution in the presence of the barrage.

Table 6.7(2): The predicted change in extent of intertidal area landward of the two barrage schemes based on predicted changes in water levels alone.

Scheme	Range	Current intertidal area (ha)	Predicted intertidal area	Change in intertidal area (ha)

[100] University of Bristol – Zoology Department, 1988. Ecology of the sub-estuaries of the River Severn. ETSU Contract No. ETSU-TID-4057.

[101] Plymouth Marine Laboratory, 1988. Predicting post barrage densities of invertebrates and shorebirds: 2 Invertebrates. ETSU Contract No. E/5A/CON/4061/1786.

[102] ABPmer, 2006. Severn Estuary ChaMP Morphological assessments

The Shoots	Spring	7275	1745	-5530
	Neap	4815	1443	-3372
Cardiff to Weston	Spring	18898	4469	-14428
	Neap	9881	4039	-5842

The predicted change in intertidal area landward of each barrage is a loss of approximately 5530ha on a spring tide and 3372ha on a neap tide via The Shoots scheme and 14428ha and 5842ha of the equivalent tides for the Cardiff-Weston scheme. Correspondingly changes seaward of the barrage would also be of a lower magnitude for The Shoots scheme due to the reduced area potentially modified. This change is predicted on the basis of expected water level change alone. In reality the distribution and extent of the intertidal, mudflats, and sandflats will also be influenced by the changes to the sedimentary regime of the estuary. It may also be possible to design either barrage to operate in a manner which minimises impacts on intertidal areas, consistent with an acceptable level of energy generation. In the longer-term, as a result of increases in mean sea level due to climate change, it may even be possible to restore some intertidal areas, through management of water levels inside the barrage. The figures calculated above therefore probably represent a worst case scenario in relation to the potential loss of intertidal area in the presence of a barrage.

In addition, there will be changes to the nature of the sediments and potentially the degree of consolidation and physical properties of the sediments (Section 6.4). This will have implications for the distribution of invertebrates within the mudflats[103] and the species which they in turn support. Intertidal mudflats and sandflats are a designated feature of the estuary and as such the consequences of this loss will require further consideration under the Habitats Regulations (Section 6.10). The location of the two barrage schemes in the context of this feature is presented in Figure 6.7(1).

[103] Gray, J.S. 1974. Animal-sediment relationships. Oceanography and Marine Biology Annual Review 12, 263-289.

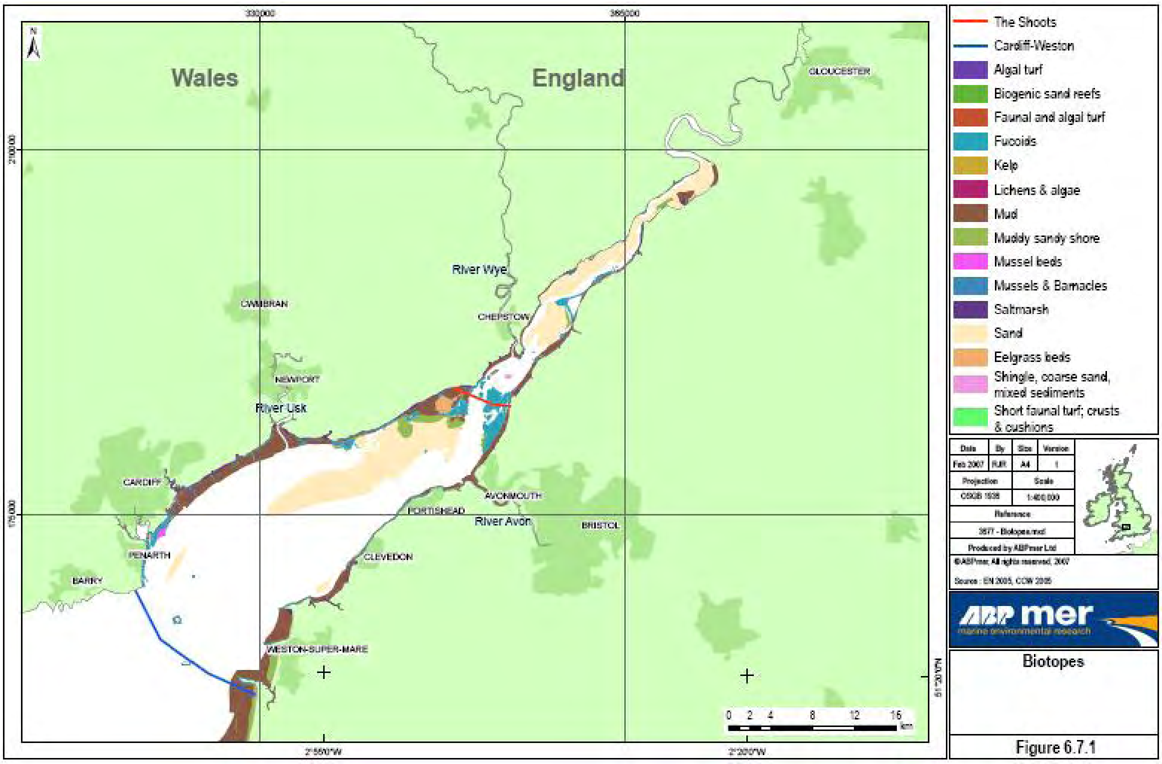


Figure 6.7(1): Location of the two barrage schemes in context to intertidal zone

Changes in the physical regime of the estuary will have implications for the invertebrate communities of the intertidal zone. Predictions of the with-barrage intertidal invertebrate associations point to an increase in abundance and biomass of species and associations characteristic of less dynamic estuaries[104]. In particular, there may be an increase in taxa such as Cyathura, *Scrobicularia*, *Cerastoderma*, *Mya* and *Hediste diversicolor* and a decrease in species associated with hypertidal estuaries such as *Hydrobia*, *Macoma* and *Bathyporeia*. Reduced turbidity could result in a higher biomass of suspension feeders. It is also anticipated that there would be a shift in the size distribution of certain species, notably *Nephtys hombergii*, *Macoma* and *Hydrobia* towards larger individuals.

This form of increased productivity has been observed in La Rance where there has been an increase in species diversity and abundance of invertebrates. Notwithstanding tThe loss of 1/3 of the intertidal area, an increase in it's the estuary's carrying capacity for invertebrates and higher organisms has been reported [105]. Indeed, species richness in soft bottom assemblages was observed to increase in three consecutive surveys in 1971, 1976 and 1995[106]. The communities correspond to well defined communities established in the southern part of the Normano – Breton Gulf.

The physical changes associated with a barrage will potentially alter the dynamics and biological interactions of an assemblage including aspects of predation, competition, bioturbation and algal smothering. Any change to the benthos and epibenthos of intertidal sediment habitats would have implications for the functioning of the system .

[104] Warwick *et al* Department Of Energy. Energy Technology Support Unit (ETSU) ; Plymouth Marine Laboratory ; Natural Environment Research Council (NERC)* (1989).

[105] Kirby, R. 2006. Links between environmental consequences of La Rance and Severn Tidal Power Barrages. Kirby – 10th October 2006.

[106] Desroy, N. and Retiere, C. 2004. Using benthos as a tool for coastal management: The impact of the tidal power station on benthic communities of the Rance basin. Aquatic Ecosystem Health and Management, 7, 59-72.

Requirements for additional studies

The investigations that were undertaken to predict the impacts of a barrage on the intertidal sedimentary habitats and species of the Severn Estuary in the presence of a barrage were largely completed in 1989. These studies would therefore require updating to ensure they adequately describe existing conditions within the estuary and to reflect advances in predictive modelling capabilities. This would include:

- Invertebrate surveys and a greater understanding of distribution patterns and associated relationships with the physical environment.
- A greater understanding of the functioning of the system.
- Mapping of intertidal areas that will be most impacted by the proposed changes in water levels and sediment patterns.

6.8.2 Saltmarsh

Coastal saltmarshes may be defined as areas, vegetated by herbs, grasses or low shrubs, bordering saline water bodies[107]. Saltmarshes form in low energy or sheltered environments with shallow water, such as estuaries, behind spits and barrier islands and in protected bays where there is a supply of suspended sediment that can accrete.

There have been a number of surveys undertaken on the estuary that have described the saltmarsh communities[108,109,110,111,112]. The most recent complete survey of the estuary was undertaken in 1998[112] and recorded a total area of saltmarsh (and associated habitats) of about 1,500ha. This total area can be subdivided into the key component parts of the system (Table 6.7(3)).

Table 6.7(3): Total areas of salt marsh within the Severn Estuary and Bridgwater Bay

Salt marsh sites	Area (ha)
Bridgwater Bay/Parrett	490
Severn Estuary – England	590
Severn Estuary – Wales	350

There are extensive areas of saltmarsh along a number of stretches of the Severn Estuary including Wentloodge Levels, Caldicott Levels, Gwent Levels, around the Severn Crossings and into the inner reaches of the estuary. Within Bridgwater Bay the saltmarsh is concentrated between Hinkley Point and Burnham-on-Sea, extending into the estuaries of the rivers Parrett and Brue[113].

Within a saltmarsh habitat complex, halophytic plant species and communities display a complete transition from marine to terrestrial habitat. There is general agreement that the main factors

[107] Adam, P. 1990. Saltmarsh ecology, Cambridge University Press, Cambridge
[108] Smith L P, 1979. A survey of salt marshes in the Severn Estuary. Volumes I and II. Nature Conservatory Council, CSD Report, No.265.
[109] Teverson, R. 1981. Salt marsh ecology in the Severn Estuary, Severn Tidal Power Report No. STP 51.

[110] Dent S, 1987. The current status and recent history of Spartina anglica in the Severn Estuary between Newport and Cardiff. Peterborough, Nature Conservancy Council.

[111] Burd F, 1989. The salt marsh survey of Great Britain: An inventory of British salt marshes: Report of the Nature Conservancy Council. Regional Supplement No. 2 West Midlands.

[112] Dargie T, 1999. NVC survey of salt marsh habitats in the Severn Estuary 1988. Report for the Countryside Council for Wales and English nature. CCW Contract Science Report No. 341.

[113] English Nature, 1997. Natural Area Profile for Bridgwater Bay.

affecting the zonation of halophytic plant species within a saltmarsh habitat relate to frequency of tidal inundation and associated effects of salinity and tidal scouring. Each species has a different tolerance to tidal flooding and therefore a different, although often overlapping, vertical range. Different communities are therefore apparent at different tidal elevations[114]. The full range of saltmarsh communities have been observed throughout the Severn Estuary including extensive areas of *Spartina* marsh and some areas of more mature marsh including Atlantic Salt Meadows. There are also large areas of higher marsh, that are frequently grazed, which are typically dominated by common salt marsh grass *Puccinellia maritima* and red fescue *Festuca rubra*. A number of nationally scarce plant species including *Alopecurus bulbosus*, *Bupleurum tenuissimum*, *Trifolium squamosum*, *Horderum marinum* and *Puccinellia rupestris* have also been recorded on the estuary.

Future evolution in the absence of a barrage

The Severn Estuary CHaMP has provided an indication of the predicted morphological evolution of the estuary assuming that the current flood defences are maintained. The implications of these changes on the designated habitats within the estuary have also been assessed over 20, 50 and 100 year time horizons. A full description of the methods that have been applied within the CHaMP can be found in ABPmer, 2006. The CHaMP has not yet been finalised and as such the predictions reported within this review should be interpreted with a degree of caution.

The predictions that have been made for the distribution of saltmarsh includes a full range of species ranging from pioneer to more mature marsh species and incorporates Atlantic saltmeadows within this definition. The area in which saltmarsh has the potential to occur, based only on elevation, fetch and water levels, and not considering site specific parameters and management practices, is predicted to be reduced by approximately 40% in 2105 as compared to 2005. A major factor limiting the potential distribution of saltmarsh is considered to be the geological (both natural and manmade) constraints that occur throughout the estuary.

Table 6.7(4): Predicted change in habitat extent as compared to 2005 (Source – provisional results from the Severn Estuary CHaMP).

Total Estuary Change (As compared to 2005)	20 year % loss	50 year % loss	100 year % loss
Saltmarsh	13	41	38

Implications of a barrage

The distribution of saltmarsh is largely dependent on the physical conditions within the system. The key physical changes associated with the presence of a barrage, which will have implications for the distribution and extent of saltmarsh, can therefore be summarised as follows:

- Change in tidal curve and inundation periods;
- Change in hydrodynamic conditions;
- Change in sedimentary regime; and
- Change in morphology of the estuary.

Previous work to investigate the possible effects of a barrage on the composition and extent of saltmarsh have focused on the association of this habitat type with the physical environment. Predictive equations of the distribution of *Spartina anglica*, in relation to variation in physical and tide-related factors were initially developed[115]. The study concluded that both the upper and lower

[114] Gray A J, Mogg R J, 2001.Climate impacts on pioneer saltmarsh plants. Climate Research 18 ,1-2: 105-112.

[115] Gray *et al* Department Of Energy. Energy Technology Support Unit (ETSU) ; Institute of Terrestrial Ecology (ITE) (1989). Prediction of marginal vegetation in a post-barrage environment; a model of Spartina anglica niche in south and west Britain. (ETSU TID; 4070). London : Department of Energy.

limits of *Spartina* were predicted remarkably well by tidal range, with variation in fetch, estuary area and position on the estuarine gradient significantly improving the prediction. The work was later extended to include more plant species (*Puccinellia maritima, Halimione portulacoides, Festua rubra and Elymus pycanthus , Juncus gerardii, Juncu maritimus, Phragmites communis, Scirpus maritimus* and *Phragmites australis*), with a greater emphasis also placed on the implications of submergence patterns[116]. It was again concluded that tidal models and submergence models provide an acceptably precise and complementary means of predicting the niche of saltmarsh plant species.

These predictive equations were applied to a scenario with a Severn Barrage (in the location of a Cardiff-Weston scheme) where tidal range was significantly reduced. Downstream of the barrage, under a slightly reduced tidal range, *Spartina* was predicted to move downshore by predictable amounts. The extent to which *Spartina* will move seaward towards the new MHWN levels above the barrage will vary with fetch and the position of the estuarine gradient. Altered submergence patterns, including the possibility of prolonged wave attack at critical levels, will have important effects. Other dominant marginal species, which may be expected to change their distributions under post-barrage conditions, include *Puccinellia maritima, Phragmites communis, Scirpus maritimus* and *Elymus pycanthus*. The most important factors influencing the competitive interactions of these species, and thus the extent to which, following barrage construction, they will move downshore the estuary, are variation in submergence, salinity, soil type and grazing.

Overall, existing estuarine saltmarshes would be inundated less frequently and as a result the upper marsh zone may become permanently exposed, resulting in more terrestrial vegetation, with the consequent loss of saltmarsh habitat and the communities they support[117]. Thus overall there is predicted to be a marked contraction in the saltmarsh area if a barrage is constructed. Ultimately the nature and magnitude of the changes to the hydrodynamic, morphological and sediment regimes of the estuary will determine the consequences for the saltmarsh of the estuary.

While the assessments that have been made have related to the line of the Cardiff-Weston scheme, the changes in the hydrodynamics and sedimentary regime of the estuary in the presence of The Shoots scheme would be expected to result in qualitatively similar effects. The magnitude of the effects on the saltmarsh under the two schemes would, however, be potentially very different. The area of saltmarsh landward of the two proposed barrage lines has been calculated based on biotope data provided by Countryside Council for Wales and Natural England (Figure 6.7(2)). The area of saltmarsh landward of the Cardiff-Weston and The Shoots scheme is approximately 539ha and 133ha respectively. The potential magnitude of change associated with each scheme is therefore considerably different.

During the construction phase of the barrage there is the potential for the direct loss of saltmarsh habitat. There is also the potential for spillages and pollution incidents during this stage of the development.

[116] Clarke, R.T, Gray, A.J., Warman, E.A., Moy, I.L 1993. Niche modelling of saltmarsh plant species. Institute of Terrestrial Ecology, ETSU T/04/00194/REP.
[117] Mitchell, R. Probert, P.K., McKirby, A.P. and Doody, J.P. 1981. Severn Tidal Power Nature Conservation. . Nature Conservancy Council.

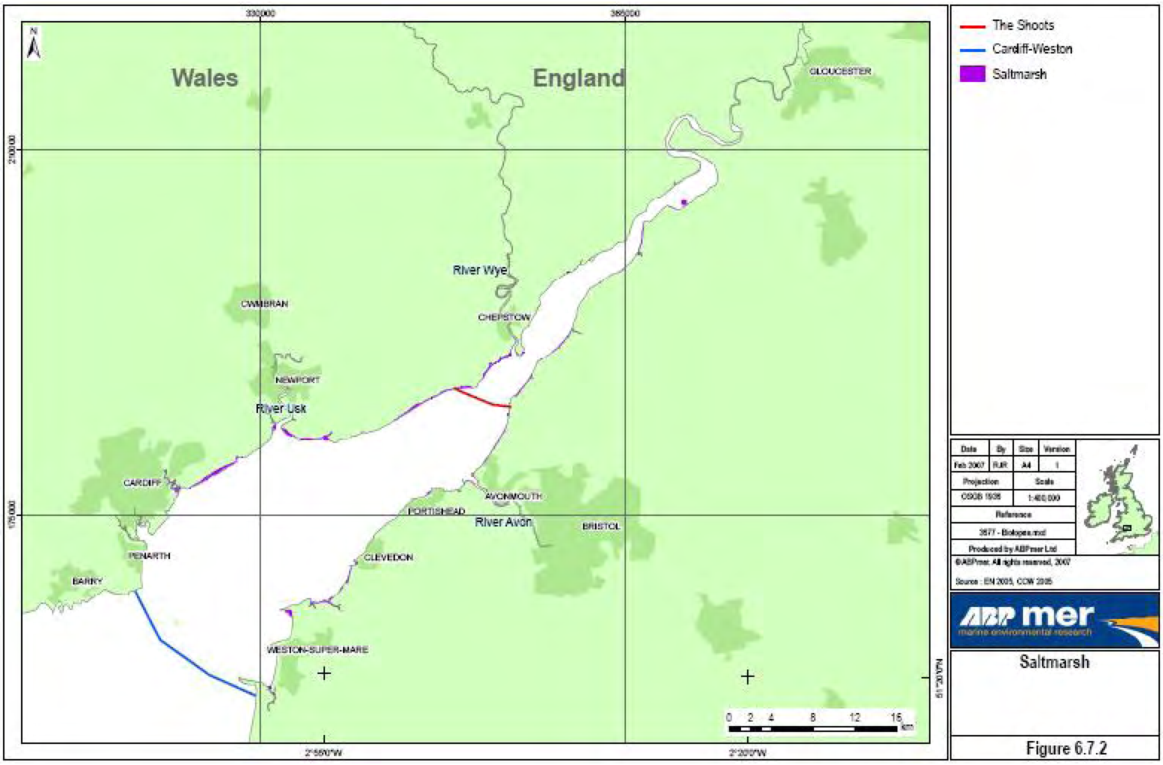


Figure 6.7(2): Areas of saltmarsh surrounding the barrage schemes

Requirements for additional studies

A greater understanding of the extent and distribution of saltmarsh, and the linkages with the physical environment, would be required to inform an assessment of a proposed barrage. Predictive tools have also been enhanced since the initial assessments were made. Techniques employed within the Severn Estuary CHaMP, for example, have looked specifically at this issue[62].

6.8.3 Rocky intertidal

There are extensive areas of rocky shore throughout the Severn Estuary covering a total area of approximately 1,500 ha. The types of habitat present include boulders, expanses of rock platforms, mussel/cobble scars and rocky pools[118].

The rocky shores support a number of invertebrate and algal species including barnacles, limpets, littorinids, fucoids and green ephemeral algae. The distribution of such species is largely influenced by the physical processes operating within the estuary. The decrease in exposure towards the inner estuary, for example, appears to be at least partly responsible for the decrease in the upper vertical limit of animal species, but has no direct effect upon algal distribution. In addition silt concentrations, in combination with the effects of tidal scour may prevent the colonisation by macroalgae at lower tidal levels[119,120]. Salinity may also play a part in determining the distribution of rocky shore species along the horizontal dimension of the estuary[121].

[118] Gifford & Partners, GeoData Institute, ABP Research and Consultancy, Peter Fraenkel Maritime and Adams Hendry, 1998. Severn Estuary Shoreline Management Plan.

[119] Little C and Smith L P 1980. Vertical zonation on rocky shores in the Severn Estuary. Estuarine and Coastal Marine Science, 11, 651-669.

Future evolution in the absence of a barrage

The Severn Estuary CHaMP has provided an indication of the predicted morphological evolution of the estuary assuming that the current flood defences are maintained. The implications of these changes on the designated habitats within the estuary have also been assessed over 20, 50 and 100 year time horizons. A full description of the methods that have been applied within the CHaMP can be found at ABPmer, 2006. The CHaMP has not yet been finalised and as such the predictions reported within this review should be interpreted with a degree of caution.

It is not predicted that there will be a significant loss of hard substratum throughout the Severn Estuary within the timescales of 100 years. It is possible, however, to provide an indication of the relative proportions of intertidal and subtidal rock through this timescale. There is an overall net loss of intertidal and a corresponding increase in rocky subtidal habitat through time. In the order of 100ha is predicted to change from intertidal to subtidal by 2105 as a result of changes in water levels. This result requires careful interpretation, as it is a crude assessment, based on predicted changes in water levels alone.

Implications of a barrage

Changes in water levels in the estuary after construction of a barrage would result in a change in inundation periods for the rocky habitats of the Severn. This will result in a change in the relative amounts of subtidal, intertidal and permanently exposed rocky habitat. The degree of change associated with the Cardiff-Weston and The Shoots schemes will be influenced by the changes in water levels upstream and downstream of the respective barrages. It will also be dependent on the current extent of this habitat type that occurs landward, and seaward, of each barrage.

The changes in physical conditions have implications for the invertebrates and algal species that occur in these environments. The distribution of rocky shore organisms is primarily determined by inundation periods[122] and as such species assemblages would be expected to change in the presence of a barrage. Similarly changes in wave action and water quality have the potential to alter rocky shore communities. This will have consequences for the biological interactions and feedback that occurs within the system.

Much of the geological interest in the coastal sites is located in wave cut platforms lying between high and low water marks; to maintain these platforms, it is essential that these are subject to continued erosion to prevent undue accumulation of sediment which would obscure the rock. Upstream of the barrage line reduced scouring is predicted but with continued wave attack the rocks may remain exposed[117]. Where currently exposed rocky intertidal habitat becomes smothered with sediment, this will have implications for the organisms that occur within this environment.

The location of the barrage will directly impact on rocky habitats which fall under or immediately adjacent to its footprint. In particular Brean Down and Lavernock Point are geological SSSIs and would be impacted by the construction of a barrage at these locations.

The barrage itself would be colonised by invertebrate species that are typical of rocky shore communities.

---

[120] Smith L P and Little C, 1980. Intertidal communities on rocky shores in the Severn Estuary. Proceedings of the British Naturalists Society, 38, 61-67. Referenced in this paper as a source of detailed species accounts for the nine sites

[121] Bassindale R, 1943. Studies on the biology of the Bristol Channel. XI. The physical environment and intertidal fauna of the southern shores of the Bristol Channel and Severn Estuary. Journal of Ecology, 31, 1-29.

[122] Lewis, J.R. 1964. The ecology of rocky shores. London, English University Press Limited.

Requirements for additional studies

A greater understanding of the changes in water levels on the relative proportions of subtidal, intertidal and fully exposed rock habitats will be required. The implications for the ecological communities can then be fully evaluated. Similarly changes to the sedimentary regime of the estuary and the implications for the smothering of rocky habitats will require further consideration.

6.8.4 Shingle

The shingle habitat within the Severn Estuary is predominantly located in Bridgwater Bay where the intertidal flats between Hinkley Point and the River Brue are backed by low shingle ridges. This feature has been described in the Bridgwater Bay Natural Area profile[113] and Rogers (1996)[123]. Some relict ridges are located landward of present day salt marshes on the Steart Peninsula. This ridge has historically been managed for flood defence reasons. Shingle ridges are also apparent landward of the rocky outcrops, on the English side of the estuary, in the vicinity of the Severn Crossing and directly opposite this area on the Welsh bank. There also used to be a series of shingle fans east of Hinkley Point which have been badly damaged in recent years. The vegetation of the shingle ridge in Bridgwater Bay has been fully described in Rogers (1996).

Future evolution in the absence of a barrage

The predicted changes to the main shingle ridges in Bridgwater Bay are based largely on the conclusions have been drawn from the Severn Estuary CHaMP. A full description of the methods that have been applied within the CHaMP can be found at ABPmer, 2006. The CHaMP has not yet been finalised and as such the predictions reported within this review should be interpreted with a degree of caution.

The CHaMP predicts accretion of the intertidal mud and sandflats which front the shingle within Bridgwater Bay. It is therefore anticipated that the areas of shingle will remain in situ with an increase in protection from waves afforded by the accretion on the affronting mudflats and sandflats. With regard to the additional shingle within the remainder of the estuary it is predicted to remain protected by the presence of hard substrata.

Implications of a barrage

Changes to the sediment regime and physical processes within the estuary have the potential to affect the shingle habitats within the estuary. It has been suggested that the shingle ridges in Bridgwater Bay would become fossil shingle ridges in the presence of a barrage[117]. The location of the barrage line will again affect the degree to which this habitat type is impacted.

Requirements for additional studies

The implication of a barrage on shingle habitats will require a full understanding of the changes in hydrodynamics and sedimentary regimes associated with the proposed scheme.

6.8.5 Sand dunes

There is one active sand dune system located within the Severn Estuary, the Berrow Dunes. This is a backshore system in which large volumes of sand are blown by the wind from the foreshore onto the land. Here it is deposited in a series of ridges that become stabilised by the growth of vegetation. The main stabilising influence on the dunes is grasses and in areas closest to the sea Lyme grass dominates. Within a matter of only a few metres this is replaced by marram grass, which is replaced further inland by finer grasses and a tighter sward becomes established.

[123] Rogers D 1996. Vegetated shingle features at Bridgwater Bay. Report for English Nature.

The Berrow Dunes are associated with the extensive sandy beach adjacent that extends from Burnham on Sea to Brean, a distance of some 6km but it is only 1/2km wide at its greatest width[124]. The southern part of the Berrow Dunes appears to be eroding rapidly due to a combination of high tides and storms although a substantial amount of sand is re-deposited during the summer period. Reposition of sand is allowing the dunes to grow seawards further to the north[113].

The sand dunes support a number of rare and scarce plants and animals including lizard orchid, round-headed club rush, Somerset rush, variegated horsetail and great-crested newt. In addition a number of excavated ponds and drainage ditches are present providing open water habitat. Within the Berrow Dunes there is also a large reedbed isolated from the sea by a narrow dune ridge.

Future evolution in the absence of a barrage

It is assumed in the absence of a barrage the processes which currently support the presence of sand dunes would not change beyond the natural variation that already exists within this dynamic environment.

Implications of a barrage

The processes that primarily drive the formation, and maintain the current extent of, sand dunes are not predicted to be changed by the presence of a barrage. The implications of a barrage on the sand dunes of the Severn Estuary are therefore given no further consideration.

Requirements for additional studies

It is not thought that a barrage located along the line of either the Cardiff-Weston scheme or The Shoots would have an impact on sand dunes and as such no specific requirements for further studies have been identified.

6.8.6 Subtidal habitats

The subtidal habitats within the Severn Estuary are less well documented than the intertidal components of the system. Subtidally the predominant unconsolidated sediments are muds and sands, the relative composition of which varies throughout the estuary. There are also small areas of gravel within the outer reaches of the estuary. Each of these sediment types, and the differing physical processes in operation, support a different invertebrate assemblage. The subtidal sandbank communities, for example, are characteristic of mobile sediment regimes and support invertebrates such as the bivalves *Spisula* and *Tellina*. Larger sandbanks of the middle and Welsh grounds have restricted fauna of the polycheate *Nephtys cirrosa* and the sea louse *Eurydice pulchra*. A detailed description of the benthic assemblages associated with the subtidal sediments of the Bristol Channel and Severn Estuary can be found in Warwick and Davies, 1977[125]; Warwick and Uncles, 1980[126] and Warwick, 1984[127]. Mettam *et al* 1989 related the distribution of benthic communities to the sediments of the Severn Estuary.

Large areas of the outer channel consist of hard scoured bottoms with reefs of the honeycomb worm *Sabellaria alveolata* and the horse mussel *Modiolus modiolus*. Rocky platforms throughout the estuary also extend from the intertidal into the subtidal; these support restricted algal

[124] Posford Duvivier Environment, 1999. Overview of coastal sand dunes, salt marsh and vegetated shingle by Natural Area. Research Report for English Nature.

[125] Warwick, R.M. and Davies, J.R. 1977. The distribution of the sublittoral macrofauna communities in the Bristol Channel in relation to the substrate. Estuarine Coastal and Marine Science, 5, 267-288.

