DECC

STRATEGIC ENVIRONMENTAL ASSESSMENT OF PROPOSALS FOR TIDAL POWER DEVELOPMENT IN THE SEVERN ESTUARY

OPTIONS DEFINITION REPORT

Version 3

Volume 1

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LIST OF ABBREVIATIONS

BAP	Biodiversity Action Plan
CFD	Computational Fluid Dynamics
D/S	Downstream
DCF	Discounted Cash Flow
DECC	Department of Energy and Climate Change
GIS	Geographical Information System
GRP	Glass Reinforced Plastic
GW	Gigawatt (one thousand million Watts)
GWh	Gigawatt hours
H & G	Hydraulics and geomorphology
Ha	Hectares
HRA	Habitats Regulations Assessment
IOAR	Interim Options Analysis Report
mAOD	Metres above Ordnance Datum
MHWN	Mean High Water Neap
MHWS	Mean High Water spring
MLWN	Mean Low Water Neap
MLWS	Mean Low Water spring
MOD	Ministry of Defence
MW	Megawatt (one million Watts)
MWh	Megawatt hours
ODR	Options Definitions Report
PRoW	Public Rights of Way
SAC	Special Area of Conservation
SEA	Strategic Environmental Assessment
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
STPG	Severn Tidal Power Group
TW	Terawatt (one million million Watts)
TWh	Terawatt hours
TWh/a	Terawatt hours per annum
U/S	Upstream
Var	Variant

EXECUTIVE SUMMARY

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Objectives and Content

As part of the Government's Feasibility Study into power generation using the Severn Estuary tidal range, five options for tidal power development were confirmed in July 2009 as the short-listed candidates. The candidate schemes have subsequently been studied in greater detail to facilitate a Government decision whether it can support an option or combination of options and, if so, on what terms.

The short list was selected from an initial long-list of ten options which were analysed in the phase 1 Interim Options Analysis Report (IOAR). The selection took account of outputs from other elements of the Feasibility Study (for example work on procurement and financing by PricewaterhouseCoopers and regional economic impacts by DTZ). The short list was subject to phase 1 public consultation between January and April 2009 and the Government published a response in July 2009.

The five short listed options comprise the following three tidal barrages and two tidal lagoons in no particular order of preference:

- Cardiff to Weston Barrage (from Lavernock Point to Brean Down, historically known as the Severn Barrage)
- Shoots Barrage (a smaller barrage located downstream of the Second Severn Crossing)
- Beachley Barrage (the smallest barrage and located upstream of the first Severn Bridge)
- Welsh Grounds Lagoon (a tidal lagoon located on the Welsh Grounds downstream of the Second Severn Crossing on the Welsh shoreline).
- Bridgwater Bay Lagoon (a tidal lagoon located downstream of Weston-super-Mare on the English shoreline).

As part of the Feasibility Study, the shortlisted options are subject to Strategic Environmental Assessment (SEA). The purpose of the Options Definition Report (ODR) is to inform the SEA by defining each scheme to a reasonable conceptual level of detail. The ODR also informs the wider Feasibility Study by providing estimates of the scheme costs, energy yields, construction programmes and energy costs. The ODR conveys the scheme definitions including possible strategic measures to prevent or reduce the adverse effects of the schemes on environmental and regional receptors and the effects that those measures have on scheme cost, energy yield and energy cost.

Preliminary Optimisation and Refinement

The form of the schemes as shortlisted (termed the 'original' schemes) did not necessarily represent the optimal form taking into account cost, energy yield and environmental and regional effects. Therefore, in phase 2, the schemes have been taken through a preliminary optimisation process to enable the SEA to focus on the most appropriate form of each scheme.

Preliminary optimisation is a term used in the SEA for the process whereby the schemes as shortlisted and a number of modifications were tested to evaluate their regional and environmental effects and energy output. Scheme costs and energy cost were also evaluated. 1-D mathematical modelling of the schemes was carried out to determine their effects on estuary water levels and these results informed an evaluation of environmental and regional effects and energy yields.

The optimisation carried out in this study is preliminary because it is only for the purpose of identifying the most appropriate form of scheme for study in the SEA and was not intended to identify the final preferred form of each scheme. Any scheme taken forward beyond the Feasibility Study would require more detailed optimisation to inform the design of the scheme.

The modifications considered in optimisation included, where appropriate, changes in operating mode (single phase ebb generation compared to two phase ebb flood generation), changes in turbine numbers and sizes, changes in sluice capacity, and changes in alignment. The form of each scheme chosen for further study in the SEA was the one which was generally favourable in all or most respects.

For some schemes, it was not possible during optimisation to determine which was the most favourable operating mode particularly in biodiversity terms because different modes were found to have opposing effects on different environmental receptors. For example, the optimisation process concluded that adopting ebb flood generation instead of ebb generation could reduce adverse effects on birds but it was less clear how the different modes would compare in terms of impacts on fish. Where this was the case, the form chosen was the one which was favourable in most respects but tests have also been carried out to determine whether an alternative operating mode would be a viable way of reducing adverse environmental and regional effects.

The forms of the schemes selected after preliminary optimisation have been subject to assessment within each SEA topic. The topic assessments have been informed by 2-D mathematical modelling. 2-D modelling has also provided greater certainty in energy yield estimates.

The optimised schemes have been subject to a refinement process whereby sufficient detail is added to inform the SEA and provide reasonable certainty over scheme costs and energy estimates. A summary of the findings of the assessment of environmental effects within the SEA is reported in the ODR and measures are recommended for inclusion in options to prevent or reduce adverse effects on the environment.

The refinements include the form of construction of lagoon impoundments for which a range of alternatives were identified in the IOAR. A conventional marine earthworks embankment with a crest height and width which would provide access to the powerhouse has been used as the base case for lagoon costs and resource estimates. As an alternative for Bridgwater Bay lagoon, a modular precast concrete pile supported wall may be feasible depending on its cost. For Welsh Grounds lagoon, work has been carried out by Fleming Energy on the application of a tied or braced precast wall panel system. The wall system is an innovative concept which if further developed with the benefit of ground investigation could be applied to the lagoon. The lagoon options definition does not adopt the wall system because until the concept is further developed it does not provide the level of certainty in cost estimates that is required for Feasibility Study. Sand filled geo-container construction has also been considered but there is no evidence that it can be relied upon to reduce the cost or construction time for a lagoon. The refined scheme definitions are presented in the ODR.

A study has been conducted for DECC by National Grid into the implications of connecting schemes to the grid. The options definition includes the local works to connect the generator terminals to the grid and, based on the findings of the grid study, includes outline requirements for new or modified sub-stations. For Cardiff to Weston barrage, consideration is also given to a new National Grid network connection across the Severn Estuary through the barrage which may be needed as part of a solution to resolve the effects of the barrage on grid stability.

Table ES1 shows the scheme configurations following the optimisation and refinement process.

Scheme	Operating Mode	Number of Turbines	Turbine Rated Output (MW)	Installed Capacity (MW)	Number of Sluices
B3 Brean Down to Lavernock Point Barrage	Ebb	216	40	8,640	166
B4 Shoots Barrage	Ebb	30	35	1,050	42
B5 Beachley Barrage	Ebb	50	12.5	625	26
L2 Welsh Grounds Lagoon	Ebb	40	25	1,000	41
L3d Bridgwater Bay Lagoon	Ebb Flood	144	25	3,600	0

Table ES1 Scheme Configurations following Optimisation and Refinement

Cost, Programme and Energy Yield

Reasonably detailed cost estimates have been prepared for each scheme allowing for all principal quantities. They include allowances for ancillary works (required to maintain functionality of existing infrastructure such as drainage outfalls, navigation channels, port accesses and flood defences) and for the potential cost of compensatory habitat required under the Habitats Directive because of the effect the schemes have on designated inter-tidal habitats. The cost of compensatory habitat has been assessed using different ratios of compensation to habitat lost (3:1, 2:1 and 1:1) to reflect current uncertainty in the amount and ratios that may be required. Cost estimates also include measures to reduce or prevent adverse effects on environmental and regional receptors.

Construction programmes have been estimated based on a study into construction sequences. The programmes assess the time period to first energy generation (governed either by the time period to achieve closure of the barrage or lagoon or the likely time that a connection will be available after works have been carried to reinforce the National Grid) and the time to full energy generation.

Costs and construction programmes take account of findings of DECC's supply chain survey, in particular, availability of caisson fabrication yards locally and further afield, and turbine availability. The programmes for Cardiff to Weston barrage and Bridgwater Bay lagoon require turbines to be installed at a rate which is likely to require the construction of new manufacturing facilities to address current supply chain constraints.

Levelised energy cost is the cost of generating energy over the life of the scheme allowing for the initial capital costs and whole life operating and maintenance costs. Levelised energy costs have been derived by calculating the sum of discounted construction costs over the construction programme and operation and maintenance costs during the scheme's operational period, and dividing these by discounted energy output, over the 120 year design life of each scheme. They include contingency but not optimism bias. Levelised costs can vary significantly depending on the discount rate. Levelised costs have been calculated with a range of discount rates, ranging from those reflecting commercial costs of capital to the social rates in HM Treasury Green Book guidance.

The results of these analyses are shown in Tables ES2 and ES3.

Scheme	Operating Mode	Construction Cost (£bn)	Period to Full Generation (years)	Energy Yield (TWh/yr)	Earliest Date of First Operation
B3 Brean Down to Lavernock Point Barrage	Ebb	23.2	8.5	14.4 – 16.7	2021 to 2023
B4 Shoots Barrage	Ebb	4.7	5	2.6 – 2.8	2019 to 2021
B5 Beachley Barrage	Ebb	3.5	4	1.3 – 1.6	2019 to 2021
L2 Welsh Grounds Lagoon	Ebb	6.8	6	2.5 – 2.7	2019 to 2021
L3d Bridgwater Bay Lagoon	Ebb Flood	12.0	6	5.6 – 6.9	2023 to 2025

Notes:

1. Construction costs include measures to prevent and reduce adverse effects and compensatory habitat required under the Habitats Directive at a 2:1 ratio of compensation to habitat lost.
2. Construction costs and programmes exclude optimism bias.
3. Construction costs exclude the cost of reinforcement of the National Grid as that cost is borne by National Grid and recovered from the operator by applying tariffs. The application of tariffs has been included in operating costs.
4. Energy yield is the mean estimate allowing for effect of measures to prevent and reduce adverse effects.
5. Construction costs include contingency.

Table ES2 Scheme Costs, Programmes and Energy Yields

Discount Rate	10% Over Whole Life	8% Over Whole Life	8% Over 35 Year Finance Period; HM Treasury Green Book Long Term Discount Rates Thereafter	HM Treasury Green Book long Term Discount Rates
Scheme	Levelised Energy Cost (£/MWh)			
B3 Brean Down to Lavernock Point Barrage	211	165	153	73
B4 Shoots Barrage	228	181	169	83
B5 Beachley Barrage	293	233	217	105
L2 Welsh Grounds Lagoon	348	272	253	116
L3d Bridgwater Bay Lagoon	248	196	183	88

Notes:

1. Levelised energy costs include measures to prevent and reduce adverse effects and compensatory habitat required under the Habitats Directive at a 2:1 ratio of compensation to habitat lost.
2. Levelised energy costs exclude optimism bias.
3. Levelised costs exclude the cost of reinforcement of the National Grid as that cost is borne by National Grid and recovered from the operator by applying tariffs. The application of tariffs has been included in operating costs.
4. Levelised costs are based on the mean energy yield estimate allowing for effect of measures to prevent and reduce adverse effects.
5. Levelised costs include contingency

Table ES3 Levelised Energy Costs

Assessment of Significant Effects on the Environment and Measures to Prevent or Reduce Adverse Effects

In the analysis of the long list, the scoping of the SEA and the optimisation of the shortlisted schemes, potential adverse effects on environmental and regional receptors were identified. The SEA topic studies, which have included a series of technical workshops with knowledgeable external parties, have assessed the effects in more detail and have identified measures which could reduce or prevent adverse effects.

The ODR provides a summary of the significant effects on environmental and regional receptors. The ODR should therefore be read in conjunction with the Environmental Report (ref xv) and Report to Inform a Stage 2 Habitats Regulations Assessment which provide a more complete assessment of significant effects and requirements for compensation.

Where possible, the ODR makes recommendations for measures to be included in options to prevent or reduce adverse effects on the environment. Some of these measures are unprecedented either because they are not established practice or are unprecedented in scale and therefore have significant uncertainty over their effectiveness, their indirect effects and their effect on scheme costs and energy yield. In some cases, recommendations on the scope and nature of measures are made in the absence of complete information.

The ODR also identifies offsetting measures and compensation that might be required under the Habitats Regulations. For those features where there is sufficient evidence and it is possible to ‘unitise’ cost, estimates of the cost of compensation using a unit rate are provided. This has been possible for inter-tidal habitat based on case studies undertaken by DECC on managed realignment projects.

All options cause changes to the tidal range in the Estuary with the most significant changes upstream of barrages and within lagoons. Changes to the tidal range reduce the extent of inter-tidal habitat resulting in the loss of designated habitats and reduced inter-tidal exposure times. Changes in the tidal regime would potentially cause adverse effects on birds. Opportunities have been identified to modify the existing topography to create new inter-tidal areas and reduce the loss of habitats and effects on birds. Inter-tidal losses resulting after topographic modification would require the provision of compensatory habitat under the Habitats Directive.

Changes to the tidal range also cause a change in the sedimentation regime. There is the potential for significant short term deposition of sediment which could cause adverse effects on marine ecology. This is estimated at some 8.2 Mt for the Cardiff to Weston Barrage and ranges between 0.9 to 2.1 Mt for the other schemes. All schemes would also potentially adversely affect fish, to the point of local extinction in some cases, due to the risk of injury or mortality when passing through turbines and potential increase in predation. Measures have been identified which could reduce adverse effects on fish, such as the operation of sluices during generation to increase the permeability of the schemes. Measures to compensate for effects on fish under the Habitats Directive have been considered but are limited and uncertain. Terrestrial and freshwater ecology (i.e. ecology present in areas above the inter-tidal range) would also be affected and measures such as seawater level management by pumping have been identified to reduce those effects.

Reductions in high water levels together with sediment deposition would reduce the depth of water available for navigation with adverse effects likely on navigation to the ports. Upstream barrages are particularly susceptible to the long term accumulation of sediment deposition with potential effects on energy yield, the fluvial capacity of the river channel and navigation. Dredging of navigation channels in the construction stage, together with modifications to sill levels at existing locks, followed by maintenance dredging during the life of the schemes, would avoid these adverse effects on navigation. Maintenance dredging may also be required within the basins of the upstream barrages to preserve energy yield and fluvial capacity whilst maintenance dredging may be required in the long term to preserve the energy yield of the lagoons. Deposition of sediment may affect the extraction of marine aggregates and require changes to the extraction processes.

For all alternative options, changes to peak tide and wave action will influence the level of flood risk. There will be lengths of flood defence that benefit from lower water levels and protection afforded by schemes against surge tides. The Cardiff to Weston Barrage and Bridgwater Bay Lagoon schemes have an economic benefit in deferring the improvement to flood defences which will be required to deal with the consequences of climate change. For example, the reduction in water levels upstream of Cardiff to Weston Barrage would negate the majority of the effects of sea level rise by up to 100 years with a present value benefit of up to £207m (deferring the investment for some 202km of flood defence within the impoundment). However, upstream flood defences will be exposed to an increase in erosion risk due to an increase in the time that water stands at high water level which will bring forward the time when maintenance to flood defences is required. For Cardiff to Weston barrage, the present value cost of bringing maintenance works forward is estimated at between £37m and £234m.

There will also be some lengths of flood defences outside the impoundments that will experience higher water levels than previously and will need to be raised as a result (primarily for Cardiff Weston Barrage (estimated at between 44 and 87km of defences as a result of the predicted far-field effects), but also up to 95km in the inner estuary (Beachley Barrage) and 25km in the outer estuary (Welsh Grounds Lagoon) for the other alternative options, with the exception of Bridgwater Bay Lagoon). Increases in flood risk resulting from erosion of flood defences were also identified; these would require provision of erosion protection for some 134km (+/- 50%) for the Cardiff to Weston Barrage scheme and between 6km (Beachley Barrage) and 70km (Shoots Barrage) (+/- 50%) for the other four schemes.

Without mitigation, restrictions to the normal operation of drains and outfalls, owing to the changed tidal regime (tide-locking), would increase flood risk. A variety of measures are available to ensure that none of the schemes causes an increase in flood risk and the cost of those measures have been included in the evaluation of scheme costs and levelised energy costs.

All schemes will require significant material and waste resources for construction and decommissioning. However, the carbon payback period for all schemes is relatively short (generally between 3 and 6 years) and with a life likely to be over 120 years, all alternative options demonstrate a significant positive effect on global and UK greenhouse gas emissions.

Beneficial society and economy effects would potentially arise from employment required during construction, operation and decommissioning but adverse effects on navigation to ports could potentially adversely affect port businesses with a reduction in employment generated by the port trade. Construction employment predictions are summarised below.

	B3 Brean Down to Lavernock Point Barrage	B4 Shoots Barrage	B5 Beachley Barrage	L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
Construction Employment	7,500 – 8,500 FTE/year during 4 peak years of construction	2,000 – 3,000 FTE/year during 3 peak years of construction	1,500 – 3,000 FTE/year during 3 peak years of construction	3,000 – 4,000 FTE/year during 4 peak years of construction	4,000 – 6,000 FTE/year during 5 peak years of construction

Table ES4: Summary of Peak Construction Employment Estimates (Source: Communities Topic Paper, 2010)

Historic environment, landscape and seascape are likely to be affected by the scheme footprints, landfall points and changes to the tidal range and sediment regime.

Development of Schemes in Combination

Some schemes can be developed in combination, with the potential advantage of providing less intermittent power output. All potential combinations have been considered in energy and cost terms with a high level evaluation of environmental and regional effects. Only the Cardiff Weston Barrage, followed some time in the future by Bridgwater Bay lagoon, could provide a levelised energy cost below £170 per MWh, a threshold level set by DECC to indicate the more promising options based on the costs of the draft Renewable Energy Strategy costs at an 8% discount rate (as set out in the response to consultation, the final RES reduced this threshold). Taking into account the effects that the individual schemes would have on tidal range, the combined energy yield would be 17 to 20 TWh/yr, around 15% lower than their aggregate energy yields.

The combination would have the advantage of providing less intermittent energy if Bridgwater Bay lagoon is operated as an ebb flood scheme and the barrage operated as an ebb scheme. Optimisation, together with mathematical modelling, will be required as part of a further combinations study if the Feasibility Study determines that the individual schemes are considered to be potentially viable.

All other combinations have lower bound levelised energy costs above £170 per MWh and are not considered worthy of further consideration at this stage.

Multiple Basin Alternatives

Multiple basin alternatives, whereby the area impounded by the barrage or lagoon is split into two or three basins, offer the opportunity of continuous power. All options could in theory be configured as multiple basin options but they generally only offer benefit over single basin alternatives if the length of the impoundment required to form the additional basins can be short enough not to prejudice the cost of the energy produced. Our assessment has concluded that multiple basin configurations of the upstream barrages and the Welsh Grounds lagoon would not be feasible in cost terms.

Bridgwater Bay lagoon and Cardiff to Weston barrage could be linked to provide more continuous energy than if constructed as a combination without a link. The Bridgwater Bay lagoon alignment would need to be modified to provide a powerhouse between the two basins. If the lagoon is taken further beyond the Feasibility Study, with the potential for it to be constructed in combination with the Cardiff to Weston barrage, such a modification would be worthy of further consideration, as the larger impounded area might also be beneficial in increasing output before the barrage construction.

Alternatively, Bridgwater Bay lagoon could be divided internally and operated as a double basin scheme on its own. Water levels in one basin would be higher than the other basin. The high basin would be filled by the sea on the flood tide and there would be a continuous flow of energy through turbines between the high basin and the low basin. The low basin would discharge to the sea via turbines on the ebb tide. However, the total output from the lagoon would be significantly less than the output from a single basin scheme due to a combination of smaller flow rates and lower heads. A double basin scheme would use pumping to raise the high basin levels and lower the low basin levels to increase the flow through the lagoon and increase operating heads but it is unlikely that pumping would mitigate for the lower heads and smaller flows compared to the single basin option.

An advantage of the double basin scheme is that the lower output would reduce the effects on the National Grid, therefore requiring less costly reinforcement works. However, it is concluded that the cost of energy from the double basin scheme would be significantly more expensive than the single basin option and is not worthy of further consideration a this stage.

During construction and decommissioning, a double basin Bridgwater Bay Lagoon is likely to largely have the same significant environmental effects as a single basin version. During operation, there are likely to be differences in the effects on the hydraulics and geomorphology of the Estuary, most notably, a greater loss in intertidal area which will have further effects on waterbirds and marine ecology.

NON TECHNICAL SUMMARY

NON-TECHNICAL SUMMARY

Background

In January 2008, the Government launched a Feasibility Study to consider whether it could support a project which exploits the major energy generation potential of the tidal range of the Severn Estuary, and if so, on what terms.

In recognition of the importance of the natural environment of the Severn Estuary, the Feasibility Study has commissioned a Strategic Environmental Assessment (SEA) which will assess a plan whose purpose is:

- to generate electricity from the renewable tidal range resource of the Severn Estuary in ways that will have an acceptable overall impact on the environment and economy both locally and nationally, will meet our statutory obligations and provide benefit to the UK.
- to deliver a strategically significant supply of renewable electricity, which is reasonably affordable compared to other sources of supply and represents value for money in the context of the UK's commitments under the forthcoming EU Renewable Energy Directive and Climate Change Act and our goal to deliver a secure supply of low-carbon electricity.

Parsons Brinckerhoff Ltd, in association with Black & Veatch Ltd, was engaged by the Department of Energy and Climate Change (DECC) to assess the options for development of power from the Severn Estuary’s tidal range, one of the highest in the World. The assessment of development options is a key part of the Feasibility Study.

Assessment of the options has been a two stage process. Phase 1, which was completed in April 2009 following public consultation, studied a broad range of options to inform government’s selection of a shortlist which has been studied in greater detail in Phase 2. Phase 2 includes the preparation of a Strategic Environmental Assessment (SEA). The scope of the SEA was determined and consulted on in Phase 1.

Phase 1 - Overview

Phase 1 identified and analysed a long-list of options for the development of tidal range power in the Severn Estuary. That work is described in the Interim Options Analysis Report (IOAR) published as part of the Phase 1 Public Consultation in January 2009. This covered the analysis of projects previously studied and summarised in the Sustainable Development Commission’s Report “Turning the Tide” (published in October 2007) and new projects, the majority of which had been submitted to the Government’s Feasibility Study through a Call for Proposals in June 2008. The Government’s Severn Tidal Power Unit (STPU) undertook an assessment of the long-list of options using the IOAR and outputs from other elements of the Feasibility Study (for example work on procurement and financing by PricewaterhouseCoopers and regional economic impacts by DTZ) and proposed a short-list of five options in January 2009. Following public consultation, the Government confirmed the list of five options in July 2009.

The five options comprise the following three tidal barrages and two tidal lagoons:

- Cardiff to Weston Barrage (from Lavernock Point to Brean Down, historically known as the Severn Barrage).
- Shoots Barrage (a smaller barrage located downstream of the Second Severn Crossing).
- Beachley Barrage (the smallest barrage and located upstream of the first Severn Bridge).
- Welsh Grounds Lagoon (a tidal lagoon located on the Welsh Grounds downstream of the Second Severn Crossing on the Welsh shoreline based on proposals submitted by Fleming Energy).
- Bridgwater Bay Lagoon (a tidal lagoon located downstream of Weston-super-Mare on the English shoreline).

There are a wide range of potential lagoon configurations. The two lagoon options represent the best candidates drawn from a number of different lagoon options studied. These included sites studied previously and a number of sites and alternative forms of construction proposed by organisations submitted under the Call for Evidence between May and July 2008.

Phase 2 – Options Definition Report

In phase 2, the shortlisted options were studied in more detail to provide the Feasibility Study with an up to date definition of options based on a comparable level of detail.

The purpose of the Option Definitions Report (ODR) is to present the short listed options, the definition of each option covers:

- The configuration in terms of:
  - The number, type and size of turbines and sluice gates;
  - The optimal mode of operation;
- Development of outline engineering designs to reflect the configuration, mitigation and refinement measures, and determination of other design requirements including structural form (with additional data and interpretation on ground conditions), levels of service (e.g. crest levels, asset life, maintenance requirements) and other infrastructure requirements (e.g. cabling, powerhouse, access etc).
- Assessment of capital and operating costs
- Assessment of construction sequences and programmes
- Assessment of energy yield, and energy cost.

Assessment of the effects of the schemes on environmental and regional receptors is reported in SEA topic and theme reports and in the Environmental Report. The significant effects of the options on the environment are summarised in this report together with recommended measures for inclusion to prevent or reduce adverse environmental effects.

This version 3 of the Options Definition Report contains the finalised options definition for the Feasibility Study following the outcome of the SEA. Version 3 supersedes earlier versions. Version 1 was a working document which dealt specifically with the preliminary optimisation process described below. Version 2 was a working document which provided the refined options definitions which were subject to SEA. Version 3 supersedes those earlier versions but contains all the relevant content which was contained within them.

Preliminary Optimisation and Refinement

The form of the schemes as shortlisted did not necessarily represent the optimal form taking into account cost, energy yield and environmental and regional effects. Therefore, in phase 2, the schemes have been taken through a preliminary optimisation process to enable the SEA to focus on the most appropriate form of each scheme if developed as an individual single basin scheme. The optimisation carried out for the Feasibility Study is only preliminary because any scheme taken forward beyond the Feasibility Study would require much more detailed optimisation to inform a final design. This would be informed by greater knowledge of the potential benefits of some measures such as fish mitigation which might change some aspects of scheme definition.

Preliminary optimisation involved a study into whether modifying a scheme's configuration (such as changing turbine numbers, sluice numbers and operating mode) would make it more favourable in terms of its regional and environmental effects, construction costs, energy output and energy cost.

Table NTS1 summarises the modifications tested during optimisation.

There are a number of other modifications which can be made to each scheme, such as changes in turbine size, turbine speed, turbine type, use of flood pumping, and changes in lock positions, but these were not considered to be fundamental to the optimisation work. Nevertheless, these modifications have been considered during the SEA to identify whether they would be appropriate as measures to prevent or reduce adverse effects.

Preliminary Optimisation – Barrage Options

For all barrages, the modifications which have a fundamental bearing on their feasibility are the operating mode, and turbine capacity. Some modifications to the alignment of Shoots and Beachley Barrages were also considered. Ebb and ebb flood modes have been evaluated for a range of different turbine and sluice capacities.

The preliminary optimisation found that the barrage schemes configurations as shortlisted were preferable in most but not all respects. For the Shoots Barrage, the alignment was modified to avoid constraints associated with a defence practice area. The preliminary optimisation also identified that there may be advantages in terms of energy, energy cost and environmental effects of adopting bulb turbine technology in the upstream barrages, which are more likely to be feasible in the Shoots than the Beachley Barrage.

Therefore, the outcome of the preliminary optimisation was that the Cardiff to Weston Barrage and Beachley Barrage remained as shortlisted but Shoots Barrage was taken forward with bulb turbine technology on a modified alignment.

Modifications Tested During Preliminary Optimisation	Example Effects on Scheme
Alternative scheme alignment	Change in energy yield Change in capital cost and/or levelised energy cost Possible reduction in energy cost For Shoots Barrage, to avoid defence constraints For lagoons, change in footprint on designated habitats and habitat features, and change in impact on historic environment, land and seascape, and local population
Alternative operating mode (ebb and flood operation). Note that flood only operation is not considered as it offers no benefit in energy, environmental and regional terms because the available head would be lower and it would cause a more significant reduction in high water levels upstream of the scheme than ebb or ebb flood generation.	Provide two periods of energy output per tidal cycle (typically four periods per day) and reduce peak output with benefits for grid compatibility Change in tidal range impact and change in effects on habitats and habitat features, water quality, port access and flood risk Change in energy value Change in risk to fish of blade strike injury due to change in proportion of flow through turbines on ebb and flood
Variation in turbine numbers	Change in flow through power plant to change impact on tidal range, change impact on inter-tidal habitats and change impact on water quality, port access and flood risk Change in energy yield and energy cost Change in risk to fish of blade strike injury due to change in proportion of flow through turbines and change in permeability for fish passage
Variation in sluice numbers	Change in flow through power plant with change in impact on tidal range, inter-tidal habitats, water quality, port access and flood risk Change in permeability for fish passage Increase flexibility of operation Change in energy yield and energy cost

Table NTS1 Modifications reviewed during optimisation

For Cardiff to Weston Barrage, the preliminary optimisation process concluded that adopting ebb flood generation instead of ebb generation might reduce adverse effects on birds by potentially causing less adverse effects on the inter-tidal area but it was less clear how the different modes would compare in terms of impacts on fish. Therefore, the Barrage was taken forward as an ebb generation scheme but ebb flood operation has been considered, alongside other measures, as a means of reducing the adverse effects of ebb generation in the SEA.

Preliminary Optimisation – Lagoon Options

For lagoons, the modifications which have a fundamental bearing on their feasibility are their operating mode, size, alignment, and turbine capacity. Ebb and ebb flood modes were evaluated for the alignments as shortlisted by varying the installed capacity to determine the preferable capacity for each mode. Alternative smaller lagoon sizes have been evaluated to assess whether a smaller lagoon may be preferable over a larger lagoon in any respects.

For the Bridgwater Bay Lagoon, the preliminary optimisation found that operating in ebb flood mode with turbine capacity increased to maximise the energy extracted from the lagoon was preferable in terms of energy yield and energy cost and preferable, or equally so compared to other configurations tested, in all environmental and regional respects except for port access within the lagoon and possibly impact on fish. However, increasing turbine capacity was found to significantly increase capital cost which may impact on the private sector role in ownership and financing.

For Welsh Grounds Lagoon, the preliminary optimisation work indicated that ebb only generation might be preferable in terms of its impact on fish, subject to further study, particularly because of the proximity of the turbines to the mouth of the Usk. In terms of other biodiversity effects, water quality and flood risk, it was not clear from the preliminary optimisation whether ebb or ebb flood generation would be preferable. However, ebb flood mode with turbine capacity selected to maximise energy yield was found to be preferable in terms of energy yield and energy cost.

As it was not conclusive whether the operating mode for Welsh Grounds should be changed to ebb flood mode, it was taken forward as an ebb only scheme. Bridgwater Bay Lagoon was taken forward as an ebb flood scheme with an increased turbine capacity. Studying the two lagoons with different operating modes provided the opportunity in the SEA to study whether one or other operating mode could be an appropriate measure to prevent or reduce the adverse environmental or regional effects of a lagoon.

Tests were carried out to determine the effects of increasing the turbine capacity of the Welsh Grounds Lagoon. Tests on ebb flood generation with 2100MW capacity identified that the high rate of discharge through the turbines caused a backwater effect believed to be due to hydraulic constraints within the Newport Deep channel. This effect resulted in significant energy losses indicating that increasing generating capacity would reduce the generating efficiency of the lagoon. Increasing the rated output of the Welsh Grounds turbines to 50MW, as originally proposed by Fleming Energy, was also studied but issues relating to turbine submergence depth and high flow speeds were identified. As a result of these tests, the Welsh Grounds Lagoon was taken forward as an ebb generation scheme with 25MW turbines and a total installed capacity of 1,000MW.