[126] Warwick, R.M. and Uncles, J.R. 1980. The distribution of benthic macrofauna associations in the Bristol Channel in the Bristol Channel in relation to tidal stress. Marine Ecology Progress Series, 3, 97-103.

[127] Warwick, R.M. 1984. The benthic ecology of the Bristol Channel. Marine Pollution Bulletin, 15, 70-76.

communities[120]. Similarly relatively small areas of cobbles and mussel beds extend throughout both the intertidal and subtidal zones of the estuary[94].

Future evolution in the absence of a barrage

The Severn Estuary CHaMP has demonstrated that the processes and morphological form of the estuary are predicted to change over the next 20, 50 and 100 years. This therefore has implications for the distribution, extent, composition and functioning of the habitats and species that the system supports. The overall extent of the intertidal and subtidal components of the system is predicted to change. By 2105 there is predicted to be a net increase of approximately 5% (2400ha) of subtidal habitat, predominantly occurring in the inner estuary. At the strategic level of the Severn Estuary CHaMP, the future behaviour of individual sandbanks was not modelled. While subtidal sandbanks would be expected to change in both extent and distribution throughout the next 100 years, this habitat type would be expected to remain within the Severn Estuary.

Table 6.7(5): Predicted change in subtidal area as compared to 2005 (Source – provisional results from the Severn Estuary CHaMP).

Total Estuary Change (As compared to 2005)	20 year % gain	50 year % gain	100 year % gain
Subtidal area	3	3	5

Large areas of the outer channel consist of hard scoured bottoms with reefs of the honeycomb worm *Sabellaria alveolata* and the horse mussel *Modiolus modiolus*. The results of the CHaMP do not provide a prediction of where suitable conditions (both physically and ecologically) will exist for the establishment and continued survival of such biogenic reefs. It has therefore been assumed that conditions within the estuary will remain suitable for such species. The distribution and extent may, however, change throughout the estuary dependent on localised conditions.

Implications of a barrage

The presence of a barrage is predicted to result in changes to the subtidal sediments of the estuary. These changes along with the changes in the hydrodynamic regime will have implications for the distributions of benthic communities. The area of subtidal habitat is also predicted to increase as a result of potential changes in water levels. The magnitude of these changes will again be different when comparing the Cardiff-Weston and The Shoots schemes. The increase in subtidal habitat will be greater for the Cardiff-Weston scheme as compared to The Shoots due to the overall plan area of the estuary affected by the positioning of the respective barrages.

Predictions made by Warwick *et al*, (1989)[104], for the Cardiff-Weston scheme, based on shear stress values and analogue comparisons with other estuaries indicate there could be a significant change to higher densities of a *Nephtys / Tharyx* association at the expense of *Sabellaria* reefs, at least in the short term. This would be dependent on changes in the physical regime of the estuary and the suitability of conditions created for benthic organisms. The current records of the distribution of *Sabellaria* are primarily located in the outer estuary, considerably seaward of the proposed line of The Shoots scheme. The Cardiff-Weston scheme would therefore be expected to have a greater impact on this designated feature (Figure 6.7(3)).

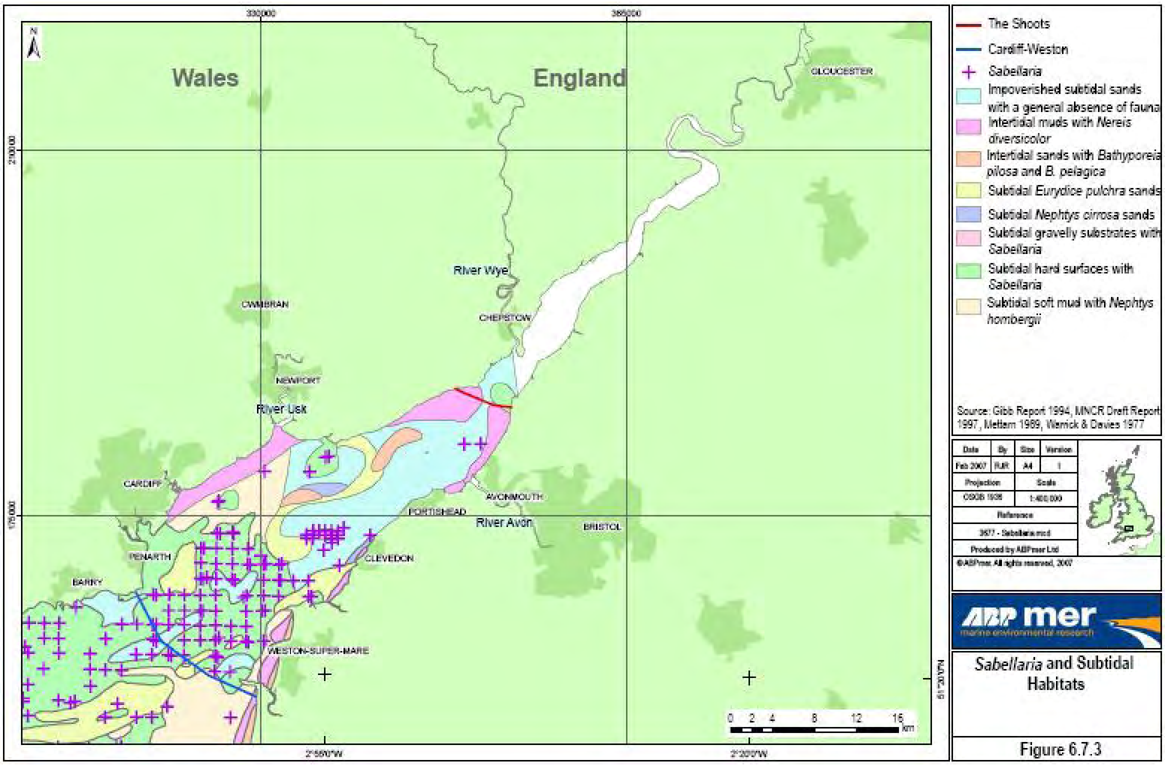


Figure 6.7(3): Impact of the two barrage schemes on the estuary

Changes to subtidal sandbanks are possible under both schemes due to predicted changes in the hydrodynamic and sedimentary regime. The behaviour of individual sandbanks would require detailed modelling to gain an understanding of potential impacts on this feature as a result of either barrage line.

Requirements for additional studies

There will be a requirement for a greater understanding of the changes in the physical regime of the estuary and the implications of these changes on the biological communities.

6.8.7 Eelgrass

Eelgrasses are marine flowering plants of sheltered environments anchored to shallow subtidal and intertidal sands and muds by a rhizome and root system. Within the Severn Estuary eelgrass is known to occur on some of the more sheltered mud and sand banks around the Welsh side of the Severn Crossing, close to Sudbrook Point. There are three species of *Zostera* in the UK, common eelgrass *Z.marina*, narrow-leaved eelgrass *Z. angustifolia* and dwarf eelgrass, *Z. noltii* and all three species are present within the Severn Estuary. There have been no detailed reports identified describing the extent and health of the eelgrass population. It is possible, however, that the eelgrass may be in decline (Environment Agency, 1997).

Future evolution in the absence of a barrage

It is assumed in the absence of a barrage (or other developments and changes in management practices) that the distribution of eelgrass would not change significantly from the current position. The distribution and extent of eelgrass has the potential to change under natural conditions and may also be sensitive to factors associated with climate change.

Implications of a barrage

Eelgrass is currently located immediately seaward of the proposed Shoots barrage and considerably landward of the Cardiff-Weston scheme. The construction of a barrage in either location therefore has the potential to affect the distribution and extent of eelgrass beds. The impact of a barrage on eelgrass has not been specifically investigated. Eelgrass is, however, known to be sensitive to changes in water quality, substratum loss, erosion and accretion, suspended sediment concentrations, emergence regime, water flow rate and wave exposure. Eelgrass landward of the Cardiff-Weston scheme could increase with reduced turbidity and a more stable sediment regime in the presence of a barrage.

Requirements for additional studies

To date only limited information on the predicted impacts of a barrage on the distribution and extent of eelgrass has been reported. The implication of a barrage on eelgrass will require a full understanding of the changes in hydrodynamics and sedimentary regimes associated with the proposed scheme. The exact location of existing eelgrass beds will also need to be fully understood in the context of the proposed line of a barrage.

6.8.8 Transitional habitats

A number of habitats are present above the high tide mark and beyond the existing sea defences. Similarly a number of transitional habitats occur between fully marine and terrestrial conditions. The types of habitat that are present along the margins of the Severn Estuary include:

- Grazing marsh
- Reedbeds
- Saltings
- Drainage channels
- Wetlands
- Grassland and woodlands
- Rivers and standing open waters
- Agricultural land and urban habitat

Future evolution in the absence of a barrage

The Severn Estuary CHaMP did not predict the changes that will occur to the habitat types that occur behind the existing geological constraints over the next 100 years. It is possible, however, that these habitats may be affected by changes in environmental parameters and management practices that may occur along the banks of the Severn Estuary. An assessment was however, made of the predicted change to transitional grassland habitats, the definition of which included mature marsh species and grazing marsh. It was assumed that this habitat type occurs between the upper limit of saltmarsh and the line of the geological constraint. Overall there was predicted to be a gain of approximately 6% of potential transitional grassland habitat by 2105 as compared to 2005. Potential gains of this habitat type were most apparent in the middle and inner sections of the estuary with losses predicted elsewhere within the system.

Table 6.7(6): Predicted change in transitional grassland as compared to 2005 (Source – provisional results from the Severn Estuary CHaMP).

Total Estuary Change (As compared to 2005)	20 year % gain	50 year % gain	100 year % gain
Transitional Grassland	13	6	6

Implications of a barrage

It is anticipated that transitional and marginal habitats would be inundated less frequently in the presence of a barrage. This would result in changes to the composition and structure of transitional habitats, which would in turn have implications for the species they support.

The potential changes to land drainage associated with a barrage have been described in Section 7.5. These changes also have implications for the transitional habitats of the Severn

Estuary. The degree to which the barrage benefited or damaged wetland habitat, for example, would depend on the nature of the changes. In principle the raising of the water table would be expected to have a positive effect and lowering it would be considered detrimental to freshwater wetland habitat[117].

In relation to reedbeds it has been suggested that there could be extensive development of reedbeds at the head of the estuary where the present intertidal sediment banks become subject to a small tidal range of low salinity water, conditions which are suited to the development of this habitat type[117].

Transitional habitats would also potentially be affected by any changes in land use associated with the barrage. During the construction phase of the barrage there is the potential for direct loss of transitional habitats. There is also the potential for spillages and pollution incidents during this stage of the development.

Requirements for additional studies

There will be a requirement for a greater understanding of the changes in the physical regime of the estuary and the implications of these changes on the terrestrial and transitional habitats. This will also need to incorporate a review in the context of predicted changes in land drainage and the associated effects. In addition impacts arising through land use changes associated with the barrage will need to be reviewed.

6.8.9 Plankton and marine algae

The plant communities of the Severn Estuary have not previously been described in great detail. There is, for example, little descriptive or quantitative information about phytoplankton, benthic micro-algal communities, macro-algae, intertidal plants or detritus.

Future evolution in the absence of a barrage

In the absence of further development it is assumed that the occurrence of phytoplankton and algae would not change markedly. It would, however, be anticipated that changes would arise as a result of climate change and associated changes in the physical conditions of the estuary.

Implications of a barrage

The implications of a Cardiff-Weston barrage, on plankton and marine algae in the Severn Estuary, were considered in the STPG Severn Barrage Project. The key outputs of this study[128] are summarised below:

It was predicted that in the presence of a barrage that there would be a general increase in the species diversity, standing crop and productivity of plant communities as a result of reduced turbidity and greater substrate stability. The reduction in the suspended sediment concentrations in the water column could increase the depth of the euphotic zone. It was predicted that most of the water area landward of the barrage would continue to have a sufficiently high turbidity to suppress the growth of phytoplankton populations. The implications for algal blooms are not fully understood due to the unpredictable nature of such events.

There is the potential for prolific growths of algae, particularly in the earlier years following the change in tide range. It was predicted that macro-algal abundance could increase throughout the

[128] STPG, Severn Barrage Project. Detailed Report Volume IV “Ecological Studies, landscape and nature conservation” ETSU TID 4060-P4

estuary. However, observations in La Rance indicate that the occurrence of macroalgae is equivalent to nearby open areas[129].

Overall there was not predicted to be a substantial change in the productivity of the estuary. The changes to the plankton and marine algal species within the Severn Estuary would be dependent on the physical and chemical changes, particularly water quality, within the system as a result of a barrage. This would be true of either the Cardiff-Weston scheme or the Shoots scheme.

Requirements for additional studies

A more detailed description of the current plankton and algal communities would be required for a future environmental appraisal of a Severn Barrage. This would need to incorporate a greater understanding of the implications of changes in these parameters on the functioning of the system.

6.8.10 Fish

The Severn Estuary supports a range of migratory and marine fish species. The migratory species of particular concern are the salmon, twaite, allis shad, sea and river lamprey, eel and sea trout, which are designated features of the estuary. The Rivers Usk and Wye also support migratory fish, which depending on the line of the barrage, could be more or less impacted by the development. The estuary provides feeding, spawning and nursery grounds for a number of marine species. Flounders, bass, whiting, sprat, mullet, pollack and sole, for example, are found in considerable numbers as high up the estuary as Oldbury. It should be noted that there is a degree of overlap between this section and the commercial fisheries section (Section 7.4). This section incorporates aspects that are relevant to the ecology of all fish species.

Future evolution in the absence of a barrage

In the absence of a barrage the fish population of the estuary would not be expected to change beyond the natural variability that currently exists. The effects of climate change on fish populations have, however, recently been reviewed[130,131]. Using a 25-year time series of monthly samples, Henderson (2007) has demonstrated that the fish community of Bridgwater Bay in the outer Severn estuary is rapidly responding to changes in seawater temperature, salinity and the North Atlantic Oscillation (NAO). A 2°C increase in inshore seawater temperature is predicted to increase total species richness of fish in Bridgwater Bay by 10%, although most of this gain will be warm water tourists. Predicting future communities requires consideration of combined changes in temperature, the NAO and salinity. While the system can change to a warmer water community, there is likely to be increased short-term community instability during periods with unfavourable combinations of the key environmental variables. A different combination of NAO, high temperature and salinity may, in the future, produce a considerable less favourable combination resulting in recruitment collapse for many species[131].

The Environment Agency has also investigated the potential impacts of climate change on salmon[132]. A model has been used to predict growth rates for salmon in the southwest under a ‘low emissions’ and ‘high emissions scenario’. The model predicted that salmon growth could significantly improve under a ‘low emissions’ scenario. Salmon were however likely to fall below current growth levels under the ‘high emissions’ scenario as temperatures exceed optimum levels

[129] Shaw, T.L. undated. La Rance Tidal Power Barrage Ecological Observations relevant to a Severn Barrage Project, Shawater Limited.

[130] Kirby, R. 2006. Links between environmental consequences of La Rance and Severn Tidal Power Barrages. Kirby – 10th October 2006.

[131] Henderson, P.A., 2007. Discrete and continuous change in the fish community of the Brisol Channel in response to climate change. Journal of Marine Biological Association UK, 87, 589-598.

[132] Environment Agency, 2005. Effect of climate change on salmon fisheries. Science Report W2-047/SR.

in the latter half of this century. Expected increases in winter floods and summer droughts are also likely to have adverse effects on survival and abundance. Poor knowledge of ocean processes and the marine phase of the Atlantic salmon life makes the effect of climate change on salmon in the sea much more speculative.

In addition changes in management practices and fisheries policy could have an impact on the future fish populations of the Severn Estuary.

Implications of a barrage

There are a number of potential impacts to the fish populations of the Severn Estuary through the introduction of a barrage.

Passage through turbines

There is currently unrestricted access to rivers upstream of the proposed barrage and probably all species show fidelity in their homing migration. Current mechanisms of passage along the estuary towards the rivers include passive tidal drift using flood tides to ascend the estuary and avoiding ebb tides to prevent descent. At some times this mechanism is replaced by targeted and active swimming once freshwater leads have been identified. The precise mechanisms for this are poorly understood and probably vary seasonally, diurnally and with varying environmental cues, notably freshwater discharge. The routes of migration are unknown although there is some indication of shore orientation in certain climatic conditions (wind direction and speed appears to be a relevant factor). Migrating adult and juvenile fish will therefore use passive transport mechanisms that would inevitably draw them into turbines.

The single largest fishery problem arising from tidal power generation is the inevitable passage of migratory fish through the hydroelectric turbines, with consequent injury risk[133]. A commissioned review by Solomon (1988)[134] of factors causing injury to fish during turbine passage led to the view that there was insufficient understanding of the specific injury mechanisms.

A subsequent study undertaken by Turnpenny (2001)[135] on behalf of the UK Department of Energy (DoE) and CEGB investigated this subject further. Special apparatus was designed and constructed to simulate separately the various stress factors, including rapid pressure change, hydraulic shear stress and turbulence, cavitation and runner blade strike. This allowed greatly improved estimates of fish injury rate to be made for the key species. For the nine metre diameter turbine design proposed for the Severn barrage, the following injury rates were predicted:

Table 6.7(7): Predicted injury rates of fish passage through a Severn Barrage turbine.

Fish (length)	**Injury Rate**
Adult salmon (100cm)	40%
Salmon smolt (15cm)	10%
Adult eel (70cm)	28%
Juvenile shad (7cm)	53%

133 Turnpenny, A. W. H., Clough, S., Hanson, K.P., Ramsay, R., McEwan, D. 2000. Risk assessments for fish passage through small, low-head turbines. Report ETSU H/06/00054/REP

134 Solomon, D. J. Fish passage through tidal energy barrages. Energy Technology Support Unit, Harwell. Contractors Report No, ETSU TID4056, 76pp.

135 Turpenny, A.W. H. 2001. The UK Parliament – Select Committee on Science and Technology Appendices to the minutes of evidence. Appendix 2 – Memorandum submitted by Dr Andrew Turnpenny, Fawley Aquatics Research Laboratories.

The Environment Agency (pers. Comm. 2007) would summarise the potential impact of turbine passage as:

- salmon and sea trout - high risk of high mortality with serious implications for stock status
- shad - very high risk of very high mortality. Potential effective stock eradication
- eel and lampreys - medium risk of high mortality

It is, however, recognised that impacts are sensitive to precise turbine designs, rotation speeds, fish pass size and location and patterns of generation (i.e to 2 - way or flood only).

Impacts that have been observed elsewhere include the case studies of La Rance and a pilot scheme in the Bay of Fundy. Studies of the Barrage scheme in the Bay of Fundy generally shows a very high impact level on migratory fisheries[135]. In contrast impacts at the La Rance on migratory fish species have been described as minimal[129]. Fish and cephalopods reportedly make their way through the turbines without damage[136]. In contrast SAGE (2004)[137] reported that the La Rance barrage has had an impact on the migration of certain species, particularly trout. The differences between the schemes could be attributed to the different turbine blades used.

The line of the Cardiff-Weston barrage is seaward of where both the Rivers Usk and Wye enter into the Severn Estuary. The migratory fish of the Severn Estuary and the Rivers Usk and Wye will therefore be affected by the presence of a barrage. In contrast the Shoots scheme is landward of the River Usk and as such the potential impacts of a barrage on the migratory fish species of this river are significantly reduced.

Remedial measures

The conventional method of preventing fish entry into turbines on riverine schemes is to place fine meshed screens (~12mm mesh) across the water intakes[133]. However, this is not feasible in the marine environment owing to much higher debris loads. Self cleaning screens could potentially be used, but these are expensive and could inflict fatal injuries on delicate species[135].

Provision of large fish passes will be essential, however the design of a fish pass functioning in such an environment and facilitating tidal transport mechanisms is without precedent (neither Fundy, Annapolis, La Rance or the south Wales barrages attempt to do this). Although varying proportions of some species may find and use a fish pass, the success with which they will do so is not currently predictable. Given the varying behaviour and migration route of each species it is conceivable that a large number of passes of varying design would be needed. A substantial flow would be required through these passes in order to maximise attraction of fish, and the structures would therefore have to be very large indeed. Attempting to exclude fish by screening (behavioural or the highly impractical screening approach) would be highly unlikely to work at all (Environment Agency, pers . comm. 2007). The potential for fish to change their typical migration routes in response to a large scale obstruction would require further consideration in the context of a barrage.

Changes in water quality

The potential changes in water quality associated with a barrage have been described in Section 6.6. Fish species are known to be impacted by changes in water quality. These include a sensitivity to:

- dissolved oxygen[138]

---

[136] Le Mao, P. 1985. Place de la seiche Sepia officinalis (Mollusque, Cephalopode) dans les chalnes alimentaires du Golfe normano-breton. Cahiers de Biologie Marine 26, 331-340.

[137] SAGE (Schéma d'aménagement et de Gestion de l'Eau) de la Rance et du Frémur. (Arrêté préfectoral du 5 avril 2004. Tome 1 du SAGE Rance Frémur Baie de Beaussais – La Rance et le Frémur en 2002 - Etat des lieux)

[138] Alabaster, J.S. and Gough, P.J., 1986. The dissolved oxygen and temperature requirements of Atlantic salmon, Salmo salar L., in the Thames estuary. Journal of Fish Biology, 29:613-621.

- turbidity[139]
- contaminants[140]

Fish demonstrate a number of physiological and behavioural responses to each of these parameters depending on thresholds and respective sensitivities.

Additional considerations

The presence of the barrage also has the potential to affect a number of additional parameters:

- Possibility of increased predation of juveniles by birds and fish;
- Change in prey resource;
- Changes in subtidal habitats and implications for spawning and nursery grounds;
- Delays to migration;
- Delays in the movement of smolts;
- Identification of natal rivers.

It is important to highlight, as with all potential impacts that have been identified, that different species will be impacted by a barrage to a greater or lesser extent.

Construction

The potential impacts of the construction of the barrage on fish populations have not previously been described. A number of potential impacts may, however, arise during the construction phase:

- Noise (through construction and dredging operations)[141]
- Water quality (including spillages, suspended sediment concentrations, dissolved oxygen and contaminants).
- Direct loss of habitat and prey resource.

Requirements for additional studies

The potential impacts of a barrage on the fish populations of the Severn Estuary and the Rivers Usk and Wye requires further research. The potential impacts of a barrage need to be reviewed in the context of the current status of fish stocks within these locations. This would be particularly important for species that are protected by designations and/ or of commercial interest. A greater understanding of the functioning of the system and the sensitivity of species to environmental change (both with and without a barrage) also needs to developed. Mechanisms for more friendly passage of fish have been investigated and this research is ongoing. The results of research in this field need to be explored in the context of the species supported by the Severn Estuary and its tributaries. It is important to recognise that there may be a requirement for compensatory measures to be introduced, if a barrage were to be constructed, and these would require detailed investigations.

6.8.11 Birds

The importance of the Severn Estuary for bird species has been highlighted through its designation as an SPA and Ramsar site. The estuary supports a range of species as highlighted in the citations for the estuary. The following text provides a brief description of birds using the Severn Estuary, primarily based on early datasets that were collated in STPG's Severn Barrage Report[128] The Royal Society for the Protection of Birds (RSPB) have recently collated information on bird usage

---

[139] EIFAC (1965) cited in FARL, 1995. Possible impacts of dredging on salmonids. Research Note for ABP Research. Fawley Aquatic Research Laboratories Ltd.

[140] McCain, B.B., Brown, D.W., Hom, T., Myers, M.S., Pierce, S.M., Collier, T.K., Stein, J.E., Chan, S.L. & Varanasi, U., 1996. Chemical contaminant exposure and effects in four fish species from Tampa Bay, Florida. Journal of Estuarine Research Federation 19:86-104

[141] Nedwell, J., 2003. Report on the potential effects of underwater piling noise from the Dibden Bay Phase 1 Project. Report Ref: 570 R 0202.

of the Severn and as such a current review of bird numbers is containted within Prater, 2007[142]. A future environmental appraisal of a barrage would, however, require a more complete current baseline description of the bird usage of the estuary to be produced. A recent summary of winter peak counts and species observed in internationally important numbers in the period 1984 – 2005 are presented in Tables 6.7(8) and 6.7(9) respectively.

Table 6.7(8): WeBS Winter Peak Counts for the Severn Estuary 1985-2004 (Source RSPB).

Year	Peak Count
2004/2005	64,425
2003/2004	64,814
2002/2003	64,029
2001/2002	60,872
2000/2001	63,036
1999/2000	69,604
1998/1999	75,927
1997/1998	70,336
1996/1997	80,653
1995/1996	71,335
1994/1995	101,457
1993/1994	79,872
1992/1993	69,538
1991/1992	83,329
1990/1991	85,462
1989/1990	(56,603)*
1988/1989	57, 970
1987/1988	57, 051
1986/1987	(34,474) *
1985/1986	48,333
1984/1985	51,275

***** Incomplete count – figure is a minimum

Table 6.7(9): WeBS Five Year Averages for the Severn Estuary 1985-2004

Range	Peak Count Average	Species in Internationally Important Numbers

[142] Prater, T. 2007. Ecological aspects of the Severn Barrage. Royal Society for the Protection of Birds.

99/00-03/04	64, 967	shelduck, teal, pintail, dunlin, redshank
94/95-98/99	78, 944	Bewick's swan, shelduck, dunlin, redshank
89/90-93/94	81,669	Bewick's swan, shelduck, gadwall, curlew, dunlin, redshank
84/85-88/89	51,216	Data not available

The estuary is used as a feeding ground, roosting and loafing site and supports numerous birds as part of their migratory passage. Some species of waterbird are considered to be under-represented on the Severn Estuary whilst others occur in internationally important numbers. The timing of the seasons of the principal bird species using the Severn Estuary as summarised in STPG Severn Barrage Report[128] is presented in Table 6.7(10).

Table 6.7(10): Timing of the seasons of the principal bird species using the Severn Estuary.

	Breeding season	**Autumn passage**	**Winter**	**Spring Passage**
Shelduck	Apr - Jun	Jul – Oct	Nov - Mar	*
Oystercatcher	Apr - Jun	Aug – Oct	Nov - Mar	*
Ringed plover	May- Jul	Aug – Sep	Oct - Mar	Apr - May
Golden plover	May – Jun	Aug – Oct	Nov - Mar	Apr
Grey plover	Jun- Jul	Aug – Sep	Oct - Mar	Apr - May
Lapwing	Apr – Jun	Jul – Sep	Oct - Mar	*
Knot	Jun – Jul	Aug – Sep	Oct - Mar	Apr - May
Dunlin	May – Jun	Jul – Sep	Oct - Mar	Apr - May
Snipe	May – Jun	Jul – Sep	Oct - Mar	Apr
Curlew	Apr - Jun	Jul – Sep	Oct - Mar	*
Redshank	Apr - Jun	Jul – Sep	Oct - Mar	*
Turnstone	Jun	Jul – Sep	Oct - Mar	May

During the winter of 1987/1988 counts were made in 162 count areas on 14 occasions. Fifty percent of birds were reported to feed on just 13 sites which cover 12% of the total intertidal area. Six of these were in Bridgwater Bay and the Parrett Estuary, seaward of the line of either of the proposed barrages. These are therefore amongst the most important areas in the whole estuary. A further 43 sites held the next 40% of birds. Maps of these key areas of usage can be found in STPG's Severn Barrage Report[128]. Intertidal areas upstream of the location of a possible Shoots barrage are generally utilised less by overwintering birds than areas downstream.

Most of the species using the Severn Estuary roost on or near the intertidal areas used for feeding. Areas of mud below the saltmarsh zone are used for roosting even at high tide during neap tides. Birds congregate in this zone and do not then form roosts away from intertidal areas. During periods of high spring tides, their roosts are on the upper areas of saltmarh or fields in the estuary hinterland[143].

The estuary also supports the Annex I species Bewick's swan (*Cygnus columbianus bewickii*), which can be present in internationally important numbers. For example, the SPA citation records a 5 year peak mean (1988/9 to 1992/3) of 289 birds representing 1.7% of the North West Europe population, although the latest 5 year count (1999/0 to 2003/4) indicates that the numbers were below the qualifying threshold. Bewick's swan occurs in the upper Severn Estuary around Slimbridge. The intertidal areas of the estuary can be used as a safe refuge area when the birds are disturbed. The birds also feed on the saltmarsh and the transition from saltmarsh to coastal grazing marsh in front of the sea defences in the upper estuary at the Dumbles, although they primarily feed on wet meadows outside the SPA boundary.

Future evolution in the absence of a barrage

In the absence of a barrage, in the short-term the bird population of the estuary would not be expected to change beyond the natural variability that currently exists. In the longer-term, the predicted loss of intertidal as a result of sea level rise has the potential to affect overall bird usage. Changes in land use and management practices around the estuary also have the potential to affect the birds that are supported by the estuary and its margins.

The distributions of eight out of nine common species of waders overwintering on UK estuaries have been reported to have changed in association with recent climate change. During warmer winters, smaller proportions of seven species wintered in south-west Britain[144]. Dunlin, for example, is a designated feature of the Severn Estuary SPA because numbers there exceed the 14 000 international threshold for this species. However, although in the national context numbers of dunlin have remained relatively stable since the mid-1980s, those on the Severn Estuary have been declining steadily and in the most recent winters the overwinter average has dropped below this threshold. This highlights how the importance of estuaries may change through time, both within Britain and elsewhere in Europe. The potential implications of climate change for the avian ecology of the Severn Estuary further considered in Prater 2007[142].

Implications of a barrage

A number of studies have attempted to model and predict the potential impacts of a barrage on the bird populations that are supported by the Severn Estuary. These studies are, however, all reliant on an understanding of how the physical and ecological environment will change in the presence of a barrage and as such this has introduced considerable uncertainty to any predictions that have been made.

The introduction of a barrage and the associated reduction in tidal range would have two key impacts on the bird populations supported by the Severn Estuary:

- Reduction in intertidal area and associated prey resource;
- Reduction in time available to feed.

Their ability to survive the winter or to build up fat reserves prior to migration could thus be impaired. This could potentially affect numbers not sjut locally but nationally and internationally[145]. In contrast, the construction of a barrage could bring about changes in the

[143] Ferns, P.N. 1988. Waterbird Community Changes in the Post-barrage Severn Estuary, report to Severn Tidal Power Group No. SBP 41.

[144] Austin, G.E and Rehfisch, M.M (2005) Shifting nonbreeding distributions of migratory fauna in relation to climatic change Global Change Biology 11, 31-38.

[145] Goss Custard, J.D. & Moser, M.E. 1988. Rates of change in the numbers of dunlin, Caldris alpine, withering in British estuaries in relation to the spread of Spartina anglica. Jounral of Applied Ecology, 25, 95-109.

biological productivity of the estuary which could offset some or all of the effects of reduced foraging time and feeding area. This is thought to be particularly likely in the Severn[146].

Multiple regression analysis was undertaken to predict the numbers of birds that the new Severn might be able to support after a barrage was built along the line of the Cardiff-Weston scheme. This was based on conditions in a wide range of estuaries in the south-west of Britain[147]. The following variables were included in the analysis:

- Invertebrate densities – food supply is the most important variable for predicting the densities of waders on different estuaries[148 149].
- The size of the invertebrates (length and ash-free dry weight) and therefore the preys value and attractiveness of the area to birds.
- Shore width- some species are thought to avoid narrow beaches.
- Foraging time.

The results demonstrated that the densities of prey species and particular size classes of a prey species were key variables for supporting the bird species that utilise the Severn Estuary.

The results of the analysis were used to predict possible bird densities in the perspective of a barrage in the location of the Cardiff-Weston scheme. The following conclusions were reached:

- There was no evidence that the length of the foraging period available to the birds significantly affected their densities.
- Predictions should be based primarily on the predicted post-barrage densities of the major prey categories.
- Attention should be focused on a limited range of prey species and the size classes of prey species are important.

The approximate increase in prey density required post barrage to allow the existing number of birds to live in the reduced area was also calculated. It was assumed that approximately 50% of the existing feeding areas would be lost if a barrage was introduced along the Cardiff-Weston scheme. It is assumed that this figure is based on a combination of a predicted loss of intertidal area combined with the assessment of the main areas of bird usage STPG's Severn Barrage Report[128].

With the exception of dunlin, predicted increases in prey density of the order required fell well within the range of prey densities recorded at other estuaries. With the exception of dunlin and possibly shelduck, the elevated bird densities that would be necessary in the Severn fell within the values occurring in the other groups of sites. It is important to highlight that this should only be seen as a broad indicator and large confidence intervals exist around the data. Whether or not bird densities could double on the Severn depends on the extent to which the physical changes upstream and downstream of either barrage option might support increases in the densities of key invertebrates. It is also important to recognise that there are key behavioural differences between species such that the impacts may also vary by species. Bird densities and their distribution may also be affected by factors such as location, proximity of suitable roosting sites and beach characteristics (e.g. sediment type). A greater understanding of the system would be required before implications for the birds could be more fully evaluated.

---

[146] Kirby, R. 1988. The ecological implications of possible changes in the sedimentological regime caused by the proposed Severn Barrage. Report to Severn Tidal Group, 75pp.

[147] Institute of Terrestrial Ecology, 1988. Prediction of post-barrage density of shorebirds: birds. ETSU Contract No. E/5A/CON/4059/1705.

[148] Goss-Custard, J.D. Kay, D.G. & Blindell, R. M. 1977. The density of the migratory and overwintering redshank, Tringa tetanus and curlew Numenius arquata in relation to the density of prey in the south-east England. Estuarine and coastal marine science, 5, 497-510.

[149] Bryant, D. M. 1979. Effects of prey density and site character on estuary usage by overwintering waders (Charadrii). Estuarine and Coastal Marine Science, 9, 369-384.

The predictions that were made were in the context of existing mudflats and these areas and the sediment composition could change with a new barrage, which would again affect the predicted outputs. Some new prey categories may also occur, particularly among the suspension feeders. Oystercatchers, for example, occur at very high densities on beds of *Mytilus edulis* and *Cerastoderma edule* and large numbers could be accommodated on the Severn if these invertebrates were to establish themselves. The predictive equations were also trialled in the case study of the La Rance. However, overall the association between predicted and observed densities at La Rance was considered disappointingly poor.

Whatever the final configuration of intertidal banks, the actual area exposed between tides will be much less than at present. While some of the birds may be able to remain in the reduced area at higher density than occur at present, others may feed in less preferred areas where ingestion rates are likely to be lower. Food supplies for these species could be depleted more quickly and so reduce the efficiency with which food supplies and feeding space could be utilised. This could ultimately lead to some individuals leaving the area.

In the context of the Shoots scheme the area of intertidal loss predicted by the presence of a barrage is considerably less than that of the Cardiff-Weston scheme. The potential impacts on the bird populations supported by the estuary are therefore considered to be significantly less than those of the Cardiff-Weston scheme. Key areas of bird usage (waders and shelduck) identified in the maps presented in STPG's Severn Barrage Report[128] are all primarily seaward of the Shoots scheme. In particular, species such as dunlin rarely utilise areas upstream of the possible location of the Shoots Barrage and only in low numbers, such that the impacts on this species might be expected to be minimal. This assessment would, however, require a detailed review of current areas of bird usage when giving further consideration to a proposed barrage.

Additional considerations

The presence of the barrage also has the potential to affect a number of additional parameters:

- Associated buildings could reduce roosting sites;
- Increased disturbance;
- Distance between roosts and feeding grounds could be altered;
- Invertebrates upstream of the barrage which change may not be as suitable as prey resource;
- Changes in high level vegetation and marginal vegetation may affect roosting sites.

A range of other ecological changes could occur up estuary of either barrage option as a result of changes in the physical regime. The effects of such possible changes on bird populations cannot be readily evaluated at this stage.

Construction

The potential impacts of the construction of the barrage on bird populations have not previously been described. A number of potential impacts may, however, arise during the construction phase:

- Noise (through construction and dredging operations);
- Disturbance;
- Direct loss of habitat and prey resource.

Requirements for additional studies

There would be a key requirement for an up to date evaluation of bird usage on the Severn Estuary to include:

- Update to bird count data;
- Understanding of key areas of bird usage; and
- A review of ecosystem functioning and linkages to the physical environment.

Confident predictions about post-barrage densities of both the invertebrates and birds cannot be made until:

- Factors for prey density are established and quantified; and

- How the physical regime and morphology of the estuary will be altered by a barrage is fully evaluated.

Since the original predictive models were developed [128], individual based models which follow behavioural responses of individual animals to changes in the environment and predict variables such as population mortality rates from the fate of all individuals have been developed[150]. It is thought that these models could provide more reliable predictions than those made originally. It should be noted, however, that a degree of uncertainty would remain even in the presence of these additional information sources.

6.8.12 Mammals

The Bristol Channel/ lower Severn Estuary is not considered an important breeding ground for any marine mammal but it is used as a feeding area. Grey seals (*Halichoerus grypus*) occur in the Bristol Channel and outer Severn Estuary, although usually in small numbers. No breeding colonies exist in the Severn Estuary or inner part of the Bristol Channel with the nearest colony at Lundy island[151]. Harbour porpoises (*Phocoena phocoena)* are resident in the Bristol Channel and the outer Severn Estuary. Watkins and Colley (2004)[152] have identified important populations occurring along the Gower Peninsula and Swansea Bay area. There are no other resident cetacean species found in the Bristol Channel although other species (mainly common, risso and bottlenose dolphins) are occasionally sighted, mainly in the outer Bristol Channel[152,153]. The Eurasian otter *(Lutra lutra)* is commonly found throughout the Severn catchments but its distribution appears to be mainly restricted to non-tidal parts of the Severn[154], although they have been observed up the tidal Usk at Newport.

Future evolution in the absence of a barrage

In the absence of a barrage the marine mammals that are observed within the Severn Estuary and its tributaries would not be expected to change beyond the natural variability that currently exists. The effects of climate change may, however, have an effect on the distribution and abundance of such species.

Implications of a barrage

The potential impacts of a barrage on marine mammals have not previously been described. The limited number of sightings within the estuary suggests that there is limited potential for any impacts on these species as a result of either of the reviewed schemes. It is possible that there could be a limited increase in mortality due to collisions with turbine blades.

Requirements for additional studies

There would be a requirement to ensure that previously reported marine mammal data is still applicable to the current Severn Estuary. The sightings of marine mammals would need to be

---

[150] West, A.D. and Caldow, R.W.G. 2006. The development and use of individuals based models to predict the effects of habitat loss and disturbance on waders and waterfowl. Ibis, 148, 158-168.

[151] SCOS 2006: Scientific Advice on Matters Related to the Management of Seal Populations Scientific (smub.st-and.ac.uk/CurrentResearch.htm/SCOS2006/SCOS%202006%20collated%20document%20FINAL.pdf)

[152] Watkins, H and Colley, 2004. Harbour Porpoise *Phocoena phocoena* Occurrence Carmarthen Bay - Gower Penninsula - Swansea Bay

[153] Reid, J.B., Evans, P.G.H., & Northridge, S.P., (2003), Atlas of Cetacean distribution in north-west European waters, 76 pages, colour photos, maps. Paperback

[154] Environment Agency Fourth Otter Survey of England 2000-2002: Severn Catchment. (www.environment-agency.gov.uk/commondata/acrobat/severn_region.pdf)

reviewed in the context of the proposed line of a barrage. Changes within the prey resources of these species would also need to be evaluated in the context of the functioning of the system.

6.9 ARCHAEOLOGY

6.9.1 Background

The Severn Estuary and its associated levels and hills offer a rich and varied archaeological landscape. They are a finite record that contributes to our understanding of the evolution of human interaction with, and modification, of the changing environment. A maritime heritage of Bronze Age, Roman and Medieval boats may be located within the accumulation of marine sediments and peat which make up the Severn Levels. A brief overview of important sites includes later prehistoric sites which can be found at Brean Down, Gwent Levels, Caldicott and Goldclif. Roman settlement and drainage systems are apparent on the North Somerset and Wentlodge levels. Strategic defences from more modern times are found on Flat Holm and Steep Holm, dating from Napoleonic and 2nd World Wars, not to mention industrial heritage and important geological sites. Important archaeological features can also be found within the intertidal and subtidal sediments of the estuary. This includes a number of wrecks as identified by the hydrographic office (Figure 6.8(1)).

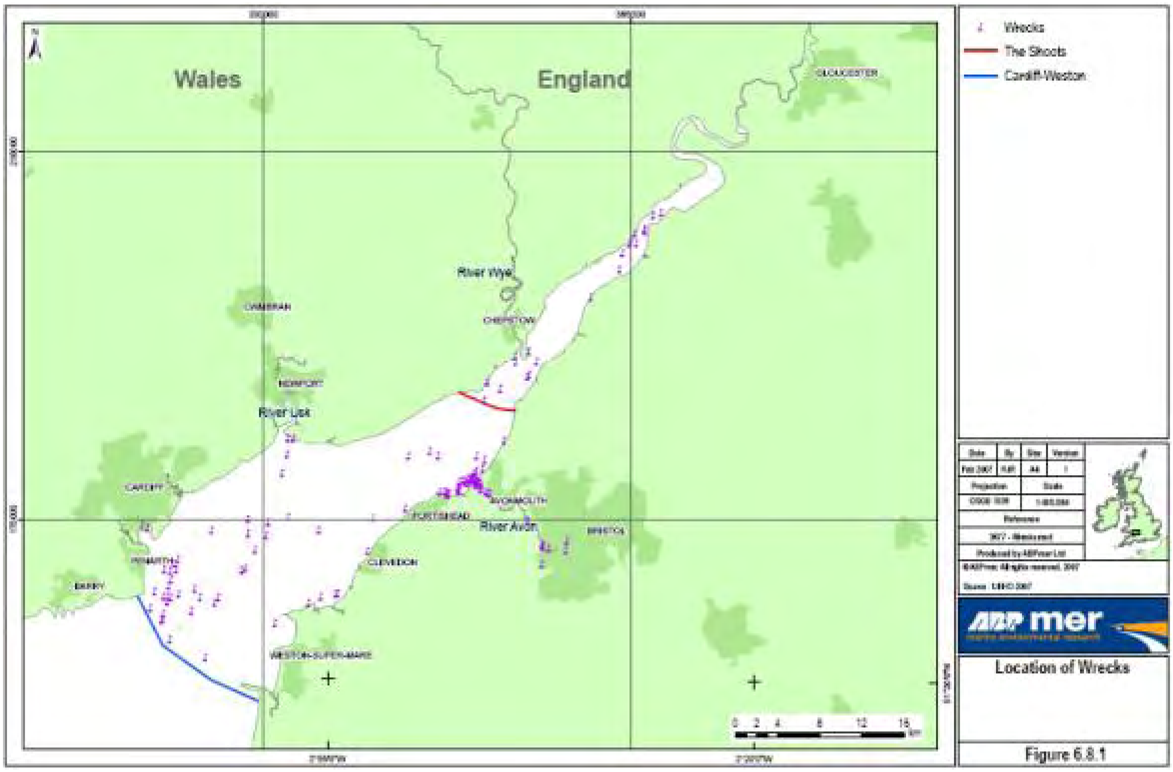


Figure 6.8(1): Wrecks in the Severn Estuary

Reviews of the existing archaeological information for the Severn Estuary are provided in Bell and Neumann (1997)[155], STPG Severn Barrage Report, 1989[156], Severn Estuary Partnership (2001, 2006)[157] and the Severn Estuary Levels Research Committee (1988, 2001)[158]. In addition the

---

[155] Bell, M. and Neumann, H. 1997. Prehistoric Intertidal Archaeology and Environments in the Severn Estuary, Wales. World Archaeology, 29, 95-113.

[156] STPG, Severn Barrage Project. Detailed Report Volume IV “Ecological Studies, landscape and nature conservation” ETSU TID 4060-P4

[157] Severn Estuary Partnership, 2001. Strategy for the Severn Estuary.

Bristol Channel Marine Aggregates Study (2000)[159] mapped limited existing data for the subtidal archaeological resource in the Bristol Channel and Severn Estuary. The study indicated the likely archaeological heritage and importance and susceptibility of specific areas.

In Wales, Planning Policy Wales Chapter 6 provides guidance for the conservation of the historic environment within the planning process whilst in England the equivalent is Planning Policy Guidance Notes 15 and 16. The highest rating of archaeological protection is given to those sites that are designated as Scheduled Ancient Monuments (SAMs). There are several SAMs in the region of the Severn and these have statutory protection. Cadw is responsible for the protection of Welsh SAMs and English Heritage the English ones. Sites that had been designated as SAMs in 2001 are presented in Figure 6.8(2). Development requiring planning permission and work undertaken by statutory undertakers should also be assessed for its impacts on unscheduled sites. Historic Environment Records or Sites and Monuments Records are typically available from the local authorities that surround the estuary in England and Royal Commission on the Ancient and Historical Monuments of Wales in Wales. Additional protection is afforded to historic landscapes which includes the Gwent Levels.

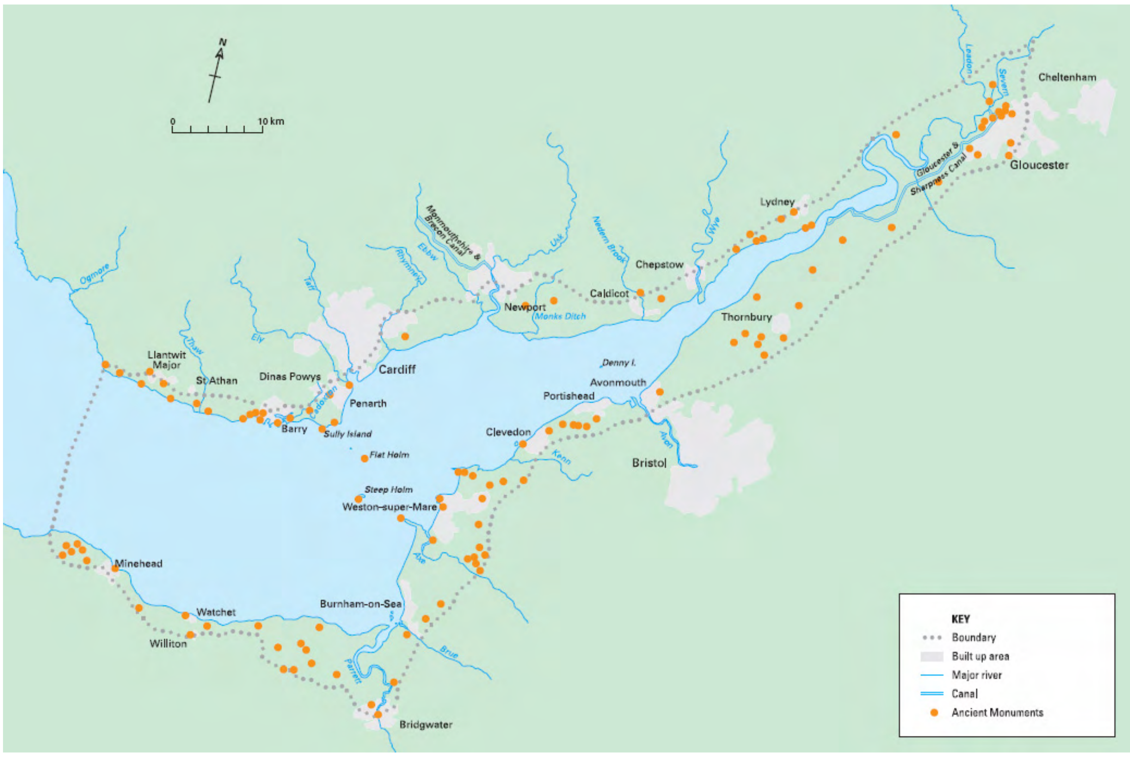


Figure 6.8(2): Scheduled Ancient Monuments[157]

With respect to historic land and properties that are adjacent to the Severn Estuary the National Trust has provided preliminary information. The National Trust[160] owns several properties adjacent to the Severn Estuary which may be affected by a tidal barrage including:

Severn Estuary Partnership, 2006. The Archaeology of the Severn Estuary. A guide for planners, developers, decision makers and local communities.

[158] Severn Estuary Levels Research Committee, 1988. The archaeological potential of the Severn Estuary, and initial assessment for STPG.

Severn Estuary Levels Research Committee, 2001. Estuarine Archaeology, the Severn and Beyond Archaeology in the Severn Estuary. Edited by Stephen Rippon, Department of Archaeology, University of Exeter.

[159] Posford Duvivier and ABP Research, 2000. Bristol Channel Marine Aggregates Study.

- Brean Down;
- Undeveloped coastline at Middle Hope;
- Undeveloped coastline at Sand Point; and
- Westbury Court in Gloucestershire.

The National Trust also owns sites seaward of a potential barrage line including Lundy Island along the West Somerset/ North Devon coast and also on the South Wales coast. The National Trust has identified a number of potential concerns to these sites, in the presence of a barrage, which would all need to be addressed within a full EIA process.

6.9.2 Future evolution in the absence of a barrage

In the absence of a barrage it is assumed that archaeological features and coastal sites would be subjected to the natural processes that occur within the dynamic environment in which they are located. Physical changes associated with climate change do, however, have the potential to impact on the preservation and status of historic features.

6.9.3 Implications of a barrage

The potential impacts of a barrage on the archaeological interests of the Severn Estuary were previously reviewed in STPG Severn Barrage Report, 1989[156]. In the case of the proposed Severn Barrage, four geographical areas for archaeological attention were identified:

- The caisson construction sites and their associated sources of raw materials.
- The barrage site and its associated on-land road works.
- The intertidal area of the estuary.
- Areas of land use change post-barrage.

The review of implications of a barrage in these areas was limited by the data available at the time of the assessment. Key physical changes as a result of the barrage, which have implications for archaeology, include:

- Change in intertidal area and submergence patterns landward of the barrage;
- Minor changes in water levels seaward of the barrage;
- Change in the sedimentary regime (erosional and accretional trends);

A change in the emergence regime could, for example, result in the submergence of some sites of interest. Conversely existing sites within the higher intertidal zone may no longer be tidal in the presence of a barrage, which could affect the preservation of these features. In addition the raising of water table levels could help to preserve archaeological information but make it difficult and costly to investigate. Archaeological interest features will be impacted by changes in the sedimentary regime through both masking in areas of accretion and exposure in areas of erosion. These types of physical changes would be expected under either the Cardiff-Weston or The Shoots scheme. The area affected by The Shoots scheme would, however, be expected to be considerably less than the Cardiff-Weston scheme. This does not reflect on the relative importance of archaeological features and their location within the estuary.

The protection of archaeological features in the process of extracting raw materials for the construction of the barrage, such as marine aggregates, will be incorporated into the licensing of these activities.

---

[160] National Trust, 2006. Letter to the Sustainable Development Commission regarding scoping issues if tidal energy in the UK.

6.9.4 Requirements for additional studies

The areas previously identified as of potential archaeological importance[156] require further definition in the context of a proposed barrage. This would need to include the collation of all relevant archaeological data sets and a review in the context of relevant legislation and planning policies as outlined above. The implications of a barrage on the physical regime of the estuary and the associated consequences for archaeological features would require further definition. It is also important to highlight that some excavations may need to occur before a barrage could be built and this could potentially be a costly and time consuming exercise.

6.10 VISUAL ASSESSMENT

6.10.1 Background

The current landscape of the Severn Estuary has been shaped by the geology, physical processes, habitats and associated land uses that are present along its margins. Areas of outstanding Natural Beauty which are located along the Severn Estuary include Quantock Hills, Somerset Levels, Mendip Hills, North Somerset Levels and Moors, Cotswolds and the Wye Valley (Figure 6.9(1)). A review of the potential impacts associated with the presence of a Severn Barrage was previously presented in STPG's Severn Barrage Project (1989) and more recently documented in a Land Use Consultant (2007)[161] report to Natural England.

The design and location of a barrage would need to take into account current planning and environmental policies that are relevant to landscape and development.

These include:

- *Guidance for Coastal Defence in relation to their Landscape and Visual Impacts*, CCW Science report 531
- PPS 22 Renewable Energy
- PPG20 Coastal Planning
- TAN14 Coastal Planning (1998)
- Welsh spatial plan

[161] Land Use Consultants, 2007. Advice on Potential Landscape/Seascape and Visual Impacts of a Severn Barrage. A report for Natural England.

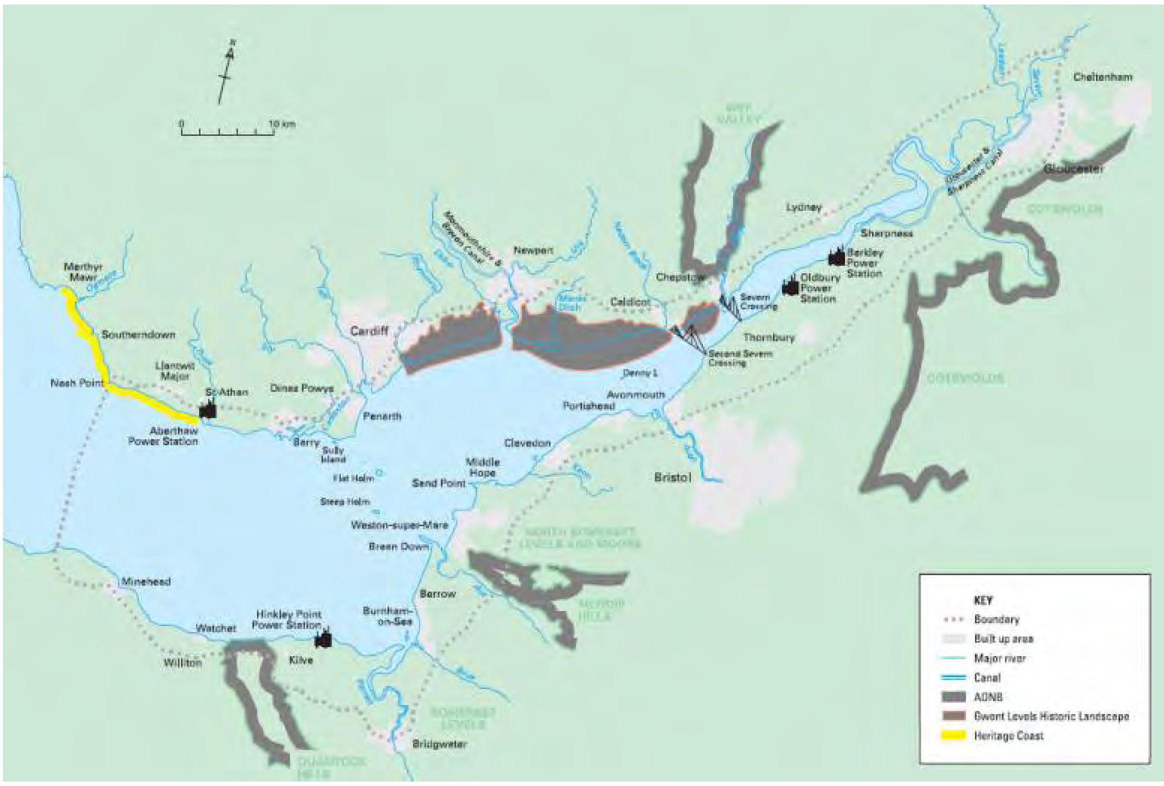


Figure 6.9(1): Landscape of the Severn Estuary[157]

6.10.2 Future evolution in the absence of a barrage

The nature of the landscape in the absence of a barrage would be dependent on a number of parameters including:

- Future developments;
- Changes associated with climate change;
- Changes in land use and management practices; and
- Dynamic nature of coastal environments.

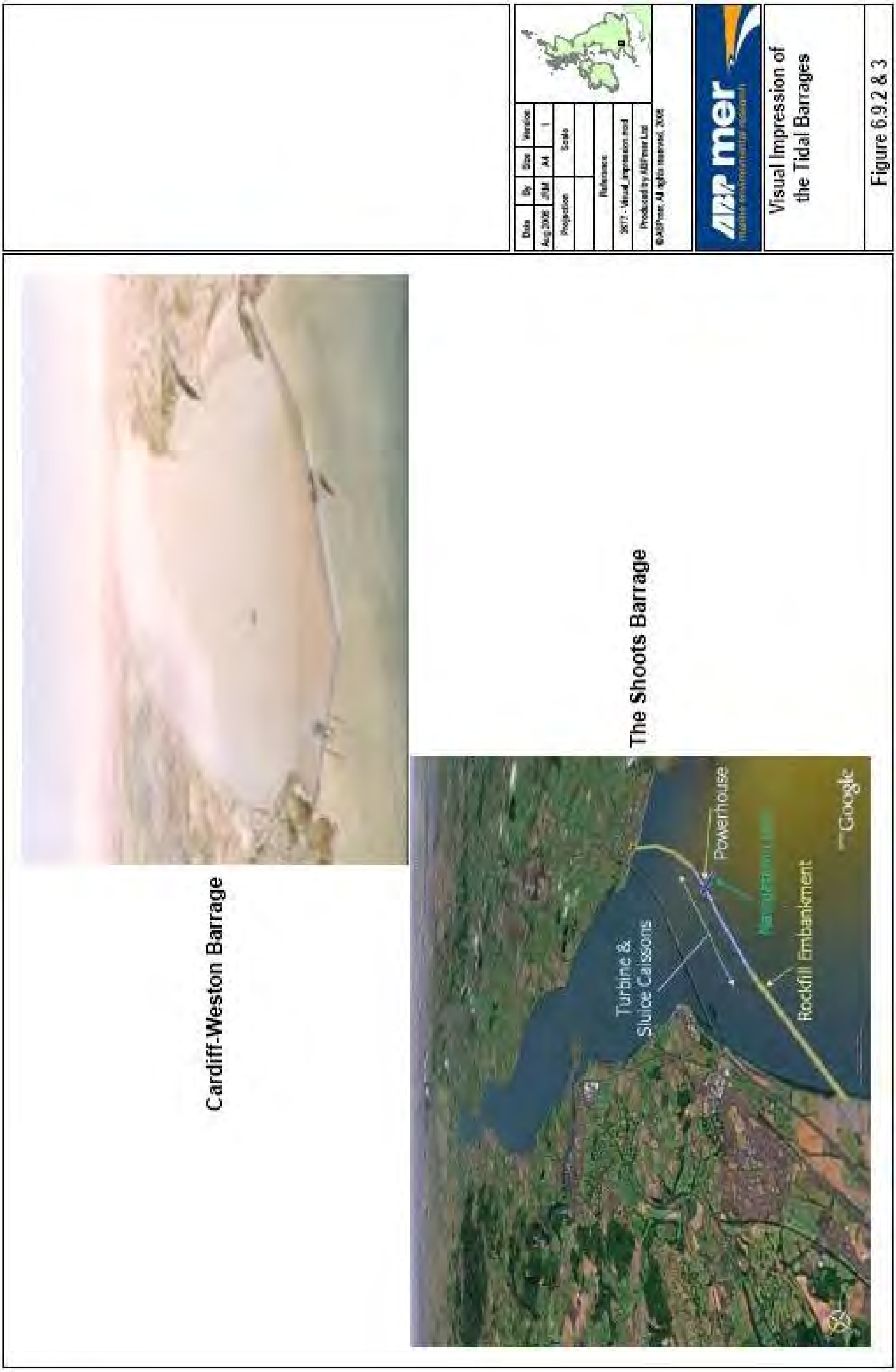
6.10.3 Implications of a barrage

Landscape and visual impact assessments are important components of the overall planning and design process with respect to seeking the best 'environmental fit' for any given development. Landscape impacts can be described, broadly, as changes in the fabric, character and quality of the landscape as a result of development, and visual impacts are a subset of landscape impacts and relate solely to changes in the appearance of the landscape and the effects of those changes on people.