Selected Barrage and Lagoon Options

Table NTS2 summarises the form of the schemes taken forward in the study following the preliminary optimisation work and Table NTS3 summarises the factors considered in their selection.

Scheme	Operating Mode	Number of Turbines	Turbine Rated Output (MW)	Installed Capacity (MW)	Number of Sluices
B3 Cardiff to Weston Barrage	Ebb Only	216	40	8,640	166
B4 Shoots Barrage	Ebb Only	30	35	1,050	42
B5 Beachley Barrage	Ebb Only	50	12.5	625	26
L2 Welsh Grounds Lagoon	Ebb Only	40	25	1,000	41
L3d Bridgwater Bay Lagoon	Ebb Flood	144	25	3,600	0

Table NTS2 Summary of Scheme Forms Taken Forward Following Preliminary Optimisation

Table NTS3 Summary of Key Considerations in Selection of Each Scheme Form Following Preliminary Optimisation

Scheme	Key Considerations in Selection		
	Energy and Cost	Environmental	Regional
B3 Brean Down to Lavernock Point Barrage	Modifying installed capacity and operating mode was found to increase energy cost.	Operating the barrage in ebb flood mode, or in ebb only mode with a higher installed capacity, were found to reduce impacts on the inter-tidal area, saltmarsh and water quality but with a possible increased risk to fish.	All modifications had potential negative impacts on port access. Varying the barrage capacity in ebb only mode made little difference to effects on port access whilst ebb flood mode was found to be more adverse in terms of port access due to larger reductions in high water levels. Ebb and ebb flood generation

Table NTS3 Summary of Key Considerations in Selection of Each Scheme Form Following Preliminary Optimisation			
Scheme	Key Considerations in Selection		
	Energy and Cost	Environmental	Regional
			were both found to reduce upstream flood risk by lowering high water levels.
B4 Shoots Barrage	Modifying installed capacity and operating mode was found to increase energy cost.	Modifying the installed capacity in ebb only mode was found to have little benefit in terms of environmental effects. Ebb flood generation was found to have a possible small advantage in impact on changes in extent of inter-tidal area within the spring tidal range and water quality but was not thought preferable due to issues with risk to fish and reductions on exposure time of inter-tidal area.	All modifications had potential negative impacts on port access at Sharpness. Modifying the installed capacity in ebb only mode was found to make little difference to port access. Ebb flood generation was found to be less preferable due to larger reductions in high water levels compared to ebb generation. Ebb and ebb flood generation were both found to reduce upstream flood risk by lowering high water levels.
B5 Beachley Barrage	Modifying installed capacity and operating mode was found to increase energy cost.	Modifying the installed capacity in ebb only mode was thought to have little benefit in terms of the environmental criteria. Ebb flood generation	All modifications had potential negative impacts on port access at Sharpness. Modifying the installed capacity in ebb only mode was found to

Table NTS3 Summary of Key Considerations in Selection of Each Scheme Form Following Preliminary Optimisation

Scheme	Key Considerations in Selection		
	Energy and Cost	Environmental	Regional
		could have less negative impact on water quality but preliminary optimisation work indicated that ebb flood generation might increase the risk of injury to fish.	make little difference to port access. Ebb flood generation was found to be less preferable due to larger reductions in high water levels compared to ebb generation. Ebb and ebb flood generation were both found to reduce upstream flood risk by lowering high water levels.
L2 Welsh Grounds Lagoon	Adopting ebb flood mode with an installed capacity that maximised energy yield was found to provide the lowest energy cost and highest energy yield.	Adopting ebb only mode was thought to be preferable in terms of impacts on fish due to proximity of turbines to the mouth of the River Usk. Ebb flood mode was preferable in terms of impact on inter-tidal within spring tidal range and risk to saltmarsh.	Port access outside the lagoon was not found to be an influencing factor in selection of the lagoon form. All variants have positive indicators of effect on flood risk inside the lagoon. Ebb and ebb flood generation were both found to reduce upstream flood risk by lowering high water levels.
L3d Bridgwater Bay Lagoon	Adopting ebb flood mode with an installed capacity that maximised energy yield was found to provide the lowest energy cost and highest energy yield.	Adopting ebb flood mode with an installed capacity that maximised energy yield was found to be preferable in terms of changes in extent of inter-tidal area within spring tidal range, bird feeding times and risk to saltmarsh but ebb	Port access outside the lagoon was not found to be an influencing factor in selection of the lagoon form. All variants have positive indicators of effect on flood risk inside the lagoon. Ebb and ebb flood generation were both found to reduce

Table NTS3 Summary of Key Considerations in Selection of Each Scheme Form Following Preliminary Optimisation			
Scheme	Key Considerations in Selection		
	Energy and Cost	Environmental	Regional
		generation configurations were thought likely to be preferable in terms of risk of injury to fish. Smaller enclosure alternatives were found preferable in terms of impact on SAC features and habitat areas at risk.	upstream flood risk by lowering high water levels. Test results indicated potential increases in surge tide level outside the lagoon.

Impoundment Construction

Lagoon schemes have not benefited from the same amount of design development as some barrage schemes and some of the forms of construction put forward by lagoon proposers for lagoon impoundment construction were novel. The phase 1 analysis of the lagoons was based on certain assumptions on their form subject to further study in phase 2. The Welsh Grounds Lagoon was based on precast concrete tied wall proposals submitted by Fleming Energy. For Bridgwater Bay Lagoon, in phase 1 consideration was given to the construction of the impoundment using geo-containers, originally proposed for an offshore lagoon configuration.

Other forms of impoundment construction considered in phase 1 were:

- Precast wall solutions submitted by Fleming Energy for L2 Welsh Grounds Lagoon;
- An embryonic technology comprising glass fibre reinforced box structures and recycled rubber coated bead hoops sourced from disused tyres submitted by Rubicon Marine;
- A modular pile supported reinforced concrete wall system submitted by Halcyon and considered for Bridgwater Bay;
- A conventional rock fill embankment.

Selection of an appropriate form of impoundment construction for strategic level study is important in providing a reliable estimate of scheme cost, construction period and requirements for material resources. Therefore, in phase 2, the impoundment construction alternatives have been studied further to determine the form, or forms, of the lagoon which provide reasonable certainty of their technical feasibility taking into account the available information on the site conditions.
Impoundment design parameters have been determined and applied to all alternatives.

- The enclosure construction should achieve a minimum 120 year design life as standard without major reconstruction within that life. This is consistent with the minimum design life which would be expected from the main powerhouse caisson structures.
- The enclosure needs to be sufficiently robust to withstand storm waves in combination with high water levels and needs to be reasonably, but not necessarily completely, impermeable.
- A minimum crest width is required so that the impoundment serves an access function. There are two levels of access; access to power-houses, sluices and locks required under the majority of conditions, and access to the impoundment structures and transmission cables for which some restrictions may be acceptable.

Minimum crest heights have been set for the two levels of access to provide access during wave heights of one year probability for access to powerhouses, sluices and locks and two months for access to impoundment structures and transmission cables. In more extreme conditions, the embankment crests would be overtopped but access would be strictly controlled at such times.

Fleming Wall Proposals

The Fleming Energy proposals adopt a 13m wide structural wall comprising parallel precast concrete wall panels braced together with precast concrete frames and infilled with dredged material. Raking anchors are proposed to provide adequate lateral stability. The wall system is an innovative concept which if further developed with the benefit of ground investigation could be applied to the lagoon. The lagoon options definition does not adopt the wall system because until the concept is further developed it does not provide the level of certainty in cost estimates that is required for Feasibility Study.

Embankments Constructed of Geo-Containers

This concept has been reviewed and refined in consultation with suppliers of geo-containers and contractors experienced in their construction. The study has found that geo-container construction could save a small proportion of rock material compared to conventional rockfill construction but is unlikely to provide any time or cost savings and is a higher risk solution compared to conventional rockfill construction. Geo-containers may be more suited to the shallower Welsh Grounds lagoon than Bridgwater Bay Lagoon.

Halcyon Pile Supported Wall Panels

The Halcyon solution is an innovative modular solution to the construction of the lagoon enclosure. It was developed originally for Halcyon's tidal wing proposal, a large lagoon enclosure proposed off the North Somerset coast between Hinkley and Minehead. The proposal is intended to provide a rapid method of construction using a line of precast concrete mini caissons installed between precast concrete pile supported columns. Some details need further study but in general terms it is concluded that the modular wall system and construction methodology is likely to be a technically viable solution.

Rubicon Technology

The Rubicon Marine submission proposes a structural solution to the construction of lagoons which comprises box structures fabricated using a composite of glass fibre panelling reinforced with a mesh constructed of recycled rubber coated bead hoops sourced from disused tyres. This is an embryonic technology which would need to be subject to further research and development, including prototyping within a marine environment, prior to application in tidal energy context. No substantive evidence is yet available on this embryonic technology to support estimated costs or to inform further study into its application to lagoon construction.

Rockfill Embankments

Design data and embankment stability analyses for rockfill embankments available from earlier Severn tidal power studies indicate that a rockfill embankment provides a reasonable base case for the study of a lagoon enclosure construction. It has been adopted as the base case form of lagoon impoundment and barrage embankment construction for the purposes of estimating cost and resource quantities. It is considered to be the lowest risk impoundment option.

Definition of Options

Following the preliminary optimisation process and review of impoundment construction alternatives all options have been defined to a common level of detail to inform measurement of principal quantities for estimating costs and resource requirements. The ODR defines the options in terms of:

- Optimised scheme layouts and configurations
- Geological conditions and caisson foundation requirements
- Turbine generator types and sizes
- Turbine caisson designs for ebb and ebb flood generation
- Lock designs
- Lock and sluice gate requirements
- Temporary dredging for caisson towing
- Temporary and permanent dredging for shipping channels
- Embankment construction
- Export cables between the generator terminals and sub-stations for grid connection
- Onshore temporary and permanent infrastructure requirements, including improvements to access routes

Planning and Procurement

The time required for planning and procurement is likely to be determined by the EIA requirements (although the SEA outputs will play a helpful role in scoping and planning the required EIA work) and / or the Habitats Directive requirements for compensatory measures. It is proposed that, allowing for public consultations during the planning process, and the majority of studies being undertaken in parallel where possible, a period of at least 4 years would be reasonable to receive planning consent for all schemes except B3 Cardiff to Weston which will more likely require at least 5 years.

Construction

A construction sequence has been developed for each scheme drawing based largely on the construction sequence developed by STPG for the Cardiff to Weston Barrage. All construction sequences are based on the following general approach:

- Onshore Facilities: Onshore construction facilities at the landfall points, access road improvements and off site facilities would all be completed as early as possible.

- Navigation: Ship locks need to be completed as early as possible, so that ships can be routed through the locks before construction commences in or near the existing shipping channel.

- Caisson Construction and Installation: Installation of precast concrete caisson structures, which house the turbines and sluice gates, is typically critical to the overall construction period. Dredging for caisson installation would start as soon possible followed by installation of the caissons themselves. Water passages in turbine and sluice caissons would be opened up as soon as possible after placing each caisson, in order to keep the structure as permeable as possible.

- Build out from shore early: Embankments would be built out early to avoid creating strong currents adjacent to shore which could mobilise sediments near to the shore.

- Mechanical and Electrical Installation: Turbines and generators will be transported to the site as complete units on a barge and lifted in by heavy lift crane.

- Grid Reinforcement: During construction of the tidal power schemes, works will also be required by National Grid to provide additional capacity within the grid so that a connection is available when the barrage or lagoon is ready to generate power. In some cases, the work to the National Grid will take longer than the construction of the tidal power scheme itself.

The overall construction periods and the earliest likely windows for connection to the National Grid are shown in Table NTS4. The window for connection of Cardiff to Weston Barrage assumes that a grid connection would be provided across the barrage to avoid the possible need for a new overhead line from the Severn Estuary down towards Southampton and significant reconductoring works to reinforce the grid. The later window for connection of Bridgwater Bay lagoon assumes that those works to the grid would also be required. The other options require less significant works to the grid.

Cardiff to Weston Barrage and Bridgwater Bay Lagoon would require faster rates of turbine supply and installation than other schemes. Study into supply chain capacity as part of the Feasibility Study has identified that new manufacturing facilities would be required for these schemes to supplement the existing supply chain.

Scheme	Pre-Construction Period (yrs)	Construction Period to First Generation	Construction Period to Full Generation	Year of First Generation (if Connection Available)	Year of Full Generation (if Connection Available)	Likely Grid Connection Window	Likely Year of Opening
B3 Cardiff to Weston Barrage	5	6	8.5	2021	2023	2021 to 2023	2021 to 2023
B4 Shoots Barrage	4	4	5	2018	2019	2019 to 2021	2019 to 2021
B5 Beachley Barrage	4	4	4	2018	2018	2019 to 2021	2019 to 2021
L2 Welsh Ground Lagoon	4	5	6	2019	2020	2019 to 2021	2019 to 2021
L3d Bridgwater Bay	4	5	6	2019	2020	2023 to 2025	2023 to 2025

Table NTS4 Construction Periods and Earliest Likely Windows for Grid Connection

Operation and Maintenance

Operation and maintenance costs have been estimated for each scheme to include staff and staff overhead costs, business rates, insurances, National Grid tariffs and annual maintenance.

The operation and maintenance costs include operational dredging to maintain shipping channels, fluvial channel capacity and live storage volume where required.

Annual operation and maintenance costs, including contingency but excluding optimism bias, are shown in Table NTS5.

In addition to these costs, experience from other marine and hydro-electric schemes indicates that gates and turbines will require major maintenance every 20 and 40 years respectively and these costs have been included in the levelised energy costs.

Scheme	Annual Operation and Maintenance Costs (£m)
B3 Cardiff to Weston Barrage	286
B4 Shoots Barrage	54
B5 Beachley Barrage	32
L2 Welsh Grounds Lagoon	56
L3d Bridgwater Bay Lagoon	111

Table NTS5 Annual Operation and Maintenance Costs

Decommissioning

Decommissioning costs for tidal power schemes with long asset lives are difficult to estimate as the life of structures typically extends beyond the nominal 120 years assigned to fixed civil engineering structures. It is normal practice not to decommission but to maintain and replace components as and when they reach the end of their life.

The question of when and what should be decommissioned has to be addressed as part of a decommissioning plan. Decommissioning could comprise either removal of the sluice gates and turbines to allow natural tidal levels to be restored or wholesale removal of the structure. Costs of decommissioning would be less than construction due to the fact that buried foundation structures would not be removed and that a shorter timeframe would be required to demolish and remove the structure. Significant volumes of waste would be generated but much of that volume could be recycled.

It is also worth noting that planned decommissioning costs would only be incurred at the end of the useful economic life of the project (notionally 120 years after first operation). By the time decommissioning costs (whether they are 25%, 50% or 100% of the construction cost) are discounted back to the present day, their impact on the cost of electricity in £ per MWh is not significant. A more important component therefore in any decommissioning plan is not the impact that decommissioning will have on cost of energy but to ensure instead that a sinking fund is created at the start of the project to enable the small contribution from energy revenue and the associated interest to accrue over the lifetime of the project to build the decommissioning fund.

Complete decommissioning would generally be a reverse of the construction process and a process to full decommissioning has been defined for the study.

Assessment of Significant Effects on the Environment Measures to Prevent or Reduce Adverse Effects

The SEA topic studies, which have included a series of technical workshops with knowledgeable external parties, have assessed the significant effects of the shortlisted schemes in line with the scope of the SEA which was consulted on in phase 1.

The SEA Directive requires that information is provided on: '*… the measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the plan or programme (Annex I (g)).*' The SEA Directive therefore requires that where significant environmental and regional effects have been identified, such measures should be described. These can be split into measures to prevent or reduce effects, and measures to as fully as possible offset effects.

The ODR provides a summary of the significant effects on environmental and regional receptors. The ODR should therefore be read in conjunction with the Environmental Report (ref xv) and Report to Inform a Stage 2 Habitats Regulations Assessment which provide a more complete assessment of significant effects and requirements for compensation.

Where possible, the ODR makes recommendations for measures to be included in options to prevent or reduce adverse effects on the environment. Some of these measures are unprecedented either because they are not established practice or are unprecedented in scale and therefore have significant uncertainty over their effectiveness, their indirect effects and their effect on scheme costs and energy yield. In some cases, recommendations on the scope and nature of measures are made in the absence of complete information.

It is therefore assumed that the measures would be the subject of further development as part of subsequent project implementation stages. Any assumptions made on the effect and applicability of these measures would need to be verified as part of project level planning and design. Some measures recommended in the SEA may change in subsequent stages or they may be substituted for other measures which are found to be more effective. Some recommended measures may later be excluded if further study on their effectiveness, indirect effects and effects on cost and energy determines that they can not be taken forward.

The ODR also reports on the effect of the prevent/reduce measures and therefore the residual effect which informs the consideration of measures to offset effects and compensation that might be required under the Habitats Regulations. For those features where there is sufficient evidence and it is possible to 'unitise' cost, estimates of the cost of compensation using a unit rate are provided. This has been possible for inter-tidal habitat based on case studies undertaken by DECC on managed realignment projects.

All options cause changes to the tidal range in the Estuary with the most significant changes upstream of barrages and within lagoons. Changes to the tidal range reduce the extent of inter-tidal habitat resulting in the loss of designated habitats and reduced inter-tidal exposure times. Changes in the tidal regime would potentially cause adverse effects on birds. Opportunities have been identified to modify the existing topography to create new inter-tidal areas and reduce the loss of habitats and effects on birds. Inter-tidal losses resulting after topographic modification would require the provision of compensatory habitat under the Habitats Directive. Other measures such as sluicing after generation and seawater level management by pumping are recommended to reduce the effects on inter-tidal habitats.

Cardiff to Weston Barrage and the Welsh Grounds Lagoon, which have been primarily studied as schemes which generate only on the ebb tide, could generate on the ebb and flood tide as a means of reducing their effects on the inter-tidal range, but it is not recommended. This is because ebb flood generation would increase the risk to fish as the number of passages through the turbines would increase. There would also be a greater reduction in high water level which, in the case of B3 Barrage, would require more significant works to dredge shipping channels and modify port accesses. Ebb flood generation would increase the cost of both options whilst causing a 5% reduction in energy yield for Cardiff to Weston Barrage and a 15% increase in energy yield for Welsh Grounds Lagoon. The levelised energy cost of the Cardiff to Weston Barrage would increase but the levelised energy cost of the Welsh Grounds Lagoon would not be significantly affected. A fuller explanation of the levelised energy costs is provided in Section 10.3.7 (page 158).

Changes to the tidal range also cause a change in the sedimentation regime. There is the potential for significant short term deposition of sediment, (ranging from 0.9 Mt for

Bridgwater Bay Lagoon to 8.2 Mt for Cardiff to Western Barrage), which could cause adverse effects on marine ecology. All schemes would also potentially adversely affect fish, to the point of local extinction in some cases, due to the risk of injury or mortality when passing through turbines and potential increase in predation. Measures have been identified which could reduce adverse effects on fish, such as the operation of sluices during generation to increase the permeability of the schemes. Measures to compensate for effects on fish under the Habitats Directive have been considered but are limited and uncertain. Terrestrial and freshwater ecology (i.e. ecology present in areas above the inter-tidal range) would also be affected and measures such as seawater level management by pumping have been identified to reduce those effects.

Reductions in high water levels together with sediment deposition would reduce the depth of water available for navigation with adverse effects likely on navigation to the ports. Upstream barrages are particularly susceptible to the long term accumulation of sediment deposition with potential effects on energy yield, the fluvial capacity of the river channel and navigation. Dredging of navigation channels and modifications to sill levels at existing locks in the construction stage, together with maintenance dredging during the life of the schemes, would avoid these adverse effects on navigation. Maintenance dredging may also be required within the basins of the upstream barrages to preserve energy yield and fluvial capacity whilst maintenance dredging may be required in the long term to preserve the energy yield of the lagoons. Deposition of sediment may affect the extraction of marine aggregates and require changes to the extraction processes.

For all alternative options, changes to peak tide and wave action will influence the level of flood risk. All schemes have an economic benefit in deferring the improvement to flood defences which will be required to deal with the consequences of climate change. For example, the reduction in water levels upstream of Cardiff to Weston Barrage would negate the majority of the effects of sea level rise by 100 years with a present value benefit of up to £207m. However, upstream flood defences will be exposed to an increase in erosion risk due to an increase in the time that water stands at high water level which will bring forward the time when maintenance to flood defences is required. For Cardiff to Weston barrage, the present value cost of bringing maintenance works forward is estimated at between £37m and £234m.

There will be lengths of up to 202km of flood defence that benefit from lower water levels and there will also be lengths of up to 95km (for the Beachley Barrage) outside the impoundments that will experience higher water levels than previously, and will need to be raised as a result. The changes to the estuary will also mean that increases in erosion to existing flood defences may occur, this will require up to 134km (±50%) of erosion protection to be provided. Flood risk will be adversely affected by restrictions to the normal operation of drains and outfalls, owing to the changed tidal regime (tide-locking). A variety of measures are available to ensure that none of the schemes causes an increase in flood risk.

All schemes will require significant material and waste resources for construction and decommissioning. However, the carbon payback period for all schemes is relatively short (generally between 3 and 6 years) and with a life likely to be over 120 years, all alternative options demonstrate a significant positive effect on global and UK greenhouse gas emissions.

Beneficial society and economy effects would potentially arise from employment required during construction, operation and decommissioning but adverse effects on navigation to ports could potentially adversely affect port businesses with a reduction in employment generated by the port trade. Construction employment predictions are summarised below.

	B3 Brean Down to Lavernock Point Barrage	B4 Shoots Barrage	B5 Beachley Barrage	L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
Construction Employment	7,500 – 8,500 FTE/year during 4 peak years of construction	2,000 – 3,000 FTE/year during 3 peak years of construction	1,500 – 3,000 FTE/year during 3 peak years of construction	3,000 – 4,000 FTE/year during 4 peak years of construction	4,000 – 6,000 FTE/year during 5 peak years of construction

Table NTS6: Summary of Peak Construction Employment Estimates (Source: Communities Topic Paper, 2010)

Compensation under the Habitats Directive for loss of designated inter-tidal habitats has been studied by DECC, focussing on the potential for managed realignment and regulated tidal exchange to provide compensatory habitat. DECC's Compensation Study has identified a cost of £45k per hectare of compensation, excluding optimism bias, for use in a strategic study. Optimism bias has not been applied in the ODR but has been covered in the Impact Assessment, reference xviii. It should be noted that the actual compensation requirements for a project would need to be determined as part of the detailed assessment process. Taking inter-tidal habitat losses determined in the SEA and the compensation requirements and unit costs determined by the Compensation Workstream, the ODR makes an estimate of the cost associated with compensation for loss of inter-tidal habitat. Other offsetting measures are also considered.

It is possible that the range of measures proposed to prevent or reduce effects may need to be re-visited after the end of the Feasibility Study, if the Government decides it can support a preferred option or combination of options. Measures to prevent and reduce effects will also be studied as part of an Environmental Impact Assessment for any scheme taken forward beyond the Feasibility Study. At that stage, some of the more novel measures could be studied in more depth.

Figure NTS1 illustrates the process for defining prevention and reduction measures.

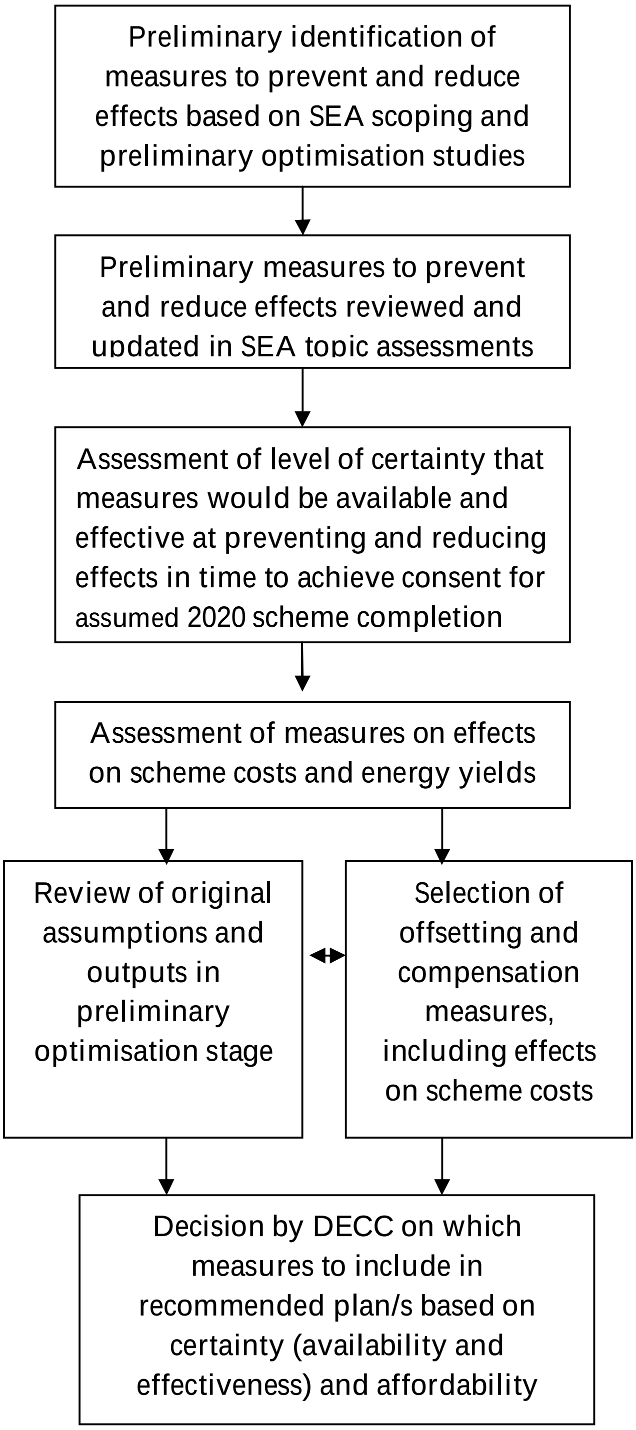


Figure NTS1 Process for Identifying and Selecting Measures to Reduce, Prevent and Offset Adverse Effects

Energy Yield

The energy yields have been estimated by mathematical modelling of the short listed schemes. All energy yield estimates allow for a 5% reduction in energy yield for outages. The energy estimates take account of the effect of measures to prevent and reduce adverse environmental effects and the effect of pumping which could raise upstream high water levels with ebb only and ebb flood generation and also reduce upstream water low levels with ebb flood generation in order to increase energy yield.

The adopted energy estimates for all schemes are summarised in Table NTS6

Scheme Cost Estimates and Cost of Energy

Project cost estimates have been prepared to a common level of detail for the primary variants of all shortlisted schemes defined. Cost estimates for the alternative variants have been extrapolated from the primary variant estimates. The accuracy of cost estimates has been assessed and a contingency allowance has been applied to civil, mechanical and electrical engineering elements. Optimism bias (OB) has not been included in the cost and programme estimates but has been included by DECC in the Impact Assessment (ref xviii).

Civil, mechanical and electrical engineering cost estimates have been based on measurement of principal quantities for all the major components. The cost estimates include ancillary works for modification of port facilities, navigation aid requirements, pumping at outfalls, permanent works for dredging and additional flood protection. Measures to prevent or reduce adverse effects of the schemes are also included. Substantial additional costs are likely to be incurred for Habitats Directive mitigation and compensation measures for other features such as fish and birds and for sub-features which have not been considered in detail. Compensatory habitat costs are included at the rate of £45k per Ha before optimism bias and sensitivity tested over ratios of 3:1, 2:1 and 1:1 of compensation to habitat area lost.

All costs have been estimated at 1st quarter 2008 prices.

Levelised energy cost is the cost of generating energy over the life of the scheme allowing for the initial capital costs and whole life operating and maintenance costs. Levelised energy costs have been derived by calculating the sum of discounted construction costs over the construction programme and operation and maintenance costs during the scheme's operational period, and dividing these by discounted energy output, over the 120 year design life of each scheme. They include contingency but not optimism bias. Levelised costs can vary significantly depending on the discount rate. Levelised costs have been calculated with a range of discount rates, ranging from those reflecting commercial costs of capital to the social rates in HM Treasury Green Book guidance.

The project costs, excluding optimism bias are shown in Table NTS7 and levelised energy costs, excluding optimism bias, are shown in Tables NTS8.

Scheme	Estimated Annual Energy Yield (TWh/yr)	Scheme Costs (£m)		
		1:1 Compensation Ratio	2:1 Compensation Ratio	3:1 Compensation Ratio
B3 Cardiff to Weston Barrage	14.4 to 16.7	22,567	23,199	23,831
B4 Shoots Barrage	2.6 to 2.8	4,599	4,743	4,887
B5 Beachley Barrage	1.3 to 1.6	3,336	3,450	3,565
L2 Welsh Grounds Lagoon	2.5 to 2.7	6,449	6,771	7,093
L3d Bridgwater Bay Lagoon	5.6 to 6.9	11,877	11,971	12,066

Notes:

1. Scheme costs exclude optimism bias but include contingency
2. Construction costs exclude the cost of reinforcement of the National Grid as that cost is borne by National Grid and recovered from the operator by applying tariffs. The application of tariffs has been included in operating costs.
3. Energy yields allow 5% reduction for outages

Table NTS7 Estimated Energy Yields and Project Cost Estimates

Scheme	Habitats Directive Compensation Ratio	Levelised Energy Cost (£/MWh)			
		10% Discount Rate Over Whole Life	8% Discount Rate Over Whole Life	8% Discount Rate Over 35 Year Finance Period; HM Treasury Green Book Long Term Discount Rates Thereafter	HM Treasury Green Book Long Term Discount Rates
B3 Cardiff to Weston Barrage	1:1	204	160	149	72
	2:1	211	165	153	73
	3:1	217	169	158	75
B4 Shoots Barrage	1:1	221	176	164	81
	2:1	228	181	169	83
	3:1	235	187	174	85
B5 Beachley Barrage	1:1	283	225	210	102
	2:1	293	233	217	105
	3:1	303	240	224	107
L2 Welsh Grounds Lagoon	1:1	331	259	241	112
	2:1	348	272	253	116
	3:1	366	285	265	121
L3d Bridgwater Bay Lagoon	1:1	246	194	181	87
	2:1	248	196	183	88
	3:1	250	198	184	88

Notes:

1. Levelised energy costs exclude optimism bias.
2. Levelised costs exclude the cost of reinforcement of the National Grid as that cost is borne by National Grid and recovered from the operator by applying tariffs. The application of tariffs has been included in operating costs.
3. Levelised costs are based on the mean energy yield estimate allowing for effect of measures to prevent and reduce adverse effects
4. Levelised costs include contingency

Table NTS8 Levelised Energy Costs

Application of Phase 2 Findings to Schemes Excluded from the Shortlist (Feedback Loop)

In phase 1, the fair basis evaluation of long listed options was based on the application of a common set of principles and assumptions behind the derivation of energy and cost estimates. The fair basis evaluation and outcomes were reported in the Interim Options Assessment Report (IOAR).