In the presence of the barrage there would be an associated change in the character of the shoreline along the enclosed coastline. This would be true of both the habitats that are present along the margins of the estuary but also through associated changes in land use and infrastructure. The extent of the intertidal visible at low water would also be much reduced. In addition there is the potential for the colour of the water to moderate if the high sediment levels were to drop substantially below present levels. The presence of the barrage itself would create a visual impact on the estuary including in areas such as the Gwent Levels and Lower Wye Valley which have been designated as historic landscapes. It may be possible, however, to alleviate some of the visual effects of a barrage through considerate design planning and landscaping. Figures 6.9(2) and 6.9(3) represent artistic impressions of The Shoots and Cardiff-Weston schemes respectively.

6.10.4 Requirements for additional studies

There is a need for a greater understanding of the projected appearance of the barrage and associated infrastructure, based on current scheme designs. This would need to include a review of the materials used within the barrage and the associated dimensions of the schemes. A visual impression of the predicted changes in habitats and land use along the periphery of the estuary would facilitate this process. A review of the predicted visual impacts of a barrage would also be required in the context of current planning policies.



Figures 6.9(2) and 6.9(3): Artists Impression of The Shoots Barrage and the Cardiff-Weston Barrage

6.11 ENVIRONMENTAL LEGISLATION IN THE CONTEXT OF A SEVERN BARRAGE

6.11.1 Issues

The promotion of either barrage option will require compliance with a wide range of environmental legislation and policy. Some of these requirements are likely to change in the coming years and new requirements may be added, for example, through the proposed Marine Act.

The environment in and around the Severn Estuary is of special importance for nature conservation. This has been recognised through the many nature conservation designations that are in force and/or proposed for the area. The scale of environmental changes that will be introduced by either barrage option will also be very large. Given these major changes and the environmental importance of the area, there will need to be a very strong justification for any barrage proposal if the case for development is to override the importance of maintaining the nature conservation and wider environmental interests.

This section discusses the potential issues in relation to specific legislation and summarises key environmental, legal and policy issues that would need to be addressed in progressing a barrage scheme.

Habitats Regulations

Predicted Impacts

The evaluation of impacts is an important step in the assessment required under the Habitats Regulations as the nature and extent of any impact determines the legal route that a development must follow.

Either Severn Barrage option would cause major changes in the physical and biological environment upstream and downstream of the barrage structure.

These changes would affect the following international nature conservation sites:

- Severn Estuary SPA
- Severn Estuary pSAC
- River Wye SAC
- Severn Estuary Ramsar site

The Cardiff-Weston scheme would additionally affect the River Usk SAC.

A summary of the key broad predicted changes for the two options based on section 6.7 of this report, is presented below:

Receptor	Shoots Scheme	Cardiff-Weston Scheme
SPA Features		
• Annex 1 species – Bewick's swan	• No specific assessment available – possible impacts to population	• No specific assessment available – possible impacts to population
• Overwintering assemblage of waterfowl	• No specific assessment available; limited impact likely based on existing information on bird distributions	• Species specific assessments generally lacking; broad overview studies suggest that overall populations may be relatively unaffected
• Intertidal mudflats and sandflats	• Potential loss of up to c. 5,500ha of intertidal habitat	• Potential loss of up to c. 14,500 ha of intertidal habitat
• Saltmarsh	• Unquantified but substantial loss of existing 133ha resource	• Unquantified but substantial loss of existing 539ha resource
• Intertidal rock and shingle	• Unquantified loss of intertidal rock and shingle	• Unquantified loss of intertidal rock and shingle
pSAC Features		
• Atlantic saltmeadows/ saltmarsh	• Unquantified but substantial loss of existing 133ha resource	• Unquantified but substantial loss of existing 539ha resource
• Estuary	• Reduction in tidal range and flows u/s of barrage; small local reduction in tidal range d/s of barrage	• Reduction in tidal range and flows u/s barrage; small local reduction in tidal range d/s of barrage
• Mudflats and sandflats	• Potential loss of up to c. 5,500ha of intertidal habitat	• Potential loss of up to c. 14,500 ha of intertidal habitat
• Reefs (*Sabellaria*)	• Unquantified but minor	• Unquantified, but significant
• Subtidal sandbanks	• Unquantified change	• Unquantified change
• Fish (allis and twaite shad)	• Very high risk of very high mortality. Potential stock eradication.	• Very high risk of very high mortality. Potential stock eradication.
• Fish (river and sea lamprey)	• Medium risk of high mortality	• Medium risk of high mortality
River Usk SAC Features		
• Fish (allis and twaite shad)	• Low risk of impact	• Very high risk of very high mortality. Potential stock eradication
• Fish (river and sea lamprey)	• Low risk of impact	• Medium risk of high mortality
• Fish (atlantic salmon)	• Low risk of impact	• High risk of high mortality
River Wye SAC Features		
• Fish (allis and twaite shad)	• Very high risk of very high mortality. Potential stock eradication	• Very high risk of very high mortality. Potential stock eradication
• Fish (river and sea lamprey)	• Medium risk of high mortality	• Medium risk of high mortality
• Fish (atlantic salmon)	• High risk of high mortality	• High risk of high mortality

No SAC priority habitats or species would be significantly affected by either barrage option. The impacts to the Ramsar site are essentially similar to those described above for the Severn Estuary SPA and pSAC and therefore have not been considered separately.

Evaluation for Severn Barrage options

An extensive package of mitigation measures would be required to seek to minimise impacts on the designated sites. These would need to be incorporated into the preferred design option and construction, operation and decommissioning programmes. These measures would most likely be expensive in their own right and also impose very significant additional costs on the construction and operation of a barrage.

Notwithstanding such mitigation measures, the changes introduced by either barrage option would, without question, constitute an adverse effect on the integrity of the Severn Estuary pSAC and the River Wye SAC. The Cardiff-Weston option would also have an adverse effect on the integrity of the River Usk SAC. Both options would also constitute an adverse effect on the integrity of the Severn Estuary SPA in relation to the conservation objectives for the site.

In such circumstances, for either project to proceed, it would be necessary to demonstrate that:

- There were no alternatives solutions;
- There were imperative reasons of over-riding public interest ; and
- It was possible to secure that all necessary compensatory measures were taken to ensure that the overall coherence of Natura 2000 is protected

Alternatives

The promotion of any barrage proposal would have to be undertaken in the context of a wider consideration of potential alternative means of delivering the public interest benefits that such a scheme might offer. These might possibly include:

- other renewable energy generation schemes in similar or different locations;
- other energy generation schemes in similar or different locations;
- carbon capture and storage at existing fossil fuel generating stations; and/or
- measures to improve energy efficiency;

The range of options to be considered would need to be related to the public interest benefits that any proposal was intended to deliver. For example, on the assumption that the proposal was being promoted as a means of reducing national greenhouse gas emissions, it might therefore be inappropriate to consider alternatives involving new energy generation from fossil fuels unless these included proposals for carbon capture and storage (CCS).

Such an assessment would most properly be undertaken in the context of a formal SEA for UK high level energy policy in accordance with the requirements of the SEA Directive (2001/42/EC). Indeed, this is considered to be an essential pre-requisite for taking forward broad choices for energy policy in the context of required reductions in greenhouse gas emissions. This is discussed in more detail below.

Assuming that this broad assessment was undertaken as part of a prior SEA, and that a barrage option remained as a preferential option, the consideration of alternatives under the Habitats Regulations in relation to a specific barrage proposal might therefore be relatively limited, for example, consideration of minor variations to routes and details of design.

Imperative reasons of overriding public interest

Assuming that a Severn Barrage was promoted on behalf of the UK Government on the basis of reducing the UK’s greenhouse gas emissions as a contribution to tackling climate change and there were no alternative solutions, it is possible that the project would meet the IROPI criteria. The project is only likely to be promoted if it is considered imperative to do so and it is considered to be in the public interest to seek to reduce greenhouse gas emissions. This would then require a judgement by the competent authority on whether the public interest was sufficient for it to be overriding. This would be an issue for determination by the government of the day.

Compensatory measures

The precise nature and extent of compensatory measures required for either barrage proposal would be determined as part of a detailed assessment of the impact of the proposals on Natura 2000 features. It is likely that there would be considerable uncertainty about some of the impact predictions, which would also need to be reflected in the package of compensation measures. Similarly there may be issues of timing of delivery of some compensation measures that might also influence the overall package of measures required.

For impacts to the SPA features, a key issue will be the extent to which the reduced intertidal areas upstream of the barrage options might be able to provide for the birds for which the SPA is designated. Broad-based predictions made by Goss-Custard and Mosser (1988)[162] for the Cardiff-Weston scheme suggest that post-barrage, the intertidal areas may be capable of supporting the existing populations of many of the bird species occurring on the estuary, with the possible exception of dunlin and shelduck. However, more detailed assessment of the potential impacts is required. The level of certainty in any future predictions and issues associated with the timing of improvements in the intertidal food resource will dictate whether, and the extent to which, compensation might be required in relation to impacts on the SPA. Given the nature and scale of either development, it is likely that some significant uncertainties may remain even following more detailed studies.

Similar requirements may apply to impacts to the Ramsar site, although, as noted in section 6.1.3, paragraph 31 of ODPM Circular 06/2005 identifies some further specific requirements in relation to Ramsar sites, which could affect the requirements for compensation.

The specific impacts to habitats and species associated with the River Wye SAC and the River Usk SAC would need to be compensated for. Similarly, assuming that the Severn Estuary SAC is confirmed, it would be necessary to compensate for impacts to those relevant habitats and species also. In the unlikely event that a decision on whether to designate the Severn Estuary SAC had not been taken at the time a barrage development was being promoted, given the Government's guidance that planning authorities should take note of such potential designations in their consideration of development applications that may affect such sites, it is likely that stakeholders would seek to ensure that a similar level of compensation was provided. If the Government decided not to proceed with designation of the Severn Estuary SAC, the requirements of the Habitats Directive would no longer apply to that possible site.

Available evidence suggests that impacts to migratory fish would be very significant and largely unavoidable as mitigation measures are likely to be ineffective or unproven (section 6.7.10). Compensation measures might need to include artificial stocking to seek to maintain populations, enhancement of populations in other designated estuaries, or enhancement of populations in non-designated estuaries which are then subsequently designated. Such measures have been applied elsewhere in the UK and Europe with varying success.

Options for the provision of compensation for damage to habitats might include:

- re-creation of habitats within the site
- re-creation of habitats within other designated sites
- re-creation of habitats at non-designated areas which are subsequently proposed for designation
- designation of UK estuaries within the same biogeographical region which support relevant habitats and species but that are currently not included within the list of SACs.

While re-creation of habitats on the scale required to fully offset the impacts would be very challenging, possibly to the point of not being deliverable, a package of measures that included designation of some estuaries supporting relevant features but that are currently not included

[162] Goss Custard, J.D. & Moser, M.E. 1988. Rates of change in the numbers of dunlin, Caldris alpine, withering in British estuaries in relation to the spread of Spartina anglica. Jounral of Applied Ecology, 25, 95-109.

within the list of SACs (as provided for in the MN2000 guidance) might provide a solution that met the requirements of the Habitats Directive. Even so, a requirement to identify and designate some 14,500ha of compensatory intertidal habitat for the Cardiff-Weston scheme (based on a preliminary assessment of habitat loss) might prove particularly challenging. For example, the next largest comparable estuary on the west coast of England – the Mersey – has an intertidal area of only around 5,000ha.

One view promoted by the conservation agencies is that to ensure the overall coherence of Natura 2000, it might be necessary not only to compensate for the impacts to habitat types, but also to compensate in a manner that maintained the range of variation within such habitat types. Given that the Severn is a uniquely hypertidal estuary, it would not be physically possible to provide directly comparable compensation for the habitat taken as a whole. The conservation agencies suggest that recent guidance from the European Commission[163] (EC, 2007) supports this view. While the revised guidance provides additional focus on the functional requirements of compensatory measures and indeed, specifically refers to the consideration of the 'uniqueness' of areas impacted by projects or plans, there must clearly be limits to how such policies might be interpreted or they would serve to frustrate all forms of development affecting designated sites. Nevertheless, we would caution against taking an optimistic view on how such policies might be interpreted.

Water Framework Regulations

The construction of either barrage option is considered likely to compromise the achievement of WFD objectives in the Severn Estuary and the Wye Estuary, although work is ongoing to define the relationship between hydromorphological change in water bodies and their classification in terms of ecological status. The Cardiff-Weston scheme would also be likely to compromise WFD objectives for the Usk Estuary and Cardiff Bay. Thus for a barrage proposal to proceed, it would need to satisfy the four tests set out in WFD Article 4(7).

The requirements to provide mitigation measures under the Water Framework Directive are effectively limited to taking practicable measures to minimise or cancel the adverse impacts on the water bodies affected. In this respect the requirements are potentially less onerous than the requirements to provide mitigation and/or compensation under the Habitats Directive which does not have regard to the cost of measures and can involve measures at locations remote from those affected by the project or plan.

The framework for considering overriding public interest under the Water Framework Directive is broadly similar to that applied under the Habitats Directive i.e. the public interest benefits of the proposal are required to be deemed sufficient to override the benefits that would be provided by achievement of WFD objectives. While the reference to the importance of public opinion in determining public interest is specific to the Water Framework Directive, similar considerations have also previously been applied in relation to the IROPI test under the Habitats Directive (see, for example, the Dibden Bay decision).

If a barrage proposal is able to satisfy the requirements for IROPI under the Habitats Directive, it is likely that the proposal would also satisfy the equivalent tests under the Water Framework Directive.

The weighing of the public interest benefits of a proposal against the merits of achieving WFD objectives is similar in many respects to the judgement required under the Habitats Directive concerning whether the public interest benefits of proposals outweigh the benefits of achieving conservation objectives. While the analysis of costs and benefits under the WFD potentially

[163] Guidance document on Article 6(4) of the Habitats Directive: Clarification of the concepts of: Alternative Solutions, Imperative Reasons of Over-riding Public Interest, Compensatory Measures, Overall Coherence, Opinion of the Commission. European Commission, January 2007.

involves some additional moneterisation of cost and benefits, inevitably, it will not be possible to moneterise all costs and benefits and decision-makers will be required to make a judgement on the relative merits of the competing objectives, in a similar manner to the existing process under the Habitats Directive. It is considered likely that if either barrage proposal was considered to meet the IROPI requirements of the Habitats Directive, it would also meet the similar requirements of the WFD.

The test of alternative means has similarities to the consideration of alternatives both under the Habitats Directive and to the consideration of alternatives under the EIA Directive (85/337/EEC). There is currently no experience of applying the requirements of Article 4(7) to developments. Nevertheless, the consideration of alternatives under the Water Framework Directive will not be any more onerous than the consideration required under the Habitats Directive.

Strategic Environmental Assessment

Strategic environmental assessment is already being applied to the consideration of marine renewable energy development (for example, the SEA conducted for the second round of offshore wind licensing (BMT Cordah, 2004) and the marine renewable energy SEA being conducted in Scotland). The oil & gas SEA programme is now also ensuring that its studies are framed to facilitate future SEA for offshore renewable energy where plans or programmes are proposed.

However, such assessments are focused on the marine renewable energy sector and do not consider broader issues of energy policy or the more fundamental options associated with seeking to reduce greenhouse gas emissions. Such a broader assessment is considered to be an essential pre-requisite to determining whether a Severn Barrage might be an appropriate option. This assessment should address broad alternatives for achieving greenhouse gas emission reductions including consideration of energy efficiency measures, renewable energy developments (including a barrage option), and other sources of energy generation that did not result in significant greenhouse gas emissions (e.g. nuclear power generation, application of CCS technologies). To comply with the requirements of the Habitats Directive, the assessment would need to consider the extent to which the alternatives could meet the public interest need and their relative impact on European sites. If alternatives were identified which were capable of meeting the public interest need with demonstrably smaller impacts to European sites, the barrage proposal would not meet the strict tests of the Habitats Directive.

Environmental Impact Assessment

The promotion of either barrage option would require an extensive formal environmental impact assessment in accordance with the requirements of the EIA Directive. The scope of this assessment would encompass aspects of the environment not covered by any assessment under the Habitats Regulations, for example, emissions to air or land, impacts on landscape etc.

The consideration of alternatives required under EIA legislation is narrower than that required under the Habitats Directive. The decision on overall acceptability of a proposal is essentially a judgement in relation to the benefits of the proposal and its impacts which is informed, *inter alia,* by information in the Environmental Statement. For either barrage option, the impacts afforded highest significance are likely to be those relating to the designated nature conservation interest. If it was considered appropriate for a barrage proposal to proceed on the grounds of IROPI under the Habitats Regulations, it is likely that the proposal would also receive a favourable view in relation to the acceptability of environmental impacts under the Barrage Act.

Wildlife & Countryside Act

Both barrage options would affect features associated with the following SSSIs:

- Upper Severn Estuary SSSI
- Severn Estuary SSSI
- River Wye SSSI

The Cardiff-Weston scheme would also affect the River Usk SSSI and possibly also the Steep Holm, Flat Holm, Bridgwater Bay, Penarth Coast and Sully Island SSSIs

In considering whether to grant approval for the scheme, the decision-making authority would need to follow the procedures set out in section 28I of the Wildlife & Countryside Act. It is unlikely that the nature conservation agencies would give their assent to either scheme under section 28I in view of the likely damage to the SSSIs. However, notwithstanding the decision of a conservation agency not to grant assent, the schemes could still be granted approval by the licensing authority once the procedures set out in section 28I had been exhausted. While it would be open for the conservation agencies to take legal action in exceptional circumstances, past practice indicates that where a suitable compensation package has been provided for impacts to European Sites, legal action would not be taken under section 28I.

Both schemes also pose risks to species protected under Schedule 5 of the Act (for example, allis and twaite shad). Mitigation measures will be required under the Act to minimise these impacts. Such measures are likely to be the same as those required under the Habitats Regulations and the Wildlife & Countryside Act is therefore not considered to apply any additional constraints beyond those of the Habitats Regulations.

Food & Environment Protection Act

The provisions of FEPA would be applied to any barrage application to ensure that the marine environment was protected from construction and operational impacts where practicable. It may also provide the mechanism for imposing and monitoring the delivery of environmental controls and requirements. Given that both appropriate assessment under the Habitats Regulations and EIA under the relevant EIA Regulations would be required, it is unlikely that the evaluation required under FEPA would add any additional significant environmental constraints on the construction and operation of the barrage.

Water Resources Act

Any potentially polluting discharges arising from the construction, operation or decommissioning of the barrage would require consenting under the Water Resources Act. Either barrage option may also give rise to a need to review existing discharge consents to take account of changes in flows and available dilution in the receiving environment up-estuary of the barrage. If changes to consent conditions for existing discharges were required, it is likely that costs of meeting tighter standards would fall to the barrage promoter.

The Severn Barrage would provide flood defence related benefits (reduction in wave fetch and control of storm surges, including protection from higher tide levels associated with sea level rise) but could also give rise to some flood defence impacts (as a result of possible changes in morphology up and down estuary of the barrage with attendant risks to the integrity of existing defences). The extent of such changes would need careful evaluation and an agreement on the long-term maintenance of these defences.

6.11.2 Summary of Key Issues

While compliance with all environmental requirements will be an important requirement for a barrage proposal, the specific requirements of the Habitats Regulations are likely to present the most significant challenges in seeking approval for a project.

For either barrage proposal to proceed in accordance with the requirements of the Habitats Regulations, it would need to demonstrate that there were no less damaging alternatives, that the project met the grounds for IROPI and that all necessary compensatory measures could be delivered to secure the overall coherence of the Natura 2000 network.

The consideration of alternatives under the Habitats Regulations requires that the decision making authority is satisfied that there are no less damaging alternatives that can deliver the public interest benefits of the proposal. Given the broad nature of the alternatives consideration, a formal SEA of UK energy policy in relation to the delivery of greenhouse gas emission reductions would appear to be an essential pre-requisite to taking forward a barrage proposal. This would mean that decisions on the broad approaches to tackling greenhouse gas emissions from energy generation would be taken well in advance of any detailed consideration of a specific barrage proposal. The importance and significance of such an exercise cannot be over-emphasised in the context of demonstrating compliance with the Habitats Regulations.

While consideration of IROPI has often proved challenging for major infrastructure projects in the past, it may be less of an issue for a barrage proposal. Assuming that a Severn Barrage was promoted on behalf of the UK Government on the basis of reducing the UK's greenhouse gas emissions as a contribution to tackling climate change and there were no alternative solutions, it is possible that the project would meet the IROPI criteria. The project is only likely to be promoted if it is considered imperative to do so and it is considered to be in the public interest to seek to reduce greenhouse gas emissions. This would then require a judgement by the competent authority on whether the public interest was sufficient for it to be overriding. This would be an issue for determination by the Government of the day.

Some specific uncertainties about compensation requirements have been identified that could render a barrage scheme impractical. For example:

- if significant effects on bird populations are predicted, it would be necessary to compensate for such impacts through appropriate habitat creation schemes. If the scale of these requirements was large, it may not be practicable to deliver these requirements within the appropriate biogeographic region (because of the size of area that needed to be recreated);
- the compensation requirements under the Habitats Directive are currently uncertain. It may be possible to compensate for some impacts to habitats through designation of additional sites supporting the relevant features. However, there is currently significant uncertainty concerning how the requirement to 'secure the overall coherence of Natura 2000' should be interpreted. Some interpretations of that requirement could render the compensation requirements infeasible, for example, if it was necessary to compensate by recreating a hypertidal estuary feature somewhere else. Similarly if the scale of habitat creation requirements for other habitats was large, it may not be practicable to deliver these requirements within the appropriate biogeographic region (because of the size of area that needed to be recreated);
- if the compensation requirements were determined to require habitat creation on a scale comparable to that of the impacts, the very high costs of providing such compensation may preclude either barrage option from being taken forward.

To progress the environmental considerations relating to a barrage and to obtain realistic predictions of compensation requirements, it would be necessary to make a significant investment in additional studies to better evaluate the likely impacts of possible proposals and how such impacts may be mitigated/ compensated for. This would include a series of major morphological and ecological studies. Such studies would also need to be completed in sufficient detail to inform the suggested high-level SEA and to support decisions on practicability at that stage.

While it is possible that a Severn Barrage might be deliverable in compliance with the Habitats Regulations (even should a Severn Estuary SAC be designated), it must be recognised that achieving such compliance is uncertain and could be very expensive. Although we differ from the view expressed in the Position Statement prepared by CCW, NE and EA[164] that "A Severn Barrage development would not be possible within the current legal framework provided by the EU Habitats and Birds Directives", it is important to emphasise the strict nature of the tests that will need to be applied to any forthcoming barrage proposal and the uncertainties and costs associated with complying with the legal requirements.

Aside from the requirements of the Habitats Regulations, the requirements of other existing environmental legislation and policies are not considered to pose such significant challenges, although the requirements relating to the Water Framework Directive have yet to be applied to

---

[164] Position Statement on A Severn Barrage, Environment Agency, Countryside Council for Wales and English Nature/Natural England, May 2006.

development projects. However, marine environmental legislation and policy will continue to evolve, particularly with the implementation of a Marine Act. Such changes are likely to introduce additional legal and procedural requirements.

7 ECONOMIC AND SOCIAL ASPECTS

7.1 INTRODUCTION

This chapter reviews the available information on the impacts that a Severn barrage would have on economic and social aspects, with particular focus on the regional economic development implications for employment, navigation and ports, aggregates industry, fishing industry, land drainage, flood protection, transportation links, recreation and tourism, and coastal development and other regional impacts. The in-depth studies that were carried out for the Cardiff-Weston scheme and, to a lesser extent, the English Stones scheme mainly date back to the 1980s although some update of this information is provided in STPG's 2002 report. No comparable work has been carried out for the Shoots barrage although impacts would be similar to those predicted earlier for the English Stones barrage.

Therefore the available information is out of date and in some cases incomplete. These significant limitations make it difficult to draw definitive conclusions on some key issues and regional economic and social implications of a Severn barrage within the scope of this study. Further work, including new primary research, would be needed to address these gaps. Where possible, these limitations are noted and further research requirements are identified. In particular, the impact on the region's ports is identified as a significant issue that would need further detailed consideration.

7.2 EMPLOYMENT

There are a number of impacts that a Severn Barrage would have on employment, both direct and indirect. In particular it would attract additional workers into the sub – regions during the construction phase.

If the Severn Barrage created new employment activities in the Severn side regions, this could attract in migration, both from within the UK and internationally, although employment generation would be mainly during the construction phase. Other employment opportunities as a result of the operation of the scheme would be limited, but increased visitor numbers might create additional jobs. Employment creation would also depend on the extent to which procurement of materials, goods and services could be made in the region.

An indirect effect of an increase in employment in the region would result in an increase in consumption (e.g. accommodation, food, retail, transport etc). These impacts are likely to be temporary, however, during the construction phase, although increased visitor numbers to the region would have a knock on effect on increasing demand for goods and services.

There have been a series of reports that have looked at some of the regional economic and social development which would be stimulated by the development of a tidal power facility on the Severn Estuary. These are highlighted in Appendix C. These reports look at various aspects of the potential economic and social impact of the Severn barrage on the regional economy, which includes a number of local authorities on both the Welsh (Cardiff, Vale of Glamorgan) and English (North Somerset, South Gloucestershire and Bristol) sides of the Severn estuary.

The 1986 study by the STPG[165] is the only report that provides a comparison of the employment effects of the two schemes. Other later studies only concentrate on the Cardiff-Weston scheme. There have been no comparable regional studies for the Shoots scheme but earlier work on the English Stones alignment can be taken as indicative.

Table 7.1 (1) provides a comparison between the two Barrage Schemes and their effects on direct and indirect employment, based on a review of the 1986 STPG report[165].

---

[165] STPG, 1986. Tidal Power from the Severn. Engineering and economic studies – The Cardiff-Weston scheme and English Stones scheme. The Severn Tidal Power Group.

The employment estimates highlighted in Table 7.1 (1) will need revising as they are based on dated assumptions which relate employment creation to investment. New technologies will have impacts of employment generation, both direct and indirect, particularly during the construction phase of the project i.e. the factor productivity of labour has changed. It is furthermore not clear from the source reports on what basis indirect employment was estimated, nor the employment multiplier assumptions. Another employment impact that needs to be taken into consideration is that of induced employment generated by expenditure by additional direct and indirect unemployment.

The most comprehensive study covering the regional economic aspects, however, is that published by STPG/CEGB and the Department of Energy in 1989 for the Cardiff-Weston scheme[166]. Volume V of this study contains the regional studies. The key findings of these are highlighted in Table 7.1 (2) (assuming construction commenced in 1994). In order to model the impacts over the years a number of scenarios reflecting the regional economy in 2001 and 2021 were developed. Scenario 1 – assumes cautiously optimistic growth in gross domestic product but weak regional development in terms of regional development assistance through grants and other incentives.

Scenario 3 – assumes more optimistic scenarios for annual growth in national gross domestic product with an average of 2.75% per year over the period 1991 – 2021.

In barrage construction high/low refers to a range of multiplier effects, and in Industrial and Commercial development refers to promotional and marketing effort made.

[166] STPG, 1989 - Severn barrage project detailed report, Volume V. Regional Studies and Legal Background, contractor report, ETSU TID 4060-P5 EP 57

Table 7.1 (1): Comparison of the employment effects[165]

Category	ENGLISH STONES	CARDIFF-WESTON
EMPLOYMENT CREATION		
Direct Employment		
Construction phase		
Primary	12,300 persons/year	44,600 persons/year
Secondary	1,400 persons/year	2,100 persons/year
Operational phase		
Primary	350 persons/year	1,770 persons/year
Secondary	3,000+ persons per year	+21,500 persons/year
Indirect Employment		
Construction phase		
Primary	6,150 persons/year	22,300 persons/year
Secondary	700 persons/year	1,050 persons/year
Operational phase		
Primary	110 persons/year	570 persons/year
Secondary	960+ persons/year	+6,900 persons/year
Maritime conservancy	60	small
Barrage related services	60	Not quantified
Off barrage plant maintenance	150	Not quantified
Recreation + tourism sector	2,000+	11,500+
Industry	1000+	10,000+
Commercial maritime	Not quantified – small	Not quantified – small
Total water based sports, tourism, commercial maritime, industry, commerce and services including employment multiplier	3,000+	30,000+

Table 7.1 (2): Employment Generation (man years) - STPG Regional Studies (1989)[166]

Barrage Construction 1994 - 2002[1]	
High	112,000
Low	99,000

Barrage Operation 2003 - 2021	
Scenario 1	19,000
Scenario 3	21,000
Tourism - Tourist expenditure (2001 – 2021)	
Scenario 1	23,000
Scenario 3	27,000
Tourism – Construction of Facilities (2001 – 2021)	
Scenario 1	6,000
Scenario 3	7,000
Industrial and Commercial Development (2001 – 2021) Workforce[2]	
Scenario 1	
High	239,000
Low	119,000
Scenario 3	
High	471,000
Low	236,000
Industrial and Commercial Development – Construction of Premises (2001 – 2021) [2]	
Scenario 1	
High	28,000
Low	13,000
Scenario 3	
High	52,000
Low	24,000

In addition to the STPG Regional Studies report, the STPG 2002 Definition Report[167] also provided updated figures for employment as follows:

- Construction phase 200,000 person years peaking at 30,000 – 40,000 per year in years 2 – 5 years (50 % would be employed in the Severnside region)

Based on the review of the various reports a summary of our key findings are provided below:

[167] STPG. The Severn Barrage – Definition Study for a New Appraisal of the Project. Final Report: January 2002. ETSU Report No. T/09/00212/00/REP, 2002

- The economic data and assumptions in the reports are outdated and would need to be recalculated to take account for labour productivity, updated labour costs and the mix skill sets that would be required. This will include employment, value added to the local economy, employment and expenditure multiplier impacts. There have been many changes in the Severnside regions since these reports were completed. These include population growth, movement/migration and sectoral employment. Also, the development of new economic sectors – services, technology and knowledge based industries and deindustrialisation, particularly in the industrial and mining areas of South Wales will need to be taken into account. In particular the STPG Definition Study (2002)[167] notes that since the employment estimates since STPG report (1989)[166] improved labour efficiency is likely to lead to a reduction in labour requirements of between 10 and 20%. This estimate will again need to be updated in the light of new construction technologies and labour productivity.

- No estimates of the value of employment 'disbenefits' (negative economic impacts) are contained in the reports e.g. reduced visitor numbers and spend at certain sites, including National Trust and designated sites. Additionally, there appears to be no evidence that the impacts of Ports are taken into account. Port traffic, in terms of traffic movements and the type of traffic, may also have changed since the original studies (e.g diversion of traffic to other ports, increasing containerisation etc).

- More consideration needs to be given to the retention of employment within and without the region (the leakage factor). While the project will undoubtedly generate employment and have spin offs for local businesses a certain proportion of the expenditure will leak out of the region. On the other hand the barrage may attract new investments and businesses into the region.

- It is unclear whether the likely displacement economic impacts of the project on employment in Wales, the South West and the remainder of the UK has been considered in any detail. No references to these impacts have been found in the reports.

- The deadweight impacts should also be considered. In particular analysis should be undertaken on employment if no barrage project were to go ahead.

- Net employment generation is important in that some jobs may be lost with a change in balance between renewable and non renewable power generation. Also – as mentioned in the leakage factor above – how much of the employment (direct, indirect and induced) is actually retained in the sub regions during the construction and post construction operational phases.

7.3 NAVIGATION AND PORTS

7.3.1 Introduction

The potential impact of a Severn barrage on navigation and ports in the Severn estuary is likely to be very significant, depending on the alignment of a barrage. A barrage at the Cardiff-Weston alignment would enclose a number of major ports which are currently recognised as significant contributors to the regional economies of south Wales and the south-west of England. There is uncertainty as to the extent of this impact. Although the barrage schemes make provision for ship locks, the impact on the economic position and operation of the ports has not been considered. Furthermore, the information available on the impacts is out-of-date and further investigation of navigation and ports issues would be required to take into account the cost and timing issues associated with ship locks for ports operating in a competitive international shipping market.

7.3.2 UK Ports Policy

In November 2000, the Department for Transport published their consultation document on UK Ports Policy and a further consultation document, *Ports Policy - your views invited*, was released in May 2006 as part of a ports policy review which is ongoing alongside other current Government reviews of planning, transport and marine policy.[168] This review recognises the importance of ports to international trade and economic development, including the Government's strategic interests in competition and resilience. Ports in the UK are mainly privatised with port infrastructure and development is commercially operated and financed, and Government policy is broadly that a market-oriented approach is appropriate.

7.3.3 Severn estuary ports and harbour authorities

The Severn Estuary is the home of four commercial ports:

- Cardiff, owned by Associated British Ports (ABP)
- Newport - ABP
- Bristol (Avonmouth and Portbury), owned by Bristol Port Company Limited
- Sharpness / Gloucester.

In addition, there are heritage harbour facilities at:

- Lydney
- Chepstow.

All of the above would lie upstream of the Cardiff-Weston barrage. Sharpness is located at the limit of navigation along the Severn Estuary and a point where ships must pass onto the Gloucester and Sharpness Canal to reach Gloucester Docks. Harbour facilities at Chepstow, Lydney, Sharpness and Gloucester are all located upstream of The Shoots barrage.

Of these ports, the major operations are at Bristol, Cardiff and Newport. Bristol, comprised of Avonmouth and Royal Portbury docks, has been privately owned since 1991. At the Portbury site, the company operates 7 deep water berths for vessels of up to 14.5 metres draught. Two berths are designed for container operations and are capable of handling vessels of up to 6,000 TEU in size. At Avonmouth, a short-sea container terminal is serviced by two large gantry cranes and accommodates vessels of up to 11 metres draught. Bristol Port is served by a M5 Motorway (north/south) access junction, is close to the junction of the M4 Motorway (east/west) and is linked to the existing main line rail access northbound and eastbound and into Wales. The port company handles 12m tonnes annually and annual revenue is £63m.[169] Over £330m has been invested in the dock estate and the Port is now recognised as being one of the most productive and technically advanced in Europe.

ABP, which owns and operates 21 ports in the UK, owns Cardiff and Newport ports which are both linked to the M4 motorway and rail. The Port of Newport handles vessels of up to 10.5 m draught and up to 40,000 dwt, and Cardiff up to 10.37m draught and 35,000 dwt.[170]

In the adjacent area downstream of the Cardiff-Weston barrage, and the area generally regarded as the Inner Bristol Channel, there are further ports at:

- Barry (ABP)
- Bridgwater.

---

[168] Department for Transport, 2000. Modern Ports: A UK Policy. http://www.dft.gov.uk/pgr/shippingports/ports/

[169] Bristol Port Company: www.bristolport.co.uk/.

[170] Associated British Ports: www.abports.co.uk/.

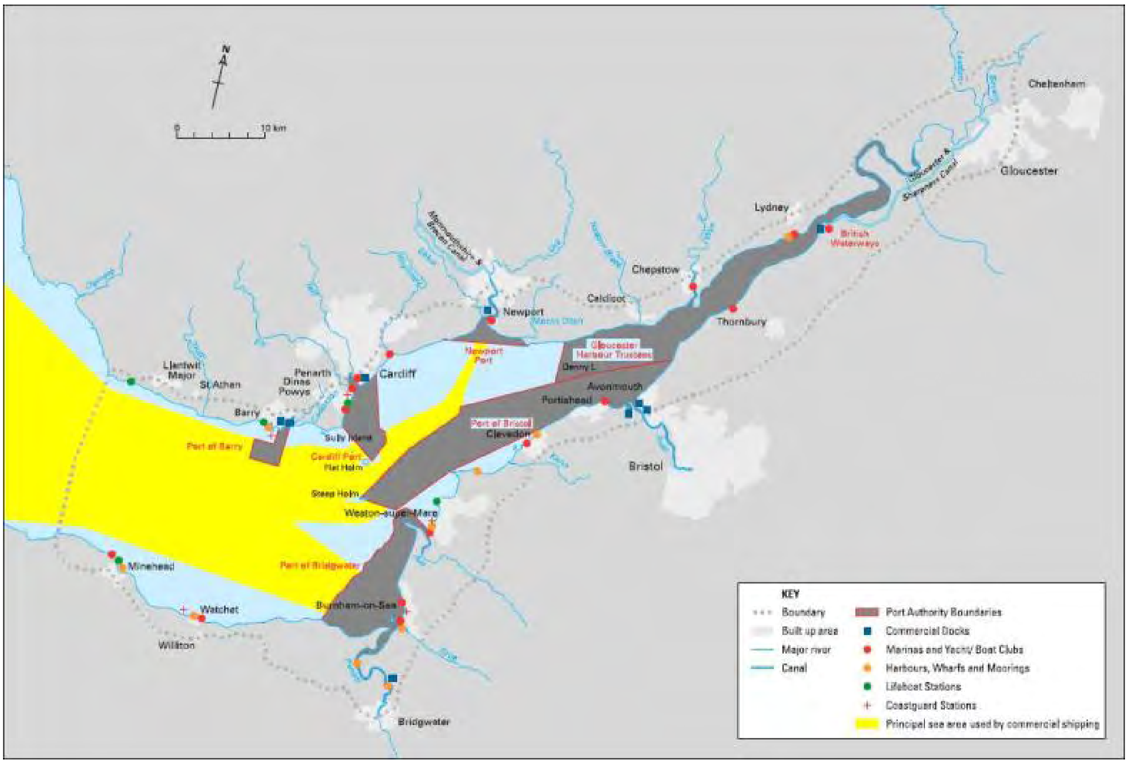


Figure 7.2(1): Ports and Harbour Authorities[167]

There is no single port authority for the estuary. ABP has jurisdiction to the approaches into Barry, Cardiff and Newport. The Port of Bristol has responsibility from Steep Holm up to Avonmouth. Sedgmoor District Council is the harbour authority for the port of Bridgwater and in 2002 a harbour revision order extended Gloucester Harbour Trustees jurisdiction westward to Goldcliff. Representatives from all these authorities meet as the Severn Ports Panel.

7.3.4 Locking

All the ports presently rely on locking into their respective docks and each carefully plan for ship movements according to available draughts as a direct consequence of the extremely large tidal range and advertised high waters. Bristol is presently the largest commercial port in the area (ranked at 16 in the UK for tonnage) and receives the largest ships with draughts up to 14.5m.

7.3.5 Maintenance dredging

All the ports rely on maintenance dredging to clear their approaches and berths of siltation, although in the future the SAC designation could have implications for the ports' operation by affecting maintenance dredging consent requirements. This spoil is almost entirely fine silts. In 2002, dredging returns indicate that around 1.5 million (wet tonnes) of spoil were disposed of at discrete licensed sites within the estuary. The lack of accumulation at these sites indicates that the sites offer rapid dispersion with the material quickly returned to the estuary sediment regime.

7.3.6 Economic contribution

The Severn Estuary's ports are extremely important to the local, regional and, in some cases, the national economy. Cumulatively the ports accounted for 17.2 million tonnes freight in 2004, equivalent to 3% of the UK trade[171]. Good motorway connections exist on both sides of the estuary which aid onward transport.

The ports and related businesses are a major source of employment. The total employment generated by Bristol Port alone is estimated at 7,660 jobs SWRDA, 2004[172]. The value of the South Wales ports to the regional economy was examined in a report by Cardiff Business School's Welsh Economy Research Dept in 2004. Over 8,000 people were employed directly or indirectly by ABP and a further 15,800 jobs were supported by activities of port based companies.

7.3.7 Port development

Bristol Port Company has plans to develop a new deep-sea container terminal with riverside berths which can receive up to 4 Post-Panamax vessels with draughts to 16m. This project represents a major capital investment and expansion for the port with consequences for both the number of port related jobs and local economy. The expansion would involve the construction of a quay wall in front of the port's foreshore; reclamation of the intertidal area behind to provide a container handling/storage area; dredging of the area immediately in front of the wall to form the berths and turning area, and deepening of approximately 11 nautical miles of a deep water navigation channel.

No other current port infrastructure development plans in the Severn are known of at this time

Implications of a barrage

Barrier

The direct and immediate effect of any barrage arrangement across the estuary is to provide a physical obstacle to navigation that will require suitable ship locks (in number and size) to maintain present and future levels of ship movements. Both barrage options include provision for ship locks. The Cardiff-Weston barrage design made provision for 'Panamax' (70,000dwt) vessels and a higher vessel traffic than was measured at the time of design[173]. Further consideration of future navigation requirements would be required for each barrage design.

The outline design for The Shoots barrage includes a lock and approach channel to accommodate the largest vessels that could reasonably reach the Northwick Deep anchorage.

For the Cardiff-Weston barrage, the Bristol Port proposal directly affects the design of ship locks, as this proposal both increases the size of vessels and the number of vessel movements.

However, the size of vessels visiting the ports in the Bristol Channel and Severn Estuary has increased since 1989 up to at least 120,000dwt and expansion plans are being actively pursued by the Bristol Port Company as noted above. The 2002 STPG Definition Report noted that the "issue of the size of vessel allowed to pass through the Barrage is one of the most significant changes since the tripartite studies were carried out. Agreement as to the optimum size of lock that would be incorporated in the Barrage is of fundamental importance to the future development of the Project." The provision of larger locks also has implications for capital cost of a barrage project and for timing of the construction phase.

The onward arrangements, costs and timing implications for using ship locks would need to be managed carefully to avoid excessive queuing around high water period. At the present time there remains little detail on this subject.

[171] Department for Transport, 2006. Focus on Ports. 2006 Edition.

[172] SWRDA, 2004. Bristol Port Economic Assessment. Final Report. March 2004

[173] STPG, 1989. The Severn Barrage Project. General Report.

Construction

Navigation would be able to be maintained at all times during construction, although provisions for safe navigation would also be required during the construction phase. These arrangements would need to constrain ship passage away from any construction activity up until the point that ship locks become operational. For the Cardiff-Weston barrage the ship locks were due to be constructed within the first 4 years of the programme and within the first three years for the Shoots barrage[174].

Water Levels

A further consequence of a barrage will be in terms of gross modifications to the rise and fall of the tide, predominantly in the upstream basin, a feature which will be governed by the operating method of the barrage. Ebb, ebb & flood or flood operation of the barrage will each affect the water levels differently. It is presently understood that the Cardiff-Weston barrage would be operated as an ebb generation scheme with reverse 'flood' pumping at around the time of high water to increase the level and amount of water in the basin. The Shoots barrage would adopt ebb tide only generation. The predicted modified water level profiles for ebb tide generation have the effect of keeping water levels above present mid-tide levels, but importantly also reducing the height of high water. These effects are described in more detail in Section 6.3.

The consequence of maintaining water levels above present mean tide is presumed to be favourable for navigation of shallow draughted vessels as it reduces some of the tidal restrictions by increasing the period of time available for transits through the estuary. However, for Sharpness, which for larger vessels (6,5000 dwt) is only accessible during spring tides, then any reduction of water levels around the high water period would be have a major impact as this port would no longer be reached without significant modifications to the approaches and locks.

Previous comment from the various port authorities on the issue of reduced high waters was given in EP46[175]:

> "The port Authorities are not able to agree that arrivals of the larger vessels could be programmed to avoid the lower tides. They stress that if it were necessary to advertise to their customers that the number of tides available for entry into the ports over a given year were reduced by reason of lower high tide levels, then customers would be likely to go elsewhere. This matter would need to be re-examined in rather more detail than has been possible in the present study".

Downstream effects on water levels are likely to be less pronounced and are presumed not to be an immediate concern for any ports around 50km beyond the barrages. However, existing predictions suggest that there would be a reduction in high water levels close to the barrage which may affect access to Barry and Bridgwater ports.

Flows

A reduction in the upstream tidal range will lead to an associated general reduction in flow speeds across the estuary. This may have some beneficial effect for ship movements on riverside berths, such as the proposed container terminal at Bristol. Towards the barrage sluices and turbines there will be focused areas of high flows over flood and ebb phases, respectively. These enhanced flows may have consequential effects on seabed morphology which as yet have not been assessed.

---

[174] STPG, 1986. Tidal Power from the Severn. Vol. 1.

[175] Department of Energy, 1981. Tidal Power from the Severn Estuary. Volume II. Analysis, studies, reports and evaluations. Commissioned by: The Severn Barrage Committee. Energy Paper Number 46.

Seabed morphology

Longer-term effects on seabed morphology, both upstream and downstream of any barrage, remain uncertain as this topic has not been included in any previous study. The location of the Cardiff-Weston barrage coincides with an area generally regarded by sedimentologists as a bedload parting zone, with net transport of bed material in the main part of the estuary both westwards and to the north-east, the overall effect of which is to denude the local seabed of any coverage of non-cohesive sediments, apart from some localised areas of gravel. The impacts on the navigational channels upstream of the barrage are also uncertain, however, it is likely that this would result in implications for future dredging requirements.

Although not the subject of any concerted study, there is some evidence that the position of Cardiff Grounds shifted after the construction of the Cardiff Bay Barrage. Cardiff Grounds, previously one large spit of sand, was observed to have split in two and to have migrated to the south-east and towards Monkstone Lighthouse, leading to the repositioning of the Cardiff Spit buoy.

Siltation

Finally, with energy being deliberately taken out the estuary by the barrage, the further consequence for a heavily laden sediment regime is a reduction in flows and the heightened potential for increased siltation rates, both in the short-term for existing sediments and also for the medium to long-term for any new sediments being introduced from the main tributaries. It has also been suggested that the new sediment regime might approach conditions presently experienced during neap tides (i.e. the predicted tidal range on present spring tides will moderate to something less than the present neap range), with the balance between present day spring and neap suspended loads approximating the quantity of siltation. Where this siltation might occur is unclear, so the need to remove siltation from navigation channels needs to be examined in more detail against the benefits gained from a modified water level profile. On the basis of this present understanding there is the potential for increased maintenance dredging and the need to establish a new spoil disposal ground which might be either inside or outside of the barrage.

Bridgwater Bay is immediately downstream of the Cardiff-Weston barrage. The bay has a distinct regime of muds and silts, with the River Parrett a major source of this material. The Port of Bridgwater lies upstream in the river, with the harbour authority having responsibility between the River Axe and Hinkley Point. With the Cardiff-Weston barrage there is an increased risk that this sediment regime would change and inhibit access into the port, apart from any increased difficulties in access if high tide levels on this side of the barrage were also reduced, as suggested by previous studies. The understanding in this subject is summarised in EP46 as 'Tentative Predictions'.

A risk of increased siltation is also perceived for The Shoots barrage. In the 1986[165] studies this issue was deemed to be so severe that the barrage was not considered viable. The present proposal offers measures to minimise siltation and in relation to the operating methods for sluices. The Parson Brinckerhoff report[176] also identifies that further studies will need to be undertaken to confirm that sedimentation of the tidal basin can be properly controlled.

7.3.8 Economic effects

The commercial viability of all the ports identified in the general area remains at risk if the net effect of a barrage was to further restrict access and increase dredging costs. Impact on the existing ports could result in displacement effects (if existing ports become less favourable) with knock-on effects in the wider UK transport (road and rail) network. The 2002 STPG Definition Report referred to the possibility that new, downstream port facilities might need to be developed. The viability of existing ports as well as potential new port development have significant implications

[176] Parsons Brinckerhoff, 2006. Severn Estuary. Shoots Tidal Barrage. Updated Financial Assessment. November 2006.

for carbon emissions, the, efficient and economic use of infrastructure, and coastal habitats. A barrage design would need to mitigate accessibility by providing sufficient (in number and size) ship locks and compensate for any further restrictions in access around high waters. The onward cost to use the ship lock on the barrage is a further consideration.

Need for more detailed studies

A recommendation from STPG[167] was that a more detailed study was needed to examine the social, environmental and economic cost benefits of the existing and possible new port locations in the Bristol Channel and Severn Estuary in the context of regional, national and European issues. The study would need to take into account potential changes to the transport infrastructure resulting from transport links on a barrage. This study should also include consideration of the benefits of encouraging a coastal trade network among the UK and European Ports.

La Rance

St Malo is the sole fishing port which is located at the mouth of La Rance. Upstream of the barrage there are several marinas which gain access through a small lock and no major commercial ports. As a roadway and bridge take traffic across the barrage then lock operation requires the opening of the bridge, which occasionally results in conflict between road traffic and ship traffic.

7.4 AGGREGATES INDUSTRY

7.4.1 Existing situation

The prominent inter-tidal sandbank features within the Severn Estuary provide an important source of well-sorted sand that is extracted under licence and used to supply around 80 to 90% of the demand from the construction industry in South Wales. Upstream of the Holmes there are presently two active Crown licences and a further licence from Swangrove Estate on Bedwyn Sands (Figure 7.3.(1)). It is also known that additional licenses and renewals are being requested at the present time. A characteristic of the key interest areas is that they mainly exist as an inter-tidal resource that presents tidal restrictions on access.

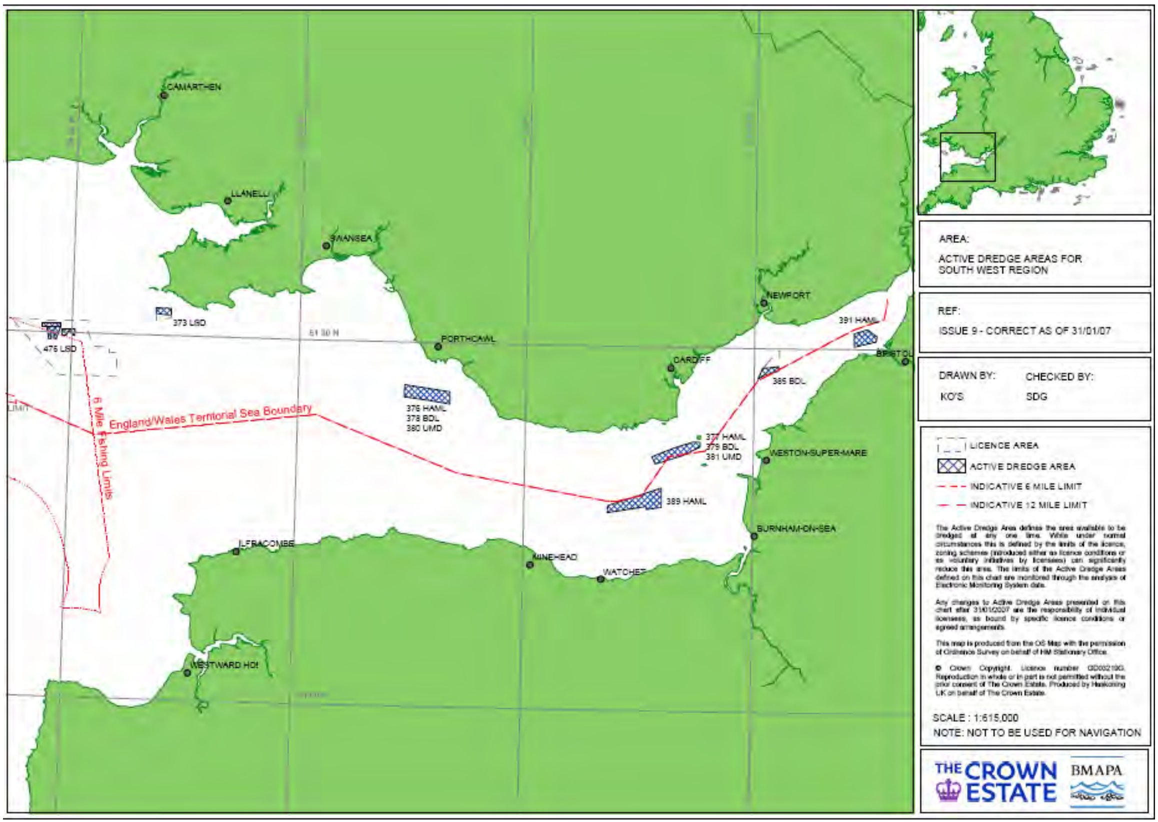


Figure 7.3(1) Aggregate extraction sites licensed from The Crown Estate[177]

Approximately 1.5M tonnes of aggregate is landed in the Severn Estuary ports on an annual basis, although it should be noted that tonnages landed at Cardiff and Barry are predominantly sourced from Nash Bank and Holm Sand which are outside of the Severn Estuary. BMAPA estimate that around 1,700 jobs are linked directly or indirectly to aggregate dredging in South Wales.

7.4.2 Strategy and policies

The Interim Marine Aggregates Dredging Policy[178] forms a part of the integrated strategy for the supply of fine aggregates to South Wales. It sets out the strategy and policies for the extraction of aggregates from the Bristol Channel, Severn Estuary and the River Severn.

One of the interim polices states that aggregates dredging will progressively, over the next ten years, become focused in areas offshore and to the west of the Bristol Channel where this remains consistent with the principles of sustainable development. Not more than 1 million tonnes of annual dredged aggregate will come from Welsh waters in the Severn Estuary and Inner Bristol Channel. By 2015, with the move offshore and to the west, it is expected that 800,000 tonnes or less will come from these areas.

[177] The Crown Estate, 2006. Marine aggregates reserves, The Crown Estate licences – TCE/MR 31.03.06.

[178] WAG (2004) Interim Marine Aggregates Dredging Policy: South Wales. Welsh Assembly Government, November 2004.

7.4.3 Implications of a barrage

Sediment regime

According to the sediment regime study, the modification of the hydrodynamics of the basin will induce an accumulation of fine particle on the seabed reducing the turbidity of the water column. The deposition of fine material will be associated with the deposition of sands, implying the modification of the seabed composition from a mainly sand content substrate to a mixed substrate (sand/mud), at least in the surface layer. Such a transformation of the seabed sediment component would have an implication on dredging activity. Particularly, the following issues need to be taken into account:

The main supply of marine aggregates to South Wales and the south-west of England is well-sorted sands (used for construction industry). Thus, when this type of material exists naturally, the sediment can be extracted directly from the seabed, and there is little added cost to sort and grade the materials. However, if a mixed material is dredged there are both economic and environmental implications associated with sorting the material to the required grade and disposing of the residual material.

- The potential for re-supply of the aggregate resource from seaward may be affected by the barrage, although the flood tide is little changed outside the barrage.
- The potential for the barrage to alter the hydrodynamic regime may affect the integrity of the seabed morphology. In upstream areas, the present banks may stabilise under a more benign flow regime, whereas downstream the balance in flood and ebb dominance may change the sand transport pathways.
- The Shoots scheme has the potential for most direct influence on downstream resources of Bedwyn Sands and Area 391 (Denny Shoal), whereas the Cardiff-Weston scheme entraps upstream both these sites and Area 385 (Middle Ground) as well. Downstream effects of the Cardiff-Weston scheme may extend to Area 377, 379 (The Holms) and Area 389 (Culver Sand), noting Culver Sands is a very mobile feature.

Water levels

Predicted modifications to the upstream water levels has the potential to improve access to the resource for longer periods, with many of the inter-tidal sites becoming fully submerged, if only by a few metres.

Demand for sands and gravels

The construction of any barrage will require large quantities of sands and gravels for fill and concrete although caissons are likely to be built in work yards located outside the estuary. The availability of local aggregate resources provides an opportunity for the present licences along the South Wales coast to meet this demand. This short-term demand may provide the potential to mitigate any longer term concern of loosing the present licences.

By example, the Cardiff Bay Barrage used a special (short-term) licence in Bristol Deep to provide fill. This licence is now expired.

7.5 FISHING INDUSTRY

7.5.1 Existing situation

A review of fish species using the Severn Estuary has been presented in the ecology section of this report (Section 6.7).

The commercial fishing interests within the Severn Estuary have been documented in a number of reviews including Lockwood, 1988[179], Severn Estuary Partnership, 2001[180] and Pawson *et al*,

---

[179] Lockwood, S.J. 1988. The potential impact of the proposed Severn Tidal Barrage on Commercially Exploited Marine Fish Species. Report to Severn Tidal Power Group No. SBP 44.

2002[181]. The following stakeholders have been contacted to provide information on the current fishing efforts within the estuary:

- Environment Agency as Sea Fisheries Committee for the estuary to the west of Cardiff;
- South Wales Sea Fisheries Committee; and
- Marine Fisheries Agency.