In phase 2, further study into the shortlisted options has led to changes to the phase 1 estimates of their energy yields and costs. The findings which have affected energy yield and cost have been applied to some of the schemes excluded from the shortlist to update their estimated energy yields and costs. The purpose of this feedback exercise is to enable the Feasibility Study to decide whether some excluded schemes could be feasible in light of the evidence now available.

The findings were applied to excluded barrage and lagoon schemes. The findings are not directly applied to schemes based on emerging technologies which have been studied separately under the Severn Embryonic Technologies Scheme (SETS).

Table NTS8 provides updated scheme costs, energy yields and levelised energy costs for the excluded schemes. The scheme costs and levelised energy costs exclude compensatory habitat because phase 1 inter-tidal loss estimates have not been updated in the feedback exercise.

The B1 Outer Barrage was not shortlisted by Government as it was not considered feasible on the grounds of affordability. The updated cost estimate of B1 Outer Barrage indicates that it is likely to be more expensive than estimated in phase 1 and therefore no more affordable. Energy yields for the B1 Outer Barrage were not updated.

The B2 Middle Barrage from Hinkley to Lavernock Point was not considered feasible due to the additional cost and greater scale of habitat loss for the extra energy generated compared to the B3 Cardiff Weston Barrage. In phase 1, B2 Hinkley to Lavernock Point Barrage was estimated to have a 20% increase in cost for a 15% increase in energy yield compared to B3. Using the updated costs, the cost difference reduces to 16%. Therefore, mainly due to the increased cost of shipping locks, the B2 barrage becomes relatively more favourable than was the case in phase 1. Energy yields for the B2 Middle Barrage were not updated.

The L3a English Grounds Lagoon, L3c Peterstone Flats Lagoon and L3e(i) Bridgwater Bay Offshore Lagoon were excluded from the shortlist because L2 Welsh Grounds Lagoon and L3d Bridgwater Bay Lagoon were considered to be better candidates for further study on the grounds of having more favourable energy yields and/or energy costs. All lagoon scheme cost estimates have increased due to an increase in assumed installed capacity and an increase in the estimated cost of their embankment construction. The update indicates that the L3d Bridgwater Bay land connected lagoon remains more favourable than the excluded land connected lagoons in terms of energy yield and energy cost. The L3d Bridgwater Bay land connected lagoon remains more favourable than the L3e Bridgwater Bay offshore lagoon in terms of energy cost but the offshore lagoon becomes more favourable in terms of energy yield. The levelised energy cost of all the excluded lagoons exceed £170 per MWh, a threshold set by Government in phase 1 for shortlisting based on comparison with other renewable energy costs.

Scheme	Phase	Operating Mode	Updated Energy Yield (TWh/yr)	Updated Scheme Cost (£bn)	Updated Levelised Energy Cost (£/MWh)
B1 Outer Barrage	Phase 1 (IOAR)	Ebb	25.3	29.0	139.4
	Phase 2 (ODR)	Ebb	Not updated	32.6	Not updated
B2 Middle Barrage (Hinkley to Lavernock Point)	Phase 1 (IOAR)	Ebb	19.3	21.9	139.6
	Phase 2 (ODR)	Ebb	Not updated	24.5	Not updated
L3a English Grounds Lagoon	Phase 1 (IOAR)	Ebb	1.41	2.6	197.2
	Phase 2 (ODR)	Ebb flood	3.1 to 4.0	10.3	271 to 339
L3c Peterstone Flats Lagoon	Phase 1 (IOAR)	Ebb	2.33	3.3	159.3
	Phase 2 (ODR)	Ebb flood	4.8 to 5.9	11.7	207 to 254
L3e(i) Bridgwater Bay 90km^2 Offshore Lagoon	Phase 1 (IOAR)	Ebb	2.6	5.8	259.0
	Phase 2 (ODR)	Ebb flood	6.8 to 7.9	19.9	265 to 312

Notes:

1. Energy yields allow 5% reduction for outages.
2. Scheme cost estimates include contingency but exclude optimism bias and exclude compensatory habitat required under the Habitats Directive.
3. Levelised energy costs are based on 8% discount rate over scheme life.
4. Levelised energy costs include contingency but exclude optimism bias and exclude compensatory habitat required under the Habitats Directive.
5. Compensatory habitat costs are excluded because phase 1 inter-tidal loss estimates have not been updated.

Table NTS9 Updated Energy Yield, Scheme Cost and Levelised Energy Cost of Schemes Excluded from the Shortlist

On the evidence available from the application of phase 2 findings, there does not appear to be a case for including any of the previously excluded schemes, listed in Table NTS9, on the shortlist. However, if the B3 barrage is taken forward, further consideration could be given to modifying its alignment along the B2 line but further study would be needed to compare their effects on the environment, including far field effects which could be more onerous with B2. Further study would also be required into the effects of a higher installed capacity on the National Grid.

Development of Schemes in Combination

Some schemes can be developed in combination, with the potential advantage of providing less intermittent power output. All potential combinations have been considered in energy and cost terms with a high level evaluation of environmental and regional effects. Only the Cardiff Weston Barrage followed some time in the future by Bridgwater Bay lagoon could provide a levelised energy cost below £170 per MWh, a threshold level set by DECC to indicate the more promising options based on the costs of the draft Renewable Energy Strategy costs at an 8% discount rate (as set out in the response to consultation, the final RES reduced this threshold). Taking into account the effects that the individual schemes would have on tidal range, the combined energy yield would be 17 to 20 TWh/yr, around 15% lower than their aggregate energy yields.

The combination would have the advantage of providing less intermittent energy if Bridgwater Bay lagoon is operated as an ebb flood scheme and the barrage operated as an ebb scheme. Optimisation, together with mathematical modelling, will be required as part of a further combinations study if the Feasibility Study determines that the individual schemes are considered to be potentially viable.

All other combinations have lower bound levelised energy costs above £170 per MWh and are not considered worthy of further consideration at this stage.

Multiple Basin Alternatives

Multiple basin alternatives, whereby the impounded basin is divided into two or three interconnected basins, offer the opportunity of continuous power and potentially increase in energy yields. All options could in theory be configured as multiple basin options but they generally only offer benefit over single basin alternatives if the length of the impoundment required to form the additional basins can be short enough not to prejudice the cost of the energy produced. Multiple basin configurations of the upstream barrages and the Welsh Grounds lagoon would not feasible in cost terms.

Bridgwater Bay lagoon and Cardiff to Weston barrage could be linked to provide more continuous energy than if constructed as a combination without a link. The Bridgwater Bay lagoon alignment would need to be modified to provide a powerhouse between the two basins. If the lagoon is taken further beyond the Feasibility Study with the potential for it to be constructed before the Cardiff to Weston barrage, such a modification is worthy of further consideration as the larger impounded area might also be beneficial in increasing output before the barrage construction.

Alternatively, Bridgwater Bay lagoon could be divided internally and operated as a double basin scheme on its own. Water levels in one basin would be higher than the other basin. The high basin would be filled by the sea on the flood tide and there would be a continuous flow of energy through turbines between the high basin and the low basin. The low basin would discharge to the sea via turbines on the ebb tide. However, the total output from the lagoon would be significantly less than the output from a single basin scheme due to a combination of smaller flow rates and lower heads. A double basin scheme would use pumping to raise the high basin levels and lower the low basin levels to increase the flow through the lagoon and increase operating heads but it is unlikely that pumping would mitigate for the lower heads and smaller flows compared to the single basin option.

An advantage of the double basin scheme is that the lower output would reduce the effects on the National Grid, therefore requiring less costly reinforcement works. However, it is concluded that the cost of energy from the double basin scheme would be more expensive than the single basin option and is not worthy of further consideration at this stage.

During construction and decommissioning, a double basin Bridgwater Bay Lagoon is likely to largely have the same significant environmental effects as a single basin version. During operation, there are likely to be differences in the effects on the hydraulics and geomorphology of the Estuary, most notably, a greater loss in intertidal area which will have further effects on waterbirds and marine ecology.

SECTION 1

INTRODUCTION

1 INTRODUCTION

1.1 Feasibility Study Context

In January 2008, the Government launched a Feasibility Study to consider whether it could support a project which exploits the major energy generation potential of the tidal range of the Severn Estuary, and if so, on what terms.

In recognition of the importance of the natural environment of the Severn Estuary, the Feasibility Study has commissioned a Strategic Environmental Assessment (SEA) which will assess a plan whose purpose is:

- to generate electricity from the renewable tidal range resource of the Severn Estuary in ways that will have an acceptable overall impact on the environment and economy both locally and nationally, will meet our statutory obligations and provide benefit to the UK.
- to deliver a strategically significant supply of renewable electricity, which is reasonably affordable compared to other sources of supply and represents value for money in the context of the UK's commitments under the forthcoming EU Renewable Energy Directive and Climate Change Act and our goal to deliver a secure supply of low-carbon electricity.

The study has been split into two phases. In Phase 1, to define the plan for the strategic environmental assessment, the Government identified a short list of potential tidal power schemes on the Severn from a list of potential schemes that was drawn up following a call for proposals issued in May 2008. Other work included investigation of regional economic impacts, financing and the scope of the SEA. The draft short-list was published in January 2009 and was subject to a public consultation from 26 January 2009 to 23 April 2009. The Government finalised the short-list of options on 15 July 2009 having considered all responses to the public consultation. At the same time, the scope for the SEA was also confirmed. This completed Phase 1. Phase 2 comprised the more detailed study of the short-listed options and completed the SEA and other Feasibility Study work with the objective of publishing reports as part of a second public consultation.

This report examines the short-listed options in more detail and in particular takes the options through a refinement process so they are defined to a sufficient and common level of detail to inform the SEA which includes simulation, through mathematical modelling, of the energy yield and key environmental and regional effects. Updated cost, programme and energy estimates for the optimised schemes have been prepared. Measures to prevent, reduce and offset adverse effects on environmental and regional receptors, and the implications of those measures on scheme cost and energy yield, have then been identified.

The output from this report is a summary of the options definitions (for the purposes of the Feasibility Study) for each option and an assessment of their cost, programme, environmental / regional effects, and energy yield. The work undertaken is sufficient to inform a decision on whether to support a Severn tidal power project and further refinement of designs and mitigation of effects would be anticipated as subsequent stages of work should Ministers decide to support development of tidal power in the Severn. Designs and concepts used in this report are therefore not necessarily definitive but representative of options that could subsequently be developed, in line with the strategic nature of this study.

The final decision on whether to support a Severn tidal power project will take into account the feasibility and cost of other non-Severn based options to meet Government's renewable energy objectives and goals on low-carbon electricity and carbon reductions. The Feasibility Study is also considering a 'do nothing' option in respect of Severn tidal power.

1.2 Scope, Purpose and Objectives of the Options Definitions Report

Five options for the development of tidal power using the tidal range of the Severn Estuary have been confirmed as the short-listed candidates for more detailed study to determine a preferred option. The five options comprise three tidal barrages and two tidal lagoons. These options are described below:

- Cardiff to Weston Barrage (from Lavernock Point to Brean Down, historically known as the Severn Barrage).
- Shoots Barrage (a smaller barrage located downstream of the Second Severn Crossing).
- Beachley Barrage (the smallest barrage and located upstream of the first Severn Bridge).
- Welsh Grounds Lagoon (a tidal lagoon located on the Welsh Grounds downstream of the Second Severn Crossing on the Welsh shoreline originally submitted by Fleming Energy in response to the call for proposals).
- Bridgwater Bay Lagoon (a tidal lagoon located downstream of Weston-super-Mare on the English shoreline).

The purpose of the Option Definitions Report (ODR) is to present the short listed options. Each option is defined as follows:

- The configuration in terms of the number, type and size of turbines and sluice gates and the mode of operation which are considered most optimal for the purpose of a strategic study;
- Development of outline engineering designs to reflect configurations of turbines, sluices, mitigation and refinement measures, and determination of other design requirements including structural form (with additional data and interpretation on ground conditions), levels of service (e.g. crest levels, asset life, maintenance requirements) and other infrastructure requirements (e.g. cabling, powerhouse, access etc);
- Assessment of capital and operating costs;
- Assessment of construction sequences, programmes and earliest possible dates of first operation; and
- Assessment of energy yield, and energy cost.

This version 3 of the Options Definition Report contains the finalised options definition for the Feasibility Study. Version 3 supersedes earlier versions. Version 1 was a working document which dealt specifically with the preliminary optimisation process described below. Version 2 was a working document which provided the refined options definitions which were subject to SEA. Version 3 supersedes those earlier versions but contains all the relevant content which was contained within them.

ODR version 3 takes account of the findings of the SEA as reported in SEA topic and theme reports and the environmental report and includes:

- A summary of the significant effects of the options on the environment;
- The measures recommended for inclusion in the options to prevent or reduce adverse effects on the environment; and
- Energy yield estimates, scheme costs and levelised energy costs taking into account the effects on cost and energy of the measures recommended for inclusion to prevent or reduce adverse effects on the environment

The report also includes a high level evaluation of the potential to develop schemes in combination and to generate less intermittent energy by configuring schemes with multiple basins.

Section 1.7 below explains the structure of the ODR and is intended as guide to its content.

1.3 Phase 1 Consultation

The Government's response to the public consultation on Phase 1 was published on 15th July 2009 and confirmed the five options to be studied in Phase 2 (listed in 1.2 above and illustrated in Figure 1.1). It also included how more embryonic options would be considered in addition to the five short-listed conventional technology options and published details of three proposals that would be developed under the SETS programme (see 1.5 below) to increase confidence in energy yield, costs and time to enable them to achieve an equivalent output standard as the Phase 1 outputs. It also described how a feedback loop would be included in the Phase 2 work to ensure that new or changed assumptions / data were tested on previously rejected options to see if they should be re-examined using the new assumptions / data.

1.4 SEA and Other Feasibility Study Interactions

The definition of short-listed options both informs and is informed by the studies being undertaken as part of the Strategic Environmental Assessment (SEA) being carried out for the Severn Tidal Energy Study. In particular, the optimised schemes for each option are simulated using complex 2-D mathematical models to confirm energy yields, hydrodynamic effects and geomorphological effects. The results from these studies, and the effects they simulate for each option, then inform the strategies to prevent and reduce adverse effects and ultimately the engineered design for the defined option.

The ODR has informed DECC's Supply Chain Study with estimates of turbine requirements, material resource requirements, dredging volumes, caisson fabrication requirements and employment estimates. The Supply Chain Study has in turn informed Section 5 Construction, particularly in terms of the available supply of turbines, dredgers, caisson yards, and earthworks materials. The interaction between the ODR and Supply Chain Study has been an iterative process.

The ODR has informed DECC's Grid Study with information on installed capacities and energy outputs. The Grid Study has in turn informed Section 3 with grid reinforcement requirements.

The preliminary optimisation work (which in turn informed the H&G studies) and subsequent refinements of the schemes after optimisation (such as materials resources estimates, labour estimates, onshore infrastructure requirements, construction processes etc) have all informed the SEA topic assessment work. The ODR identifies where possible reduction and prevention measures and compensation requirements, informed by the topic assessments and DECC's Habitats Directive Compensation Study, including the implications on cost, energy and programme.

The topic assessment work has informed the assessment of adverse effects on habitats and the potential measures to prevent and reduce those effects. That assessment work has informed work within DECC's Habitats Directive Compensation Study. The evidence base is not sufficiently robust to enable compensatory measures for migratory fish to be fully quantified and costed. Some measures have been conditionally included but require further development and/or consideration of their policy implications. Provisional costs of compensation for the loss of inter-tidal habitat, which are expected to be the largest part of the compensation cost, have been included in ODR scheme cost estimates.

1.5 SETS Interaction

The Severn Embryonic Technologies Scheme (SETS) was a match funded programme designed to assist proposers of embryonic technologies to better determine the costs, energy yields and key environmental / regional effects of their technologies as applied to the Severn Estuary as well as development road maps for each of the technologies. The proposers' analysis of environmental and regional effects have allowed the Feasibility Study to take a view on whether the technologies have the potential to cause less adverse environmental and regional effects than the short listed schemes. Following a Call for Proposals launched in April 2009, three proposals received funding from DECC, DEFRA, SWRDA and Welsh Assembly Government. These were as follows:

- A tidal fence located either between Cardiff and Weston-super-Mare or between Aberthaw and Minehead, comprising a line of tidal stream devices as proposed by the Severn Tidal Fence Consortium;
- A tidal fence located either between Cardiff and Weston-super-Mare or between Aberthaw and Minehead, comprising a series of modular units which diverts water through a Kaplan turbine in a secondary circuit using venturi action. This has been proposed by Verd-Erg; and
- A tidal barrage located between Aberthaw and Minehead or Cardiff and Weston-super-Mare utilising a new turbine variant that operates on reduced tidal range as proposed by Rolls-Royce and Atkins.

The output from each of the SETS schemes has been reported and evaluated by government but will not be considered as part of the SEA at this time.

1.6 Application of Phase 2 Findings to Schemes Excluded from the Shortlist (Feedback Loop)

A feedback loop has been introduced to ensure that new or changed assumptions / data are tested on previously rejected options to see if they should be re-examined using the new assumptions / data. The feedback loop has provided updated scheme costs, energy yields and construction programmes for schemes which are based on mature technologies but were excluded from the shortlist. The feedback loop was not applied to options based on emerging technologies as the findings of the assessment of the shortlisted schemes are generally not directly applicable to emerging technologies.

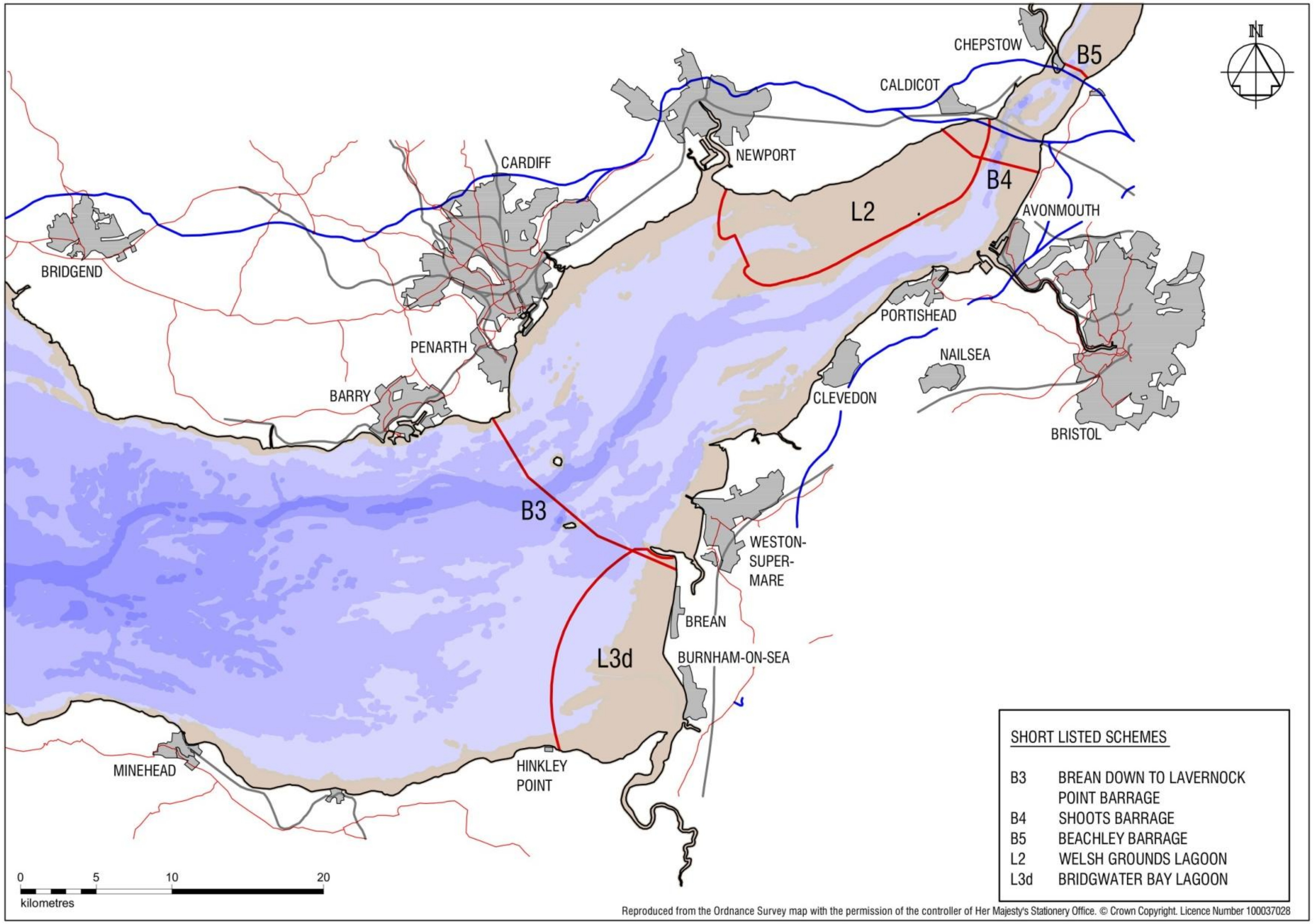


Figure 1.1 Short Listed Schemes

1.7 Structure of the Options Definitions Report

Table 1.1 outlines the structure of the ODR.

Section	Content
1 Introduction	Sets the context of the ODR within phase 1 and 2 of the Feasibility Study and its interactions with the SEA and SETS.
2 Background	Sets out the phase 1 conclusions and the phase 2 process for optimising and refining the short-listed options
3 Short-Listed Options	Presents the form of the options as short-listed prior to optimisation and refinement in phase 2
4 Pre-Construction Requirements	Sets out the requirements for pre-construction studies and procurement
5 Construction	Provides a detailed description of the construction processes and programmes.
6 Operation and Maintenance	Sets out the operation and maintenance requirements, including costs. Excludes operational measures required to prevent or reduce adverse environmental and regional effects.
7 Decommissioning	Sets out decommissioning scenarios and processes
8 Likely Significant Effects on the Environment and Measures to Prevent, Reduce and Compensate for Adverse Effects	Provides an executive summary of the significant environmental effects, sets out the process for determining measures to prevent and reduce significant adverse effects and identifies those measures which should be adopted for the Feasibility Study, including measures to offset and compensate for significant adverse effects
9 Energy Yield	Provides estimates of energy yield based on 2D and 1D modelling,
10 Scheme Costs and Levelised Energy Costs	Provides estimates of pre-construction and construction costs including the cost of measures required to prevent and reduce adverse environmental effects, compensation measures and the cost of ancillary works (e.g. works required to flood defences and port accesses). Provides levelised energy costs determined by discounting costs and energy output to the present day using a variety of discount rates.
11 Combinations and Multiple Basin Options	Provides a comparison of strategies for the development of schemes in combination or as multiple basin alternatives focussing on cost, programme and energy issues
12 Application of Phase 2 Findings to Schemes Excluded from the Shortlist (Feedback Loop)	Updates scheme costs for excluded barrage options and scheme costs, energy yields and levelised energy costs for excluded lagoon options using findings from phase 2 work

Table 1.1 Structure of the ODR

SECTION 2

BACKGROUND

2 BACKGROUND

2.1 Phase 1 Conclusions

The objective of the engineering work undertaken in Phase 1 was to analyse, from a technical perspective, potential tidal range power options in the Severn Estuary to inform Government in developing a draft short-list of options.

A common set of principles and associated assumptions was applied to the analysis of each option to enable a "fair basis" assessment of costs (the application of common assumptions and principles across all options). The options studied during Phase 1 are summarised in Table 2.1. Figures quoted are based on a discount rate of 8% and exclude the costs of providing compensatory habitat required under the Habitats Directive or grid reinforcement. Inclusion of compensatory habitat costs increases the capital costs by between 6% and 20% for larger barrage options and typically between 10% and 35% for the other options (dependent upon replacement ratios). With compensatory habitat included in the costs, the relative differences between the larger barrage options and the other, smaller options become smaller and, in some cases are reversed. This is because the loss of inter-tidal areas as a percentage of energy yield is smaller for the larger options. Full details of the Phase 1 work in analysing the different options to help inform Government selection of the short-list of options can be read in the Interim Options Analysis Report (IOAR)– Volumes 1 and 2 – published in January 2009 as part of the Severn Tidal Power Public Consultation.

Five of the options summarised in the table below were subsequently shortlisted. These were:

- Tidal Barrages: Cardiff to Weston (B3), Shoots (B4) and Beachley (B5)
- Tidal Lagoons: Welsh Grounds (L2) and Bridgwater Bay (L3d).

The remainder of this reports deals with these five shortlisted options.

Table 2.1 Options Studied under Phase 1

Option	Option Name	Phase 1 Findings
B1	Outer Barrage from Minehead to Aberthaw	• A conventional tidal barrage, producing the highest energy yield (25TWh/a) but with highest capital cost (£29bn); cost of energy was £139.4/MWh excluding compensatory habitat costs ; • Largest environmental impact footprint, and will result in reduction of water levels and tidal range, loss of habitats and impacts on bird and fish populations in the Severn; Benefits include protection from effects of storm surges, sea level rise and reduced turbidity; • Severn Ports upstream will be affected, primarily Barry, Bristol, Cardiff, Newport and Sharpness.
B2	Middle Barrage from Hinkley to Lavernock Point (Shawater concept)	• Longest barrage option - based on the Cardiff to Weston (B3) option but with additional embankment extending the barrage to Hinkley Point - Energy output of 19TWh/a; cost of energy was similar to Option B1 at £139.6/MWh; • Environmental effects are similar to those for B1 as this option seeks to provide similar flood defence benefits by crossing Bridgwater Bay; • Severn Ports upstream will be affected, primarily Bristol, Cardiff, Newport and Sharpness.
B3	Middle Barrage from Brean Down to Lavernock Point (commonly known as the Cardiff to Weston Barrage)	• Most studied of any of the options and reported on in Energy Paper 57; • Annual energy output of 17TWh and a capital cost of £18bn; cost of energy was £129.4/MWh excluding compensatory habitat costs; • Environmental impacts are potentially significant, as with other large barrage options, and will result in reduction of water levels and tidal range, loss of habitats and impacts on bird and fish populations in the Severn; Benefits include protection from effects of storm surges, sea level rise and reduced turbidity. • Severn Ports upstream will be affected, primarily Bristol, Cardiff, Newport and Sharpness.
B4	Inner Barrage (Shoots Barrage)	• Significantly smaller than the large barrage options, this option is located just downstream of the Second Severn Crossing; • Generates 2.77TWh per year at a capital cost of £2.6bn with cost per unit energy at £104/MWh; • Environmental impacts are similar in type to other barrage options although there is an increased risk of sedimentation; • This option does not impact the Ports of Bristol or the ABP Ports on the Welsh coast.

Table 2.1 Options Studied under Phase 1		
Option	Option Name	Phase 1 Findings
B5	Beachley Barrage	• Located upstream of the Wye, smallest barrage option studied (£1.8bn) and has similar characteristics to Option B4; • Annual energy output is 1.59TWh/a, 57% of Option B4 whilst the cost per energy is £125.8/MWh; • Similar environmental effects as Option B4 except that the Wye is not impounded; • This option affects ports in the Gloucester Harbour Trustees administered waters.
F1	Tidal Fence Proposals submitted by Pulse Tidal	• A fence of tidal stream propeller turbines initially, proposed between Cardiff and Weston but a more feasible alignment was subsequently considered between Minehead and Aberthaw; • Annual energy output of 3.3TWh was achievable at a cost of £6.3bn. Cost of energy was £227.2p/MWh; • Assumes future development costs will reduce significantly from the current demonstration project costs for tidal stream technology. This implies a significant period of further development and experience before large scale implementation could be achieved. It does offer the possibility of less significant environmental effects than barrage options although the area affected is as large as the biggest barrage option.
L2	Tidal Enclosure on the Welsh Grounds proposed by Fleming Energy	• Land connected lagoon located on the relatively high Welsh Grounds just downstream of the Shoots Barrage (B4); • It has an annual energy output (2.3TWh/a) achieved at a cost of £3.1bn. Cost per unit energy was £154.6/MWh ; • Land connected lagoons, like barrages, result in loss of habitats because of the significant reduction in tidal range within the impounded area. Other environmental effects are similar to smaller barrages except that impacts on fish and navigation are expected to be less because they do not form a barrier across the estuary.

Table 2.1 Options Studied under Phase 1		
Option	Option Name	Phase 1 Findings
L3	Tidal Lagoon Concept (which has been subsequently modelled as four land-connected lagoons and three offshore lagoons based on various general submissions received from the Call for Evidence)	• Various land connected and offshore lagoon configurations have been studied using different forms of lagoon wall construction; • As lagoon costs are influenced by the length and depth of wall forming the impounded basin, a range of methods of wall construction have been considered - a geotextile solution using material dredged from the estuary and protected by rock armour (externally) and revetment (internally) was one of several forms proposed for the L3 lagoons; • Bridgwater Bay offers the most cost effective lagoon option with a higher energy yield (2.64TWh/a) and a cost per kWh of £130.2/MWh. • An offshore lagoon, located below the low water contour (and reduced impact on habitats), has been modelled to produce a similar energy output using the same forms of construction. Because of the much deeper wall construction required, it is more expensive with a capital cost of £5.8bn for almost the same energy output of 2.6TWh/a as the £3bn Bridgwater Bay land connected option. This is also reflected in the cost of energy which is more than double the land connected lagoon alternative.
R1	Tidal Reef proposed by Evans Engineering.	• Entirely new concept that has continued to evolve during the study period. • Studied and reported on to a level commensurate with the information available but the assessment has not been able to provide as definitive estimates as other options on which to develop reliable cost base and energy yields. Outline estimates provide a capital cost of £18.1bn with an energy yield of 13TWh/a with a preliminary estimated cost of energy of £203.0/MWh. • Development period would be greater than other options and require demonstration projects to test the concept – this would take between 10 and 15 years if tidal stream technology is taken as a benchmark.

Table 2.1 Options Studied under Phase 1		
Option	Option Name	Phase 1 Findings
U1	Severn Lakes (promoted by Gareth Woodham)	• Originally included because one of its objectives is to produce power using the tidal range of the Severn. • The cost of constructing a 1km wide causeway 16km in length would be significantly more than a conventional tidal barrage and clearly requires additional investment streams to justify its cost. On the basis of the information within the public domain, this is also recognised by the proposer who envisages other revenue streams from land, recreational and other energy developments as part of this scheme. • This study is only examining potential options from an energy perspective. For this reason this option is not considered as a feasible option specifically within the terms of the Feasibility Study.

2.2 Phase 2 Process

The objective of the Options Definition Report (ODR) is to define, to an appropriate level of detail, the short listed options which have been the subject of consultation following the completion of phase 1 of the Feasibility Study. The option definitions provided in this report have informed the Strategic Environmental Assessment (SEA) and the wider Feasibility Study work. The overall process is set out in Figure 2.1.