Lockwood (1988) undertook a review of published information and fishing activities in the Bristol Channel and Severn Estuary to establish the existing marine fisheries resources. The species of particular interest to commercial fishermen were recognised as:

- Lesser spotted dogfish
- Small eyed ray
- Thornback ray
- Flounder
- Plaice
- Sole
- Conger eel
- Whiting
- Cod
- Ling Bass

Salmon and eels are commercially the most important species for the estuary, although this fishery has declined in productivity and importance[180]. The recreational exploitation of these species and privately owned salmon fishing rights does, however, still have a significant economic value. Commercial fishing for white sea fish also takes place on the estuary, including trawling, longlining and the use of beach nets for cod, whiting, bass, sole, plaice and mullet. There is very little shellfishing on the Estuary, but traditional activities include the use of 'mud horses' by a small number of fishermen, taken out over the intertidal mud in Bridgwater Bay to fish for shrimps[180]. In addition angling from the shore and from boats on the estuary is a popular leisure activity (Section 7.8). Fisheries interests within the Severn Estuary are presented in Figure 7.4(1).

An overview of the commercial fisheries in the vicinity of the Severn Estuary and Bristol Channel based on research by Pawson *et al*, 2002 is presented below:

Weston-super-Mare to Chepstow

The licensed Salmon/Sea trout fishery comprises 4 seine nets, 20 (half season) lave nets and 7 fixed engines (e.g. putchers). Dip nets are used to catch elvers from around November to March. The principal fisheries are in the upper Severn Estuary, above Sharpness. There is a lot of angling activity off Weston-super-Mare, particularly for cod in winter and bass in summer.

Newport to Chepstow

Elver fishing occurs on the tidal reaches of the Wye during March - May. Fyke nets are also fished on the Wye, taking yellow/brown eels in spring and summer and silver eels from late summer through autumn. Six or seven beam trawls (under 10m) from Newport/Usk catch flat fish and brown shrimps. Charter angling trips also occur in the area targeting mainly Cod. On Stert Flats, fishermen maintain ranks of about 100 fixed stake-nets catching shrimps and small quantities of other species such as mullet, rays and sole. Several part time boats also set pots and nets close inshore and mollusks are gathered by hand. Salmon and sea trout are taken in 7 lave nets

---

[180] Severn Estuary Partnership, 2001. Strategy for the Severn Estuary, 2001 Severn Estuary Partnership, Cardiff.

[181] Pawson, M.G., Pickett, G.D and Walker, P.2002.The coastal fisheries of England and Wales, Part IV: A review of their status 1999-2001. Sci. Ser Tech Report., CEFAS Lowestoft, 116: 83pp

in the Wye Estuary between 1 June and 31 August. Gill nets, which used to be set for bass, mullet and flounders, have almost disappeared in this area due to enforcement of Environment Agency byelaws.

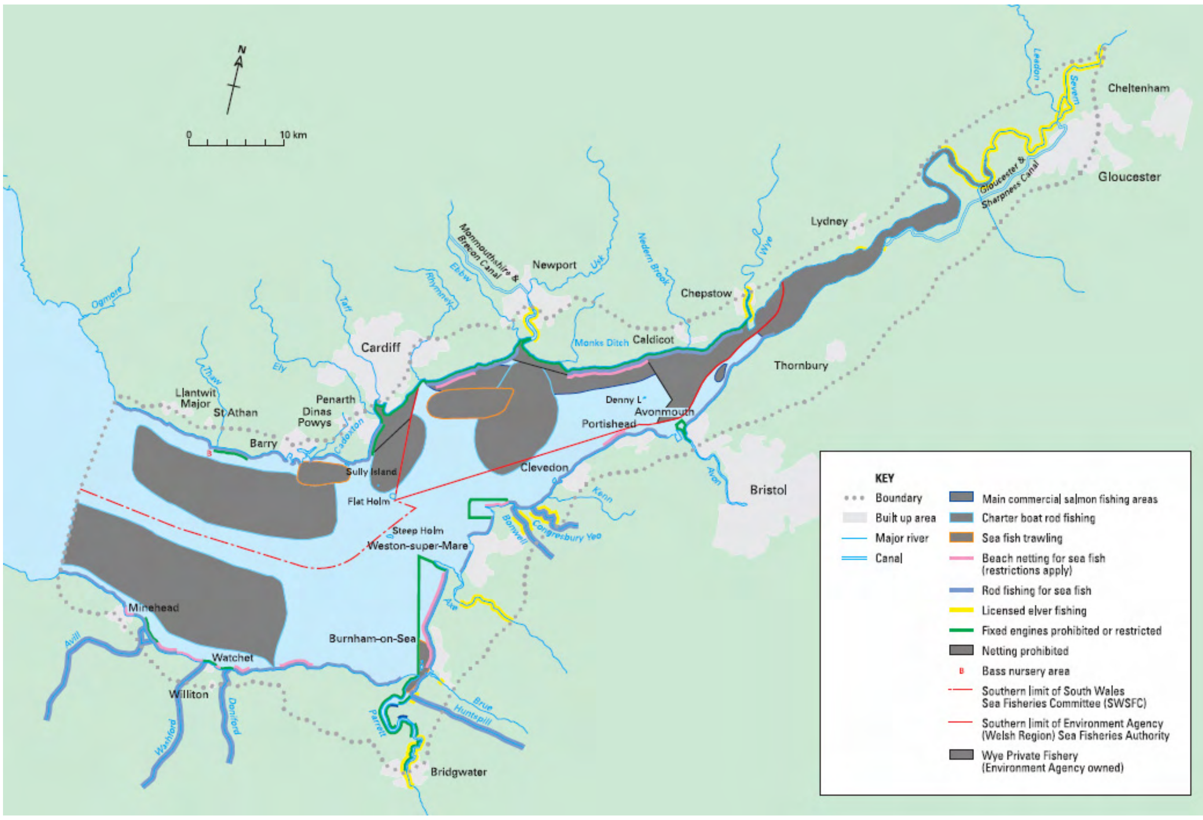


Figure 7.4(1): Fisheries and Angling [180]

7.5.2 Future evolution in the absence of a barrage

The future evolution of fisheries within the Severn would be influenced by a number of key factors including:

- Changes in fishing policy;
- Changes in fishing practices;
- Influences of climate change.

Information relating to the ecology of the fish can be found in Section 6.7.

7.5.3 Implications of a barrage

The implications of a barrage for the ecology of commercial fish species have been reviewed in Section 6.7. This includes aspects of passage through turbines, change in habitat types and prey availability as well as the implications for spawning and nursery grounds. The presence of a barrage could also influence:

- The species that are caught within the Severn;
- The movement of vessels (see Section 7.2)
- The commercial viability of fishing effort;
- Fishing practices that are employed.

It is possible that the less turbid waters would be able to support commercial shellfisheries but this would also be dependent on wider water quality issues.

These changes potentially apply to either a Cardiff-Weston or The Shoots scheme. The area affected by The Shoots scheme would, however, be expected to be considerably less than the Cardiff-Weston scheme. The main sea fish trawling, for example, occurs seaward of The Shoots scheme but partially landward of the Cardiff –Weston scheme (Figure 7.4(1)). The relative effects of the two schemes therefore need to be considered in the context of current fishing practices, taking into account that this is a mobile resource.

Experience drawn from the La Rance scheme suggests that fishing activity can be restricted through the presence of a barrage through the limitation of vessel movements[182]. Changes in traditional fishing practices have also been observed, where there has been a decline in crab potting (or the Lançon fishing activity) mainly due to the accumulation of sediment (Le Comité Opérationnel des Elus et Usagers de la Rance). However, water quality has been sufficient to allow fish farming in the form of salmon cages.

7.5.4 Requirements for additional studies

In order to assess the implications of a Severn Barrage on fishing effort a full review of current fishing practices and associated catches would be required. This would need to incorporate all types of fishing:

- Shellfisheries
- Trawling
- Sea angling

The information collated to inform the assessment of fish usage and ecology of the Severn Estuary would need to be integrated into the review of commercial fisheries.

7.6 LAND DRAINAGE

7.6.1 Introduction

Upstream of Watchet and Cardiff (Figure 7.5(1)[180]), there are about 80,000ha of low-lying areas, including the major areas of the Somerset Levels, the land between Weston super Mare and Gloucester on the English shore, and the Wentlooge and Caldicott Levels near Newport on the Welsh shore. Apart from the Somerset levels which comprise about half of this area, the remainder drains into the estuary landward of the Cardiff-Weston barrage. Upstream of the Shoots barrage, there are large areas of low-lying land around Gloucester. This low-lying land is drained by many separate drainage schemes of widely varying capacity. There are also several rivers and high-level drainage systems that carry drainage from higher land across the low-lying land in embanked channels. Some of this land is residential, especially around Bristol, and other areas have been developed for nationally important heavy industry especially around the ports of Newport and Avonmouth. Much of this land is of nature conservation importance, and is used for low-intensity agriculture.

[182] Bilans de L'usine "4.3 Bilan ecologique" 2000 EDF-SHF Urtin Cyril & Poulain Pierre http://membres.lycos.fr/larance/, 2000

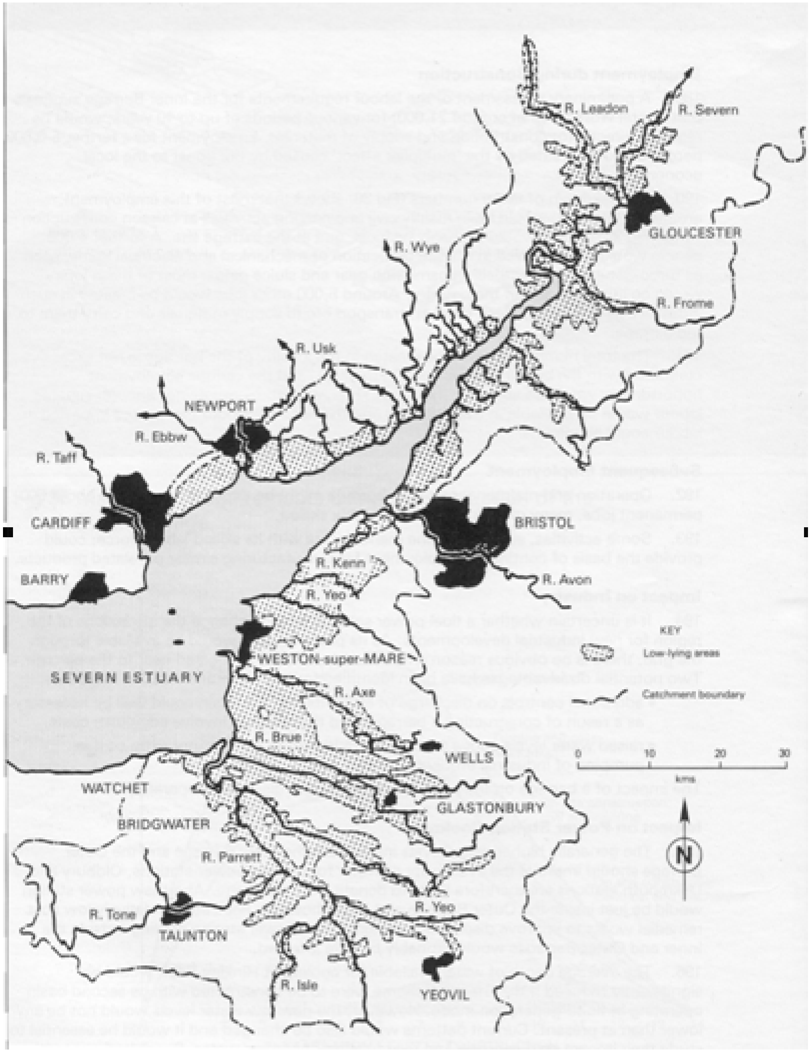


Figure 7.5(1): Low-lying areas around the Severn estuary

In EP57[183], STPG summarises the findings of a number of reports into land drainage aspects. A key report by Tinkler[184] identifies 123 drainage outfalls along the estuary and Severn up to Minsterworth. Of these, 68 are seaward of Sharpness and have flap valves to prevent reverse flow during high tide. Most of the outfalls upstream of Avonmouth drain at about +5mOD or higher, so would hardly be affected by the Cardiff-Weston barrage.

Tinkler's study is now nearly 20 years old, and it has not been possible within this review to assess whether the data on which he based his assessment are all still valid. The results summarised below benefit from updating.

7.6.2 Effects of a tidal power barrage

A tidal power barrage would have the following effects on the land drainage systems:

- High water levels would be reduced, typically in the range 0.5 to 1m. This would have little effect.

[183] STPG, 1989 - Severn barrage project detailed report, Volume 1. Tidal hydrodynamics, sediments, water quality, land drainage and sea defences, contractor report, ETSU TID 4060-P1 EP 57

[184] Tinkler, J A: *Severn Barrage Development Project. Implications of Severn Barrage for land drainage.* 1988.

- There would be a high water 'stand' between high water and the start of generation, typically 2-3 hours. This would increase the times during which an outfall would be tide locked, and this could adversely effect the overall performance of a drainage system, with the secondary effect of increasing groundwater levels.
- Low water level would rise to about present mid tide level. This would adversely affect those outfalls relying on the lower part of the tide to discharge.
- Where sea defences are on pervious foundations, extra local drainage would be needed on the landward side to control saline intrusion.

7.6.3 Remedial works to outfalls – Cardiff-Weston barrage

Tinkler carried out for STPG a preliminary assessment of the situation for each of the 68 outfalls affected by the Cardiff-Weston barrage. Outfalls were divided into the following categories:

- Category 1: Permanently submerged and requiring pumping stations: 4 outfalls
- Category 2: Increased tidelock requiring increased storage or pumping station: 14 outfalls.
- Category 3: Increased tidelock accommodated by increased storage: 24 outfalls.
- Category 4: Unaffected:16 outfalls (plus outfalls upstream of Avonmouth)

Combining capital costs and the present value of pumping costs, the total cost for each of Categories 1, 2 and 3 above, were estimated by STPG as follows, after allowing escalation by a factor of 1.65 from 1988 to 2006:

- Category 1: £19.0M or £17.2M if a relief channel for the Axe is built to discharge seaward of the barrage.
- Category 2: £40.6M for pumping option, £5.0M for increased storage option.
- Category 3: £2.3M for increased storage.

These costs total between £61.9M and £24.5M. More specific costs would require a detailed assessment for each outfall.

7.6.4 The Shoots barrage

As explained above (Section 1.1.1), the outfalls upstream of the Shoots drain at +5mOD or higher. Spring tide high water levels behind the barrage would range from about +6.5m at the barrage to about +8mOD at a distance of 60km upstream. There would again be a pronounced high water stand which can be expected to increase the times during which outfalls are tide locked. Neap tide high water levels would be in the range +3mOD to +4mOD. Low water levels would rise to about mean tide level as far as Maisemore Weir, near Gloucester, above which they would be unchanged.

No assessment has yet been made by either STPG[185] or PB of the effects on the longer high water stand on land drainage. Based on the assessment for the Cardiff-Weston barrage summarised above, the cost should be of second-order importance.

7.7 FLOOD PROTECTION

7.7.1 Responsibility

Flood risk management in the Severn Estuary is the responsibility of the operating authorities; the Environment Agency regions of Wales, Midlands and South West, and the local authorities. The Environment Agency is the principal flood risk management operating authority, with permissive powers (as opposed to a legal obligation) to manage flood risk from designated main rivers and the sea, under the Water Resources Act 1991. Local authorities have similar powers for ordinary watercourses (that is those not designated main river). Coastal local authorities also have powers to

[185] STPG: Tidal power from the Severn: Engineering and economic studies: English Stones barrage and The Shoots Barrage. 1986.

carry out works to manage the risk from coastal erosion and in some areas may also manage the risk from sea flooding.

The Severn Estuary Coastal Group was formed in 1993 to share knowledge and experience initially to deal with the preparation and completion of the first Shoreline Management Plan (SMP) for the estuary. The group, which includes the Environment Agency, will shortly begin revising the first SMP, based on revised guidance from Defra. The group has also become a forum for exchanging information and good practice on coastal issues generally, as well as estuary matters.

Coastal defences have been constructed, over hundreds of years, in order to reduce tidal flooding and coastal erosion risks. Today, thousands of people depend upon constructed defences to protect coastal land and property[180].

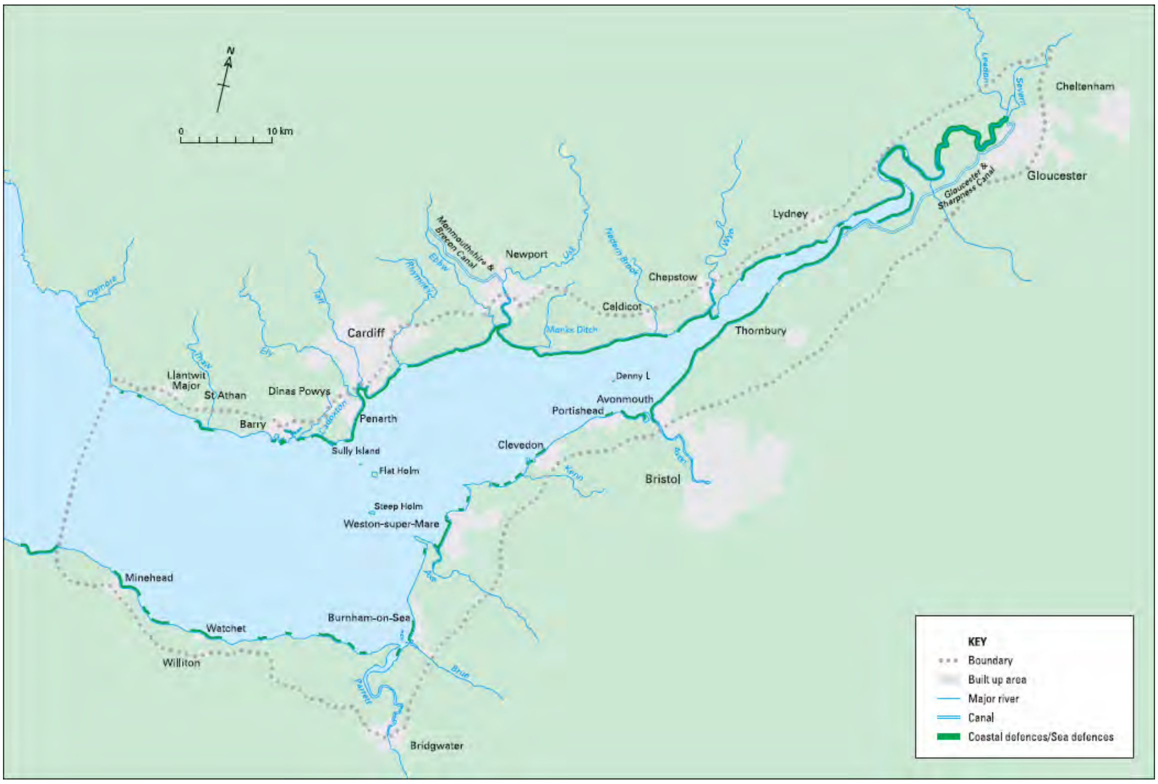


Figure 7.6(1): Coastal Defences around the Severn Estuary[180]

7.7.2 Flood risk parameters

The principal risk of flooding in the estuary results from the extremely high tides combining with surge events, which on occasion can increase water levels by up to 2m. In upstream reaches a further flood risk is from high river discharges; this is the subject of the Severn Catchment Flood Management Plan and the River Severn Flood Management Strategy, which also covers coastal flooding, and the Severn River Basin District management plans (more information on these can be found on the Environment Agency website*.

Climate change factors are believed to increase these risks in the future through elevated mean sea levels, increased storminess and more intense and localised rainfall events.

* www.environment-agency.gov.uk

7.7.3 Flood risk areas

The estuary is presently defended from flooding by a variety of devices, most notably embankments which in some locations originate from the Roman period, and border low-lying areas known as the Gwent Levels and Somerset Levels. These low-lying areas occupy around 840km^2 and have been reclaimed from the sea and now are dependent on the presence of flood defence structures to prevent inundation of large tidal floodplain areas[186].

Initially the reclamation progressed in a staged manner, with new embankments being constructed either seaward, or laterally alongside existing banks to increase the area of inter-tidal reclaimed. However it has been noted that in some areas, like the Wentlooge Levels, sections of the Earliest Roman banks were lost to the sea during the Medieval period and new banks were created inland, set back from the original line of defence.

Without the flood embankments these sites would normally be submerged around high water periods and exist as part of the natural flood plain. However, the sea defences are not all robust, nor were they designed for significant rises in sea level.

Land drainage is used across the levels to manage the soil water so that the land can be used for agriculture. A network of drains discharge into the estuary through tidal flaps.

UK Government guidance on Development and Flood Risk and on Coastal Zone Planning requires Local Planning Authorities (LPAs) to take into account the risk of flooding and coastal erosion, both present and future, when considering new development. These issues will become increasingly important given predicted sea-level rises.

7.7.4 Cost of flood protection

The Environment Agency has a programme of maintenance and capital investment in flood and coastal defence. Across England and Wales, the total spend (central and local government) on flood and coastal erosion risk management is in the order of £600 million for 2005/6 (DEFRA). This funding is prioritised with consideration of cost of the scheme against the value of the assets to be defended, improving public safety and the need for sustainability of the scheme to accommodate future influences from climate change.

The expenditure on present defences and future flood protection schemes within the Severn Estuary is a subject for the Environment Agency.

7.7.5 Implications of a barrage

None of the original barrage schemes were deliberately intended to act as flood barriers. This situation has now changed and a secondary function of any new barrage is expected to be as an active flood management device. The key benefit is being able to manage a reduction in the high water levels for the upstream pound. The secondary benefit appears to be a slight reduction of high water levels downstream of the barrage, an effect that is detectable in model predictions for up to 75km seaward of the barrage. As an example, the level of mean high water spring at Minehead is assumed to be reduced by around 0.5m with a barrage (Figure 7.6(2)). It is strongly recommended that the effects of a barrage on water levels (upstream and downstream of a barrage) is verified by further and more detailed analysis, as intuitively the expectation is for water levels to increase at the barrage as the water is held up and 'backwaters'. If this were to be the case, then flood risk downstream of the barrage would be heightened.

---

[186] Gifford & Partners, GeoData Institute, ABP Research and Consultancy, Peter Fraenkel Maritime and Adams Hendry, 1998. Severn Estuary Shoreline Management Plan.

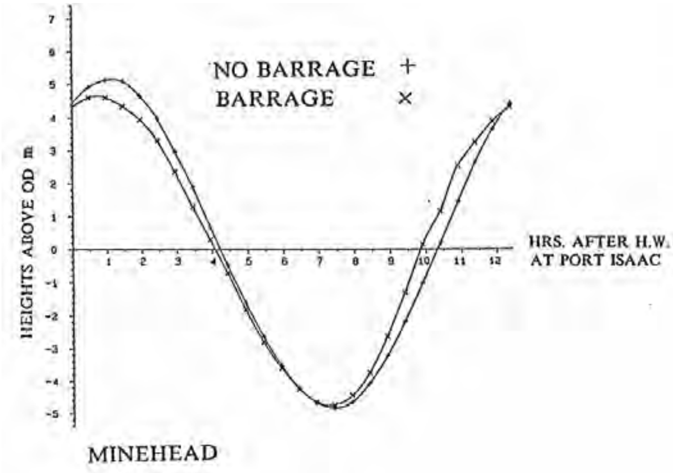


Figure 7.6(2): Predicted water levels at Minehead [180]

The operating mode of the barrage may also have to consider forecasted surge events and alter its generating cycle should flood tide waters become too much of a risk.

The Shoots scheme would be most sensitive to excess river flows from the River Severn.

Somerset County Council (SCC) has interest in the Cardiff-Weston scheme to protect more of the Somerset Levels and through an extension across Bridgwater Bay and over to Hinkley. STPG paper EP46[175] identifies that such a scheme may require a weir across the river Parrett to maintain depths for amenity and inland navigation.

More recently, SCC has expressed reviewed interest in the Outer barrage (as described in Chapter 2) with landfalls near Minehead and Aberthaw. This would provide additional protection against high tides and sea surges to major infrastructure in the county between Minehead and Weston-Super-Mare (landfall of the Cardiff-Weston barrage).

Possible increased frequency of surge tides will require more frequent operation of the barrage to exclude high water levels from the basin and thus prevent flooding.

7.8 TRANSPORT LINKS

A barrage could provide opportunity for both road and rail crossings. For the Cardiff-Weston scheme the introduction of a new road crossing has been postulated, although this has not been costed in the original studies and the implications with ship locks would have to be considered. In addition, the Second Severn Crossing has been constructed since the original studies were completed. In terms of the Shoots scheme it is currently proposed that a high speed rail link is developed, given its close proximity to existing Severn crossings.

There are a number of impacts that a Severn Barrage would have on transport. For example, with an additional fixed crossing across the Severn traffic movements could be improved which would reduce congestion costs. However, issues of cost recovery from traffic using the barrage crossing would need to be addressed as well as the need for a new crossing.

For sea transport, which is discussed in detail in section 7.2, it is assumed that there would be no or limited disruption to shipping during the construction and post construction phases of the barrage schemes. The change in water depth as a result of the schemes might also allow larger vessels to use Severnside ports which could lead to increased efficiency depending on the locks used and the impacts of time for passing through a lock.

There have been a series of reports that have looked at some of the regional economic and social development which would be stimulated by the development of a tidal power facility on the Severn Estuary. These are highlighted in Appendix C. These reports look at various aspects of the potential economic and social impact of the Severn barrage on the regional economy, which includes a number of local authorities on both the Welsh (Cardiff, Vale of Glamorgan) and English sides (North Somerset, South Gloucestershire and Bristol) of the Severn estuary.

The 1986 study by the STPG is the only report that provides a comparison of the transport effects of the two schemes. Other later studies only concentrate on the Cardiff-Weston scheme.

The following table provides a comparison and commentary between the two Barrage Schemes and their effects on transportation, based on a review of the 1986 STPG report[165].

Table 7.8(1): Comparison of the regional economic impacts of the English Stones and Cardiff-Weston crossings – transport effects[185]

Category	**ENGLISH STONES**	**CARDIFF-WESTON**
Road transport	Transport demand would be affected by construction work; tourism, barrage operation; barrage would generate extra traffic; there would be some redistribution of traffic flows within the region; the road should be installed during the construction phase.	At that time there was only one Severn crossing. There are now two. The study stated that the incorporation of a road crossing would reduce traffic demand on the existing crossing; it would have impacts on existing local and trunk road networks; extra traffic would be generated during construction; extra transport generation through tourism; a rail link would be possible but is not incorporated in the project costs; there would be some cost recovery through toll charges; road construction should be incorporated in the construction phase.
Sea Transport	Main impact will be on ship access to Sharpness, Lydnet and Chepstow. Need for more assessment of land use, planning and social implications of the prospects for shipping; Shipping flows will have impacts on lock and other physical infrastructure.	No detailed analysis of shipping; main impacts on Sharpness; impact of shipping traffic will depend on ship size, demand etc. Need for more assessment of land use, planning and social implications of the prospects for shipping. Shipping flows will have impacts on lock and other physical infrastructure.

Based on the review of the various reports on the barrage schemes, a summary of our key findings are provided below:

- The economic data and assumptions in the reports are outdated and will need to be recalculated to take account of new physical infrastructure such as roads and the Second Severn Crossing and updated Port data.

- No estimates of the value of transportation ‘disbenefits’ (negative economic impacts) are contained in the reports e.g. traffic congestion costs during construction.

- Depending on routing, extra traffic generation may have a negative economic impact through higher traffic user costs through increased congestion during the construction period. There may also be economic impacts on local businesses

- The deadweight impacts should also be considered. In particular analysis should be undertaken on transportation if no barrage project were to go ahead.

The need for more detailed regional studies is recognised in all the reports reviewed. In particular, the 1986 STPG study says that the regional study will have to define actual targets as well as other issues such as traffic demand and the impacts of other Severn crossings.

7.9 RECREATION AND TOURISM

7.9.1 Overview

Tourism is one of the largest employment sectors in the Severn Estuary. There are several million visitors to the estuary each year, sustaining a large and varied number of tourist attractions, accommodation types and transport links, Figure 7.8(1)[187].

Figure 7.8(1): Tourist Attractions and Recreational Areas[187]

STPG Energy Paper 46[188] provides a summary of pertinent issues related to recreation and tourism, and relevant at the time of publication. The combination of high tidal range, strong currents and high levels of turbidity are suggested to limit the amount of recreational use in the estuary for activities such as angling, water skiing, swimming and sub-aqua sport.

Given the large volume of people that live in close proximity to the estuary and with increases in leisure time and disposable income, recreational and tourism pressure as well as tourism related benefits will increase in the future. Housing development will also lead to a rise in demand for recreational amenities.

---

[187] Severn Estuary Partnership, 2001. Strategy for the Severn Estuary.

[188] STPG, 1981. Tidal Power from the Severn Estuary. Volume II. Analysis, studies, reports and evaluations. Commissioned by: The Severn Barrage Committee. Energy Paper Number 46.