The starting point of the options definition work is the shortlisted schemes as studied in phase 1 and reported on in the IOAR. The schemes as shortlisted were defined sufficiently for the phase 1 fair basis comparison but they are not necessarily in the most favourable form having regard to energy and economic issues, and their regional and environmental effects. Therefore, the schemes have been subject to a preliminary optimisation process to determine the form of each scheme which appears to be preferable and a reasonable choice for more detailed study. Preliminary Optimisation is a term used in the SEA for the process whereby the schemes as shortlisted and a number of modifications were tested to evaluate their regional and environmental effects, scheme costs, energy output and energy cost. The optimisation carried out in this study is preliminary because it is only for the purpose of identifying the most appropriate form of scheme for study in the SEA and was not intended to identify the final preferred form of each scheme. Any scheme taken forward beyond the Feasibility Study would require more detailed optimisation to inform the design of the scheme.

The modifications considered in optimisation included, where appropriate, changes in operating mode (single phase ebb generation compared to two phase ebb flood generation), changes in turbine numbers and sizes, changes in sluice capacity, and changes in alignment. The form of each scheme chosen for further study in the SEA was the one which was generally favourable in all or most respects.

For some schemes, it was not possible during optimisation to determine which was the most favourable form particularly in biodiversity terms because different operating modes were found to have opposing effects on different environmental receptors. For example, the optimisation process concluded that adopting ebb flood generation instead of ebb generation was likely to reduce adverse effects on birds but it was less clear how the different modes would compare in terms of impacts on fish. Where this was the case, the form chosen was the one which was generally favourable in most respects but sensitivity testing has been carried out in the SEA to study whether an alternative operating mode would be a viable way of reducing the adverse effects of the selected mode.

The ODR reports on the preliminary optimisation work carried out and the resulting scheme definitions which are proposed to inform the SEA of the schemes, the subsequent refinement work, and the detailed study into engineering requirements and finalisation of energy yields and construction/operating costs for the options under consideration. The findings of the assessment of significant effects on the environment within the SEA are reported in summary and measures are recommended for inclusion in the options to prevent or reduce adverse environmental effects. The implications of these measures on scheme costs, energy yield and levelised energy costs have been evaluated in this ODR.

For lagoons, as there is a very large range of different forms and alignments that could be considered for each scheme, the selection of each scheme for further study also takes into account the need for the study to provide a breadth of knowledge that could be applied to study the feasibility of lagoons on a more generic basis.

The optimised schemes have then been subject to a refinement process whereby sufficient detail is added to inform the SEA and provide reasonable certainty over scheme costs and energy estimates. Energy estimates have been derived using a combination of 1-D and 2-D modelling techniques. The 2-D flow modelling was carried out within the Hydraulics and Geomorphology SEA topic and is reported in references (xii) and (xiv). The 2-D flow modelling work also informed the assessment of other physiochemical effects such as flood risk and water quality as well as biodiversity effects such as changes in inter-tidal areas. The flow modelling work is described in outline in Section 9.

Following optimisation and refinement of the options, further high level study has been carried out into the potential for combinations of individual schemes.

The ODR provides the definitions of the schemes, and measures to prevent and reduce adverse effects, on which the findings of the Feasibility Study will be based.

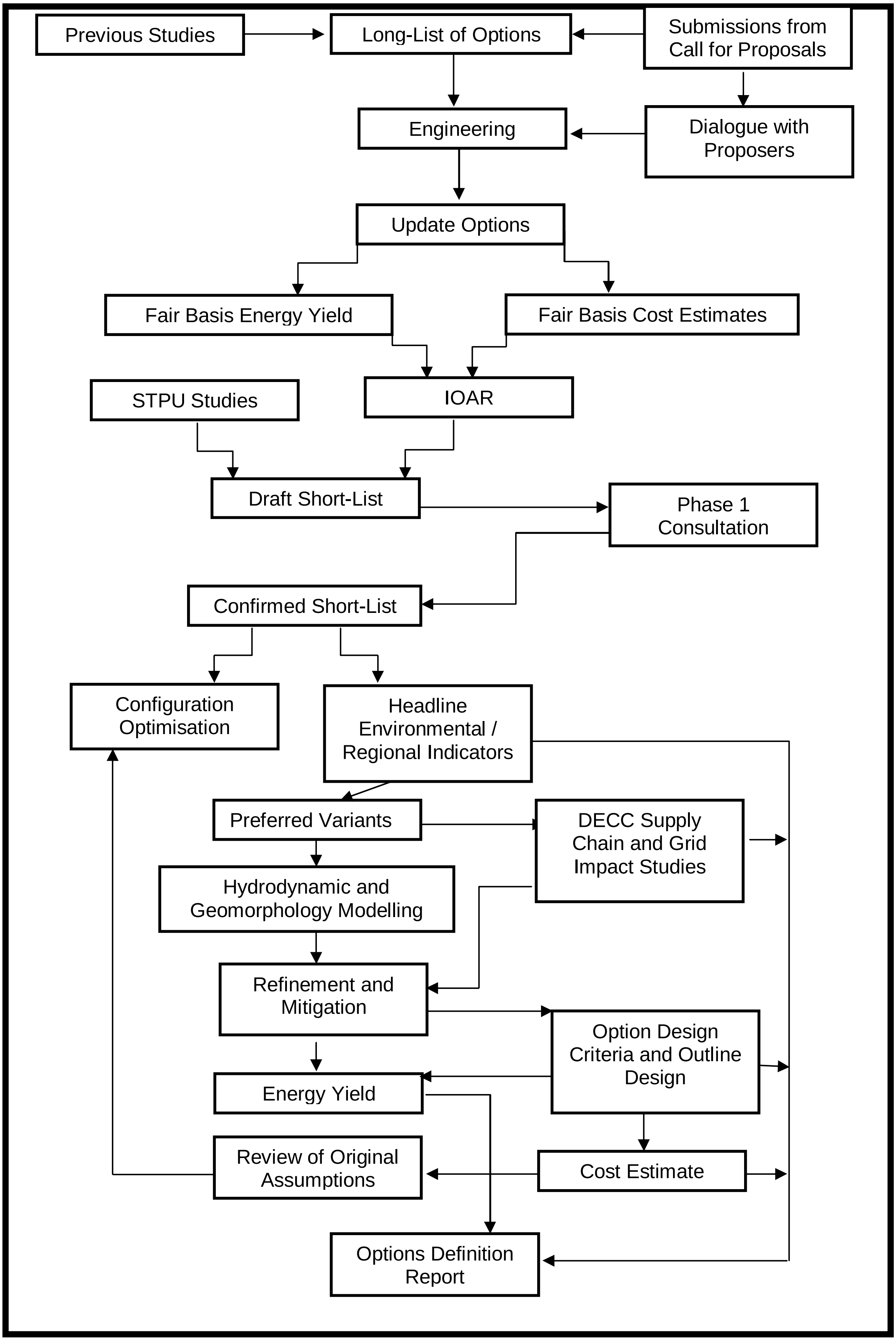


Figure 2.1 Process to Finalise Engineering Evaluation of Options

2.3 Inputs from Proposers

A small number of the short-listed options are based on submissions to the Call for Evidence - either as a whole scheme or because they incorporate specific forms of construction. Proposers have been consulted through the development work undertaken in Phase 2 as their proposals are reviewed and studied in detail. This has led to a number of changes to the original proposals through the development phase.

Tidal barrages, where no specific proposers have been involved, have been assessed on the basis of the same recommendations made in previous studies updated to suit present day requirements. Engineering for tidal barrages is relatively well understood and the main issues relate to the selection of gates and turbine types to maximise power generation whilst adequately reducing and preventing environmental effects.

Tidal lagoons involve similar engineering components as barrages although, due to the longer lengths of wall construction required to form an impoundment, different forms of wall construction have been considered in an attempt to reduce costs by comparison with a more conventional embankment. These, more innovative, forms of wall construction involve greater risk in terms of engineering design, estimation of costs and durability. They are considered in section 3 and in detail in Appendix A.

L2 Welsh Grounds Lagoon was originally submitted by Fleming Energy in response to the Call for Proposals. The scheme has been subject to the same preliminary optimisation, refinement and assessment process as other short listed schemes. Fleming Energy has been informed of the work on the L2 lagoon during the study and invited to comment at each stage in the process. The preliminary optimisation and refinement process has led to the scheme defined in the ODR being different in many respects from the scheme concept proposed by Fleming Energy. The differences are highlighted in Sections 3, 9 and 10.

SECTION 3

SHORT-LISTED OPTIONS DEFINITIONS

3 SHORT-LISTED OPTIONS DEFINITIONS

3.1 Introduction

This section presents the short listed options which have been assessed within the SEA and whose scheme costs, energy yields and levelised energy costs have been estimated and reported in Sections 9 and 10. The development of the shortlisted options has been the subject of detailed engineering studies which have been reported in full in Appendix A. This section therefore merely provides an outline of the options definition process and summary definitions of the options.

3.2 Methodology

The starting point for development of the options definition was the schemes as shortlisted at the end of phase 1 and reported in the IOAR.

The form of the schemes as shortlisted did not necessarily represent the optimal form taking into account cost, energy yield and environmental and regional effects. Therefore, in phase 2, the schemes have been taken through a preliminary optimisation process to enable the SEA to focus on the most appropriate form of each scheme if developed as an individual single basin scheme. The optimisation carried out for the Feasibility Study is only preliminary because it is not intended to provide a final definition of the schemes. Instead, it provides a preliminary definition of each scheme which is considered to be potentially preferable having regard to energy, cost, economic, regional and environmental effects. Any scheme taken forward beyond the Feasibility Study would require much more detailed optimisation to inform a final design. This would be informed by greater knowledge of the potential benefits of some measures such as fish mitigation which might change some aspects of scheme definition.

Preliminary optimisation involved a study into whether modifying a scheme's configuration (such as changing turbine numbers, sluice numbers and operating mode) would make it more favourable in terms of its regional and environmental effects, construction costs, energy output and energy cost. Preliminary optimisation focuses only on individual schemes. Similarly, the optimisation focuses only on single basin forms of the scheme. Appendix A contains the preliminary optimisation methodology in detail.

Following preliminary optimisation, the options definitions were further refined in order to provide sufficient detail to inform the assessment. The options definitions represent the form of the schemes which are potentially preferable based on the evidence obtained during the study. Any preferred scheme (or combination) which is determined to be feasible at the end of the study is expected to require further more detailed engineering studies, environmental impact assessment, regional and other studies before it could be considered final for consenting purposes.

Lagoon schemes have not benefited from the same amount of design development as some barrage schemes and some of the forms of construction put forward by lagoon proposers for lagoon impoundment construction in phase 1 were novel. Selection of an appropriate form of impoundment construction for strategic level study is important in providing a reliable estimate of scheme cost, construction period and requirements for material resources.

Therefore, a key stage in the refinement of the lagoon scheme definitions was a study into impoundment construction alternatives to determine the form, or forms, of the lagoon which provide reasonable certainty of their technical feasibility taking into account the available information on the site conditions.

Following the appraisal of impoundment construction alternatives, a conventional rockfill embankment has been adopted as the base case for lagoon impoundment construction as it provides a reasonable basis for determining the cost, programme and resource requirements for the Feasibility Study. The optimal form of construction should be determined by further study for any scheme taken forward beyond the Feasibility Study.

3.3 Outline Descriptions

<u>B3 Middle Barrage from Brean Down to Lavernock Point</u> (commonly known as, and hereinafter called, the Cardiff to Weston Barrage)

The Cardiff Weston barrage would run from Lavernock Point, west of Cardiff, to Brean Down, south-west of Weston-Super-Mare. It was studied in detail as a single basin ebb only generation scheme by Severn Tidal Power Group (STPG) for the Department of Energy in the late 1980s. A reasonably detailed preliminary design of the barrage was developed by STPG. Those study reports have been reviewed for this study and most of the general principles of the barrage proposals remain relevant for an ebb generation scheme. The principal update to the scheme since the STPG studies is the resizing of the navigation locks to provide for the use of Panamax II class vessels. .

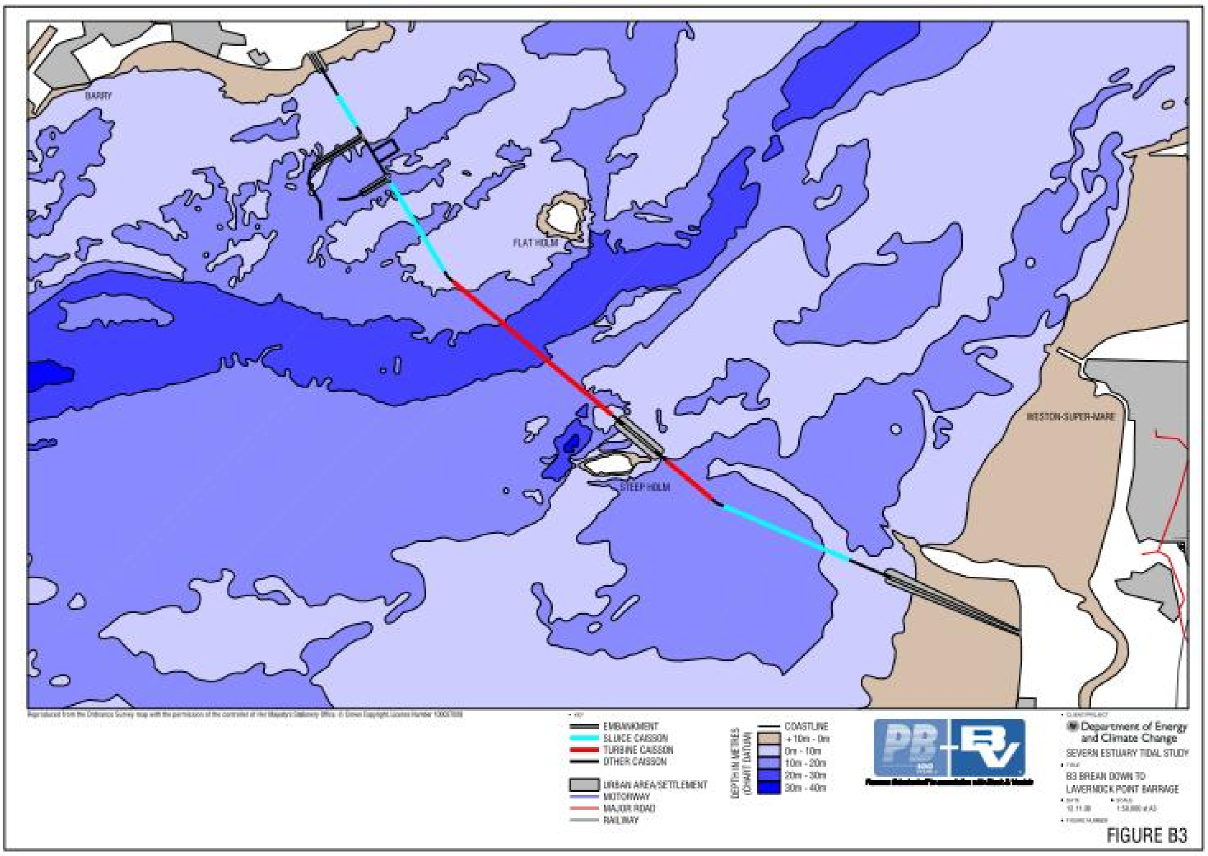


Figure B3 Cardiff to Weston Barrage (from IOAR)

The ebb generation scheme with updated lock sizes is the scheme as shortlisted for phase 2 of the Feasibility Study. The scheme is 16.2km long and contains 129 caissons accommodating 216 nr 40MW bulb turbines and 166 sluices providing a total installed capacity of 8,640MW. The caissons are located in water depths reaching between 30 metres to 40 metres. In shallower areas where bed levels are generally higher than -10m AOD, towards the land fall points and alongside Steep Holm, the barrage is constructed with a conventional rockfill embankment.

The scheme is shown schematically in Figure B3 taken from the IOAR and shown in detail in the Volume 3 drawings.

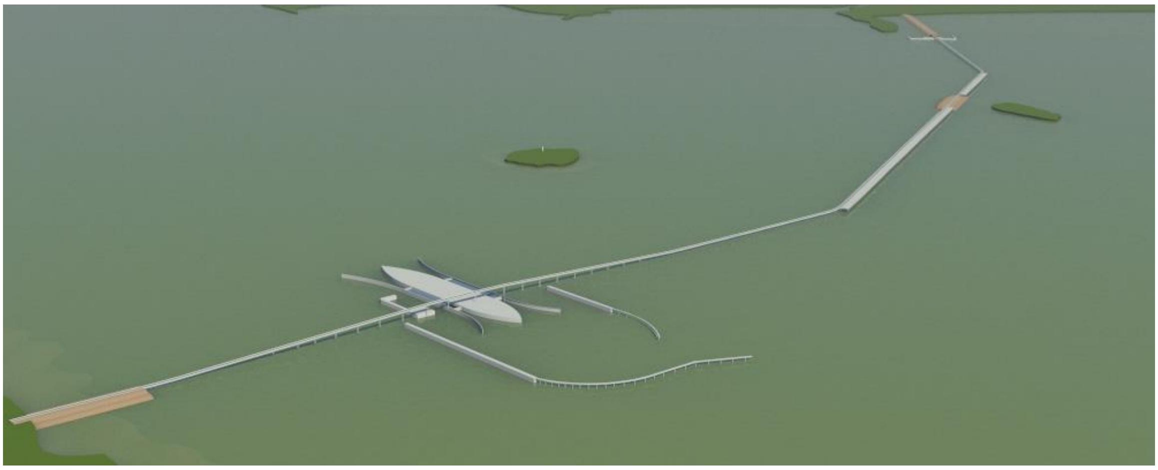


Figure 3.1 Computer Generated Image of the Cardiff to Weston Barrage

B4 Shoots Barrage (also known as English Stones)

The Shoots barrage would run between Caldicot and Severn Beach, downstream of the M4 Second Severn Crossing. The scheme shortlisted for the phase 2 study was the Shoots scheme updated to inform the 2007 Sustainable Development Commission (SDC) study. Its alignment was designed to facilitate a high speed rail link to replace the Severn Tunnel.

As a result of the preliminary optimisation, the alignment has been modified to avoid a Ministry of Defence training area at Rogiet, near Caldicot. Preliminary optimisation also identified that there may be advantages in terms of energy, energy cost and environmental effects of adopting bulb turbine technology in the upstream barrages compared to the Straflo turbines included in the scheme as shortlisted. As bulb turbines are more likely to be feasible in the Shoots than the Beachley Barrage, due to space constraints on the Beachley alignment, bulb turbine technology has been adopted for the Shoots scheme for the purpose of the study. Adoption of bulb turbine technology does not indicate that bulb turbines would be adopted in a final design but taken together with the study into B5 Beachley Barrage which includes Straflo technology, provides a useful comparison between the application of the different turbine types to upstream barrages.

With the modified alignment and change to turbine type, the scheme is a 7.2km long ebb only generation barrage which accommodates 30 nr 35MW Bulb turbines within the deepwater Shoots channel providing a total installed capacity of 1050MW. 42 radial sluice gates are accommodated above and on the Welsh side of the turbines. A lock structure is included for navigation to and from Sharpness Docks. Conventional rockfill embankments constructed over the inter-tidal areas complete the barrage structure.

The scheme as shortlisted is shown schematically in Figure B4 taken from the IOAR and in detail in the Volume 3 drawings.

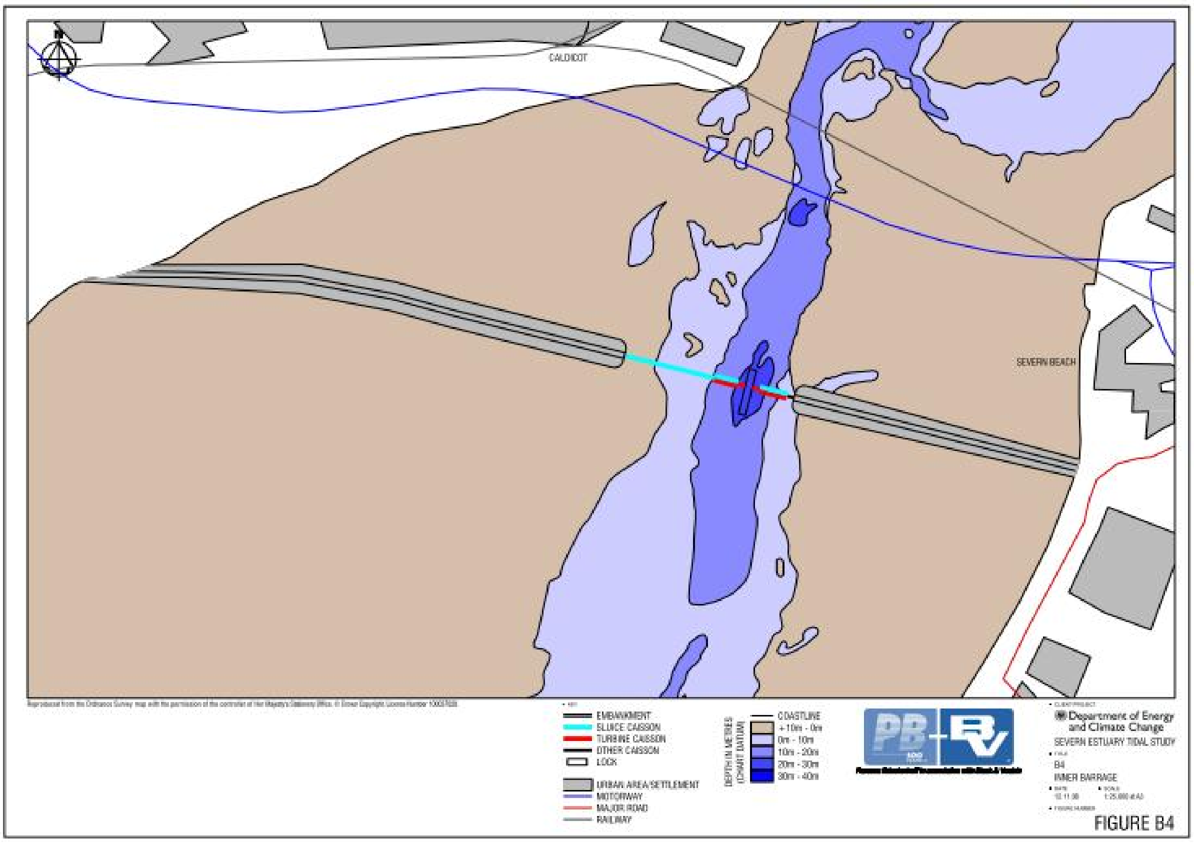


Figure B4 Shoots Barrage (from IOAR)

Figure 3.2 Computer Generated Image of the B4 Shoots Barrage

B5 Beachley Barrage

The Beachley barrage would run between Beachley and Aust, upstream of the M48 Severn bridge crossing. The scheme shortlisted for the phase 2 study was the concept developed for the phase 1 study. The phase 1 study did not include optimisation of the concept and the original installed capacity was based only on limited 0-D and 1-D energy modelling. However, preliminary optimisation has confirmed that the scheme as shortlisted was an appropriate form for strategic study.

The scheme is a 1.9km long ebb only generation barrage comprising 50 nr 12.5 MW Straflo turbines and 26 radial sluice gates providing a total installed capacity of 625MW. Adopting a similar form to the Shoots barrage, most sluice gates would be located above the turbines due to space constraints. A lock structure is included for navigation to and from Sharpness Docks. Conventional rock fill embankments constructed over the shallow inter-tidal areas complete the structure.

The scheme is shown in figure B5 taken from the IOAR and shown in detail in Volume 3 drawings.

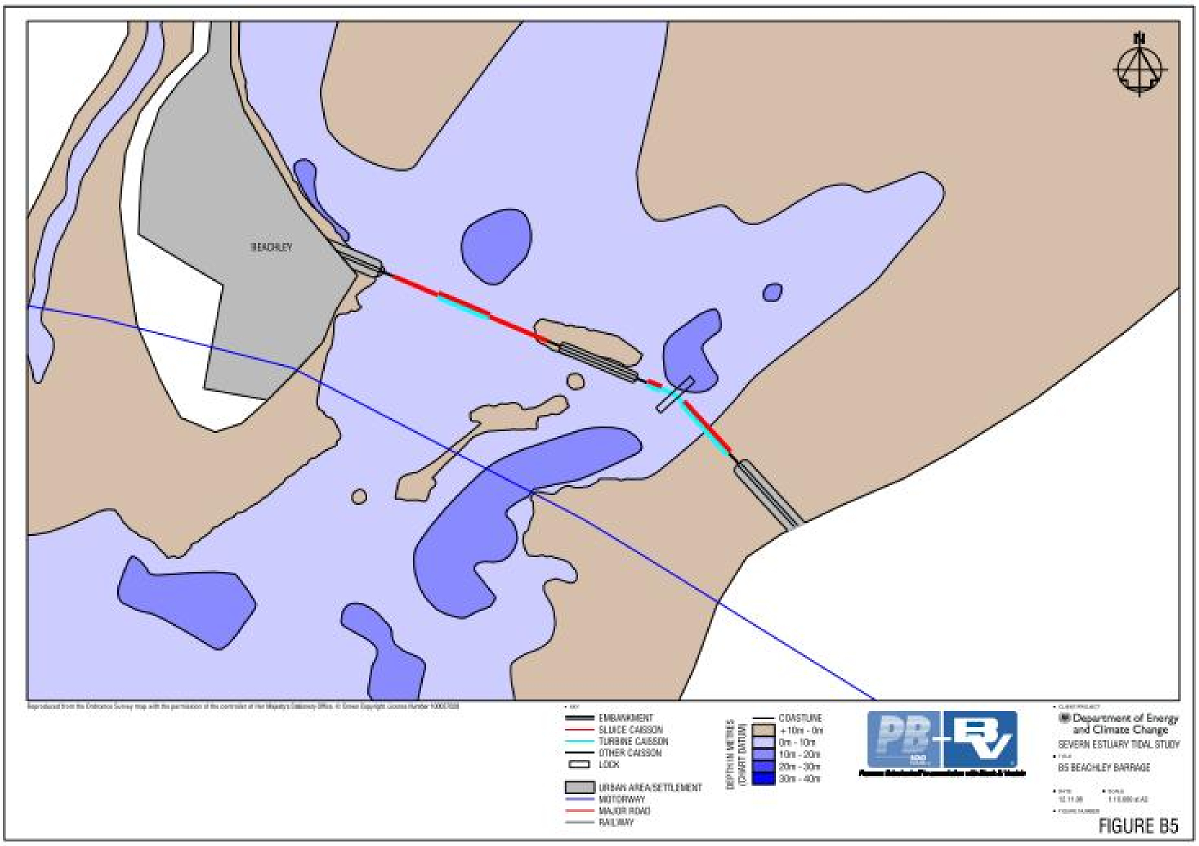


Figure B5 Beachley Barrage (from IOAR)

L2 Welsh Grounds Lagoon

The Welsh Grounds lagoon was originally submitted by Fleming Energy in phase 1 in response to the Call for Proposals. The lagoon would enclose the Welsh Grounds with potential landfall points at Uskmouth to the South and Sudbrook to the North.

The lagoon enclosure is an update of one of the three Russell Lagoon concepts studied by SDC. The enclosure is an ebb only generation scheme which has an overall length of some 28km and an impoundment area of 86km^2. The turbines are located in the Newport Deep channel near the mouth of the River Usk.

Based on limited 0-D and 1-D energy modelling, the phase 1 study estimated an installed capacity of 1360MW using turbines within a range of 12.5MW to 25MW as turbine size was expected to be constrained by available water depth. Fleming Energy originally proposed 1500MW capacity using 50MW turbines.

The preliminary optimisation work indicated that ebb only generation might be preferable in terms of its impact on fish, subject to further study, particularly because of the proximity of the turbines to the mouth of the Usk. In terms of other biodiversity effects, water quality and flood risk, it was not clear from the preliminary optimisation whether ebb or ebb flood generation would be preferable. However, ebb flood mode with turbine capacity selected to maximise energy yield was found to be preferable in terms of energy yield and energy cost.

The preliminary optimisation work did not provide sufficient evidence to conclude on whether the operating mode for Welsh Grounds should be changed to ebb flood mode and it has therefore been taken forward as an ebb only scheme. Bridgwater Bay Lagoon (see below) was taken forward as an ebb flood scheme with an increased turbine capacity. Studying the two lagoons with different operating modes provided the opportunity in the SEA to study whether ebb flood mode could be an appropriate measure to prevent or reduce the adverse environmental or regional effects of the Welsh Grounds lagoon operating in ebb only mode.

Tests were carried out to determine the effects of increasing the turbine capacity of the Welsh Grounds Lagoon. Tests on ebb flood generation with 2100MW capacity identified that the high rate of discharge through the turbines caused a backwater effect believed to be due to hydraulic constraints within the Newport Deep channel. This effect resulted in significant energy losses indicating that increasing generating capacity would reduce the generating efficiency of the lagoon. Increasing the rated output of the Welsh Grounds turbines to 50MW, as originally proposed by Fleming Energy, was also studied but issues relating to turbine submergence depth and high flow speeds were identified. As a result of these tests, the Welsh Grounds Lagoon was taken forward as an ebb generation scheme with 40 nr 25MW turbines and a total installed capacity of 1,000MW. 41 sluices were included at different points around the enclosure to charge the lagoon basin.

The selection of 1,000MW capacity differs from the Fleming Energy's proposals. Fleming Energy has carried out further 1D and 2D modelling since the original selection of 1500MW and has determined that 2,000MW is a more appropriate selection for Feasibility Study. It is understood that the backwater effect described above has not been apparent in Fleming

Energy's modelling.   Despite the large difference in installed capacity, PB's and Fleming's energy estimates are reasonably similar and PB has adopted the lower capacity as it will lead to a lower levelised energy cost. This is discussed in more detail in Section 9.

The scheme is shown in Figure L2 taken from the IOAR and in detail in the Volume 3 drawings.

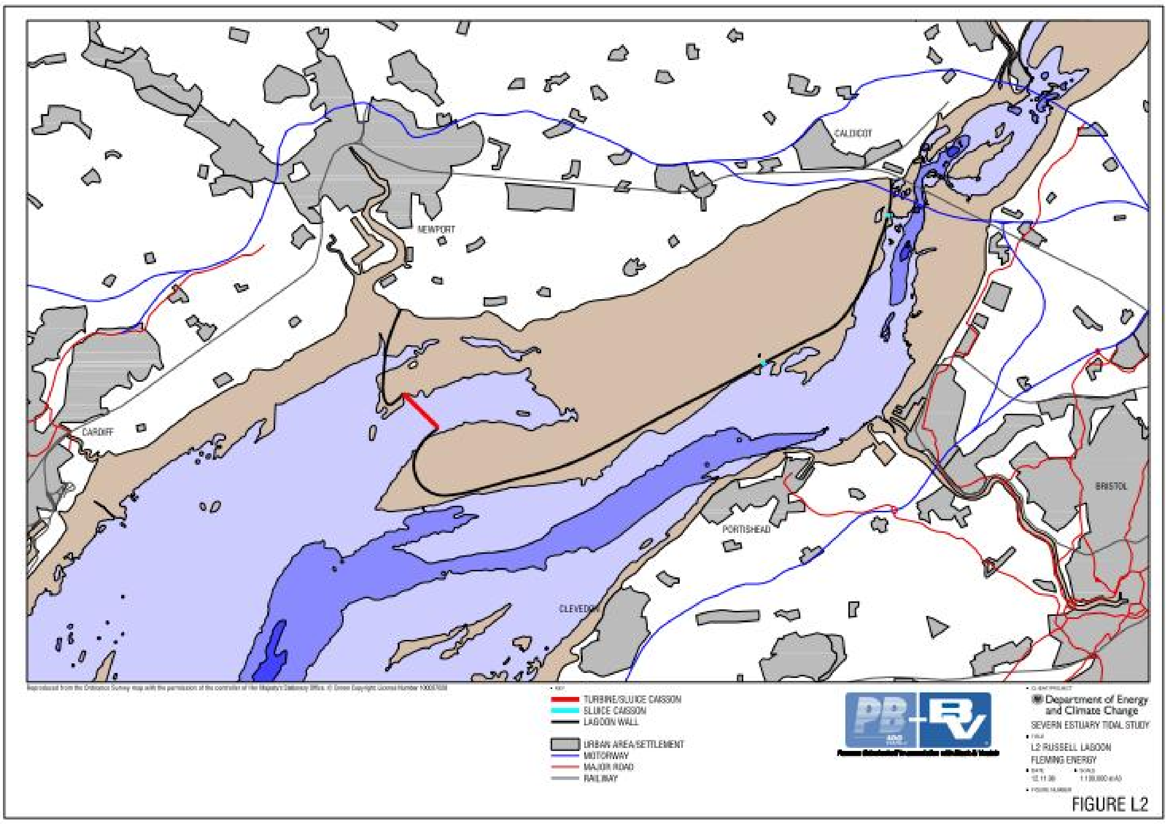


Figure L2 Welsh Grounds Lagoon (from IOAR)

Figure 3.3 Computer Generated Image of the Welsh Grounds Lagoon

<u>L3d Bridgwater Bay Lagoon</u>

The lagoon would enclose Bridgwater Bay with potential landfall points at Brean Down to the North and Hinkley to the South. The scheme shortlisted for the phase 2 study was the concept developed for the phase 1 study.

The scheme is a 16km long ebb only generation enclosure with an impounded area of 87km^2. The turbines are located in two locations, in deep water near to Brean Down and seaward of the River Parrett navigation channel. A lock structure is included for navigation.

The phase 1 study did not include optimisation and the original installed capacity of 1350MW using 12.5MW turbines was based only on limited 0-D and 1-D energy modelling. 41 radial sluice gates are included.

The scheme is shown in Figure L3d taken from the IOAR and in detail in Volume 3 drawings.

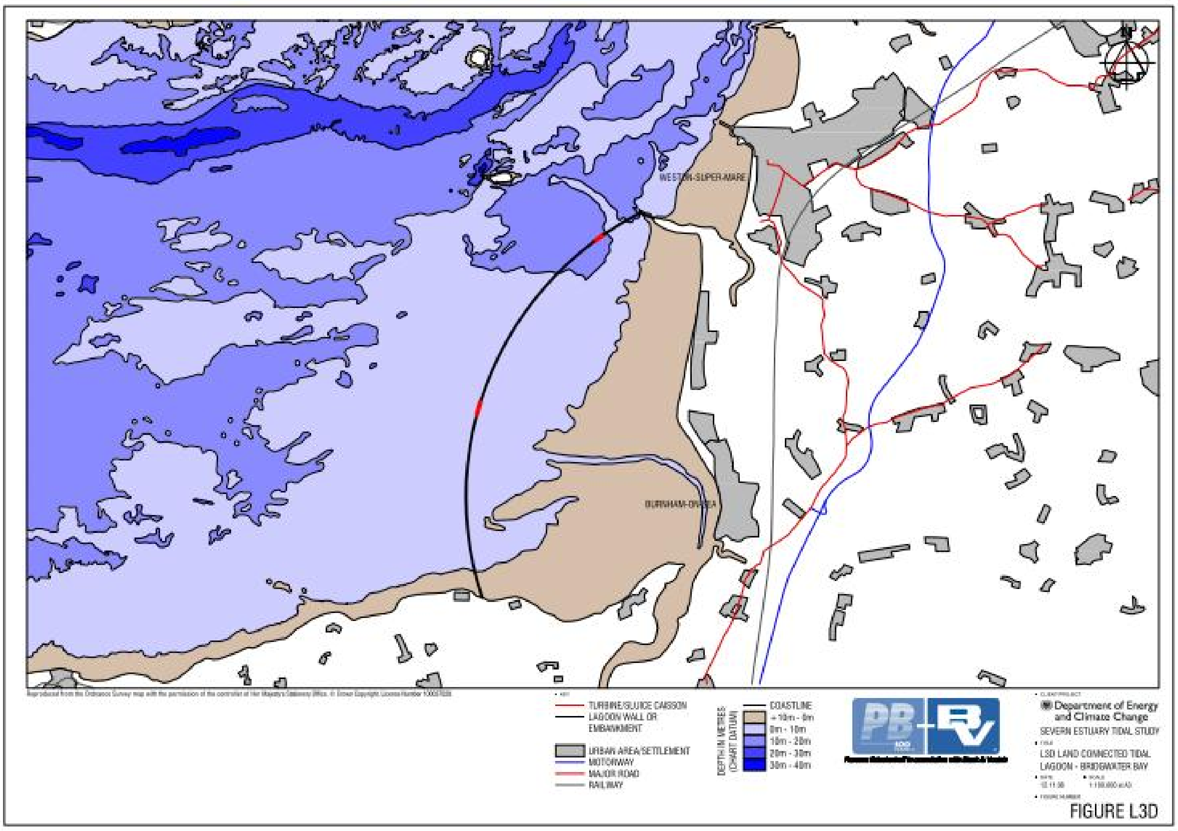


Figure L3d Bridgwater Bay Lagoon (From IOAR)

For the Bridgwater Bay Lagoon, the preliminary optimisation found that operating in ebb flood mode with turbine capacity increased to maximise the energy extracted from the lagoon was preferable in terms of energy yield and energy cost and preferable, or equally so compared to other configurations tested, in all environmental and regional respects except for port access within the lagoon and possibly impact on fish. However, increasing turbine capacity was found to significantly increase capital cost which may impact on the private sector role in ownership and financing.

For this study, ebb flood operation has been adopted with 144 nr 25MW turbines providing an installed capacity of 3,600MW. No sluices have been included as for energy generation in ebb flood mode, all flow in and out of the lagoon would be via the turbines. Addition of sluices may be a requirement during construction to enable closure but that issue requires further study if the scheme is taken forward.

3.4 Summary of Scheme Engineering Data

The following tables provide summary data of scheme definitions. More information is available in Volume 2 Appendix A.

3.4.1 B3 Cardiff to Weston Barrage

Brief Description	This barrage is approximately 16km long structure impounding the Bristol Channel between Lavernock Point near Cardiff and Brean Down, adjacent to Weston-Super-Mare. Key features include: 129 caissons (29 plain caissons, 46 sluice caissons, 54 turbine caissons), 2 large shipping locks (Lavernock Point end), two small ship locks		
Energy Generation	Operating Mode		Ebb Only
Mechanical and Electrical	Turbine Details	Size and Type	9.0m diameter Bulb
		Number	216
		Rated Output (MW)	40
		Major maintenance period	40 years
	Sluice Details	Type	Orifice
		Number	166
		Size	112 nr 16m wide, 54 nr 22m wide
		Major Maintenance period	20 years
Civil Engineering	Design life (years)		120 years
	Overall Length of Structure (m)		16,000 approx
	Embankment Details	3,278m approx total length 778m Central Embankment (with 80m crest) 500m approx Welsh embankment (50m crest) 2,000, approx English embankment (50m crest) Hydraulic sand fill, rock containment mounds, filter layers and rock control structure. 1 in 2 side slopes (seaward) and 1 in 3 side slopes (landward)	
	Caisson Details	12,200m total length Average +9.5m AoD Top of Caisson Height 141 Caissons (excluding lock caissons) 54 Turbine caissons, 46 Sluice caisson, 41 Plain caissons	
Permanent Onshore Infrastructure Requirements	Lavernock Point landfall	2.5ha for offices and welfare facilities, car parking, security and gate, workshops and stores, on site access roads and drainage and a visitors centre	
	Bean Down landfall	2.5ha for offices and welfare facilities, car parking, security and gate, workshops and stores, on site access roads and drainage and a visitors centre	
Indicative Grid Connection Requirements	50% export to the Welsh shore and 50% to the English shore. New sub-station between the landfalls and the National Grid, each occupying five to ten hectares, or substantially smaller if Gas Insulated Sub-stations are used. It is likely that either a new National Grid connection would be required across the barrage or potentially a new overhead line from the Severn Estuary down towards Southampton.		
Construction	Pre-Construction Period		5 years
	Construction period to First Energy Generation		6 years
	Construction period to Full Energy Generation		8.5 years
	Likely Window for Grid Connection (from DECC Grid Study)		2021 to 2023
	Earliest Year of First Generation		2021 to 2023

Table 3.1 B3 Cardiff Weston Barrage Scheme Data

3.4.2 B4 Shoots Barrage

Brief Description	This barrage is a 7.2km long structure impounding the Inner Bristol Channel between land adjacent to West Pill on the Welsh side and Severn Beach on the English side. The proposed structure comprises a combination of embankments within the shallow water and caissons within the deeper channel. Key features include: 49 caissons and 1 shipping lock (40m) at the centre of the channel.		
Energy Generation	Operating Mode		Ebb only
Mechanical and Electrical	Turbine Details	Size and Type	8.15m diameter Bulb
		Number	30
		Rated Output (MW)	35
		Diameter (m)	7.6
		Major maintenance period	40 years
	Sluice Details	Type	Radial
		Number	42
		Size	30m
		Major Maintenance period	20 years
Civil Engineering	Design life (years)		120 years
	Overall Length of Structure (m)		Approximately 7.2km
	Embankment Details	5,400m approx total length 30m Crest including service road and cable ducts Hydraulic sand fill, rock containment mounds, filter layers and rock control structure (closure zone only). 1 in 3 side slopes (seaward) and 1 in 3 side slopes (landward)	
	Caisson Details	1,765m total length 48 Caissons (excluding lock caissons) 15 Turbine/Sluice caissons 27 Sluice caisson 6 Plain caissons	
Permanent Onshore Infrastructure Requirements	West Pill landfall	Security, gate and small car park only	
	Severn Beach landfall	2.5ha for offices and welfare facilities, car parking, security and gate, workshops and stores, on site access roads and drainage and a visitors centre	
Indicative Grid Connection Requirements	100% export to the English shore, requiring modification to the new Aust 400kV sub-station next to the Aust junction of the M48.		
Construction	Pre-Construction Period		4 years
	Construction period to First Energy Generation		4 years
	Construction period to Full Energy Generation		5 years
	Likely Window for Grid Connection (from DECC Grid Study)		2019 to 2021
	Earliest Year of First Generation		2019 to 2021

Table 3.2 B4 Shoots Barrage Scheme Data

3.4.3 B5 Beachley Barrage

Brief Description	This barrage is a 2km long structure running from Beachley on the Welsh side of the River Severn to land directly to the east on the English side. Key features include 1364m caissons, a 40m wide shipping lock and 570m approx. embankment.		
Energy Generation	Operating Mode		Ebb
Mechanical and Electrical	Turbine Details	Size and Type	4.65m diameter Straflo
		Number	50
		Rated Output (MW)	12.5
		Major maintenance period	40 years
	Sluice Details	Type	Radial
		Number	26
		Size	30
		Major Maintenance period	20 years
Civil Engineering	Design life (years)		120 years
	Overall Length of Structure (m)		1,950m
	Embankment Details	570m approx total embankment 30m Crest including service road and cable ducts Hydraulic sand fill, rock containment mounds, filter layers and rock control structure. 1 in 2 side slopes (seaward) and 1 in 3 side slopes (landward)	
	Caisson Details	1,364m total length 31 Caissons (excluding lock caissons) 13 Turbine/Sluice caissons 9 Sluice caisson 9 Plain caissons	
Permanent Onshore Infrastructure Requirements	Beachley landfall	Security and gate only	
	Aust landfall	2.5ha for offices and welfare facilities, car parking, security and gate, workshops and stores, on site access roads and drainage and a visitors centre. Access and cable route provision will require approximately 400m of road construction along the foreshore.	
Indicative Grid Connection Requirements	Assumed to be similar to B4 Shoots Barrage requirements.		
Construction	Pre-Construction Period		4 years
	Construction period to First Energy Generation		4 years
	Construction period to Full Energy Generation		4 years
	Likely Window for Grid Connection (from DECC Grid Study)		2019 to 2021
	Earliest Year of First Generation		2019 to 2021

Table 3.3 B5 Beachley Barrage Scheme Data

3.4.4 L2 Welsh Grounds Lagoon

Brief Description	The Welsh Grounds Lagoon is a proposed 28.4km structure starting from land adjacent to the mouth of the River Usk, running in a general easterly direction across an area referred to as Welsh Grounds, continuing to the south of Denny Island and reaching land fall adjacent to the Second Severn Crossing. The scheme was submitted by Fleming Energy in response to the Call for Proposals.		
Energy Generation	Operating Mode		Ebb only
Mechanical and Electrical	Turbine Details	Size and Type	6.7m diameter Bulb
		Number	40
		Rated Output (MW)	25MW
		Major maintenance period	40 years
	Sluice Details	Type and number	18 submerged orifice sluices and 16 surface radial sluices
		Size	30m width (surface) 20m width (submerged)
		Major Maintenance period	20 years
Civil Engineering	Design life (years)		120 years
	Overall Length of Structure (m)		28,400m approx
	Embankment Details	26,200m approx total embankment 25m crest between Uskmouth landfall and turbine house 16m crest width between turbine house and landfall adjacent to Second Severn Crossing Hydraulic sand fill, rock containment mounds, filter layers and rock control structure (closure zone only). 1 in 3 side slopes (seaward) and 1 in 3 side slopes (landward)	
	Caisson Details	2,225m total length 34 Caissons (excluding lock caissons) 10 Turbine caissons 14 Sluice caisson 10 Plain caissons	
Permanent Onshore Infrastructure Requirements	Uskmouth landfall	2.5ha for offices and welfare facilities, car parking, security and gate, workshops and stores, on site access roads and drainage and a visitors centre.	
	Sudbrook landfall	Security and gate only	
Indicative Grid connection requirements	100% of power exported to the English shore due to capacity issues in Wales. Export is assumed via a 0.2ha Gas Insulated Sub-station on the Welsh shore, with reinforcement required to increase the transmission capacity out of Wales, across the Severn.		
Construction	Pre-Construction Period		4 years
	Construction period to First Energy Generation		5 years
	Construction period to Full Energy Generation		6 years
	Likely Window for Grid Connection (from DECC Grid Study)		2019 to 2021
	Earliest Year of First Generation		2019 to 2021

Table 3.4 L2 Welsh Grounds Lagoon Scheme Data (as developed by PB from the original scheme submitted by Fleming Energy)

The scheme concept in Table 3.4 has been developed by PB from the original scheme submitted by Fleming Energy. The scheme differs from the concept which has been subject to ongoing development by Fleming Energy since the original submission. Dialogue between PB and Fleming Energy has been maintained throughout the Feasibility Study. The differences in scheme proposals have arisen from differences in assumptions made in the concept development. Assumptions have generally been made by PB based on available information to provide the Feasibility Study with reasonable certainty of estimates of cost and programme. In contrast, assumptions have been made by Fleming on the innovations which Fleming would make in taking the scheme forward. The ODR has not adopted the same innovations as Fleming because they are subject to further concept development before they can provide the level of certainty required for Feasibility Study. There is also a difference between the adopted installed capacities which is discussed in Sections 3.3 and 9. The key differences between the scheme concepts studied by PB and Fleming are summarised in Table 3.5 below.

Scheme Data	Scheme Concept Developed by PB	Scheme Concept Developed by Fleming Energy
Operating Mode	Ebb only	Ebb only
Mechanical and Electrical	40 nr 6.7m diameter 25MW turbines providing an installed capacity of 1,000MW	40 nr 50MW 8.25m diameter turbines providing an installed capacity of 2,000MW
Embankment/Structural Wall Proposals	Conventional rockfill embankment (see Table 3.4) over whole impoundment length	Uskmouth landfall to powerhouse: conventional embankment. Powerhouse to Sudbrook landfall: A 13m wide structural wall comprising parallel precast concrete anchored wall panels braced together with precast concrete frames and infilled with dredged material.
Turbine Caissons	58m wide precast concrete cellular caissons of similar form to the caissons designed by STPG for Cardiff to Weston Barrage. Caisson designed to be precast off site, towed and sunk in location requiring dredging of navigation channels for caisson towing.	Concrete caissons of similar shape to the La Rance turbine caisson with a 52m turbine draft tube supporting a 30m wide powerhouse. The lower part of the caisson is precast and towed to site with the aid of buoyancy tanks to avoid temporary dredging. The upper part of the caisson is constructed in-situ.
Plain Caissons	Approximately 50m wide precast concrete cellular caissons of similar form to the caissons designed by STPG for Cardiff to Weston Barrage.	20m wide precast concrete box caissons with 0.5m wide wall sections.
Sluice Caissons	50.5m wide surface sluice caissons similar to Shoots Barrage and 47m wide submerged sluice caissons similar to those designed by STPG for Cardiff to Weston Barrage	20m wide precast concrete surface sluice caissons.
Shipping Locks	Lock included for maintenance access	Lock excluded
Construction Period to First Energy Generation	5 years (50% of generation)	4 years and 2 months (100% of generation)
Construction Period to Full Energy Generation	6 years	4 years and 2 months

Table 3.5 Comparison between Welsh Grounds Lagoon Concepts Developed by PB and Fleming Energy

3.4.5 L3d Bridgwater Bay Lagoon

Brief Description	The Bridgwater Bay lagoon is a land connected tidal lagoon comprising a 16km long embankment, proposed to run from land falls at Brean Down in the north to just east of Hinckley Point in the south. Key features include approximately 3,800m caissons, a 40m shipping lock and approximately 12,200m of embankment		
Energy Generation	Operating Mode		Ebb
Mechanical and Electrical	Turbine Details	Size and Type	8.9m diameter Bulb
		Number	144
		Rated Output (MW)	25
		Major maintenance period	40 years
	Sluice Details	Type	N/A
		Number	None
		Size	N/A
		Major Maintenance period	N/A
Civil Engineering	Design life (years)		120 years
	Overall Length of Structure (m)		28,400
	Embankment Details	25,000m approx total embankment 25m crest between landfalls and turbine houses 16m crest width between turbine houses Hydraulic sand fill, rock containment mounds, filter layers and rock control structure (closure zone only). 1 in 3 side slopes (seaward) and 1 in 3 side slopes (landward)	
	Caisson Details	3,400m total length 45 Caissons (excluding lock caissons) 36 Turbine caissons 9 Plain caissons	
Permanent Onshore Infrastructure Requirements	Brean Down landfall	2.5ha for offices and welfare facilities, car parking, security and gate, workshops and stores, on site access roads and drainage and a visitors centre.	
	Hinkley Point landfall	2.5ha for offices and welfare facilities, car parking, security and gate, workshops and stores, on site access roads and drainage and a visitors centre.	
Indicative Grid connection requirements	100% export is assumed to be at the upstream end, requiring a new sub-station in the vicinity of Brean/Weston Super Mare. Requirements likely to be similar to the English-side connection of Cardiff Weston Barrage. There is a possibility that a new overhead line could be required from the Severn Estuary down towards Southampton.		
Construction	Pre-Construction Period		4 years
	Construction period to First Energy Generation		5 years
	Construction period to Full Energy Generation		6 years
	Likely Window for Grid Connection (from DECC Grid Study)		2023 to 2025
	Earliest Year of First Generation		2023 to 2025

Table 3.6 L3d Bridgwater Bay Scheme Data

3.5 Review of Embankment Crest Levels and Wave Wall Heights

In phase 2 of the SEA, development of options definitions and cost estimates took place over a similar time period to the wave modelling due to constraints on the overall Feasibility Study programme. Therefore, a preliminary assessment of water levels and wave heights was made based on data available within STPG studies to determine the embankment crest levels and wave wall heights on which scheme cost estimates and material resource requirements have been assessed. The derivation of proposed crest levels is contained in Appendix A.

The preliminary assessment of water levels and wave heights has been reviewed against the findings of the hydraulics and geomorphology studies and it has been established that crest levels and wave wall heights of B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon may need to be increased by around 1.5m in the more exposed areas with a lesser increase near to shore. The increase results mainly because wave and wind data available for the SEA studies indicate a higher wave height than the data available for the STPG studies which were measured over a shorter timescale.

Embankment designs will need to be refined if taken forward to a detailed design stage when the issue can be addressed either by increasing embankment crest height or wave wall height or a combination of the two measures. Increased wave exposure may also affect the design of embankment armouring. Wave wall heights on caissons will need to be increased.

It is estimated that the modifications required to embankments and caissons will cause an increase in the reported scheme costs of B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon of 0.5% and 3% respectively. Material resource requirements will also increase.

SECTION 4

PRE-CONSTRUCTION REQUIREMENTS

4 PRE-CONSTRUCTION REQUIREMENTS

The nature of pre-construction requirements may be different for the different options depending upon the scale of the options. A high standard of submission with achievement of consensus through pre-application consultation insofar as this is possible will be required to achieve consent. This implies significant pre-application work being undertaken by the planning applicant to address areas of uncertainty and achieve an informed consensus amongst statutory consultees on issues and impacts. This will require significant work and Table 4.1 outlines the key elements:

Table 4.1 Pre-Construction Requirements

Key Work Areas	Description
Ground Investigation	The preferred option will require a significant ground investigation to update assumptions on ground conditions and amend / refine design assumptions relating to ground conditions.
Outline Design Development	The preliminary designs used for the purposes of the Feasibility Study will require development to outline (and for some aspects - detailed) design and development of technical specifications to enable accurate assessment of requirements and costs by prospective bidders, and to provide a satisfactory level of detail for planning submissions and stakeholders.
Operational Mode Simulation	The modes of operation of the finalised design will require further study and modelling to enable the appropriate effects and their technical, environmental, regional and economic implications to be adequately assessed. These studies will also confirm energy yields and the development of associated power purchase agreements and the underpinning support mechanisms.
Grid Connection Application	A formal application to connect to the National Grid will be required to ensure that they have adequate time to assess the grid reinforcement requirements, enter into contract, achieve the necessary consents and construct / commission the necessary infrastructure.
Legal and Project Promotion Studies	Studies will be required to investigate the legal implications of the changed water regime (and associated groundwater, and land drainage effects), other legal implications, identification of land owners and the role, responsibilities, powers and liabilities of the project owner and, if under separate ownership, the compensatory habitats owner.
Land Requirements	A study will be required to determine the requirements for land purchase / way-leaves and the associated research necessary to inform the land acquisition strategy.

Table 4.1 Pre-Construction Requirements	
Key Work Areas	Description
Environmental Impact Assessment	A comprehensive environmental impact assessment will be required for all elements of the scheme. This would include not only the tidal power scheme itself (and its associated temporary construction requirements) but also any grid reinforcement measures and construction of Habitats Directive compensatory habitats and other mitigation works, remote from the power scheme. The EIA is likely require supporting research studies and will result in the preparation of an Environmental Statement(s).
Statutory Consultee Engagement	An important precursor to the development of designs and undertaking impact assessments will be engagement with the appropriate statutory consultees in terms of planning and the habitats directives. This will be an ongoing activity throughout the planning , construction and operation phases
Regional Economic Impact Assessment	Further work on regional economic issues and appropriate mitigation will be necessary to inform design requirements and planning considerations. In particular, issues that are of concern to the Severn Ports, the local population and the local / regional economies need further consideration so that appropriate requirements can be incorporated into construction requirements (e.g. temporary construction camps and yards, local service infrastructure, mitigation works on flood defences, land drainage and modifications to existing ports). Other significant issues include tourism and recreation, industrial and property development and potentially review of transportation requirements if future revisions of National Policy Statements confirm such a need.
Mitigation Considerations	The design and specification of the proposed power scheme and associated works will not be finalised until appropriate mitigation measures are confirmed and agreed (preferably during any planning pre-application stage but ultimately by the appropriate planning authority)
Habitats Directive, Water Framework Directive and Other Compensatory Measures	It is likely that all options will require compensatory measures under the Habitats Directive and further study will be required to inform size, function, location, design, cost, planning and timing. Strategies for procurement and delivery will be developed following substantive outputs from these further studies. Other offsetting measures (including compensation where applicable) will be considered for other areas of legislation.

Table 4.1 Pre-Construction Requirements	
Key Work Areas	Description
Power Purchase Agreements	Studies will be required to establish the framework for sale of power.
Stakeholder Engagement	Stakeholder engagement and consideration of any issues raised will be an ongoing process as the requirements for the project converge to a finalised design.
Public Consultation	A significant public consultation will be required prior to finalisation of design and associated requirements and the submission for planning consent.
Preparation of Written submission	Irrespective of the planning / consenting route, a comprehensive written application covering all aspects of the studies referenced in this table will be required.

In terms of programme, the length of time required for the above studies will be option specific with the larger options requiring more extensive research studies than the smaller options. The precise length of time required will also be dependent on how many studies are undertaken in parallel and the extent of work undertaken "at risk" during public consultations. The critical path is likely to be determined by the EIA requirements (although the SEA outputs will play a helpful role in scoping and planning the required EIA work) and / or the Habitats Directive compensatory habitats requirements. It is proposed that, allowing for public consultations and the majority of studies being undertaken in parallel where possible, a period of 4 years would be reasonable for all schemes except B3 Cardiff to Weston Barrage for which a period of 5 years should be allowed.

SECTION 5

CONSTRUCTION

5 CONSTRUCTION

5.1 Introduction

Appendix A provides a detailed description of the construction processes and construction periods for each shortlisted scheme. This section summarises the construction processes in generic terms and provides specific details of construction periods and construction employment requirements.

5.2 Generic Construction Sequence

The basis of the construction sequences for both barrages and lagoons is as follows:

- Onshore Facilities: Onshore construction facilities at the landfall points and access road improvements would need to be completed as early as possible to support the early build out from shore and other shore based operations. Off site facilities, particularly caisson construction yards, precasting yards for concrete armour units for embankments, and rock handling facilities, would also need to be prepared as early as possible as they are critical to caisson installation and embankment construction.

- Navigation: Ship locks need to be completed as early as possible, so that ships can be routed through the locks before dredging and caisson placing commences in – or near to - the existing shipping channel. It may be necessary to create a temporary shipping channel in order to limit the overall duration of construction.

- Caisson Construction: The caisson construction programme will need to match the installation programme, because installation of caissons is typically the key to the overall programme. The number of caisson construction yards required will depend on the capability of each yard and the duration of construction for each caisson type.

  Construction of each caisson will need to be completed 2 to 3 months before the target installation date, to allow for tow to the site (including weather down time) and to be able to take advantage of any earlier caisson placing opportunities.

  All schemes require dredging in the early stages of construction, typically starting within a few months of the start of construction. Installation of caissons typically follows soon afterwards. An issue highlighted in the DECC Supply Chain Study is the availability of vessels for dredging and jack up barges for construction operations. Up to two years lead in time may be required for such vessels. This will be a key consideration in the procurement of any scheme and it is likely that separate contracts may be required for the provision of vessels, at least for dredging, well in advance of the main contracts and possibly 'at risk' before consents are obtained, to avoid the lead-in time delaying the project start.

- Caisson installation: One caisson is assumed to be placed per month, on average, on each working front during Neap tides. There will be several available Neap tides each month at the earlier stages of construction, reducing to one or two per month as construction proceeds towards closure. Overall, the programme of one caisson per month allows for a precautionary 100% programme contingency for unsuitable weather (wind and waves), as allowed in the STPG studies. Following set-down of a caisson, ballasting with sand and grouting of the foundation mat has to be completed within 2 weeks, so that the next caisson can be placed during the next Neap tide period if the tide and weather is suitable. (See ref. ii, chapter 16 for more information on caisson installation timing, suitable tides, etc)

- Open up caisson water passages: Water passages in turbine and sluice caissons are opened up as soon as possible after placing of the caisson, in order to keep the velocities in the remaining gaps as low as possible. This will also reduce the risk of local scour around the last caisson placed.

- Build out from shore early: The purpose of this is to avoid creating strong currents adjacent to shore which could mobilise sediments near to the shore. Thus at least the first section of embankment at each shoreline is constructed early before any significant estuary blockage is created by placing caissons.

- Embankment construction: Embankments will be constructed below water by depositing material from a side dump barge. Embankments in more exposed locations and in closure zones will initially require construction of a rock control mound to protect the main embankment construction from the action of waves and tidal currents. Construction of lagoon embankments and the central embankment for B3 Cardiff to Weston Barrage will require embankment construction above water without land access. This would be achieved by constructing a pontoon at the embankment for the offloading of plant, materials and labour. A caisson needs to be placed before the adjacent section of embankment can be completed, because the caisson will need to be founded on rock and also the embankment will wrap around the caisson. The caisson could serve as the pontoon.

- Barrage closure using caissons: The method of closure assumed for a barrage is to place a specially designed caisson in the final gap. This stage of construction was modelled, using a 2D hydraulic model (ref. iii) for the STPG study of Cardiff Weston barrage. This modelling provided current velocities to allow forces on the caisson to be estimated (ref. ii, chapter 16). Also, scale model tests were carried out later to check the behaviour of the caisson and to confirm the forces on the caisson, thus confirming feasibility of the method (ref. iv). The caisson would need to be placed on a foundation which is robust enough to withstand the velocity of tidal flow through the gap. A bed prepared with mattress stone encased in a mattress may be feasible but a more robust solution would be installation of large diameter stub piles. Sluicing during construction is important in reducing tidal flow through the gap during closure. Any scheme taken forward beyond the Feasibility Study would require further more detailed studies into the closure sequence to determine the optimum size and position of sluices required for closure.

- Closure using embankment: Closure using embankment is assumed for lagoons but may also be appropriate for barrages if in detailed design it is concluded that a robust caisson foundation is not viable. For B3 Cardiff to Weston Barrage and B5 Beachley Barrage, adopting an embankment for closure would require a change in the barrage arrangement and possibly a reduction in turbine capacity. The likely method to achieve this is to construct a rock sill in the embankment gap as rapidly as possible over a Neap tide period, to block the currents in the gap and then complete the embankment as designed. This method was used for closure of the embankment for Cardiff Bay barrage. The method will need to be modelled, using a 2D hydraulic model, to confirm feasibility and to provide current velocities in the gap so that the rock sill and embankment design for the closure area can be determined. The use of sluices to control flow (described above for closure using caissons) is equally applicable to closure using embankment. For L2 Welsh Grounds Lagoon there is potential to optimise the position of sluices on the lagoon for ease of closure. For L3d Bridgwater Bay Lagoon, it is possible that sluices may need to be added to the scheme.

- Mechanical and Electrical Installation: Turbines will be transported to the site as complete units on a barge and lifted in by heavy lift crane. This method was selected in the STPG study (see ref. v, chapter 4) for two main reasons: firstly, because it minimises the on-site erection time and hence the cost and risk associated with offshore working below water level and, secondly, because it allows the water passages through the caisson to be closed for as short a time as possible which is necessary for the overall construction sequence and methods. In order to proceed as early as possible with installation and commissioning of mechanical and electrical equipment, access for labour and equipment will be by boat / helicopter initially. Access is made available by road from land as soon as sufficient embankment / caissons are completed. A study of power house building and associated works has not been carried out at present. These works will also need to proceed using marine access only prior to land connection being available.