The CROW (Countryside and Rights of Way) Act (2000) includes a commitment for open access to be extended to the coast by 2009, potentially opening up areas of coast which have historically received little tourism and recreation pressure.

A major issue currently being grappled with is the effect of recreation and access on the Severn Estuary Marine Site, particularly the issue of disturbance by human activity on over-wintering bird sites. Management techniques such as mapping of recreational pressures and conservation data are proving useful in addressing this issue to ensure that recreation and access improve rather than compromise the features of the marine site, e.g. developing interpretation for the visitor about the site and how to mitigate effects.

7.9.2 Angling

Angling for migratory fish in the river tributaries upstream of the barrage is an important recreation, with some 6,000 participants for salmon alone[188].

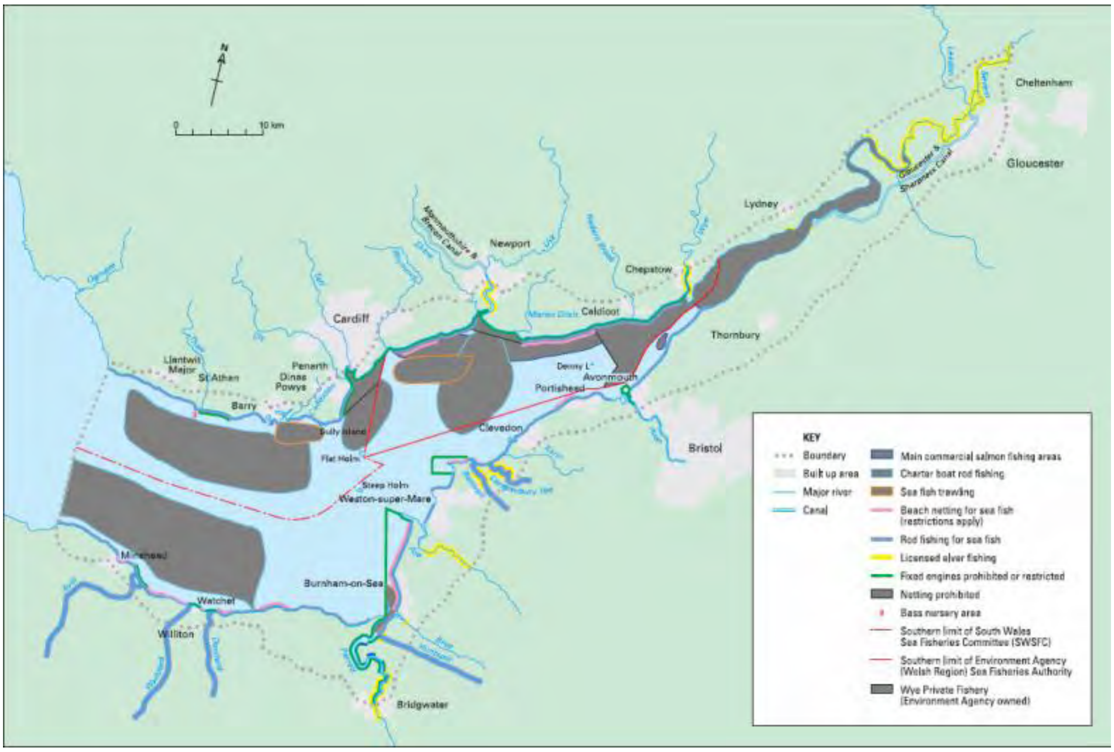


Figure 7.8(2): Fishing and Angling[187]

7.9.3 Wild-fowling

Thirteen wild-fowling clubs with over 500 members use the English and Welsh shores[188].

7.9.4 Bird watching

Bird watching takes place, particularly at Bridgwater Bay and Slimbridge, the latter having about 200,000 visitors a year[188].

7.9.5 Tourist resorts

The main holiday resorts in the general area are Penarth, Clevedon, Burnham-on-Sea, Barry Island, Weston-super-Mare and Minehead. The largest area is Weston-super-Mare which ranks in the top ten British holiday resorts for staying resorts[188].

7.9.6 Cardiff Bay barrage

The Cardiff Bay Barrage was completed in November 1999 as part of the redevelopment of former dock estate and riverside area (Taff and Ely) by impounding water and providing a more attractive waterside. This project post-dates any studies offered on the Severn Barrage. The impoundment traps river flows from the Taf and Ely resulting in mainly freshwater conditions and a near constant water level. With the Cardiff-Weston barrage, there would be a tidal range of 3-5m to seaward of the Cardiff Bay barrage.

7.9.7 Penarth Link walkway

A related development planned for this area is the Penarth Link Walkway, a public facility that aims to extend from the southern edge of the Cardiff Bay Barrage at the Penarth Marina housing development around the cliff face to the esplanade at Penarth.

The proposed walkway coincides with the proposed landfall of the Cardiff-Weston scheme.

7.9.8 Yacht havens

There are a relatively small number of yacht havens (marinas and river moorings) available in the Severn Estuary which includes:

- Penarth Marina (inside of Cardiff Bay Barrage)
- Portishead
- Bristol
- Chepstow

Chepstow is the only site located upstream of The Shoots barrage.

7.9.9 Surfing

The unique character of the Severn Tidal Bore provides a special opportunity for surfers to ride a ‘wave’ over very long distances, and potentially up to 12km. The bore is a function of spring tides (typically >9m tide at Sharpness) and the progressive up-estuary steepening of the tidal ‘wave’ to a point in the estuary above Epney when the ‘bore’ can be detected. This feature of the estuary is used by the Severn Tidal Bore Riders Club.

7.9.10 Implications of a barrage

EP57 suggests that the levels of tourism for the region might increase by the order of 5% and 20%, depending on the assumptions made. This includes the assumption that less severe conditions (hence improved amenity) created by the barrage may stimulate greater water-based recreational usage. The present design of the Cardiff-Weston barrage includes two ‘small boat’ locks in addition to the main ship locks, one within the breakwaters for the main locks near the Welsh shore, the other within its own breakwaters near the English shore. This avoids the need for boats to cross the main shipping lane when approaching from the English shore, and vice versa.

The impact of the Cardiff-Weston scheme on amenity beaches at Weston-super-Mare and Barry has been identified as a risk.

The Cardiff-Weston scheme has the potential to reduce the amount of inter-tidal feeding areas for birds which may impact on bird populations.

Each barrage option may become a visitor attraction.

Each barrage option is likely to prevent the potential of a bore forming.

7.9.11 La Rance

La Rance tidal barrage constitutes an industrial tourist site which attracts in the range of 200,000 visitors each year. In addition, uses of the ship lock by leisure craft amount to around 16,000 movements each year[189].

7.10 COASTAL DEVELOPMENT

There are a number of impacts that a Severn Barrage would have on coastal development. This would include the environment, land and property values, tourism and leisure, agriculture, fisheries and Investment. The regional impacts of these are discussed briefly below:

- Environment

  The impacts on existing wetlands could mean reduced visitor numbers with negative local economic impacts. This is likely to be enhanced during the construction period as a result of extra traffic, noise and dust pollution. Counter to this is the possible economic impacts of improved flood control on land and agriculture.

- Land and Property Values

  Land and property values could be enhanced by the barrage and associated infrastructure development. This would, however, depend on the balance between land and property demand and supply and other macroeconomic factors in the sub region which impinge on the demand for land and property.

- Tourism and Leisure

  The development of the Severn Barrage as a visitor attraction; boating and other recreational activities would enhance the local economic impacts.

- Agriculture

  There is likely to be a loss of agricultural land for development as a result of the Barrage schemes, which may have a positive impact on land values if agricultural land is released for other development.

- Fisheries

  There is likely to be an effect on fish movements and spawning and a change in species distribution linked to changes in water composition and chemistry. Proper mitigation measures such as fish ladders/shoots will be required to limit the damage to fish passing through the sluices.

There have been a series of reports that have looked at some of the regional economic and social development which would be stimulated by the development of a tidal power facility on the Severn Estuary. These are highlighted in Appendix C. These reports look at various aspects of the potential economic and social impact of the Severn barrage on the regional economy, which includes a number of local authorities on both the Welsh (Cardiff, Vale of Glamorgan) and English sides (North Somerset, South Gloucestershire and Bristol) of the Severn estuary.

The 1986 study by the STPG[185] is the only report that provides a comparison of the coastal development effects of the two schemes. Other later studies only concentrate on the Cardiff-Weston scheme.

---

[189] Le Barrage de la Rance http://www.dinard.com/barrage-rance.php Accessed 20th February 2007

The following table provides a comparison and commentary between the two Barrage Schemes and their effects on coastal development, based on a review of the 1986 STPG report[185].

Table 7.9(1): Comparison of the regional economic impacts of the English Stones and Cardiff-Weston crossings – Coastal Development effects.

Category	ENGLISH STONES	CARDIFF-WESTON
Land Use and Planning	Further studies needed on alignment of outer sections of the structure. Importance of land planning issues including power lines, road alignments, car parking, visitor centre. Further studies are required on overall land take including: road use on the barrage and visitor numbers. No estimates of land use because of the issue of sedimentation.	Further studies needed on alignment of outer sections of the structure. Importance of land planning issues including power lines, road alignments, car parking, visitor centre Further studies are required on overall land take including: road use on the barrage and visitor numbers.
Tourism and Recreation	The scheme is likely to stimulate water sports and tourism and recreation visits in a region which already has a number of tourism attractions; the barrage is likely to meet increased demand for water sports, although there remains the issue of sedimentation and access; there is a need for more studies on tourism and recreation demand; no figures are given.	

Based on the review of the various reports on the barrage scheme a summary of our key findings are provided below:

- The economic data and assumptions in the reports are outdated and will need to be recalculated to take account of inward investment, population growth, changes in land practice (e.g. EU Common Agricultural Policy) etc.
- No estimates of the value of coastal development ‘disbenefits’ (negative economic impacts) are contained in the reports e.g. impacts on estuarine fisheries, associated stocks, species distribution and catch values, loss of agricultural land and environmental assets (loss of biodiversity values).
- The deadweight impacts should also be considered. In particular analysis should be undertaken on coastal development if no barrage project were to go ahead.
- Land values benefits will need recalculating in the light of land values and the demand/supply situation for different categories of property.
- Land designations linked to any land take will need to be checked for any new designations

The need for more detailed regional studies is recognised in all the reports reviewed. In particular, the 1986 STPG study says that the regional study will have to define actual targets as well as other issues such as the demand from tourism and recreation.

7.11 OTHER REGIONAL IMPACTS

7.11.1 General

In addition to the regional economic impacts, positive and negative, on employment, transport, ports, and coastal development there will also be an effect on industry and commerce as a result of a Barrage scheme. This could include opportunities for local and regional manufacturing and construction companies to bid for construction and maintenance work. There is also likely to be a range of business opportunities in the service sector such as in tourism, recreation and retail sectors in the sub region as well as the possibility of linking the scheme to other clusters on environmental technology industries. However, potential displacement as a result of barrage development would need also to be considered.

Of the reports reviewed for this study, only the 1986 study by the STPG[185] provides a comparison of the different regional economic impacts of the two schemes. Other later studies only concentrate on the Cardiff-Weston scheme.

The following table provides a comparison and commentary between the two Barrage Schemes and their other regional economic effects, based on a review of the 1986 STPG report[185].

Table 7.10(1): Comparison of other regional impacts[185]

Category	**ENGLISH STONES**	**CARDIFF-WESTON**
Industry and Commerce	No major industrial and commercial developments expected. Considerable impact on tourism and recreation; need for marketing studies on recreation and tourism.	Some impacts on regional industry and commerce.

The most comprehensive study covering the regional economic aspects, however, is that published by STPG/CEGB and the Department of Energy in 1989 for the Cardiff-Weston scheme[183]. In 1995 (which was the modelled peak year of construction), the financial impact (in 1988 values) was estimated to be £91.5million for the low estimate, and £132.4million for the high estimate. High and Low reflect different levels of multiplier impacts on expenditure and investment and an estimate is made for income generated which is retained in the region.

In particular the financial impact on the region was investigated as shown in Table 7.10 (2) below. Scenario 1 and 3 represent a cautiously optimistic growth in gross domestic product but weak regional development in terms of regional development assistance through grants and other incentives, and then a more optimistic scenario for annual growth in national gross domestic product with an average of 2.75% per year over the period 1991 – 2021, respectively. The high and low levels carry the same assumptions as for Table 7.10 (1) above. Specifically, the financial impact on the region of barrage operation, tourism, and increased land and property values (including industrial and commercial, and residential separately) were predicted for 2001, 2011, and 2021.

Table 7.10(2): Summary of Regional Development Financial Impact (£ million) – 1988 values[183]

	2001	**2011**	**2021**
Barrage operation			
Scenario 1	0	3.3	3.3
Scenario 3	0	5.2	5.2
Tourism			

Scenario 1	2.4	23.2	51.9
Scenario 3	2.9	29.7	74.0
Increased Land and Property Values			
Industrial and Commercial			
Scenario 1			
High	53.3	373.1	106.6
Low	26.6	186.5	53.3
Scenario 3			
High	97.4	681.8	194.8
Low	48.7	340.9	97.4
Residential Betterment			
Scenario 1	51.0	357.0	102.0
Scenario 3	51.0	357.0	102.0

Based on the review of the various reports, including the 1986 STPG report[185], a summary of our key findings are provided below:

- The economic data and assumptions in the reports are outdated and will need to be recalculated to take account of updated indices and development.

- It is unclear whether the likely displacement economic impacts (i.e. relocation of industry/business) of the project on other economic development in Wales, the South West and the remainder of the UK has been considered in any detail. No references to these impacts have been found in the reports.

- The deadweight impacts should also be considered. In particular analysis should be undertaken on industry/commerce if no barrage project were to go ahead.

The need for more detailed regional studies is recognised in all the reports reviewed. In particular, the 1986 STPG study[185] says that the regional study will have to define actual targets as well as take into consideration other issues such as changes in government policy, changes in planning policy and guidelines

7.11.2 Consultation with certain stakeholders

Consultation with a number of different stakeholders was undertaken by telephone. A list of consultees is given at the end of this review in Appendix B. At the regional level it is clear that the South West of England Regional Development Agency (SWRDA) has not carried out have done no regional economic modelling to measure the potential impacts of the Severn Barrage on the South West economy nor its sub – regional components. SWRDA works with the South West Economy Centre at the University of Plymouth Business School who have developed regional accounts and an input model for South West England including sub – regional components (i.e. individual local authority areas). On the Welsh side of the Severn, the Welsh Economic Research Unit at the University of Cardiff has not carried out any regional economic impact modelling for the barrage on the Welsh side of the estuary.

Contact was made with the following bodies:

- Cardiff City Council
- North Somerset
- South Gloucestershire
- West of England Strategic Partnership.

This showed that they were aware of the Severn Barrage scheme over a number of years and were tracking events, none had carried out any comprehensive sub – regional economic impact analysis. Most of the regional economic data are those estimated in the reports reviewed here. The view of local authorities will clearly change should implementation of the Severn Barrage take place.

7.11.3 Comparators with the Severn barrage scheme

There are a number of other tidal barrage schemes which could be used as comparators with the proposed Severn Barrage, these include:

- The Annapolis Royal Generating Plant in Canada
- The Rance Scheme in the Bretagne region of France

The Rance scheme would seem to have the closest similarities with the proposed Severn Barrage scheme as it is located in a more densely populated area than the Canadian scheme. The Severn Barrage project is, however, much larger in scale and being located to significant urban areas is likely to have a much bigger regional economic impact than the Rance scheme. The Rance scheme is reported to attract annually, between 300,000 and 400,000 visitors and had 6 million vehicles crossing per year in 1983. In addition it has cut travel times and costs for motorists crossing the barrage. We have found no regional economic impact analysis for the la Rance scheme[190].

7.11.4 Summary

It is clear from the review of the economic and social aspects of the barrage schemes that further work is required to bring the analysis up to date. As has been pointed out, the regional and sub regional boundaries and authorities have changed and there is therefore a need to collect new data. Key variables are likely to include local authority boundaries, population and employment growth and migration; sectoral investments (tourism, transport and other infrastructure), labour productivity; unit capital costs (construction), unit operating costs; employment and expenditure multipliers etc. This exercise would necessitate a regional economic impact modelling exercise utilising data from various sources including:

- Wales

Updating of regional economic data (land use planning, population, employment and labour market data should be undertaken from a number of different sources. These include reports of the South East Wales Strategic Planning Group, SEWTA (South East Wales transport policy), Capital Region – Tourism, the South East Wales Economic Framework and sub – regional economic data held by the relevant local authorities including the Vale of Glamorgan, Cardiff and Newport unitary authorities, other sources of economic and spatial data useful for updating the reports include the Wales Spatial Plan, the South East Wales Strategic Planning group..

- South West England

---

190 Usine marémotrice de la Rance http://membres.lycos.fr/chezalex/projets/rance/sommaire_rance.htm Accessed January 2007.

There are a number of sources of regional economic, social and spatial data. They included the South West England Economic Observatory, the South West Economy Centre at Plymouth University Business School, the South West of England Regional Development Authority (Regional Spatial Strategy for the South West 2006 – 2021), the South West Regional Economic Strategy, the South West Area Multi Modal Study and the Greater Bristol Strategic Transport Study). Additional regional and sub regional economic data which could be used to update the study could be sources from unitary authorities including Bristol, South Gloucestershire, North Somerset and the West of England Strategic Partnership.

8 OVERALL COMPARISON OF BARRAGE SCHEMES

This section presents, in tabular form, comparisons of the main features of the Cardiff-Weston barrage and the Shoots barrage. Some of the comparisons can be based on quantifiable data, others require judgement. The comparisons are divided into broad categories comprising engineering, cost and performance, effects on mankind, and effects on the natural environment.

Parameter	Cardiff-Weston barrage	The Shoots barrage
1. The site		
Present mean tidal range (m)	7.72	8.52 (Avonmouth)
Present mean spring tidal range (m)	10.46	11.54 (Avonmouth)
Basin area (sq km)	480 at mean sea level	90
Length of barrage (km)	15.9	6.5 approx
Ports behind barrage	Avonmouth, Newport, Cardiff, Sharpness	Sharpness
Predicted reduction in tidal range on seaward side of barrage	11%	8%
2. Engineering & cost		
Turbine number x runner diameter	216 x 9.0m	30 x 7.6m
Type of turbine	Bulb, fixed distributor, variable runner blade angle	'Straflo' or rim-generator, variable distributor, fixed runner blades
Level of turbine axis	-17.4mOD	-16mOD
No. of turbines per caisson	4	2
Generator capacity (MW)	40	35
Total installed capacity (MW)	8640	1050
Annual energy output with reverse pumping (TWh)	17 approx	N/a
Annual energy, ebb generation only (TWh)	16.5 approx.	2.75
Percentage development of available power available in Severn Estuary/Bristol Channel (approx 25TWh/yr)	68%	11%

Parameter	Cardiff-Weston barrage	The Shoots barrage
Mode of turbine operation	Ebb generation with reverse pumping at high water	Ebb generation
Sluice number x type	166 x submerged radial gate 20m wide x12m	25 x open radial gate 30m wide, invert at –3mOD
Ship locks, No. x size	2 locks, each 360m x 50m, plus 2 small boat locks each 90m x 15m	1 lock, 225m x 37.5m
Ship lock capacity (dwt)	70,000t approx.	20,000t approx.
Capital cost (2006)	c. £15,000M	£1,440 -£1800M
Annual O&M cost	£115M	£22 -£27M
Construction time to first power	7 years or less	4 years
Design life (years)	120	120
Unit cost of electricity sent out (real) p/kWh	3.6 – 22.3	3.0 – 15.4
Annual saving in CO_2 (based on 0.43 kg/kWh)	7.3 Mt	1.2 Mt
3. Environmental aspects		
Mobile sediments	Some modification of erosion and deposition: lower turbidity in upstream basin	Net siltation in upstream basin could be problematic: mitigation proposed such as high level sluices
Water quality	Some impact in basin: needs re-evaluation	Some impact in basin: needs evaluation
Change in inter-tidal area (spring / neap) ha	14,428 / 5,842	5,530 / 3,372
Migratory fish	Fish passes required: some injury passing downstream through turbines: further studies needed	Fish passes required: some injury passing downstream through turbines: further studies needed
Wading birds	Reduction in inter-tidal area, increase in sub-tidal area and lower turbidity in large basin	Reduction in inter-tidal area, increase in sub-tidal area and lower turbidity in smaller basin
Marine mammals	Limited sightings in estuary	
Habitats Directive	Key issue: demonstrate no less damaging alternatives, meet grounds for IROPI and secure overall coherence of Natura	

Parameter	Cardiff-Weston barrage	The Shoots barrage
	2000 network	
Other environmental legislation	Challenges less significant than Habitats	
4. Social aspects		
Navigation and ports	Provision of ship locks: some impact on Cardiff, Newport, Bristol, Sharpness, Lydney, Chepstow	Provision of ship locks: some impact on Sharpness, Lydney, Chepstow
Land drainage	Some impact on 68 drainage outfalls	No assessment made
Rising sea level/surge tides	Protection of Gwent & Somerset Levels plus other areas from surge tides and impacts of climate change	Protection of low lying areas upstream of barrage from surge tides and impacts of climate change
Recreation and tourism	Increase of perhaps 5 to 20%	No assessment made

9 REFERENCES

1. Posford Haskoning for the Environment Agency: “South West Region: Report on Extreme Tide Levels based on Proudman Institute Methods”, 2003.
2. Severn Barrage Committee: “Tidal power from the Severn Estuary”. HMSO EP46, 1981.Volume II “Analysis, reports, studies and evaluations”.
3. Sir Robert McAlpine Ltd on behalf of the Severn Tidal Power Group: “The Severn Barrage – Definition Study for a new appraisal of the Project – Main Report”, DTI/Pub URN 02/644, 2002 *Appendices*.
4. Dawson Construction Plant Ltd: The “Dawson Plan” for sustainable, continuous tidal power generation, 2006.
5. Severn Lake News http://www.severnlake.co.uk/news.shmtl: accessed 19/2/07.
6. Severn Tidal Power Group (STPG): Tidal power from the Severn. 1986.
7. Report of the Severn Barrage Committee, 1933; HMSO.
8. Severn Barrage Committee: Tidal power from the Severn Estuary, 1981; HMSO.
9. Severn Tidal Power Group (STPG): Tidal power from the Severn. 1986.
10. Parsons Brinckerhoff Ltd: “Severn Estuary, Shoots Tidal Barrage – updated financial assessment”. November 2006.
11. Severn Barrage Committee: “Tidal power from the Severn Estuary”. HMSO EP46, 1981.General Report.
12. Severn Tidal Power Group (STPG): Tidal power from the Severn. 1986 “General Report” and detailed “Engineering and Economic Studies”.
13. STPG: Severn Barrage Project: General Report and Detailed Vol I-V, 1989. EP57, HMSO.
14. STPG: Severn Barrage Project: Further Environmental and Energy Capture Studies, ETSU TID 4099, 1993
15. STPG: The Severn Barrage – Definition study for a new appraisal of the Project; ETSU T/09/00212/REP, 2002.
16. Dawson Construction Plant Ltd: The “Dawson Plan” for sustainable, continuous tidal power generation, 2006.
17. Renewable Energy Access: *Sihwa Lake Tidal Power Plant*; May 2005.
18. La Usine Maramotrice, Alexandre Pigeard.
19. Menint l: *The new design of bulb turbine units based on the experience fron the Rance tidal station and on-the-river bulb units.* Proc. 3rd International Symposium on Wave, Tidal, OTEC and Small scale Hydro Energy. BHRA, 1986.
20. Delory, R P: *The Annapolis Tidal Generating Station.* Proc. 3rd International Symposium on Wave, Tidal, OTEC and Small Scale Hydro Energy. BHRA, 1986.
21. Wilmington Media, 2004.
22. Bernstein, L: *Tidal energy for electric power plants*: Israel Program for Scientific Translations, Jerusalem, pp 208-344. 1965.
23. Cotillon J: *La Rance: 6 years of operating a tidal power plant in France.* Water Power, 1974.
24. Rendel, Palmer & Tritton for Dept. of Energy: *Sand embankments and diaphragm walling for tidal power barrage construction.* March 1988.

25. E.G. Gilfillan *et al*: *Steel caissons for tidal barrages.* Tidal Power, Thomas Telford, 1987

26. Sir Robert McAlpine & Sons: *Severn tidal power feasibility study. Further report on caissons and other civil engineering.* Sept 1980, STP 55.

27. Taywood Engineering Ltd: *Severn tidal power study Stage 2: Report on the design, construction and placing of caissons.* Nov. 1980. STP80.

28. STPG: *Tidal power from the Severn.* 1986, and *Severn Barrage Project, Detailed Report.* 1989.

29. "Balance of Energy and Greenhouse Gas Emissions Throughout the Life Cycle of Natural Gas and Heating Oil as Fuel for Domestic Heating", RDC, Feb. 2005 and "Carbon Energy Balances for a Range of Biofuel Options", DTI Report B/B6/00784, 2003.

30. Hammond, G and Jones, C *"Inventory of carbon & Energy (ICE)"* Version 1.5 Beta. Department of Mechanical Engineering, University of Bath, 2006.

31. Severn Barrage Committee: *Tidal Power from the Severn Estuary*. EP46, 1981.

32. STPG: *Tidal power from the Severn*, 1986.

33. STPG: *Severn Barrage Project: Detailed Report*, EP57, STPG, 1989.

34. STPG: *Severn Barrage Project: Further environmental and energy capture studies*, ETSU TID 4099, 1993.

35. Water Research Centre for STPG: *2-D Plan hydrodynamic modelling of the Bristol Channel and Severn Estuary with and without barrage.* 1989.

36. STPG: *Severn Barrage Project: Further environmental and energy capture studies*, ETSU TID 4099, 1993.

37. Binnie & Partners for STPG: *Dynamic modelling of an English Stones tidal power barrage.* 1986.

38. STPG: *Severn Barrage Project.* 1989, Vol. I , Section 2.

39. Department of Environment, Food and Rural Affairs: *Flood & Coastal Defence Appraisal Guidance – FCDPAG93: Economic Appraisal,* Oct 2006.

40. Intergovernmental Panel on Climate Change: *Climate Change 2007: The Physical Science Basis;* February 2007.

41. RSPB The Severn Estuary – its Nature Conservation Value and Regulatory Protection. 2006.

42. http://membres.lycos.fr/chezalex/projects/rance/.

43. Carr, JG: The economics of *the Severn Barrage.* Proc. Conference on developments in tidal energy, ICE, 1989, Paper 18.

44. Severn Barrage Committee: *Tidal power from the Severn Estuary.* Energy Paper 46, 1981.

45. Carr J.G., *The economics of the Severn barrage.* Paper 18 in proc. Conference on Developments in Tidal Energy, ICE, 1989.

46. Dept. of Trade & Industry: *Public Sector Construction Works: Quarterly Building Price & Cost Indices.*

47. STPG: *The Severn barrage – Definition study for a new appraisal of the project.* ETSU T/09/00212/REF. 2002.

48. Shaw, T.L. & Watson, M.J. "Flexible power generation from the tides". Engineering Sustainability, 156, Issue ES2, pp119-123, 2003.

49. Severn Barrage Committee: *Tidal Power from the Severn Estuary*. EP46, 1981 Volume I

50. Severn Barrage Committee: *Tidal Power from the Severn Estuary*. EP46, 1981 Volume II "Analysis, reports, studies and evaluations".

51. British Energy http://www.british-energy.com

52. Guidance doc on Article 6(4) of the Habitats Directive: Clarification of the concepts of: Alternativve Solutions, Imperative Reasons of Over-riding Public Interest, Compensatory Measures, Overall Coherence, Opinion of the Commission, European Commission, January 2007.

53. Sir Robert McAlpine Ltd on behalf of the Severn Tidal Power Group: "The Severn Barrage – Definition Study for a new appraisal of the Project – main report" 2002.

54. Parsons Brinckerhoff, 2006. The Severn Estuary; Shoots Tidal Barrage. Updated Financial Assessment. November 2006.

55. Department of Trade and Industry. Nuclear Costs. http://www.dti.gov.uk/energy/review/Financial%20Models/page32771.html

56. STPG, The Severn Barrage Project: General Report, EP57, 1989.

57. Sustainable Development Commission, The role of Nuclear power in a low carbon economy: Paper 4; The Economics of Nuclear Power, March 2006.

58. Department of Trade and Industry http://www.dti.gov.uk/files/file33302.xls Accessed February 2007.

59. Commission Decision of 29 November 2006 concerning the national allocation plan for the allocation of greenhouse gas emission allowances notified by United Kingdom in accordance with Directive 2003/87/EC of the European Parliament and of the Council.

60. STPG, 1986. Tidal Power from the Severn. Engineering and economic studies – The Cardiff-Weston Scheme and English Stones scheme. The Severn Tidal Power Group.