- Commencement of Generation: Generation can commence once closure has been achieved, National Grid capacity is available, transmission infrastructure has been completed and turbines have been commissioned. Not all turbines would need to be commissioned before generation can start. Construction programmes to first energy generation and full generation have been considered in the following sections. In all cases, it has been assumed that the proportion of full energy yield would equal the proportion of full turbine capacity available. When partial capacity is available, there would be the opportunity for the proportion of full energy yield to exceed the proportion of full capacity by developing a higher head differential across the turbines and generating for a longer period of time. However, this would cause different effects on the tidal range than would occur with full capacity and it has instead been assumed that flows would be controlled by sluicing so that the tidal range effects caused with partial and full capacity would be similar. This is worth studying in more detail beyond the Feasibility Study as a higher energy yield in the initial months would reduce levelised energy costs.

5.3 Construction Periods

Construction periods have been estimated based on assumed construction sequences shown in Volume 3 drawings. The programme to first and full energy generation has then been compared to the likely time that the National Grid connection would be available to determine the earliest date of energy generation.

The likely window of connection is only an estimate and the actual connection date would only be known once a formal connection application is submitted and assessed. An actual connection date could be earlier or later.

Full details of the assumed construction sequences and periods are provided in Appendix A.

5.3.1 B3 Cardiff to Weston Barrage

The assumed construction period is based on a 6 year programme to barrage closure and first generation. This is a very demanding schedule requiring a very large commitment of resources drawn from the UK and international sources. However, it is a reasonable programme as a basis for Feasibility Study provided thorough planning and all consents are in place, plus full design, prior to commencement of construction. The main points to note about the proposed construction sequence and programme are as follows:

The programme requires installation of 216 turbines in 40 months (months 44 to 84). The STPG studies and DECC Supply Chain Survey found that new manufacturing and assembly facilities will be required to meet this timetable. Installation and commissioning of turbines and associated mechanical / electrical equipment will require a large number of teams on site. Availability of these specialist teams is likely to be a limiting factor on the generation % achievable following barrage closure.

The profile to full energy generation with 44 turbines installed and commissioned per year can be assumed to be as show in Table 5.1.

Months	No Turbines	% of full generation
72	110	50%
84	154	70%
96	198	90%
102	216	100%

Table 5.1 B3 Cardiff to Weston Barrage (Original Ebb Scheme) - Programme to Full Energy Generation

The programmes to full generation in Table 5.1 assume that grid reinforcements will be completed in time to make the connection. The Grid Study report identifies a likely window for connection of 2021 to 2023 assuming a new National Grid connection across the barrage, which is similar to the programme to part and full generation assuming a five year pre-construction period.

5.3.2 B4 Shoots Barrage

The assumed construction period achieves 50% of full generation by month 48 and full generation by month 60. In order to meet the programme, 15 turbines need to be installed and commissioned in 18 months, followed by a further 15 machines in the final 12 months. The Grid Study report identifies a likely window of connection of 2019 to 2021 which is likely to govern the programme to full generation.

5.3.3 B5 Beachley Barrage

The assumed construction period achieves 100% of full generation by month 48. In order to meet the programme, 15 turbines need to be installed and commissioned in 18 months, followed by a further 15 machines in the final 12 months. The Grid Study report identifies a likely window of connection of 2019 to 2021 which is likely to govern the programme to full generation. The programme requires the 50 turbines to be installed and commissioned in 24 months. This is a fast programme, particularly in view of the significant on site element of erection, and will need detailed discussion with the turbine supplier. This has not been carried out in this study.

The Grid Study report identifies a likely window of connection of 2019 to 2021 which is likely to govern the programme to full generation.

5.3.4 L2 Lagoon Welsh Grounds Lagoon (drawing 97051A/L2/051)

The construction sequence and programme for L2 Welsh Grounds Lagoon is determined mainly by the rate of construction of the embankment and also by the assumed closure method and location.

The total length of L2 Welsh Grounds enclosure is 28.4 km, of which approximately 26 km is embankment (or Fleming wall if feasible). The assumed sequence is based on a rate of construction of 150m per month per front, except for the section to be built on soft sediments near Uskmouth where a rate of 100m per month is assumed. These rates of construction are based on judgement at present and need further study. In order to achieve an overall programme of lagoon closure in about 4 years, five concurrent embankment construction fronts would be required. The assumed sequence results in closure at 2 locations, spaced about 12km apart, which seems reasonable to avoid excessive sediment transport within the very long lagoon area.

In order to meet the programme of full power after 6 years, 40 turbines would need to be installed and commissioned in 24 months. Alternatively, the installation of the first turbine could be brought forward to month 36 – without land access to the power house until month 48. With turbine installation commencing in month 49, 50% of full energy generation could be achieved by month 60 with 100% generation by month 72.

The Grid Study report identifies a likely window of connection of 2019 to 2021 which is likely to govern the programme to full generation.

5.3.5 L3D Bridgwater Bay Lagoon

As for L2 Welsh Grounds Lagoon, the construction sequence and programme for L3d Bridgwater Bay Lagoon is determined mainly by the rate of construction of the embankment and also by the assumed closure method and location.

The total length of L3d Bridgwater Bay enclosure is 16.3 km, of which approximately 13.2 km is embankment. The proposed sequence is based on a rate of construction of 50m per month per front. The slower rate of construction compared to L2 Welsh Grounds Lagoon reflects the deeper water and greater exposure to waves. In order to achieve an overall programme of lagoon closure in about 5 years, 6 concurrent embankment construction fronts are required. The rate of construction of 50m per month is based on a preliminary and possibly conservative assessment of a sequence of operations. The proposed sequence results in closure at 2 locations, spaced about 7km apart, which have a group of turbines located between them.

In order to meet the programme of full power after 6 years, turbine installation would need to commence without land access with 144 machines installed and commissioned in 42 months. With a rate of turbine installation comparable to B3 Barrage (41 per year), new manufacturing and assembly facilities would be required.

Assuming a rate of turbine installation and commissioning of 41 per year, the profiles to full energy generation shown in Table 5.2 could be achieved:

Months	Installation Commences Month 30	
	No Turbines	% of Full Generation
42	41	0%
54	82	0%
60	102	0%
62 (Closure)	109	76%
66	123	85%
72	144	100%
84	144	100%

Table 5.2 L3d Bridgwater Bay Lagoon – Programme to Full Energy Generation

The Grid Study report identifies a likely window of connection of 2023 to 2025. This is later than other schemes because of the potential requirement for a new overhead line and significant reconductoring works to reinforce the grid. The availability of the grid connection is likely to govern the programme to full generation.

5.4 Temporary Onshore Facilities

The following temporary facilities will typically be required onshore at the landfall points:

- Security, visitor centre and public car parking.
- Temporary offices, welfare facilities and car parking for the construction work-force.

- Temporary storage areas for materials delivered by land. These are likely to include: buildings (sub-stations, etc), road materials and possibly materials for part of the upper part of the embankment, cable drums and electrical equipment (switchgear, etc).

Areas required for these temporary facilities are indicated below based on assumed distributions of working areas between landfall points. The actual distribution between landfalls and precise location of the facilities will depend on availability of land and planning issues, as well efficiency of operations. The areas do not allow for a temporary construction camp as the need for a camp has not been identified by the SEA Communities study.

For B3 Cardiff to Weston Barrage, assuming that the temporary facilities are split equally between the landfall points, approximately 10ha will be required at Lavernock Point and at Brean Down. The actual distribution between landfalls and precise location of the facilities will depend on availability of land and planning issues, as well efficiency of operations.

For B4 Shoots Barrage, assuming that the temporary facilities are split equally between the landfall points, approximately 7.5ha will be required at Caldicot and at Severn Beach.

Due to access constraints at Beachley, the facilities for B5 Beachley Barrage will primarily be required at Aust (approximately 7.5ha). Only security and a gate will be required at Beachley and minor office and welfare facilities for access construction.

For L2 Welsh Grounds Lagoon, temporary facilities are assumed to be split in a 3:1 ratio between Uskmouth (7.5ha) and Sudbrook (2.5ha) with the visitors centre being at Uskmouth.

For L3d Bridgwater Bay Lagoon, temporary facilities are assumed to be split in a 2:3 ratio between Brean Down (7ha) and Hinkley (10.5ha).

5.5 Construction Stage Employment Requirements

5.5.1 Introduction

This section provides estimates of the person years employment required in the construction stage for the shortlisted schemes including:

- The total number of person years employment for each scheme;
- The component of overall construction employment requirements within the region (including split between England and Wales for the B3 Cardiff to Weston Barrage) profiled over the construction stage; and
- Proportion of construction employment requirements in the region in different skills categories

5.5.2 Methodology and General Assumptions

The total number of person years employment for each scheme has been estimated using the earned value per person year reported by DTZ in the 2008 regional impact study as £139,000 to £149,000.

The likely local labour share of the total employment requirements has been estimated for each construction activity for each scheme taking into account the likely location of the work. The regional employment labour requirements have been profiled over the construction periods in line with the construction sequences and programmes reported in Section 5.3.

The following general assumptions have been made in the employment estimates:

- It is assumed that all turbine manufacture will take place outside the region. Due to the large numbers of turbines for B3 Barrage and L3d Lagoon, new manufacturing facilities will be required to provide capacity to deliver turbines at the required frequency for the programmes assessed. These facilities could be within the region or elsewhere. Labour requirements for turbine manufacture have not been included in regional employment estimates.

- Other than B3 Cardiff to Weston Barrage, it is assumed that all caisson fabrication will take place within the region with concrete aggregates sourced within the region or supplied by sea from outside the region.

- B3 Cardiff to Weston Barrage caisson yard employment in the region represents one third of total UK caisson yard employment.

- For B3 Cardiff to Weston Barrage, the employment profile will be based on an 8.5 year overall construction period assuming the installation of 44 turbines per year.

- M&E labour employed in material manufacture is assumed to be related only to transmission equipment and cranes, not turbine equipment and gates.

- For B4 Shoots Barrage, civils employment is split 50:50 between shores; 90% of M&E employment assumed on English shore.

- For B4 Shoots Barrage, L2 Welsh Grounds Lagoon and L3d Bridgwater Bay Lagoon, the regional employment required for material supply is assumed to be the same as B3 Cardiff to Weston Barrage. There is considerable uncertainty over this estimate due to uncertainty in material sources.

The full derivation of construction employment estimates in provided in Appendix A.

5.5.3 Overall Construction Employment and Leakage Estimates

In the DTZ study, rates of £139,000 to £149,000 per person year were used to determine overall construction employment requirements. These were based on Office of National

Statistics data for site preparation and earth moving/demolition respectively. These rates have been applied to determine the overall construction employment requirements.

The likely share of local labour was reported generically in the DTZ Regional Impact Study for each stage of construction and applied to the long listed options. For each short listed scheme, the likely local labour share has been reviewed and updated to provide a specific local labour share for each stage of each scheme. The updated local labour shares are provided in Table 5.3.

Construction Activity	Skill Level Low/Medium/ High	Key Skill Sets	Likely Share of Local Labour (%)				
			B3	B4	B5	L2	L3d
Preliminaries and Site Overheads	30/60/10	General labourers/building trades/ civil engineers	50	85	90	85	85
Caissons	20/60/20	General labourers/building trades/ civil engineers	45	90	90	90	90
Embankments	30/60/10	General labourers/building trades/ civil engineers	85	80	85	80	80
Navigation Locks	20/60/20	General labourers/building trades/ civil engineers	65	90	90	85	85
Surface Buildings	20/70/10	General labourers/building trades/ civil engineers	50	50	50	50	50
Mechanical and Electrical	5/50/45	Apprentices/technicians/ engineers	10	10	10	10	10
Design & Supervision	0/0/100	Professional Engineers	50	50	50	50	50
Site Investigation	10/50/40	General labourers/building trades/ civil engineers	25	25	25	25	25
Ancillary Works	20/60/20	General labourers/building trades and technicians/ professional engineers	70	70	70	70	70

Table 5.3 Estimated Skills Profile and Local Labour Shares

The local labour shares shown in Table 5.3 have been used to determine the overall employment leakage rate for each scheme by applying them in proportion to the value of each construction activity. The overall construction employment requirements, estimated leakage rates and regional person years employment are shown in Table 5.4.

Scheme	Project Cost Inc Contingency Excl Habitats Directive Compensation (£bn)	Overall Person Years Employment	% Leakage	Regional Person Years Employment
B3 Cardiff to Weston Barrage	20,832	140,000 to 150,000	Around 60%	50,000 to 55,000
B4 Shoots Barrage	3,931	25,000 to 30,000	Around 40%	15,000 to 18,000
B5 Beachley Barrage	2.659	Around 20,000	Around 45%	Around 9,000
L2 Welsh Grounds Lagoon	5,501	35,000 to 40,000	Around 35%	22,000 to 26,000
L3d Bridgwater Bay Lagoon	10.643	70,000 to 80,000	Around 50%	36,000 to 41,000

Table 5.4 Employment Requirements and Leakage Rates

5.5.4 Regional Construction Employment Profiles

The regional employment profiles for the shortlisted schemes are shown in Tables 5.5 to 5.9 based on an analysis of employment requirements over the assumed construction periods and applying the likely local labour shares shown in Table 8.4.

Location	Construction Year																	
	1		2		3		4		5		6		7		8		9	
	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E
Caisson Yards (all assumed to be in Wales)	1,000 to 2,000	-	3,000 to 5,000	-	3,000 to 5,000	-	2,000 to 4,000	-	1,000 to 3,000	-	1,000 to 2,000	-	-	-	-	-	-	-
English Shore and Offshore	Up to 1,000	-	1,000 to 2,000	-	1,000 to 2,000	-	1,000 to 2,000	Up to 1,000	1,000 to 2,000	Up to 1,000	Up to 1,000	Up to 1,000	-	-	-	-	-	-
Welsh Shore and Offshore	1,000 to 2,000	-	3,000 to 4,000	-	3,000 to 4,000	-	3,000 to 4,000	-	3,000 to 4,000	-	3,000 to 4,000	-	-	Up to 1,000	-	Up to 1,000	-	Up to 500
Total	2,500 to 3,500	-	7,500 to 8,500	-	7,500 to 8,500	-	6,500 to 7,500	Up to 1,000	5,500 to 6,500	Up to 1,000	4,000 to 5,000	Up to 1,000	-	Up to 1,000	-	Up to 1,000	-	Up to 500
Total Civil + M&E	**2,500 to 3,500**		**7,500 to 8,500**		**7,500 to 8,500**		**7,000 to 8,000**		**6,000 to 7,000**		**4,500 to 5,500**		**Up to 1,000**		**Up to 1,000**		**Up to 500**	
Notes	1. Estimates exclude labour element of material manufacture [4000 person years (Civil), 2000 – 5000 person years (M&E)] 2. Estimates exclude labour employed in material supply (3000 – 5000 person years) 3. Estimates exclude employment for gate fabrication 4. Level of uncertainty reflected in total civil and M & E estimate																	

Table 5.5 B3 Cardiff to Weston Barrage: Construction Labour Requirements within the Severn Region

B4 Shoots Barrage	Year 1		Year 2		Year 3		Year 4		Year 5	
	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E
Caisson Fabrication Total	1,500	0	1,500	0	1,500	0	100	0	0	0
English Shore and Off-Shore	500	0	600	0	400	200	300	200	0	100
Welsh Shore and Off-Shore	500	0	600	0	400	0	400	100	0	100
Total	2,500	0	2,700	0	2,300	200	800	300	0	200
Total Civil and M & E	2,000 to 3,000		2,000 to 3,000		2,000 to 3,000		500 to 1,500		Up to 500	

Notes:

1. Caisson yards would be located as close as reasonably possible to the site, downstream of the M4 bridge crossing. The yard is likely to be on the English shore where there is better access to deep water.
2. Level of certainty reflected in Total Civil and M&E estimate

Table 5.6 B4 Shoots Barrage Annual Employment Estimate

B5 Beachley Barrage	Year 1		Year 2		Year 3		Year 4	
	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E
Caisson Fabrication Total	1,000	0	800	0	500	0	0	0
English Shore and Off-Shore	700	0	1,500	0	800	300	200	300
Welsh Shore and Off-Shore	0	0	0	0	0	0	0	0
Total	1,700	0	2,300	0	1,300	300	200	300
Total Civil and M & E	1,500 to 2,000		2,000 to 3,000		1,000 to 2,000		Up to 1,000	

Notes:

1. Caisson yard would be located as close as reasonably possible to the site, probably downstream of the M48 bridge crossing and upstream of the M4 bridge crossing. The yard is likely to be on the English shore.
2. All temporary onshore construction facilities would be located at Aust, except for facilities required for minor works associated with security, gatehouse and emergency access at Beachley.
3. Level of certainty reflected in Total Civil and M&E estimate

Table 5.7 B5 Beachley Barrage Annual Employment Estimate

L2 Welsh Grounds Lagoon	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6	
	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E
Caisson Fabrication Total (all assumed to be in Wales)	1,500	0	1,500	0	1,500	0	1,000	0	0	0	0	0
English Shore and Off-Shore	0	0	0	0	0	0	0	0	0	0	0	0
Welsh Shore and Off-Shore	2,000	0	2,000	0	2,000	0	1,800	0	900	400	0	400
Total	3,500	0	3,500	0	3,500	0	2,800	0	900	400	0	400
Total Civil and M & E	3,000 to 4,000		3,000 to 4,000		3,000 to 4,000		2,500 to 3,000		1,000 to 2,000		Up to 1,000	

Note:

1. Shore based activities are assumed to be split between Uskmouth (75%) and Sudbrook (25%)
2. Level of certainty reflected in Total Civil and M&E estimate

Table 5.8 L2 Welsh Grounds Lagoon Annual Employment Estimate

L3d Bridgwater Bay Lagoon	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6	
	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E	Civil	M&E
Caisson Fabrication Total (all assumed to be in Wales)	2,000	0	2,500	0	2,500	0	2,000	0	1,500	0	0	0
English Shore and Off-Shore	2,500	0	2,500	0	2,500	400	2,500	1,500	2,500	1,000	0	1,000
Welsh Shore and Off-Shore	0	0	0	0	0	0	0	0	0	0	0	0
Total	4,500	0	5,000	0	5,000	400	4,500	1,500	4,000	1,000	0	1,000
Total Civil and M & E	4,000 to 5,000		4,500 to 5,500		5,000 to 6,000		5,500 to 6,500		4,500 to 5,500		Up to 1,000	

Note:

1. Shore based activities are assumed to be split between Hinkley (60%) and Brean Down (40%)
2. Level of certainty reflected in Total Civil and M&E estimate

Table 5.9 L3d Bridgwater Bay Lagoon Annual Employment Estimate

SECTION 6

OPERATION AND MAINTENANCE

6 OPERATION AND MAINTENANCE

Operation and maintenance costs have not been estimated in detail in previous studies but have instead used global figures expressed as a percentage of capital costs. Historically, costs have been estimated as set out in Table 6.1 below.

Study	O&M Cost Assumptions
Severn Barrage Committee (EP46 -1981)	1% of capital cost of plant or 0.75% of capital cost of structure.
STPG (EP57 - 1989)	Permanent Workforce of 844 comprising 60 professionals, 210 technical, 300 skilled and 274 clerical/administrative for Cardiff Weston. Total cost allowed was £70m per year for all operation and maintenance.
STPG (2002)	Total annual cost £112m per year (based on EP57 but escalated to 2002 costs).
SDC (2007)	350 personnel for an English Stones scheme and 1770 for a Cardiff Weston scheme (but drawn from STPG's 1989 report).
IOAR (2008)	1.75% of capital cost for smaller barrages, lagoons, fences etc and 1.25% for larger barrages – including external charges such as business rates, royalties etc.

Table 6.1 Operation and Maintenance Cost Assumptions

For this study, operational and maintenance spend has been built up for each of the shortlisted options. These costs exclude asset replacement costs which are accounted for separately. Staff numbers required for operation and maintenance have been estimated using data from the data available from La Rance and previous studies. An average salary cost of £40,000 has been assumed and it is assumed that overhead costs (excluding rates and insurance) are equivalent to 50%f the basic salary costs. Annual insurance costs have been assumed at 0.2% of the capital cost whilst annual business rates have been assumed at 0.3% of the capital cost. Annual maintenance contracts have also been included to account for maintenance dredging, bathymetric surveying and other activities that are likely to be contracted out. The annual O&M costs thus calculated typically represent approximately 1% of the capital costs.

Generation tariffs have been based on the Transmission Network Use of System (TNUoS) tariffs applicable from 1st April 2009 as published by National Grid. Changes to the generation tariffs caused by adding a large generator in the Southwest England/South Wales zone have been estimated by DECC. The derivation of generation tariffs (quoted to the nearest £m) is given in Table 6.2. It should be noted that the generation tariffs will change over time as generation capacities and demand change. Tariffs have therefore only been included as an indication of the tariffs which might be applicable over the scheme life.

Option	Capacity (MW)	Annual Wider Generation Tariff Applicable from 1st April 09 (£/kW)	Annual Local Generation Tariff Applicable from 1st April 09 (£/kW)	Estimate of Increase in Annual Generation Tariff (£/kW)	Estimated Annual Generation Tariff Applicable to Scheme (£/kW)	Estimated Annual Generation Tariff Applicable to Scheme (£m)
B3 Cardiff to Weston Barrage	8,640	-1.60	0.34	6.50	5.24	45
B4 Shoots Barrage	1,050	-1.60	0.16	1.20	-0.24	0
B5 Beachley Barrage	625	-1.60	0.16	0.00	-1.44	-1
L2 Welsh Grounds Lagoon	1,000	-1.60	0.16	1.80	0.36	0
L3d Bridgwater Bay Lagoon	3,600	-1.60	0.34	6.50	4.00	14

Table 6.2 Derivation of National Grid Tariffs

Operational and maintenance spend has been estimated as shown in Table 6.3 for each of the shortlisted options.

In addition to these costs, experience from other marine and hydro-electric schemes indicates that gates and turbines will require major maintenance every 20 to 40 years respectively and these costs have been included in the levelised energy costs.

The operation and maintenance costs do not include operational dredging to maintain shipping channels which are included in Section 10.

Option:	B3 Cardiff to Weston Barrage	B4 Shoots Barrage	B5 Beachley Barrage	L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
Staff Numbers	850	150	90	150	400
Staff Costs (£m)	34	6	4	6	16
Staff Overhead Costs (50% of staff costs) (£m)	17	3	2	3	5
Business Rates (£m)	60	12	8	18	29
Insurance (£m)	40	8	5	12	19
Annual Maintenance Contract Costs (£m)	50	10	5	10	15
Contingency 15% (£m)	30	6	4	7	13
Generation Tariff (£m)	45	0	-1	0	14
Total (£m)	276	45	27	56	111

Table 6.3 Operation & Maintenance Costs (£m)

SECTION 7

DECOMMISSIONING

7 DECOMMISSIONING

Decommissioning costs for tidal power schemes with long asset lives are difficult to estimate for a number of reasons. Firstly, the life of structures typically extends beyond the nominal 120 years assigned to fixed civil engineering structures. There are many examples of marine structures that date from the early 19th century and still exist today – primarily in the form of ports, harbours and bridges. In the normal lifetime of such structures, usual practice is not to decommission but to maintain and replace components as and when they reach the end of their life. Such costs are accounted for in the Operation, Maintenance and Asset Replacement cost streams.

The question of when and what should be decommissioned has to be addressed as part of a decommissioning plan. The worst case decommissioning scenario would be if a decision was taken to cease operation during the financing period (an emergency situation for example). It is difficult at this stage to judge whether planned decommissioning at the end of the operating life would be a complete removal of the structures above foundation level or whether parts of the structure would be preserved and over what timescale.

Partial decommissioning could comprise removal of the sluice gates and turbines to allow natural tidal levels to be restored. This would be a relatively quick process compared to complete decommissioning.

For all schemes, complete decommissioning and removal of all structures above the sea bed would be possible. It is unlikely that decommissioning would include demolition and/or removal of structures buried below the sea bed and for this reason, combined with the less precise nature of demolition (compared with construction) and the associated time savings, costs of decommissioning will be lower than costs of construction (excluding mechanical and electrical engineering costs).

A complete decommissioning would generally be a reverse of the construction process and the following decommissioning process could be applied to all the shortlisted schemes:

- Temporary facilities would be constructed at the landfall points. The general requirements and distribution of the facilities would likely be the same as assumed for the construction stage but the footprint would be smaller.
- Mechanical and electrical equipment would be removed. Components which should be salvaged for re-use where possible. The remaining components would be stripped out, materials separated on site, prepared for transportation and transported off site to suitable recycling facilities. Metal components would likely be crushed on site.
- Once all the M&E equipment has been removed, except for the navigation lock equipment, all turbine and sluice passages would be kept open so that the structure is as permeable as possible before the impoundment structure is breached.
- Surface buildings and access roads would then be removed. Materials would be separated and recycled.
- For lagoon structures with impoundment constructed of embankment, the embankment would be breached by removal of material at the original closure section. Rockfill within the closure section would be removed over a series of low tides.

- For barrages, the structure would be breached by removal of the caissons originally placed to close the structure. Further study would be required to determine the operation sequence for refloating the caissons. Most likely, a sequence would be required whereby the cells within the caisson are broken open and the ballast removed whilst sufficient voids within the caisson are flooded to maintain acceptable temporary stability. The ability to implement such a sequence is a key consideration in the design of the caissons.
- The caissons would be secured by tow lines to barges which would tow the caissons to dismantling facilities at suitable yards.
- At the yards, the caissons would be broken up, separating steel reinforcement and prestressing tendons from concrete. Concrete would be crushed for reuse as aggregate. Steel would be recycled.
- During the removal of caissons, removal of embankments would proceed. For barrages, the removal of the embankments would take place after enough caissons have been removed to reduce flows at the foreshore which would lead to erosion. Removal of embankments above water would take place from the embankment and below water by barge.
- Navigation locks would need to remain in operation until enough caissons have been removed to provide passage through the structure.

Removal of structures would generate significant volumes of construction waste although much of this could be put to beneficial use (e.g. recycling of concrete for aggregates etc). Planned decommissioning at the end of the useful economic life of the tidal power station would essentially require a similar process to the promotion of the project. A policy decision would be required confirming that the tidal power plant was no longer required, following which planning consents would have to be applied for to remove the structure, or parts of it, and restore the natural tidal regime with its associated environmental and regional economic effects.

It is also worth noting that planned decommissioning costs would only be incurred at the end of the useful economic life of the project (notionally 120 years after first operation). By the time decommissioning costs (whether they are 25%, 50% or 100% of the construction cost) are discounted back to the present day, their impact on the cost of electricity in £ per MWh is not significant A more important component therefore in any decommissioning plan is not the impact that decommissioning will have on cost of energy but to ensure instead that a sinking fund is created at the start of the project to enable the small contribution from energy revenue and the associated interest to accrue over the lifetime of the project to build the decommissioning fund. The cost of such a fund has not been considered in the operating and maintenance costs at this stage and requires further consideration.

SECTION 8

LIKELY SIGNIFICANT EFFECTS ON THE ENVIRONMENT AND MEASURES TO PREVENT, REDUCE AND COMPENSATE FOR ADVERSE EFFECTS

8 LIKELY SIGNIFICANT EFFECTS ON THE ENVIRONMENT AND MEASURES TO REDUCE, PREVENT AND COMPENSATE FOR ADVERSE EFFECTS

8.1 Likely Significant Effects on the Environment

This section provides a summary description of the likely significant effects on the environment resulting from each alternative option. In some instances, including the assessment of cumulative and consequential development effects, the effects identified are not significant and thus they are not described below. The description below does not account for measures to prevent or reduce significant effects except those already included as ancillary in the definition of alternative options (i.e. works that are necessary as a consequence of the construction of a tidal power facility to prevent or reduce the effect on day to day operation of existing assets). For each theme the key effects are explained.

This section should be read in conjunction with the Environmental Report (ref xv) and Report to Inform a Stage 2 Habitats Regulations Assessment which provide a more complete assessment of significant effects and requirements for compensation.

8.1.1 Key significant physicochemical effects

All the alternative options are shown to reduce the tidal range within the impounded part of the Severn Estuary. Under an ebb-only mode of operation (B3 Cardiff to Weston Barrage, B4 Shoots Barrage, B5 Beachley Barrage and L2 Welsh Grounds Lagoon), a high water stand and extended ebb period is created, which distorts the tidal regime within the impounded estuary. Under an ebb-flood mode of operation (L3d Bridgwater Bay Lagoon), a sustained duration of high and low water and distorted tidal regime is predicted within the impounded area. All impoundments would modify flow speeds and the existing wave climate. There is also the likelihood of a long-term trend (over the 120 year operation period of the alternative options) of intertidal erosion in response to enclosure of part of the estuary.

For all alternative options, these effects are likely to result in a change to 'characteristic physical form and flow' of the Severn Estuary (i.e. changing the existing hydraulics and geomorphology). This is feature of the Severn Estuary/Môr Hafren European Marine Site and thus the changes would result in a significant negative effect on the designated sites.

For all alternative options, changes to peak tide and wave action would influence the level of flood risk. There would be lengths of flood defence that benefit from lower water levels and there would also be lengths outside the impoundments that would experience higher water levels than previously; and would need to be raised as a result. Flood risk within rivers would also be adversely affected by restrictions to the normal operation of drains and outfalls, owing to the changed tidal regime (tide-locking). Unless managed, this would increase the flood risk to properties and assets within the floodplain.

For the B3 Cardiff to Weston Barrage only, far-field increases in high water levels are predicted on the West Wales coast and, to a lesser degree, along parts of the Irish coast. Increases in water levels on the peak of the spring tides would result in a significant negative effect in terms of a potential increase in flood risk to properties in Cardigan Bay and the Llyn Peninsula in Wales. Smaller increases in high water levels around the coasts of the Irish Sea are also possible resulting in significant negative transboundary effects, though the extent and magnitude is uncertain. Limitations of the modelling have prevented consideration of potential increases in high water levels beyond the Llyn Peninsula on to the North Wales and North West England coast. No significant far-field effects on water levels are identified for any of the other alternative options.

For all alternative options, decreased flows and flow speeds would reduce the suspended sediment concentration within the impounded areas and downstream. This would result in the deposition in the short-term (a spring neap tidal cycle) of very large quantities of sediment, mainly within the deeper, less active parts of the impoundment (see Table 8.1). This would result in an increase in light penetration and subsequent increase in plant growth and decay, which has the potential to result in a lack of oxygen and reductions in water quality, fish and other animal populations. The presence of an impoundment may also cause long-term changes (over the operational period of 120 years) in the form (morphology) of the estuary as a result of erosion and deposition at different locations. For the barrages in particular, this may result in large quantities of sediment being deposited inside their impoundment throughout their operational life.

Alternative Option	Total mass of previously mobile sediment deposited inside the impoundment in the short-term (M tonnes)
B3: Cardiff to Weston Barrage	6.9
B4: Shoots Barrage	1.3
B5: Beachley Barrage	1.3
L2: Welsh Grounds Lagoon	0.8
L3d: Bridgwater Bay Lagoon	0.7

Table 8.1 Total mass deposited as short term deposition

For all alternative options, the reduction in tidal currents may change the form of some of the linear sandbank features of the Bristol Channel such as Culver Sands, Nash Bank and Helwick Bank. This may affect the English and Welsh Grounds as well as some of the other sandbank features.

L3d Bridgwater Bay Lagoon would affect the release of warm water from the Hinkley Power Station and alter the dispersion of treated waste water from Weston wastewater treatment works; which has the potential to significantly negatively affect bathing beaches. None of the other alternative options would be expected to affect discharges from Hinkley Power Station.

With regards to the Water Framework Directive, all of the alternative options are predicted to give rise to effects that could change the chemical status of one or more water bodies in the Severn Estuary, its tributaries or the wider Bristol Channel as a consequence of potential changes in the physical characteristics of water bodies. The Water Framework Directive does, subject to specific tests, allow for new sustainable human development activities to proceed notwithstanding negative effects on status.

Prior to the application of measures to prevent and reduce effects, all alternative options would change the tidal regime within the enclosed part of the estuary, leading to the permanent submergence of large areas of previously intertidal mud and sandflat. The effects are broadly proportional to the size of each alternative option. Long-term responses over 120-years to the enclosure of the estuary may lead to erosion and additional loss of intertidal area. Large quantities of sediment would be deposited within the enclosure, which for the B4 Shoots Barrage and B5 Beachley Barrage may prove an ongoing issue for the maintenance of navigation. The B3 Cardiff to Weston Barrage may cause small but potentially significant elevated spring tide water levels remote from the Severn Estuary. All alternative options would negatively affect land drainage and flood risk that would need to be managed. In the case of B3 Cardiff to Weston Barrage this may extend to works needed on the West Wales coast. B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon would have beneficial effects on flood water levels. The L3d Welsh Grounds Lagoon may affect nearby waste and cooling water discharges.

8.1.2 Key significant biodiversity effects

Changes to water levels, bathymetry and sediment type and distribution are predicted to result in changes to the extent and nature of the Severn Estuary/Môr Hafren SAC European designated habitats and species. The modelled Estuary-wide (not just within the SAC) extent in habitat at the intertidal – terrestrial interface following scheme implementation is shown in Table 8.2 (NB this is without the application of measures to prevent or reduce significant effects). The expected long-term trend (over the 120 year operational period of each alternative option) of intertidal erosion would result in additional loss of habitat. This effect is hard to forecast but may represent a loss of approximately an additional 7% of the current intertidal extent for the B3 Cardiff to Weston Barrage. Other alternative options would see less long-term effect on habitats through erosion.

Other negative effects predicted for marine ecology receptors include a significant negative effect on subtidal sandbanks for all of the alternative options, due to changes in sand transport and mud deposition. Significant negative effects on subtidal *Sabellaria alveolata* reefs as a result of reductions in flow speed are predicted to occur if any of the options except L3d Bridgwater Bay Lagoon were implemented.

For the B3 Cardiff to Weston Barrage, there is the potential for far-field significant negative effects, particularly for saltmarsh as a result of increases in the level of high water along much of the South-West and West Wales coast. For the B4 Shoots Barrage and L3d Bridgwater Bay Lagoon, there is the potential for far-field significant negative effects, particularly for saltmarsh as a result of increases in the level of high water in the vicinity of the Kenfig/Cynffig SAC. No significant far-field effects from raised water levels are identified for any of the other alternative options.

Alternative Option	Area of habitat remaining at the terrestrial – intertidal interface (ha) following scheme implementation						
	Grass-land (ha)	Mud-flat (ha)	Sand-flat (ha)	Salt-marsh (ha)	Intertidal Rock (ha)	Intertidal Shingle (ha)	Total Intertidal (ha)
Baseline	60	12520	13860	990	2240	1310	30980
B3: Cardiff to Weston Barrage	590	8360	3850	780	1130	360	15070
B4: Shoots Barrage	110	12150	11890	1130	1430	1010	27720
B5: Beachley Barrage	120	12170	11620	1070	1950	1290	28210
L2: Welsh Grounds Lagoon	110	11580	7730	1070	2210	1080	23780
L3: Bridgwater Bay Lagoon	140	10810	13080	1240	2120	1140	28530

*to nearest 10 hectares (ha)
NB: Total intertidal represents area between the Highest Astronomical Tide (HAT) and the Lowest Astronomical Tide (LAT) and includes saltmarsh, intertidal mudflat and sandflat, intertidal rock and intertidal shingle. Estimates do not include changes arising from long term morphological processes or the intertidal areas of sub-estuaries.
The predictions of initial habitat extent take account of short-term changes in water levels, bathymetry (water depth), sediment type, tidal curve and fetch. In this context the initial changes are in relation to the outputs of a spring neap cycle immediately post scheme implementation.
This assessment does not include measures to prevent or reduce significant effects except those already included in the definition of alternative options.

Table 8.2 Areas of the intertidal-terrestrial interface following short-term changes to the Severn Estuary

With regards to water quality, it is unlikely that there would be any deterioration in the ecological status of water bodies for the B4 Shoots Barrage, B5 Beachley Barrage and the L2 Welsh Grounds Lagoon, although there may be deteriorations of some components of the relevant WFD water bodies. It is uncertain whether there would be any deterioration in the ecological status of water bodies for B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon.

The effect of changes or loss of access to the intertidal mud or saltmarsh habitat is likely to have a negative effect on the waterbird populations supported by the Severn Estuary. This includes the waterbird species of the Severn Estuary SPA and Ramsar designations. In addition, waterbirds are also likely to be negatively affected during construction and decommissioning phases by disturbance effects. Effects on each bird species vary for each alternative option, but all options would have a significant negative effect on waterbirds. For the B3 Cardiff to Weston Barrage, the effect from the operation phase of changes to or loss of intertidal habitat is likely to have an overall significant negative effect for 30 waterbird species, including ringed plover, curlew, dunlin, redshank and shelduck. Such changes to or loss of intertidal habitat, whilst still significant, affects fewer waterbird species for the other alternative options. In addition, the effect of changes to saltmarsh was also identified as a likely significant negative effect for four waterbird species for the B3 Brean Down to Lavernock Point Barrage, but none for the other alternative options. For the B3 Cardiff to Weston Barrage, the effect of changes to water-levels at far-field sites are identified as having significant negative effects on two waterbird species which are features of the Dyfi Estuary/Aber Dyfi SPA and Cors Fochno & Dyfi Ramsar Site. Effects of displacement to far-field sites was identified as a likely significant negative effect for 15 waterbird species for the B3 Cardiff to Weston Barrage and for one species (Pintail) for B4 Shoots Barrage. This might in turn affect the birds wintering at those sites through competition and density-dependent mortality. No significant far-field effects are identified for any of the other alternative options.

Fish species designated under the Severn Estuary/Môr Hafren SAC, River Usk/Afon Wysg SAC and River Wye/Afon Gwy SAC would be affected by alterations to migratory cues (sensory stimulants that trigger and/or direct fish migratory activity; e.g. freshwater discharge, light intensity and water temperature) and disruption to route of passage. Fish may also be affected by habitat change and/or loss, changes to water quality and anthropogenic noise disruption. Fish passage through tidal power schemes, in particular turbines, is likely to be the primary source of fish injury and mortality. If injuries are not immediately lethal, fish could suffer delayed and indirect mortality. Not all fish species and life stages would suffer injuries and the extent of injury sustained would differ.

A summary of the predicted effects of each alternative option on selected migratory and estuarine fish is shown in Table 8.3. In addition, all alternative options would result in the potential risk of:

- reductions in population size of sea trout and river specific stock collapse for the Rivers Wye, Severn and Usk; and
- reductions in population size of Allis shad and river specific stock extinction for the Rivers Wye, Severn and Usk and to a lesser extent the Tywi which could put the UK stock at risk of extinction.

The sea lamprey populations of the Rivers Usk and Wye are not genetically distinct, and instead form part of a wider European stock. Extinctions in these rivers therefore risk a reduction in the European stock of this species. Similarly, the river lamprey forms part of a wider UK stock and therefore extinctions in these rivers risk a reduction in the UK stock.

With regard to terrestrial and freshwater ecology, for all alternative options, the construction activities at each landfall point would result in temporary and permanent disturbance and habitat loss . This includes sites designated for nature conservation. Increased water levels within the impoundment would result in increased levels in watercourses and above the ground surface. In extreme events this could result in partial or complete flooding of designated sites (including the Gwent Levels for the B3 Cardiff to Weston Barrage and L2 Welsh Grounds Lagoon, and the Somerset Levels for the L3d Bridgwater Bay Lagoon) which may lead to degradation and / or permanent habitat loss, fragmentation at a landscape corridor level and mortality of species.

Alternative Option	Fish Species (E = population collapse / extinction and R = reductions in population size)				
	Atlantic salmon	Twaite shad	Sea lamprey	River lamprey	Eel
B3: Cardiff to Weston Barrage	E: Rivers Wye, Severn, less certainty for the Usk	E: Rivers Wye, Severn and Usk R: River Tywi	R: Rivers Usk, Wye	R: Rivers Usk, Wye	R: Rivers, Usk, Wye and Severn
B4: Shoots Barrage	E: Rivers Wye, Severn, less certainty for the Usk	E: Rivers Wye, and Severn R: River Usk and Tywi	E: River Wye R: River Usk	E: Rivers Usk and Wye	R: Rivers Wye and Severn
B5: Beachley Barrage	E: Rivers Wye, Severn and Usk	E: Rivers Wye, Severn and Usk R: River Tywi	E: Rivers Usk and Wye	E: Rivers Usk and Wye	R: Rivers Wye and Severn
L2: Welsh Grounds Lagoon	E: Rivers Wye, Severn and Usk	E: Rivers Wye, Severn and Usk R: River Tywi	E: River Usk R: River Wye	R: Rivers Usk, Wye	R: Rivers, Severn, Wye and Usk
L3d: Bridgwater Bay Lagoon	E: Rivers Wye, Severn and Usk	E: Rivers Wye, Severn and Usk R: River Tywi	R: Rivers Usk, Wye	R: Rivers Usk, Wye	R: Rivers, Usk, Wye and Severn

Table 8.3 Summary of predictions of effects on migratory and estuarine fish

Under all alternative options, water level changes and sedimentation would lead to the loss of large areas of protected habitat, including intertidal sand and mud. As well as being of conservation importance in their own right, the submergence of these habitats threatens internationally designated sites and important bird populations. Sedimentation within subtidal areas would also affect the conservation interest of the estuary and lead to the loss of designated species. All alternative options risk the loss from the estuary and its tributaries of most migratory fish species, that are internationally protected and some represent the only UK populations. Effects on land drainage pose negative effects for terrestrial ecology.

8.1.3 Key significant historic environment and landscape & seascape effects

Changes to the sedimentation and erosion patterns caused by all alternative options could lead to the covering of areas of historic interest which were previously exposed, thus increasing their protection. Conversely in other areas there could be the exposure of sites on the seabed which were previously buried thus increasing their vulnerability. Changes to the tides and wave climate caused by all alternative options could add to existing coastal erosion of soft coastline which is a major threat to part of this irreplaceable historic environment resource. For the L2 Welsh Grounds Lagoon this includes some of the most important components of the archaeological resource along the Welsh coast. For the B3 Cardiff to Weston Barrage this may include parts of the Irish and West Wales coastlines.

The historic environment may also be directly affected by the footprint of each alternative option. For B3 Cardiff to Weston Barrage, this would include effects upon the setting and context of three irreplaceable Scheduled Monuments (Brean Down, Sully Island Fort and St Mary's Well), for L3d Bridgwater Bay Lagoon, Brean Down; and for B4 Shoots Barrage, the Gwent Levels Landscape of Outstanding Historic Interest in Wales. Enabling and construction for permanent, temporary and ancillary works could result in loss or damage to a broad spectrum of the irreplaceable historic environment resource.

For all alternative options, construction (and decommissioning) disturbance could have significant negative effects on the landscape and seascape character and there would also be an altering of the views in and around the landfall points. The change in landscape character and visual effects from the presence of a structure would remain during the operational phase but at a reduced level. The physicochemical and biodiversity changes to the estuary would lead to significant negative effects in both the landscape and seascape character of the estuary and its tributaries.

With regard to significant negative effects on existing landscape character, both the B4 Shoots Barrage and L2 Welsh Grounds Lagoon could affect the Gwent Levels and the B3 Cardiff to Weston Barrage and the L3d Bridgwater Bay Lagoon would affect the character of Brean Down. With regards to visual effects, for B3 Cardiff to Weston Barrage, there would be effects at Lavernock Point, Flat Holm, Steep Holm, Brean Down and Brean Beach. For B4 Shoots Barrage, this would include the Gwent Levels and Severn Beach, especially the users of both Severn Way coastal paths and for B5 Beachley Barrage the Beachley Peninsula. For the L2 Welsh Grounds Lagoon this would include the Gwent Levels and the users of the Welsh Severn Way coastal path, and for the L3d Bridgwater Bay Lagoon the shore around Bridgwater Bay and especially at the Stolford landfall point.

All alternative options pose risks to the historic environment, visual amenity and landscape and seascape character, some of which is already designated. The nature of the risk depends on the location of the alternative option, rather than solely a function of its size. Far-field water level effects for the B3 Cardiff to Weston Barrage may pose risks of effects on the West Wales and Irish coasts.

8.1.4 Key significant air & climatic factors and resources & waste effects

For each alternative option, Table 8.4 records the significant resources and waste requirements and the emissions which would occur during construction, operation and decommissioning.

The major resources required to construct the alternative options would include aggregates and embankment materials (sand bed and sand core, gravel, crushed rock and armour rock) from within Great Britain and from Europe, albeit in varying amounts for each alternative.

Substantial quantities of other resources, including steel, would be entailed but none have been judged to be significant for any alternative option.

Table 8.4 also includes the carbon payback period (the number of years that it takes for the emissions displaced from the production of renewable electricity to offset the carbon emissions released during construction, operation and decommissioning). All alternative options demonstrate a significant positive effect on global and UK greenhouse gas emissions.

Factor	B3: Cardiff to Weston Barrage	B4: Shoots Barrage	B5: Beachley Barrage	L2: Welsh Grounds Lagoon	L3d: Bridg-water Bay Lagoon
Construction					
Net annual demand for virgin aggregates and embankment materials (m tonnes)[1] (average over total construction period)	3.6 (61%)	3.1 (28%)	0.4 (50%)	13.9 (6%)	17.9 (0%)
Operation					
Base net emissions displaced (Mt CO_2) (low-high estimates)	-114 (-147, -78)	-22 (-34, -16)	-13 (-20, -9)	-17 (-30, -9)	-47 (-54, -29)
Base carbon payback (yrs) (low-high estimates)	2.6 (-0.8, 7)	3.5 (-6.3, 7.8)	2.8 (-5.7, 7.7)	6.1 (-4.2, 13.3)	3.2 (2.6, 8.5)
[1]Proportion assumed to be from reused project dredging materials and not included in total.					

Table 8.4 Air & Climatic Factors, Resources & Waste: Selected Statistics

All alternative options would use large resource quantities in their construction and, making assumptions about the UK energy mix over a 120-year timeframe, relatively rapidly pay back the carbon used in their construction, operation and decommissioning. Alternative options would displace fossil fuel-derived emissions of carbon, in proportion to their size.

8.1.5 Key significant society & economy effects

Construction activities are likely to have significant negative temporary effects on health and quality of life of the local population adjacent to the landfall points for some of the alternative options. The reasons for this include changes to the existing flood risk, landscape and air quality. For B3 Cardiff to Weston Barrage there would be a significant effect on the local population within areas of Vale of Glamorgan and Sedgemoor, for L2 Welsh Grounds Lagoon, Monmouthshire and Newport and for L3d Bridgwater Bay Lagoon, West Somerset and Sedgemoor. Whilst it is anticipated that there would also be effects on the health and quality of life of local populations in the vicinity of B4 Shoots Barrage and B5 Beachley Barrage, these are not considered to be significant effects in terms of this SEA.

During the operational period, all alternative options would result in the loss of salmon and sea trout fisheries employment as a result of the identified closure of salmon and sea trout fisheries within the Rivers Wye, Severn and Usk. All alternative options would also result in the loss of heritage (elver) fisheries supported employment as a result of the partial or complete closure of heritage (elver) fisheries within the Severn Estuary and tributary rivers (see Table 8.5).

Only the B3 Cardiff to Weston Barrage is expected to reduce ports' trade, which may have a negative effect on employment (see Table 8.5). Based upon the conclusions of the DTZ Regional Economic Impact Study (REIS) (DTZ, 2009) and subsequent REIS update (STP Regional Workstream, 2010), a 'medium impact scenario' has been applied as an indicator for the potential effect of the alternative options on the ports sector. For the B3 Cardiff to Weston Barrage, this scenario represents loss of 30% trade from all ports affected during the construction phase, increasing to 60% by the end of the operational phase. For the purposes of this SEA, it is assumed that port-related employment corresponds directly with port trade, resulting in a significant negative effect of a loss of 1,850 full-time equivalent (FTE) employees by the end of the construction phase, increasing to 4,200 FTE lost by 2140[1]. Smaller decreases are set out under the REIS medium impact scenario for the other alternative options (2.5% by the end of construction, increasing to 5% by the end of operation) which are not considered significant in terms of the SEA.

For all alternative options, the construction period is likely to lead to a temporary increase in local employment and there would also be a permanent increase in employment during the operational period (see Table 8.5). This ranges from 7,500 – 8,500 FTE/year during 4 peak years of construction, and 750 – 1,000 FTE permanent operational employment for B3 Cardiff to Weston Barrage to 1,500 – 3,000 FTE/year during 3 peak years of construction plus 80 – 100 FTE permanent operational employment for B5 Beachley Barrage. These are considered to be positive, although non-significant effects (based on the SEA methodology described above).

Physicochemical changes have the potential to result in significant effects for navigation. Changes in tide levels would affect the access window that vessels have to access the ports. Deposition of sediment has the potential to negatively affect navigation. Changes to tidal currents could aid or hinder navigation depending on velocity, location and direction as well as affect the time it takes to navigate locks. In addition, potential negative effects during the construction phase may arise as a result of construction activities and additional ship movements. The ports of Bristol (including the Deep Sea Container Terminal), Cardiff, Newport and Sharpness Dock would all be affected by all alternative options, either during construction, operation or both. The Port of Bridgwater would be affected by B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon.

[1] NB: Results are derived from a regional level analysis (DTZ Regional Economic Impact Study (DTZ, 2009)) and subsequent update (STP Regional Workstream, 2010).

Effect	Alternative Option				
	B3 Cardiff to Weston Barrage	B4 Shoots Barrage	B5 Beachley Barrage	L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
Construction Employment[1]	7,500 – 8,500 FTE/year during 4 peak years of construction	2,000 – 3,000 FTE/year during 3 peak years of construction	1,500 – 3,000 FTE/year during 3 peak years of construction	3,000 – 4,000 FTE/year during 4 peak years of construction	4,000 – 6,000 FTE/year during 5 peak years of construction
Operational Employment	750 – 1,000 FTE permanent operational employment.	100 – 200 FTE permanent operational employment.	80 – 100 FTE permanent operational employment.	120 – 180 FTE permanent operational employment.	200 – 300 FTE permanent operational employment.
Effects on Ports During Construction[2]	1,850 FTE lost	Not significant			
Effects on Ports During Operation[2]	4,200 FTE lost	Not significant			
Effect on recreational / tourism fisheries employment.	Loss of salmon and sea trout fisheries employment and heritage (elver) fisheries supported employment 58 FTE lost	Loss of salmon and sea trout fisheries employment and heritage (elver) fisheries supported employment 58 FTE lost	Loss of salmon and sea trout fisheries employment and heritage (elver) fisheries supported employment 58 FTE lost	Loss of salmon and sea trout fisheries employment and heritage (elver) fisheries supported employment 58 FTE lost	Loss of salmon and sea trout fisheries employment and heritage (elver) fisheries supported employment 58 FTE lost
[1] These are considered to be positive, although non-significant effects (based on the SEA methodology described above). [2] Based upon the conclusions of the DTZ Regional Economic Impact Study (REIS) (DTZ, 2009) and subsequent REIS update (STP Regional Workstream, 2010), a 'medium impact scenario' has been applied as an indicator for the potential effect of the alternative options on the ports sector. It is assumed that port-related employment corresponds directly with port trade.					

Table 8.5 Summary of Significant Employment Effects for each Alternative Option

Other sea uses may also be significantly affected by physicochemical changes, effects on biodiversity and effects on the historic environment and landscape and seascape. All alternative options are likely to affect the aggregate extraction industry as a result of the diminished resupply of aggregate resource sites in the study area and for the B3 Cardiff to Weston Barrage, as a result of increases in transit time, there would be reduced access of aggregate extraction dredgers to ports upstream of the barrage. The L2 Welsh Grounds Lagoon is likely to further affect the aggregate extraction industry as the structure itself is located on several reserve sites – this may also affect employment within this industry. The waste disposal industry is also likely to be affected as the L2 Welsh Grounds Lagoon also occupies the same location as two dredged material disposal sites. The L3d Bridgwater Bay Lagoon alternative option traverses a number of telecommunication cable routes and these cables are thus at risk. The presence of the lagoon also has the potential to reduce bathing water quality at Weston-super-Mare and has the potential to increase incident response times for rescue organisations operating in the vicinity of the structure.

Within the L3d Bridgwater Bay Lagoon, peak flow speeds within Bridgwater Bay may increase and this may be undesirable for small craft users and bathers. By contrast, all other alternative options are likely to create calmer conditions within the impoundment and this would generally favour recreational users of the estuary. All barrage alternative options are likely to prevent the formation of a surfable Severn Bore, but the lagoon alternative options would not have this significant effect.

Alternative options would generate employment and some also pose health and quality of life effects to the nearby population during their construction. All alternative options but notably the B3 Cardiff to Weston Barrage, would have negative effects on navigation and port related employment. All alternative options, and the L2 Welsh Grounds Lagoon especially, risk negative effects on marine aggregate extraction. There would be positive and negative effects for recreation and tourism for all alternative options. The B3 Cardiff to Weston Barrage, B4 Shoots Barrage and B5 Beachley Barrage would result in the loss of a bore that can be surfed.

8.2 Measures to Prevent and Reduce Adverse Effects

8.2.1 Background

The SEA Directive requires that information is provided on: '*… the measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the plan or programme (Annex I (g)).*'

The SEA Directive therefore requires that where significant environmental effects have been identified, such measures should be described. These can be split into measures to prevent or reduce effects, and measures to as fully as possible offset effects (offsetting).

For the purposes of this SEA, offsetting measures are those which make good for loss or damage to an environmental receptor, without directly reducing that loss/damage. Offsetting is the term used to describe such measures in the SEA Directive. In this SEA, 'compensation', a subset of offsetting, is only used in relation to those measures within the Habitats Directive.

The measures are described further below.

Measures to prevent and reduce any significant adverse effects on the environment

For the purposes of this SEA, these are measures to prevent, or reduce any significant adverse effects. The SEA will consider the efficacy of available measures and their effects on environmental and regional receptors. The residual effect will need to be as fully as possible offset (see "Measures to as fully as possible offset any significant adverse effects on the environment " below). Determining what constitutes 'reasonable' measures will require value judgements and potential trade-offs, and so the measures selected as preferred will be considered within the wider Feasibility Study.

Measures to prevent or reduce effects which could be incorporated into the development of the options are identified in this section. Where significant adverse effects cannot be prevented, potential measures will be identified to reduce them. An indication of the likely effectiveness of these measures is to be considered. Within the Feasibility Study, it is understood that the extent to which measures to prevent and reduce effects are applied will take account of a range of factors, including compliance with policy and legislation by reference to the SEA objectives, public acceptability, cost in relation to the benefits of the scheme and uncertainty and effectiveness of such measures.

At this strategic level, sometimes only outline or principles can be identified and can only be incorporated into the assessment where it is reasonable and practicable. This section identifies those measures that the Feasibility Study considers should be incorporated into each option.

The SEA may not be able to recommend measures where there remains unacceptable uncertainty over their likely effectiveness following the study or where measures are opposed in terms of effects on other receptors. In such cases, recommendations for further investigation of measures to prevent and reduce effects will be made.

This includes consideration of measures that may be separately needed in relation to the Habitats and Water Framework Directives or other legislation identified in the SEA. Within the SEA, measures to prevent and reduce effects will be considered in relation to effects on each water quality receptor, *inter alia* to ensure compliance with WFD objectives (though not in this paper which is only intended to identify measures at a higher level).

Measures to as fully as possible offset any significant adverse effects on the environment

The SEA will identify the potential offsetting need, taking into account the efficacy of potential measures to prevent and reduce effects. It will also identify residual impact or need for compensation for Habitats Directive features. For the development of a project, Government would need to decide what compensation would be required, taking account of appropriate multipliers to address risk.

8.3 Approach to Identification of Measures to Reduce and Prevent Effects

In phase 1, measures to prevent and reduce effects were identified (such as modifications to barrage design, use of locks and alterations to land drainage). Furthermore, measures to prevent and reduce effects arising from the potential impact on tidal range (due to an altered hydrodynamic regime) were also identified. These measures were reviewed and costed to achieve a first order estimate. Other potential measures to prevent and reduce effects were also considered generally in Section 5 of the IOAR and in more detail in terms of Habitat Directive requirements and, impacts in the October 2008 report 'Preliminary Review of Possible Mitigation and Compensation Requirements under the Habitats Directive'. Preliminary consideration was also given to a range of other potential measures to prevent and reduce effects within each of the SEA Scoping Topic Papers. The phase 2 approach builds on those reports to provide a more specific high level review of potential measures to prevent and reduce effects, which will inform the SEA topic assessment work in phase 2 of the project.

The scheme optimisation process determined the form of each scheme for further study based on a high level evaluation of capital cost, energy yield, energy cost and value, regional and environmental effects. This included the first iteration, at a high-level, of measures to prevent and reduce significant adverse effects on the environment, by selecting an appropriate alignment, operating mode and turbine and sluice capacity.

The next stage in the process of options definition of individual schemes (not in combination) is, in conjunction with the SEA work, to evaluate and identify, where possible, potential measures to prevent and reduce effects on the environmental and regional effects determined in the SEA.

The optimisation process confirmed specific issues that needed addressing in modifying schemes to change their regional and environmental effects. Some of the ways schemes can be modified cause benefits in some respects but dis-benefits in others. The selection of certain measures to prevent and reduce effects therefore requires judgement on which adverse effects are more important to prevent or reduce than others. This is a potentially complex process which runs across the whole of the Feasibility Study.

It should therefore be recognised that the SEA process will *identify potential measures to prevent and reduce effects*, and assess the efficacy and effects of these measures. It is for DECC to decide, based on their objectives for the Feasibility Study and the plan(s) they recommend, which of these measures should be adopted as part of their recommended plan.

It is possible that the range of measures proposed to prevent or reduce effects may need to be re-visited after the end of the Feasibility Study, if the Government decides it can support a preferred option or combination of options.

8.4 Measures to Prevent and Reduce Adverse Effects of Options

Appendix F provides a detailed list of all potential measures to prevent and reduce effects and to as fully as possible offset any significant adverse effects which have been identified in the SEA process. The measures are necessarily conceptual at this strategic stage and only a high level evaluation of their potential effectiveness has been carried out. All the suggested measures considered would be subject to further detailed study at the Environmental Impact Assessment stage. Not all the measures will necessarily be adopted following EIA and some other measures might emerge which are preferable.

The nature and scale of the shortlisted options are unprecedented, and so are the measures to prevent and reduce their effects. Measures which are unprecedented either because they are not established practice or are unprecedented in scale have significant uncertainty over their effectiveness, their indirect effects on other receptors and their effect on scheme costs and energy yield. In some cases, recommendations on the scope and nature of measures are made in the absence of complete information.

It is therefore assumed that the measures would be the subject of further development as part of subsequent project implementation stages. Any assumptions made on the effect and applicability of these measures would need to be verified as part of project level planning and design. Some measures recommended in the SEA may change in subsequent stages or they may be substituted for other measures which are found to be more effective. Some recommended measures may later be excluded if further study on their effectiveness, indirect effects and effects on cost and energy to determine that they can not be taken forward. It is recommended that, where applicable, consideration also is given to an offset/ compensation approach for those prevention/ reduction measures which are identified as having risks to their successful implementation. Future changes in recommended measures may change the amount of offsetting and compensation required.

A series of criteria have been applied to aid the selection of those measures to be included within each option. These are intended to reflect the risks associated with the measures in terms of their costs, effectiveness, policy and legal compliance, time needed for development and effects on other aspects of the environment. By showing how these factors have been taken into account (in Appendix F), it is intended to demonstrate that reasonable measures have been selected.

The criteria and their definitions used to select measures to be included are shown in Table 8.6.

Table 8.7 provides a summary list of those measures recommended for inclusion. Those measures which have more than a marginal effect on energy yield or cost are considered further in Sections 9 and 10.

Criterion	Definition
Effectiveness of measure	Assessment of how effective the measure is in addressing the effect. This is not a judgement on the ability of a measure to prevent the effects of an STP.
Established practice	Extent to which measure has precedent and is accepted as a prevention or reduction measure. Measures with an established precedent are more likely to be meet legal, policy and consenting requirements.
Established method	Extent to which a measure relies on established technologies or techniques or requires innovation.
Development timeframe	Timescale that would be required to fully implement the measure. Measures must be achievable by 2020.
Significant adverse effect on biodiversity	Extent to which a measure has adverse environmental consequences. Judgement is in strategic context of major national project.
Significant adverse effect on society and economy	Extent to which a measure has significant adverse effect on society or economy.

Table 8.6 Criteria for Selection of Measures to Prevent or Reduce Significant Adverse Effects on the Environment

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion

SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
Marine Ecology	Reduction in inter-tidal mudflat and sandflat areas	M2. Sluice management - Sluicing after generation period in ebb only mode to prevent or reduce effect of tidal range reduction	B3, B4, B5 and L2	Energy effects considered in Section 9. Negligible effect on cost.
		M3. Topographic modification – inter-tidal creation as a measure to prevent or reduce effect of tidal range reduction.	All	Cost and energy effects considered in Sections 9 and 10
		M4. Seawater level management by pumping – pumping at high water to minimise the decrease in high water levels on flood tides thus reducing effects on saltmarsh	All except B5.	Energy effects considered in Section 9. Negligible effect on cost.
	Potential loss of areas of eelgrass	M6. Minor alignment adjustments	B3, B4 and L2	Cost and energy effects assumed to be negligible
Waterbirds	Reduction in inter-tidal area affecting feeding success of birds	M8. Operational management of barrage/lagoon regime – change water levels to prevent or reduce effect of tidal range reduction (as M2 Sluice management)	B3, B4, B5 and L2	Energy effects considered in Section 9. Negligible effect on cost.