61. The Energy Challenge, 11th July 2006.

62. BBC News Website "Nuclear power plants get go ahead http://news.bbc.co.uk/1/hi/uk_politics/5166426.stm Accessed February 2007

63. ABPmer, 2006. Severn Estuary ChaMP Morphological assessments.

64. http://www.dft.gov.uk/stellent/groups/dft_shipping/documents/page/dft_shipping_028330-03.hcsp#TopOfPage

65. EC, 2006. Guidance Ref

66. ODPM, 2005. A Practical Guide to the Strategic Environmental Assessment Directive.

67. Council Directive 97/11/EC, Official Journal L 073, 14/03/1997, p.5. http://ec.europa.eu/environment/eia/full-legal-text/9711.htm

68. English Nature and the Countryside Council for Wales, 2005. English Nature & the Countryside Council for Wales' advice for the Severn Estuary Special Protection Area given under Regulation 33(2) of the Conservation (Natural Habitats &c.) Regulations 1994.

69. STPG, 1989. The Severn Barrage Project. Detailed report Vol I "Tidal Hydrodynamics, Sediments, Water Quality, Land Drainage and Sea Defences." Chapter 3 Sediments.

70. BGS, 1986. Bristol Channel - Sheet 51ºN - 04ºW. Sea Bed Sediments and Quaternary Geology. 1:250 000 Series. NERC.

71. Allen J.R.L., 1990. The Severn Estuary in southwest Britain: its retreat under marine transgression, and fine-sediment regime. Sedimentary Geology, 66: 13-28.

72. Gifford & Partners, GeoData Institute, ABP Research and Consultancy, Peter Fraenkel Maritime and Adams Hendry, 1998. Severn Estuary Shoreline Management Plan.

73. Evans, C.D.R. 1982. The geology and surficial sediments of the Inner Bristol Channel and Severn Estuary. In: Severn Barrage (Proceedings of a symposium organised by the Institution of Civil Engineers, London 8-9 October 1981. Thomas Telford, London. 35-42.

74. Allen, J.R.L., 1991. Fine sediment and its sources, Severn Estuary and inner Bristol Channel, southwest Britain. Sediment. Geol. 75, 57–65.

75. Barrie, J.V., 1980a. Heavy mineral distribution in bottom sediments of the Bristol Channel, U.K. Estuarine Coastal Mar. Sci., 11: 369-381.

76. Barrie, J.V., 1980b. Mineralogy of non-cohesive sedimentary deposits. In: M.B. Collins and others (Editors), Industrialised Embayments and their Environmental Problems. Pergamon Press, Oxford, pp. 249-257.

77. ABPmer, 2006. Severn Estuary ChaMP Morphological Assessments Part F: Sediment budget analysis, R1260f.

78. Collins M.B., 1987. Sediment Transport in the Bristol Channel: A review. Proceedings of the Geologists Association.

79. Parker, W.R. and Kirby R, 1982. Sources and transport patterns of sediment in the inner Bristol Channel. The Severn Barrage, Thomas Telford, London, 181-89.

80. ABPMer, 2004 A Review of the Bristol Channel Sediment Regime. R1161.

81. Kirby, R., 1986. Suspended fine cohesive sediment in the Severn Estuary and inner Bristol Channel, U.K. Department of Energy, Energy Technology Support Unit, Rep. ETSU-STP-4042.

82. Kirby, R., Parker, W.R., 1983. Distribution and behaviour of fine sediment in the Severn Estuary and inner Bristol Channel, U.K. Can. J. Fish. Aquat. Sci 40 (Suppl.), 83-95

83. Kirby, R., 2005. Severn Barrage, UK – Environmental reappraisal. Proceedings of the institution of Civil Engineers, Engineering Sustainability 158, Issue ESI

84. Kirby, R., 1990. Shoots barrage, sedimentation report by Dr R Kirby of Ravensrodd Consultants Ltd (originally prepared in 1990 for the Hooker Barrage).

85. Parsons Brinckerhoff, 2006. The Severn Estuary; Shoots Tidal Barrage. Updated Financial Assessment. November 2006.

86. ABPmer, 2006. Severn Estuary ChaMP Morphological assessments Part F: Sediment Budget Analysis, R1260f.

87. Velegrakis, A.F., Houghton, A., Thompson, C., Collins, M.B., 2001. Morphological development and sediment dynamics of the Middle Grounds Bank (Severn Estuary). Technical Report. School of Ocean and Earth Sciences. University of Southampton

88. Severn Barrage Committee, 1981: Tidal power from the Severn Estuary. Energy Paper 46.

89. Severn Estuary Partnership, 2001. Strategy for the Severn Estuary.

90. Marine Biological Association, 2003. The Severn Estuary (possible) Special Area of Conservation Special Protection Area. Characterisation of European Marine Sites. Occasional Publication No. 13.

91. Radford, P.J. 1982. The effects of a barrage on water quality. Severn Barrage, Thomas Telford Ltd., London.

92. STPG, 1989. The Severn Barrage Project. Detailed report Vol I “Tidal Hydrodynamics, Sediments, Water Quality, Land Drainage and Sea Defences.” Chapter 3 Sediments

93. STPG, 1986. Tidal Power from the Severn. Engineering and economic studies – English Stones scheme. The Severn Tidal Power Group.

94. English Nature and the Countryside Council for Wales, 2005. English Nature & the Countryside Council for Wales’ advice for the Severn Estuary Special Protection Area given under Regulation 33(2) of the Conservation (Natural Habitats &c.) Regulations 1994.

95. English Nature, 1998. Bridgwater Bay National Nature Reserve. English Nature - Taunton Team.

96. ETSU, 1989. The prediction of post barrage densities of shorebirds: Volume 4: Birds. Institute of Terrestrial Ecology, ETSU TID 4059.

97. Boyden, C.R. and Little, C. 1973. Faunal distribution in soft sediments of the Severn Estuary. Estuarine Coastal and Marine Science, 1, 203-223.

98. Wimpol Ltd, 1988. Intertidal invertebrate distributions in the Severn Estuary. Report to Severn Tidal Power Group No. SBP 36.

99. Davies, J 1991. Benthic marine ecosytems in Great Britain: a review of current knowledge. Western Channel and Bristol Channel and approaches. MNCR sectors 8 and 9. Nature Conservation Council, CSD Report, No. 1173(Marine Nature Conservation Review Report, No. MNCR/0R/9)

100. University of Bristol – Zoology Department, 1988. Ecology of the sub-estuaries of the River Severn. ETSU Contract No. ETSU-TID-4057.

101. Plymouth Marine Laboratory, 1988. Predicting post barrage densities of invertebrates and shorebirds: 2 Invertebrates. ETSU Contract No. E/5A/CON/4061/1786.

102. ABPmer, 2006a. Severn Estuary ChaMP Morphological assessments

103. Gray, J.S. 1974. Animal-sediment relationships. Oceanography and Marine Biology Annual Review 12, 263-289.

104. Warwick, R.M; George, C.L. ; Pope, N.D. ; Rowden, A.A. ; Department Of Energy. Energy Technology Support Unit (ETSU) ; Plymouth Marine Laboratory ; Natural Environment Research Council (NERC)* (1989). The prediction of post barrage densities of shorebirds: volume 3:invertebrates. (ETSU TID; 4061). London : Department of Energy.

105. Kirby, R. 2006. Links between environmental consequences of La Rance and Severn Tidal Power Barrages. Kirby – 10th October 2006.

106. Desroy, N. and Retiere, C. 2004. Using benthos as a tool for coastal management: The impact of the tidal power station on benthic communities of the Rance basin. Aquatic Ecosystem Health and Management, 7, 59-72.

107. Adam, P. 1990. Saltmarsh ecology, Cambridge University Press, Cambridge

108. Smith L P, 1979. A survey of salt marshes in the Severn Estuary. Volumes I and II. Nature Conservatory Council, CSD Report, No.265.

109. Teverson, R. 1981. Salt marsh ecology in the Severn Estuary, Severn Tidal Power Report No. STP 51.

110. Dent S, 1987. The current status and recent history of Spartina anglica in the Severn Estuary between Newport and Cardiff. Peterborough, Nature Conservancy Council.

111. Burd F, 1989. The salt marsh survey of Great Britain: An inventory of British salt marshes: Report of the Nature Conservancy Council. Regional Supplement No. 2 West Midlands.

112. Dargie T, 1999. NVC survey of salt marsh habitats in the Severn Estuary 1988. Report for the Countryside Council for Wales and English nature. CCW Contract Science Report No. 341.

113. English Nature, 1997. Natural Area Profile for Bridgwater Bay.

114. Gray A J, Mogg R J, 2001.Climate impacts on pioneer saltmarsh plants. Climate Research 18 ,1-2: 105-112.

115. Gray, A.J. ; Clarke, R.T. ; Warman, E.A. ; Johnson, P.J. ; Department Of Energy. Energy Technology Support Unit (ETSU) ; Institute of Terrestrial Ecology (ITE) (1989). Prediction of marginal vegetation in a post-barrage environment; a model of Spartina anglica niche in south and west Britain. (ETSU TID; 4070). London : Department of Energy.

116. Clarke, R.T, Gray, A.J., Warman, E.A., Moy, I.L 1993. Niche modelling of saltmarsh plant species. Institute of Terrestrial Ecology, ETSU T/04/00194/REP.

117. Mitchell,R, Probert,P.K. McKirby,A.P and Doody, J.P. 1981. Severn Tidal Power Nature Conservation. Nature Conservancy Council.

118. Gifford & Partners, GeoData Institute, ABP Research and Consultancy, Peter Fraenkel Maritime and Adams Hendry, 1998. Severn Estuary Shoreline Management Plan.

119. Little C and Smith L P 1980. Vertical zonation on rocky shores in the Severn Estuary. Estuarine and Coastal Marine Science, 11, 651-669.

120. Smith L P and Little C, 1980. Intertidal communities on rocky shores in the Severn Estuary. Proceedings of the British Naturalists Society, 38, 61-67. Referenced in this paper as a source of detailed species accounts for the nine sites

121. Bassindale R, 1943. Studies on the biology of the Bristol Channel. XI. The physical environment and intertidal fauna of the southern shores of the Bristol Channel and Severn Estuary. Journal of Ecology, 31, 1-29.

122. Lewis, J.R. 1964. The ecology of rocky shores. London, English University Press Limited.

123. Rogers, D 1996. Vegetated shingle features at Bridgwater Bay. Report for English Nature.

124. Posford Duvivier Environment, 1999. Overview of coastal sand dunes, salt marsh and vegetated shingle by Natural Area. Research Report for English Nature.

125. Warwick, R.M. and Davies, J.R. 1977. The distribution of the sublittoral macrofauna communities in the Bristol Channel in relation to the substrate. Estuarine Coastal and Marine Science, 5, 267-288.

126. Warwick, R.M. and Uncles, J.R. 1980. The distribution of benthic macrofauna associations in the Bristol Channel in the Bristol Channel in relation to tidal stress. Marine Ecology Progress Series, 3, 97-103.

127. Warwick, R.M. 1984. The benthic ecology of the Bristol Channel. Marine Pollution Bulletin, 15, 70-76.

128. STPG, Severn Barrage Project. Detailed Report Volume IV “Ecological Studies, landscape and nature conservation” ETSU TID 4060-P4

129. Shaw, T.L. undated. La Rance Tidal Power Barrage Ecological Observations relevant to a Severn Barrage Project, Shawater Limited.

130. Kirby, R. 2006. Links between environmental consequences of La Rance and Severn Tidal Power Barrages. Kirby – 10th October 2006.

131. Henderson, P.A., 2007. Discrete and continuous change in the fish community of the Brisol Channel in response to climate change. Journal of Marine Biological Association UK, 87, 589-598.

132. Environment Agency, 2005. Effect of climate change on salmon fisheries. Science Report W2-047/SR.

133. Turnpenny, A. W. H., Clough, S., Hanson, K.P., Ramsay, R., McEwan, D. 2000. Risk assessments for fish passage through small, low-head turbines. Report ETSU H/06/00054/REP

134. Solomon, D. J. Fish passage through tidal energy barrages. Energy Technology Support Unit, Harwell. Contractors Report No, ETSU TID4056, 76pp.

135. Turpenny, A.W. H. 2001. The UK Parliament – Select Committee on Science and Technology Appendices to the minutes of evidence. Appendix 2 – Memorandum submitted by Dr Andrew Turnpenny, Fawley Aquatics Research Laboratories.

136. Le Mao, P. 1985. Place de la seiche Sepia officinalis (Mollusque, Cephalopode) dans les chalnes alimentaires du Golfe normano-breton. Cahiers de Biologie Marine 26, 331-340.

137. SAGE (Schéma d'aménagement et de Gestion de l'Eau) de la Rance et du Frémur. (Arrêté préfectoral du 5 avril 2004. Tome 1 du SAGE Rance Frémur Baie de Beaussais – La Rance et le Frémur en 2002 - Etat des lieux)

138. Alabaster, J.S. and Gough, P.J., 1986. The dissolved oxygen and temperature requirements of Atlantic salmon, Salmo salar L., in the Thames estuary. Journal of Fish Biology, 29:613-621.

139. EIFAC (1965) cited in FARL, 1995. Possible impacts of dredging on salmonids. Research Note for ABP Research. Fawley Aquatic Research Laboratories Ltd.

140. McCain, B.B., Brown, D.W., Hom, T., Myers, M.S., Pierce, S.M., Collier, T.K., Stein, J.E., Chan, S.L. & Varanasi, U., 1996. Chemical contaminant exposure and effects in four fish species from Tampa Bay, Florida. Journal of Estuarine Research Federation 19:86-104

141. Nedwell, J., 2003. Report on the potential effects of underwater piling noise from the Dibden Bay Phase 1 Project. Report Ref: 570 R 0202.

142. Prater, T. 2007. Ecological aspects of the Severn Barrage. Royal Society for the Protection of Birds.

143. Ferns, P.N. 1988. Waterbird Community Changes in the Post-barrage Severn Estuary, report to Severn Tidal Power Group No. SBP 41.

144. Austin, G.E and Rehfisch, M.M (2005) Shifting nonbreeding distributions of migratory fauna in relation to climatic change Global Change Biology 11, 31-38.

145. Goss Custard, J.D. & Moser, M.E. 1988. Rates of change in the numbers of dunlin, Caldris alpine, withering in British estuaries in relation to the spread of Spartina anglica. Journal of Applied Ecology, 25, 95-109.

146. Kirby, R. 1988. The ecological implications of possible changes in the sedimentological regime caused by the proposed Severn Barrage. Report to Severn Tidal Group, 75pp.

147. Institute of Terrestrial Ecology, 1988. Prediction of post-barrage density of shorebirds: birds. ETSU Contract No. E/5A/CON/4059/1705.

148. Goss-Custard, J.D. Kay, D.G. & Blindell, R. M. 1977. The density of the migratory and overwintering redshank, Tringa tetanus and curlew Numenius arquata in relation to the density of prey in the south-east England. Estuarine and coastal marine science, 5, 497-510.

149. Bryant, D. M. 1979. Effects of prey density and site character on estuary usage by overwintering waders (Charadrii). Estuarine and Coastal Marine Science, 9, 369-384.

150. West, A.D and Caldow, R.W.G. 2006. The development and use of individuals based models to predict the effect of habitat loss and disturbance on waders and waterfowl. Ibis, 148, 158-168.

151. SCOS 2006: Scientific Advice on Matters Related to the Management of Seal Populations Scientific (smub.st-and.ac.uk/CurrentResearch.htm/SCOS2006/SCOS%202006%20collated%20document%20FINAL.pdf)

152. Watkins, H and Colley, 2004. Harbour Porpoise *Phocoena phocoena* Occurrence Carmarthen Bay - Gower Penninsula - Swansea Bay.

153. Reid, J.B., Evans, P.G.H., & Northridge, S.P., (2003), Atlas of Cetacean distribution in north-west European waters, 76 pages, colour photos, maps. Paperback

154. Environment Agency Fourth Otter Survey of England 2000-2002: Severn Catchment. (www.environment-agency.gov.uk/commondata/acrobat/severn_region.pdf).

155. Bell, M. and Neumann, H. 1997. Prehistoric Intertidal Archaeology and Environments in the Severn Estuary, Wales. World Archaeology, 29, 95-113.

156. STPG, Severn Barrage Project. Detailed Report Volume IV “Ecological Studies, landscape and nature conservation” ETSU TID 4060-P4

157. Severn Estuary Partnership, 2001. Strategy for the Severn Estuary. And Severn Estuary Partnership, 2006. The Archaeology of the Severn Estuary. A guide for planners, developers, decision makers and local communities.

158. Severn Estuary Levels Research Committee, 1988. The archaeological potential of the Severn Estuary, and initial assessment for STPG. And Severn Estuary Levels Research Committee, 2001. Estuarine Archaeology, the Severn and Beyond Archaeology in the Severn Estuary. Edited by Stephen Rippon, Department of Archaeology, University of Exeter.

159. Posford Duvivier and ABP Research, 2000. Bristol Channel Marine Aggregates Study.

160. National Trust, 2006. Letter to the Sustainable Development Commission regarding scoping issues if tidal energy in the UK.

161. Land Use Consultants, 2007. Advice on Potential Landscape/Seascape and Visual Impacts of a Severn Barrage. A report for Natural England.

162. Goss Custard, J.D. & Moser, M.E. 1988. Rates of change in the numbers of dunlin, Caldris alpine, withering in British estuaries in relation to the spread of Spartina anglica. Jounral of Applied Ecology, 25, 95-109.

163. Guidance document on Article 6(4) of the Habitats Directive: Clarification of the concepts of: Alternative Solutions, Imperative Reasons of Over-riding Public Interest, Compensatory Measures, Overall Coherence, Opinion of the Commission. European Commission, January 2007.

164. Position Statement on A Severn Barrage, Environment Agency, Countryside Council for Wales and English Nature/Natural England, May 2006.

165. STPG, 1986. Tidal Power from the Severn. Engineering and economic studies – The Cardiff-Weston scheme and English Stones scheme. The Severn Tidal Power Group.

166. STPG, 1989 - Severn barrage project detailed report, Volume V. Regional Studies and Legal Background, contractor report, ETSU TID 4060-P5 EP 57.

167. STPG. The Severn Barrage – Definition Study for a New Appraisal of the Project. Final Report: January 2002. ETSU Report No. T/09/00212/00/REP, 2002

168. Department for Transport, 2000. Modern Ports: A UK Policy.

169. Department for Transport, 2006. Focus on Ports. 2006 Edition.

170. SWRDA, 2004. Bristol Port Economic Assessment. Final Report. March 2004

171. STPG, 1989. The Severn Barrage Project. General Report.

172. STPG, 1986. Tidal Power from the Severn. Vol. 1.

173. Department of Energy, 1981. Tidal Power from the Severn Estuary. Volume II. Analysis, studies, reports and evaluations. Commissioned by: The Severn Barrage Committee. Energy Paper Number 46

174. Parsons Brinckerhoff, 2006. Severn Estuary. Shoots Tidal Barrage. Updated Financial Assessment. November 2006.

175. The Crown Estate, 2006. Marine aggregates reserves, The Crown Estate licences – TCE/MR 31.03.06.

176. WAG (2004) *Interim Marine Aggregates Dredging Policy: South Wales.* Welsh Assembly Government, November 2004.

177. Lockwood, S.J. 1988. The potential impact of the proposed Severn Tidal Barrage on Commercially Exploited Marine Fish Species. Report to Severn Tidal Power Group No. SBP 44.

178. Severn Estuary Partnership, 2001. Strategy for the Severn Estuary, 2001 Severn Estuary Partnership, Cardiff.

179. Pawson, M.G., Pickett, G.D and Walker, P.2002.The coastal fisheries of England and Wales, Part IV: A review of their status 1999-2001. Sci. Ser Tech Report., CEFAS Lowestoft, 116: 83pp

180. Bilans de L'usine “4.3 Bilan ecologique” 2000 EDF-SHF Urtin Cyril & Poulain Pierre http://membres.lycos.fr/larance/, 2000

181. STPG, 1989 - Severn barrage project detailed report, Volume 1. Tidal hydrodynamics, sediments, water quality, land drainage and sea defences, contractor report, ETSU TID 4060-P1 EP 57

182. Tinkler, J A: *Severn Barrage Development Project. Implications of Severn Barrage for land drainage.* 1988.

183. STPG: Tidal power from the Severn: Engineering and economic studies: English Stones barrage and The Shoots Barrage. 1986.

184. Gifford & Partners, GeoData Institute, ABP Research and Consultancy, Peter Fraenkel Maritime and Adams Hendry, 1998. Severn Estuary Shoreline Management Plan.

185. STPG, 1989 - Severn barrage project detailed report, Volume V. Regional Studies and Legal Background, contractor report, ETSU TID 4060-P5 EP 57.

186. Severn Estuary Partnership, 2001. Strategy for the Severn Estuary.

187. STPG, 1981. Tidal Power from the Severn Estuary. Volume II. Analysis, studies, reports and evaluations. Commissioned by: The Severn Barrage Committee. Energy Paper Number 46.

188. Le Barrage de la Rance http://www.dinard.com/barrage-rance.php Accessed 20th February 2007

189. Usine marémotrice de la Rance http://membres.lycos.fr/chezalex/projets/rance/sommaire_rance.htm Accessed January 2007.

10 GLOSSARY OF TERMS

Term	***Description***
AONB	Area of Outstanding Natural Beauty
CCGT	Combined Cycle Gas Turbine
CCL	Climate Change Levy
CCW	Countryside Council for Wales
CD	Chart Datum
CDM	Clean Development Mechanism
CEGB	Central Electricity Generating Board
CHaMP	Coastal Habitat Management Plan
COPI	Construction Output Price Index
CROW	Countryside Right of Way
DEFRA	Department of Environment, Food and Rural Affairs
DNO	Distribution Network Operators
DoE	Department of the Environment
DTI	Department of Trade and Industry
DWT	Dead Weight, Tonnes
EA	Environment Agency
EAC	Equivalent Annual Costs
EIA	Environmental Impact Assessment
EN	English Nature
EP	Energy Paper
ETS	Emissions Trading Scheme
ETSU	Energy Technology Support Unit
FEPA	Food and Environment Protection Act
GWh	Giga Watt Hour (watt hours x 10^9)

Term	*Description*
HMSO	Her Majesty's Stationery Office
HW	High Water
IDC	Interest During Construction
IROPI	Imperative Reason of Overriding Public Interest
JI	Joint Implementation
kW	Kilo watts (watts x 10^3)
LASH	Lighters Aboard Ship
LAT	Lowest Astronomical Tide
LNR	Local Nature Reserve
LW	Low Water
M&E	Mechanical & Electrical
MHWS	Mean High Water Spring
MLWS	Mean Low Water Spring
MN	Managing Natura
MW	Mega watts (watts x 10^6)
NE	Natural England
NGET	National Grid Electricity Transmission
NNR	National Nature Reserve
NT	National Trust
ODPM	Office of Deputy Prime Minister
PB	Parsons Brinkerhoff
PPI	Plant Price Index

Term	***Description***
PPP	Public Private Partnership
PPS	Planning Policy Statement
pSAC	Possible Special Area of Conservation
ROC	Renewable Obligation Certificate
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SDC	Sustainable Development Commission
SEAD	Strategic Environmental Assessment Directive
SINC	Site of Importance for Nature Conservation
SPA	Special Protection Area
SQSS	Security and Quality of Supply Standards
SSSI	Site of Special Scientific Interest
STPG	Severn Tidal Power Group
Straflo	Straight flow turbine
SWRDA	South West of England Regional Development Agency
SYS	Seven Year Statement
TNUoS	Transmission Network Use of System
TWh	Tera Watt hours (watt hours x 10^{12})
WACC	Weighted Average Cost of Capital
WRA	Water Resources Act
WFD	Water Framework Directive
WRc	Water Research Centre

APPENDICES

APPENDIX A: THE CRITERIA FOR IDENTIFYING WETLANDS OF INTERNATIONAL IMPORTANCE

APPENDIX B: INSTITUTIONS AND PERSONS CONSULTED

APPENDIX C: SUMMARY OF REPORTS COVERING REGIONAL ECONOMIC AND SOCIAL DEVELOPMENT ASPECTS OF THE PROPOSED SEVERN BARRAGE

APPENDIX A: THE CRITERIA FOR IDENTIFYING WETLANDS OF INTERNATIONAL IMPORTANCE

Group A of the Criteria. Sites containing representative, rare or unique wetland types

Criterion 1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.

Group B of the Criteria. Sites of international importance for conserving biological diversity

Criteria based on species and ecological communities

Criterion 2: A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.
Criterion 3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.
Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.

Specific criteria based on waterbirds

Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.
Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.

Specific criteria based on fish

Criterion 7: A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity.

Criterion 8: A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.

APPENDIX B: INSTITUTIONS AND PERSONS CONSULTED

INSTITUTION	PERSON	FUNCTION
Cardiff City Council	A. Foster	Principal Strategy Officer
Countryside Council for Wales	Sarah Wood	Senior Maritime Policy Officer
Environment Agency	Richard Howell	Acting Head of Policy, Development & Promotion, Bristol
National Trust	Alan Watson	
Natural England	Adrian Jowitt	
North Somerset	Simon Gregory	Team Leader, Economic Development and Regeneration
Royal Commission	Susan Hughes	
Royal Society for the Protection of Birds	Daniel Pullan	
Severn Estuary Partnership www.severnestuary.net	Steve Knowles	Part time officer
South East Wales Economic Forum	John Sheppard	
South Gloucestershire Council	Kevin Chidgey	Economic Development Officer
South West Economy Centre, Plymouth Business School	Professor Peter Gripaios	Director, South West Economy Centre
South West of England Regional Development Agency	Shane Vallance	Economic Development
South West Renewable Energy Agency	Matthew Spencer	Chief Executive
Welsh Assembly	Huw Owen	Head of Research and Evaluation Group
West of England Partnership	Tim Lansley	Director

APPENDIX C: Summary of reports covering regional economic and social development aspects of the proposed Severn Barrage

AUTHOR	REPORT	ASPECTS COVERED	SECTION/PAGES
The Severn Tidal Power Group (1986)	Tidal Power from the Severn. Report. Volume I.	Regional Development Employment Environmental and Regional Planning Conclusions	Section 3.6.4 Section 3.6.5 Section 7.2.3; Section 7.3.3
The Severn Tidal Power Group (1986)	Tidal power from the Severn. Engineering and economic studies – Cardiff-Weston scheme, Volume IIA	Regional Development and Land Use Employment	
The Severn Tidal Power Group (1986)	Tidal power from the Severn. Engineering and economic studies – English Stones scheme, Volume IIB	Regional Development and Land Use Employment	Section 7.4 Section 7.5
Department of Energy, Energy Paper 46	Tidal power from the Severn Estuary, Volume I	Impact on man and the environment Recreation and Amenity Aspects with a Barrage Environmental, Social and Industrial Impacts	p. 43 pp. 55 -57 pp.88 – 89
Severn Barrage Committee (undated), Department of Energy	Tidal power from the Severn Estuary, Volume II	Employment Fisheries Tourism	pp 393 – 395 pp 407 – 408 pp 408 - 411
Department of Energy, Central Electricity Generating Board, Severn Tidal Power Group (1989)	The Severn Barrage Project: General Report	Effects on the region: Economic model, Benefit estimation, barrage construction and operation, tourism and recreation, effects on ports and shipping, effects on industrial, commercial and property development, effects on land transport Economic evaluation	Section 3.3 Section 4

AUTHOR	REPORT	ASPECTS COVERED	SECTION/PAGES
Department of Energy/Renewable Energy (1989)	Severn Barrage Project. Detailed Report Volume V. Regional Studies and Legal B	The region The regional economy Ports and shipping Tourism and recreation Economic Development Prospects Regional Development Scenarios Potential Barrage effects Construction and Operation Effects Tourism and Recreation Ports and Shipping Industrial, Commercial and Property Development Road Transport	Chapter 3 Chapter 4 Chapter 5 Chapter 6 Chapter 7 Chapter 8 Chapter 9 Chapter 10 Chapter 11 Chapter 12 Chapter 13
Department of Energy/Renewable Energy (1989)	Severn Barrage Project. Detailed Report Volume V. Regional Studies and Legal B	Road Transport Regional Development Effects Appendix 3 Appendix 10 Appendix 12	Chapter 14 Chapter 15 Severn Barrage region – development options Severn Barrage Regional Benefit Estimation Methodology.
ETSU/Severn Tidal Power Group (1993)	Severn Barrage Project. Additional Regional Studies, 1991 – 1993.	Appendix 3. Transportation of Labour, Assessment of Impacts.	Appendix A3.

AUTHOR	REPORT	ASPECTS COVERED	SECTION/PAGES
ETSU (2002)	The Severn Barrage –	Economic Evaluation	

	Definition Study for a New Appraisal of the Project	Pre construction Programme and Costs Design and Construction Programme Capital Cost Employment during Construction Overview of the Socio – Economic Case for the Barrage Export Opportunties	5.2 5.3 5.4 5.5 5.6 5.7
South West Renewable Energy (2006)	Briefing: The Severn Barrage Proposal	Key issues – environment, cost and financing, impact on energy efficiency and other renewables, history of proposal	