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
	Reduction in extent and duration of inter-tidal area exposure time (for remaining intertidal) leading to loss of bird feeding/grounding time	M9. Topographic modification (as M3)	All	Cost and energy effects considered in Sections 9 and 10
	Creation of a physical link between Steep Holm and Flat Holm islands and the mainland with detriment to birds due to potential for vermin	M10. Minor alignment adjustments	B3 only	Cost and energy effects assumed to be negligible
	Direct footprint losses of key habitats affecting bird feeding (eelgrass)	M11. Minor alignment adjustments	B3, B4 and L2	Cost and energy effects assumed to be negligible
	Disturbance to bird species during construction	M12 Alter construction timings or methods	All	Cost and energy effects assumed to be negligible
	Reduction in saltmarsh	M13. Introduction of new refuges and/or bird roosts within the Estuary area	All	Marginal cost effects and no energy effects assuming topographic modification not required

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
Migratory and Estuarine Fish	Fish injury/mortality on passage	M15. Operational management of barrage/lagoon regime – increasing permeability of barrage/lagoon by allowing some turbines to freewheel during generation and ensuring that all operating turbines are at optimum efficiency during generation	All	Energy effects considered in Section 9. Negligible effect on cost.
		M17. Type size, number and position of sluices – altering the sluice arrangements to increase permeability of barrage/lagoon	All	Energy effects considered in Section 9. It is not possible to quantify costs at this stage without detailed study into most optimal arrangement.
		M21. Intertidal habitat creation and enhancement to reduce the loss of individual fish and/or intertidal habitats within the Severn Estuary catchment	All	Cost considered in Section 10. No energy effects.
		M22. Predator Control – deterrent/exclusion systems	All	Cost effects assumed to be negligible. No energy effect.

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
	Disturbance/behavioural effects on fish species	M28. Industry standard measures to minimise noise and vibration levels during construction, operation and decommissioning	All	Cost effects assumed to be negligible. No energy effect.
		M29. Industry standard measures to minimise and control sediment disruption/displacement during construction, operation and decommissioning	All	Cost effects assumed to be negligible. No energy effect.
Terrestrial and freshwater ecology	Direct footprint losses of key habitats	M30. Minor alignment adjustments	All	Cost and energy effects assumed to be negligible
		M31. Adjustment to locations of onshore works	All	Cost effects assumed to be negligible. No energy effect.
	Disturbance of important species	M32. Timing/methods of site clearance	All	Cost effects assumed to be negligible. No energy effect.
	Detrimental effects on important habitat or species receptors due to altered freshwater/seawater levels	M33. Freshwater and seawater level management – targeted pumping	All except B5	Energy effects considered in Section 9. Negligible effect on cost.
Navigation	Risk to navigational safety during construction and decommissioning	M34. Coordination and phasing of activities	All	Cost effects assumed to be negligible. No energy effect.

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
	Increased transit time through lock structures	M35. Improved logistics to manage arrival and transit of vessels	All except L2	Costs negligible when discounted to present day costs. No energy effects.
	Disruption to commercial navigation due to increase in peak water velocities at structures	M36. Raise awareness through demarcation of high risk areas	All	Costs considered in Section 10. No energy effects.
		M37. Relocation of locks for B4 and B5 – change lock positions to align with temporary navigation channels	B4 and B5	Costs considered in Section 10. No energy effects assumed.
	Obstruction to navigation due to short term sediment deposition immediately post construction	M38. Dredging of approach channels to affected ports	B3, B4 and L3d	Costs considered in Section 10. No energy effects.
	Obstruction to navigation due to long term sediment accretion	M39. Maintenance dredging of navigation and approach channels	All	Costs considered in Section 10. No energy effects,
	Obstruction/disruption to navigation of deep draught vessels through proposed deepwater navigation channel from Lavernock Point	M40. Dredging of new channel	B3	Costs considered in Section 10, no energy effects.

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
	Reduced navigable depths to ports due to reduced high tide levels	M41. Alterations of Port Infrastructure – sill level reductions and dredging of shipping channels	B3, B5 and L3d	Costs considered in Section 10. No energy effects.
Marine Water Quality	Localised warming of the waters around Bridgwater Bay Lagoon in area for abstraction of cooling water for Hinkley B power station	M43. Reconfiguration of intakes at Hinkley B.	L3d	Costs considered in Section 10. No energy effects.
	Reduced dilution of discharge waters from Hinkley B power station	M44. Reconfiguration of outfalls at Hinkley B.	L3d	Costs considered in Section 10. No energy effects.
	Reduced marine water quality at Weston beach due to effect on pathogen plumes from Weston waste water treatment works	M45. Improved treatment at Weston waste water treatment works	L3d	Costs considered in Section 10. No energy effects.
Resources and Waste	Depletion of primary and secondary material resources	M47. Inclusion of re-used/recycled materials	All	Cost effects assumed to be negligible. No energy effects.
	Large volumes of spoil arisings requiring disposal	M48. Construction measures to minimise spoil generated	All	Cost effects assumed to be negligible. No energy effects.

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
Flood Risk and Land Drainage (FRLD)	Changes to tidal regime leading to tide-lock and upstream flood risk	M49. Pumping systems at tidal outfalls – To allow land drainage discharges that would otherwise have been prevented by the reduced tidal range	All	Costs considered in Section 9. Negligible energy effect.
	Obstruction of land drainage channels and/or outfalls	M53. Provision of a flood relief channel for the River Axe (for drainage purposes) so that flood drainage discharges to the south, rather than the north (and inside the impoundment), of Brean Down.	B3 only	Costs considered in Section 9. No energy effect.
	Flooding of receptors in the tidal floodplain at locations where post-barrage peak tide levels would be raised	M54. Improvements to tidal or sea defences - to reduce effects of raised water levels on peak tides for locations in the estuary and for far field effects.	B3, B4, B5 and L2	Costs considered in Section 9. No energy effect.
	Increased risk of flooding arising from degradation of existing tidal flood defences through erosion resulting from changes to the tidal regime.	M56. Erosion protection measures - such as large-scale revetment systems in front of tidal defences.	All	Costs considered in Section 9. No energy effect.
		M57. Monitoring of flood defences	All	Costs considered in Section 9. No energy effect.

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion

SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
Noise and vibration	Disturbance to people and species receptors[i]	M59. Measures to minimise noise & vibration levels during construction, operation and decommissioning	All	Effect on cost assumed to be negligible. No energy effects.
Communities	Adverse effects on local community arising from inward migration of labour (e.g. increasing stress on local services)	M60. Measures to encourage maximum recruitment of local labour	All	Effect on cost assumed to be negligible. No energy effects.
	Disruption to local communities due to increased traffic - due to HGV and other site traffic on local road networks.	M61. Reducing the number of vehicles on local roads through rationalising deliveries and use of larger vehicles.	All	Effect on cost assumed to be negligible. No energy effects.
		M62. Delivery of construction materials by alternative routes (e.g. rail or sea)	B3 and L3d	Costs considered in Section 10. No energy effects.
		M79. Measures (to be defined) targeted at altering the perception that the construction phase will restrict navigation to the Estuary's ports.	All	Effect on cost assumed to be negligible. No energy effects.
Freshwater and Environmental Interfaces	Loss of safe access to geological and geomorphological SSSI sites due to submergence	M64. Alternative access points to Otter Hole geological SSSI site	B3 and B4	Effect on cost assumed to be negligible. No energy effects.

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
	Reduced quality and diversity of soil resource due to water-logging	M65. Increased drainage through provision of measures extra to those outlined for FRLD (e.g. through additional pumping)	All	Costs over and above measures within FRLD likely to be negligible. No energy effects.
	Reduction in capacity of subterranean infrastructure and increased dampness in basements due to raised water tables	M66. Increased drainage through provision of measures additional to those outlined for FRLD (e.g. through additional pumping to reduce water tables in urban areas, particularly those adjacent to the coastal fringe).	All except B5	Costs considered in Section 10. No energy effects.
Historic Environ-ment	Detrimental affects to historic environment receptors	M67. Measures to prevent effects on the historic environment resource *(in situ)* - avoidance of effect through minor alignment adjustments and subsequent preservation in situ.	All	Effect on cost and energy assumed to be negligible.
		M68. Measures to reduce effects on the historic environment resource *(by record)*	All	Effect on cost assumed to be negligible. No energy effects.
Landscape and Seascape	Detrimental affects on the landscape and seascape resulting from the physical presence of a barrage / lagoon[ii].	M69. Designing structures to integrate into the landscape/seascape	All	Assumed negligible cost effects. No energy effects.

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
Other Sea Users	Damage to existing seabed (telecommunications) cables	M70. Modifying alignment to prevent adverse effects on existing seabed telecommunications cables	L3d only	Cost effects considered in Section 10. Assumed no energy effects.
	Disruption / impedance of existing marine aggregate extraction sites caused by increased siltation	M71. Use of specialist extraction / resource sorting equipment – in order to improve sorting of more mixed sand/mud resource	B3 only	Cost effect assumed to be negligible. No energy effect.
	Disruption / impedance to structural integrity of coastal infrastructure used for recreation and tourism (e.g. slipways)	M72. Structural modifications to marine recreation infrastructure	All	Cost effect assumed to be negligible. No energy effect.
	Reduction in sediment transport resulting in diminished supply of sand to pleasure beaches used for recreation and tourism.	M73. Beach recharge	All	Cost considered in Section 10. No energy effect.
	Increased emergency response times for marine and coastal rescue craft	M74. Relocation of existing rescue stations to new sites	All	Cost effect assumed to be negligible. No energy effect.

Table 8.7 Summary List of Measures to Prevent or Reduce Adverse Effects Recommended for Inclusion				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to Prevent or Reduce Effect	Options That This Measure Applies To	Effect on Energy Yield or Scheme Cost
Air and Climatic Factors	Emissions of pollutants to atmosphere from transport via shipping and road during the construction phase	M75. Efficient usage of shipping vessels – use of larger and/or more efficient shipping vessels during construction – to optimise the emissions to atmosphere per payload.	All	Cost effect assumed to be negligible. No energy effect.
		M76. Use of Euro IV or V rated site HGVs and delivery vehicles.	All	Cost effect assumed to be negligible. No energy effect.
	Carbon emissions from generation, transportation and use of primary and secondary construction materials	M77. Re-use/recycle of materials and minimisation of resource use	All	Cost effect assumed to be negligible. No energy effect.
	Carbon emissions from power consumption at on-site accommodation and offices during construction.	M78. Use of on-site renewable energy generation for heat and electricity during construction – for example, use of solar panels, small wind turbines, biomass wood burners and/or Combine Heat and Power	All	Cost and energy effects assumed to be negligible.

Table 8.8 provides a summary list of the measures to as fully as possible offset any significant adverse effects on the environment.

Table 8.8 Summary List of Measures to As Fully As Possible Offset Any Significant Adverse Effects on the Environment				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to as Fully as Possible Offset Effect	Options That This Measure Applies To	Effect on Scheme Cost
Migratory and Estuarine Fish	Reduction in populations of non-statutorily protected fish species (such as marine estuarine fish species).	OFF1. Monetary compensation in return for surrender of fishing licenses (to offset for loss of non-statutorily protected fish populations).	All	Not possible to quantify at this stage
	Reduction in populations of non-statutorily protected fish species (such as marine estuarine fish species)..	OFF2. Habitat creation, modification and ecological enhancement in other areas, targeted to be of benefit to marine estuarine species	All	Not possible to quantify at this stage
Freshwater Environment and Associated Interfaces	Loss of access to discrete SSSI outcrops caused by submergence.	OFF5. SSSI designation of existing Geological Conservation Review (GCR) sites as a substitute for a lost SSSI sites.	All but particularly to B3	Negligible
Other Sea Users	Reduction in area available for aggregate extraction	OFF8. New aggregate licenses, or alterations to existing licenses.	B3 and L2	Not quantified at this stage
	Reduction in sites available for existing dredge material disposal	OFF9. New dredge material disposal procedures or new sites - to offset the effect of lost functionality of existing dredging sites which are shown to be affected by B3 and L2	B3 and L2	Not quantified at this stage

Table 8.8 Summary List of Measures to As Fully As Possible Offset Any Significant Adverse Effects on the Environment				
SEA Topics	Likely Significant Adverse Effect on Environment	Measure Envisaged to as Fully as Possible Offset Effect	Options That This Measure Applies To	Effect on Scheme Cost
	Increased sailing distance for users of aggregate extraction and dredging sites.	OFF10. A measure to offset the effects on users of existing dredge disposal and aggregate extraction sites - due to increased distances to travel for extraction/disposal - will be needed (see OFF08 & OFF09).	B3 and L2	Not quantified at this stage

Topographic modification (Measures M3 and M9) would be intended to reduce the area of inter-tidal habitat lost and thereby reduce the amount of compensatory habitat which is required under the Habitats Directive. Table 8.9 provides an estimate of the inter-tidal areas before and after the application of measures to prevent or reduce significant adverse effects and should be read in conjunction with Table 8.2. For more information on these estimates, refer to 'Report to Inform a Stage 2 (Appropriate Assessment) Habitats Regulations Assessment', March 2010 (ref xv).

There is significant uncertainty over the potential effectiveness of topographic modification and more detailed study is required for any scheme taken forward beyond the Feasibility Study addressing issues such as the potential for erosion and accretion to occur once the scheme is operational.

Alternative Option	Estimated area loss of designated intertidal habitat *before* application of potential measures to prevent or reduce significant adverse effects		Estimated area loss of designated intertidal habitat *after* application of potential measures to prevent or reduce significant adverse effects	
	Potential Lower-bound Loss (ha)	Potential Upper-bound Loss (ha)	Potential Lower-bound Loss (ha)	Potential Upper-bound Loss (ha)
B3	14,800	18,000	11,800	16,300
B4	3,300	4,000	2,700	3,700
B5	2,700	3,300	2,100	3,000
L2	7,300	8,700	6,100	8,200
L3d	2,500	3,000	1,600	2,600

Table notes:

1. Estimates rounded to nearest 100ha.
2. Intertidal area is defined as HAT-LAT.

Table notes cont.

3. Calculations are for the area within the Severn Estuary SAC only, i.e. excluding SEA Hydraulics and Geomorphology model units 2a, 2b and 2c. These habitat area losses are small by comparison.
4. Calculations do not include sub-estuaries; habitat area losses are uncertain and small by comparison.
5. Estimates are for intertidal habitats that are a qualifying feature or sub-feature of the SAC only. These are: intertidal hard substrate communities; mudflats and sandflats not covered by seawater at low tide; Atlantic saltmeadow. The calculations for Atlantic salt meadow do not include the modelled intertidal grassland: this transitional habitat is not considered to be part of the SAC habitat.
6. Estimates include habitat losses from barrage footprints and from changes in tidal regime.
7. Calculations are based on model outputs of intertidal habitat extents at closure, provided by the Marine Ecology Topic Paper, Annexe 3, Rev 2 (Severn Tidal Power, 2010f).
8. Calculations for Atlantic saltmeadow are based on the predicted short-term losses at commencement of operations due to changes in water levels. Potential longer-term term colonisation of new areas of suitable habitat by saltmarsh communities is excluded.
9. Calculations do not include uncertain estimates of long term morphological change.
10. The range of values is calculated by applying the following to the central output provided by SEA Marine Ecology Topic Paper (Severn Tidal Power, 2010f):
    - Uncertainty around model output: +/-10% predicted area change.
    - Mitigation methods where quantifiable, as per the SEA Environmental Report (Severn Tidal Power, 2010j): pumping at high water (only quantified for B3); additional sluicing on ebb tide (only quantified for B3); topographic modification (quantified for all options with a predicted range of effectiveness).
11. The 'Minimum Loss' value = minimum loss (model output -10%) minus the maximum mitigation (greatest value for mitigation effectiveness).
12. The 'Maximum Loss' value = maximum loss (model output +10%) minus the minimum mitigation (lowest value for mitigation effectiveness).
13. This approach is consistent with that applied to individual habitat types to generate the residual effects quoted in the Habitats Regulations Assessment reporting.

Table 8.9 Estimates of Inter-tidal Areas Before and After the Application of Measures to Prevent or Reduce Significant Adverse Effects.

8.5 Ebb flood operation as a measure to reduce the adverse effects of ebb only generation

Operating modes for detailed SEA study were selected following the preliminary optimisation reported in Section 3 but preliminary optimisation identified that the ebb only generation mode of B3 Cardiff to Weston barrage and L2 Welsh Grounds lagoon may not be optimal in terms of their potential impact on SAC features at risk. In preliminary optimisation, ebb and flood operation was found to cause less reduction in tidal range upstream of the barrage and within the lagoon and should therefore be considered alongside other measures to reduce the adverse effects of ebb only generation on SAC features at risk.

Ebb flood generation has been included in the prevent/reduce measures in Appendix F as measures M1 and M7 (Operational Management of Barrage/Lagoon Regime – Ebb/Flood Generation). Hydraulic modelling has shown that ebb flood generation could substantially reduce the impact on the tidal range with a 40% reduction in adverse effect of B3 Cardiff to Weston Barrage and a 70% reduction in adverse effect of L2 Welsh Grounds Lagoon. However, ebb flood generation would increase the risk to fish because the number of passages through the turbines would increase. There would also be a greater reduction in high water level which, in the case of B3 Barrage, would increase the adverse effects on navigation and require more significant works to dredge shipping channels and modify port accesses. Ebb flood generation would increase the cost of both options whilst causing a 5% reduction in energy yield for B3 Barrage and a 15% increase in energy yield for L2 lagoon. The cost implications of ebb flood generation are considered in Section 10.

As an alternative to ebb flood generation, measures M2 and M8 (Sluice Management), M3 and M9 (Topographic Modification) and M4 (Seawater Level Management) are available to reduce the effect of ebb only generation on SAC features which may cause less indirect adverse effects on fish and navigation with less onerous effects on scheme costs and, in the case of B3 Barrage, energy yield. Those measures have therefore been recommended instead of ebb flood generation and have been included in Table 8.4.

8.6 Measures to Compensate for Adverse Effects under the Habitats Directive

The Report to Inform Stage 2 (Appropriate Assessment), reference xvi, assesses the designated features affected by the schemes and the scale of compensation required.

Compensatory measures for a project would need to relate to the detailed Appropriate Assessment for an STP preferred option. The strategic consideration of compensation ahead of a detailed study should be seen as illustrative and subject to considerable uncertainty. This could be reduced with further studies to assess the effectiveness and quantification of some possible measures.

The potential for Habitats Directive compensatory measures are considered within the ODR in order to inform the Feasibility Study of the scale of the possible contribution they might make to the overall cost of an option. It should be noted that compensation would only apply if an option was able to meet the other Habitats Directive conditions that there were no alternatives and that there were Imperative Reasons of Overriding Public Interest (IROPI) for it to proceed. The ODR presents information that might apply should these other conditions be met but does not make any judgement about whether or not they can be.

The strategic study has focused on the feasibility of compensating within European Commission guidance and the possible upper limit for such measures. A toolkit of compensatory measures within Commission guidance has been identified. Some measures have been conditionally included within the toolkit as they are either uncertain in terms of their effect, or raise points of principle or policy that would need to be addressed before they might be applied. It would be necessary to form a view on such policy issues as part of preparatory work for a scheme.

Compensatory measures studies undertaken by DECC have focused on the Natura 2000 features of sites within the Bristol Channel. Inter-tidal habitats comprise two SAC features (Atlantic saltmeadow and intertidal sandflat and mudflat) which are also the supporting habitat for seven SPA features (six internationally important populations of waterbird and the outstanding assemblage of waterbirds). Inter-tidal habitat has therefore attracted attention, with additional studies commissioned on managed re-alignment in the Severn, scaling up managed re-alignment and a review by British Trust for Ornithology of the implications of habitat creation for birds.

The extent to which Inter-tidal habitat creation through managed re-alignment will act as supporting habitat for birds depends on its design and location. Measures close to the Severn are preferred to measures at distance. Wetland habitat creation as supporting habitat for (some) SPA birds has been included within the measures. This is likely to be relatively inexpensive and may give more flexibility to compensate (for some species) close to the Severn. Quantifying how much of this type of compensation might be needed would require further investigation. As a placeholder for this measure notional costs have been included on the basis of 6000ha (B3 Cardiff to Weston Barrage) , 2000ha (B4 Shoots Barrage) and 1000ha (all other schemes) of habitat provision. Note this requirement is additional to the inter-tidal habitat compensation that is determined.

Compensatory measures for other SAC features are less well understood and there is greater uncertainty about their effectiveness. Possible measures have been considered for the following SAC features: estuary, sub-tidal sandbank (slightly covered by seawater), Atlantic saltmeadow, intertidal sandflat and mudflat, reef, and five species of migratory fish. A notional cost has been applied for survey and designation of reef based on the phase 1 report costs. This is subject to this form of compensation being found to be acceptable for features that are not the primary reason for SAC selection.

Possible measures for twaite shad have been identified for introductions into other rivers and enhancement measures in the River Tywi. It is uncertain that these measures could be ready to be deployed by 2020 but nonetheless cost estimates have been included based on phase 1 report costs and are a place-holder for the need for these measures.

There is too much uncertainty about the impact and effectiveness of measures to robustly quantify and cost measures for migratory fish such as Atlantic salmon. Moreover many possible measures are not thought feasible for a 2020 project delivery as they would require further development to determine if they could be made effective. Further work would be needed to develop the evidence base. This cost will be much more significant relative to inter-tidal compensation for those options such as B4 Shoots Barrage and B5 Beachley Barrage which have a relatively severe effect on fish but proportionately less impact on inter-tidal habitat.

The compensatory measures considered for the purpose of costing are as follows:

- Shad introduction programme with river enhancement and barrier removal, including possible River Tywi enhancements for Bridgwater Bay lagoon. Cost estimates assume that the objective would be to create one established river population for each lost river population and that that not all introductions would be successful. There is low-moderate confidence in attempting a shad introduction programme. This would entail study of the main barriers and limiting factors, development of techniques for handling, rearing and introducing UK shad species and river enhancement and barrier removal. Enhancement of the River Tywi (possible barrier removal and management upstream) might form part of this programme. Early commencement would be vital in order to secure UK population before impact from an STP. Barrier removal would form a significant part of cost. It is uncertain that this measure could be achievable by 2020 but it has nonetheless been included as a placeholder for the purposes of cost estimating.

- Freshwater wetland creation and management as alternative supporting habitat for birds. Notionally, costs have been based on areas of 6000ha (B3 Cardiff to Weston Barrage), 2000ha (B4 Shoots Barrage) and 1000ha (other schemes) based on costs from agri-environment schemes with some additional project cost applied for ten years after which designation is assumed.

- Survey and new notification for Saballaria reef, if feasible.

Measures not included for the purpose of costing are:

- Measures for other migratory fish - Uncertainty about impact prediction and uncertainty about quantification of effects of mitigation and compensation measures does not allow for robust costing. For those options where very high loss or extinction is predicted for salmon on the River Wye (B4 and B5) a large scale project to enhance a major non-salmon river might be considered. This would be likely to involve substantial re-engineering and removal of barriers. Removal or passes for 200+ barriers could cost in excess of £100m.

- Sub-tidal sandbank predictions are for no net loss although it is uncertain whether compensation would be needed for loss of function due to modification of feature.

- Measures for estuary sub-features are not covered within strategic study and would require assessment and costing in the light of detailed development of a project.

- Measures outside Commission guidance which might be required cannot be costed as they have not been determined.

Compensation outside Commission guidance might be the only way of addressing the compensation requirement for some effects of some options. The acceptability of such compensation would need to be determined, as would the detailed method for calculating the rate at which it would be applied and therefore cost.

Cost estimates for compensation measures are reported in Section 10. The estimates do not include all measures and features for which compensation is likely to be required. This is an unknown cost that is likely to be most significant for those options such as B4, B5 and L2 which have relatively high impacts on migratory fish and comparatively lower loss of inter-tidal habitat. This is an additional source of uncertainty which may cause the cost of compensation measures to increase.

At the strategic level it is assumed that most of the cost of compensating for impact on SPA birds would be through inter-tidal habitat creation which was also compensating for SAC impacts.

Estimates of the cost of compensation for inter-tidal habitat loss have been determined by applying a range of compensation ratios from 1:1 to 3:1 to build in sufficient sensitivity analysis to cover likely requirements.

SECTION 9

ENERGY YIELD

9 ENERGY YIELD

9.1 Methodology

9.1.1 1-D and 2-D Modelling

Energy yield estimates have been derived from 1-D and 2-D modelling tests. At preliminary optimisation stage, the energy yield of the original shortlisted schemes, and all the variants considered during preliminary optimisation, was estimated using 1-D modelling. The preliminary optimisation work is reported in Section 3 and in detail in Appendix A and the 1-D modelling method is described in a separate report "Severn Tidal Power Strategic Environmental Assessment 1-D Mathematical Modelling Phases 1 and 2" (ref xiii).. 2-D modelling provides a more accurate indication of discharge conditions which can lead to changes in differential heads across the turbines, particularly in two way generation, and a change in estimated energy yield. Within the Hydraulics & Geomorphology topic, two 2-D flow and water level models were developed. The short timescale of the phase 2 SEA studies required the development of the two models in parallel to allow timely delivery of the assessment. This approach provided the bonus of allowing inter-comparison between model results to confirm the extent of agreement between two independent approaches and consider the implications for project uncertainty where differences arose.

One water level model developed by HR Wallingford was intended to provide water level and flow information to the other aspects of the Hydraulics and Geomorphology topic, principally the sediment transport studies and also the projected energy output from each alternative option.

The second flow and water level model developed independently by ABPmer using the same estuary bathymetry was required primarily to provide flow information for the Marine Water Quality topic and estuary surge conditions for the Flood Risk and Land Drainage topic but was also used to predict energy output for comparison against the HR Wallingford model results .

Comparison of the performance of the two 2D models showed that for the baseline the two models predict similar high and low tide levels throughout the Severn Estuary. Uncertainty in the predicted changes to flows and water levels as a result of the proposed tidal power schemes is greater than predictions for baseline conditions as there is no data against which to validate the predicted response. In practice these factors have been quantified to a certain degree through the comparison of model results and for most circumstances, the agreement between models indicates that either model may be used to predict water levels.

However, there was a variance between the energy estimates predicted by the two 2D models of up to 10% which can not be fully explained. Uncertainties also exist in the mathematical representation of sluices and turbines in a tidal power scheme and in the operating rules used in the energy yield tests.

Energy outputs derived from the two 2-D models, together with the 1-D modelling tests on modern turbine characteristics (see 9.1.2 below) have therefore been used as the basis for setting the range of energy outputs quoted for each alternative option.

A full account of the comparison between 1D and 2D results and effect of adopting modern turbine parameters is reported in "Comparison of Results from 1D and 2D Mathematical Modelling", February 2010 (ref xiv).

9.1.2 Operating Parameters and Assumptions

The 1-D modelling work was based on a selection of turbine parameters and some optimisation of starting heads to estimate the maximum energy that each configuration tested could yield. Initially, turbine parameters were selected (diameter, speed, rated head, maximum flow rate, and efficiency) based on an initial estimate of available head under operation using a series of hill charts and parameterised equations prepared by Escher Wyss for government studies in 1979.

Turbine design has not fundamentally changed since 1979; however, improved design techniques, such as the use of computational fluid dynamics modelling, have increased their efficiency. Turbine characteristics were reviewed by PB and modern day values of efficiency majoration or degradations were allowed for as follows:

<u>Ebb generation and two way (ebb and flood) generation</u>

An increase in efficiency for technology advances of +1.5% was applied to the Escher Wyss efficiency levels of 1979. This increase was applied to the Kaplan and Straflo type turbines. In addition, a step-up majoration based on the turbine diameter was added to the hill charts. A generator efficiency of 97.5% was applied to the power output, so that a turbine rated at 30MW, for example, is limited to an electrical output of 29.25MW.

<u>Two way generation</u>

A reduction in efficiency of 1% for ebb generation and 4% for flood generation was applied. For simplicity a reduction in efficiency of 2.5% has been applied to both ebb and flood generation. This approximates to having half the turbines facing into the estuary and half the turbines facing in the opposite direction. This is not assumed to be the optimal turbine arrangement, which in practice would more likely configure all turbines in the same orientation, but provides a simplification which is suitable for comparison between schemes.

The estimated efficiency reduction was based on published and unpublished material which indicates that efficiency reductions for two way generation are likely to be modest and that CFD modelling of two way turbines would be effective in optimising the turbine design to reduce loss of efficiency compared to one way generation. It should be noted though that an absence of modern data available, specifically a lack of turbine model tests from manufacturers, raises uncertainty in the efficiency levels to adopt for two way generation at this stage. Considering the factors affecting efficiency, such as blade shape and the absence of guide vanes for reverse flow, it is possible that the average efficiency reduction for two way flow could be in the range of 2.5% to 5%. This is considered further in 9.2 below.

During the model simulation, the turbines have been programmed to start up based on the head differences across the structure. For each variant, a range of head differences are specified to cover a range of tide levels. The turbine starting heads have been set to maximise the annual energy output. Turbines generally close down when the head difference is 0.5 – 1.0m. Turbine start up and shut down generally takes place over 15 minutes.

The forms of the schemes selected after preliminary optimisation were then subject to 2-D modelling using the same turbine parameters and starting heads and shut down heads to validate the 1-D modelling estimates.

A 2008 bulb turbine hill chart was made available by Fleming Energy for the Welsh Grounds lagoon in phase 1 with a more up to date estimate of the inter-relationship between head, flow, rotation speed, operating efficiency and operating range than the 1979 Escher Wyss data. After completion of the preliminary optimisation work, permission was obtained to apply it generically to all the shortlisted schemes. Those optimised schemes using bulb turbines were remodelled in 1-D for their primary operating mode using equations based on the 2008 chart data to provide a comparison against the earlier 1-D modelling results. As the 2-D modelling was already complete, it was not possible to re-run 2-D modelling work using the 2008 chart data.

The 2008 turbine characteristics were found to result in a lower tidal range within the basin compared to the 1979 characteristics because of raised low water levels in ebb generation basins, and reduced high water levels and raised low water levels in two way operation. These changes resulted in a small (+/- 1%) change in energy yield for ebb generation and up to 12% energy yield reduction for ebb flood generation. These changes also increased the estimates of inter-tidal loss. Therefore, the operating rules were refined by allowing turbines to freewheel once head dropped below the minimum for generation (set at 25% of rated head). This had a small energy penalty (2%) for ebb generation schemes, but considerable benefit (11%) for the ebb/ flood scheme compared to the old turbine results.

As low water levels reduced in all ebb only cases, the adverse effect on intertidal area of modern turbines could be avoided for Cardiff Weston barrage and reduced for Shoots barrage and Welsh Grounds lagoon. In the case of Bridgwater Bay lagoon, the basin tide range was larger than with the old turbines, so the adverse effects on intertidal area of the new turbines is less and the energy generation larger compared with the original turbines.

All energy yield estimates allow for a 5% reduction in energy yield for outages.

9.2 Energy Estimates Before Inclusion of Measures to Prevent or Reduce Adverse Effects on the Environment

The energy estimates before inclusion of measures to prevent or reduce adverse effects on the environment are provided in Table 9.1. The energy estimates allow a 5% reduction for outages.

Table 9.2 shows the energy yield relative to the size of the impounded area to illustrate the effects of constraints on installed capacity. The barrages are all constrained by the availability of deep water for the turbines. B5 Beachley Barrage is more constrained than B3

Cardiff to Weston and B4 Shoots Barrages owing to the shallower depth of water available. L2 Welsh Grounds Lagoon is also constrained by the size of the Newport Deep channel. The energy yield of L3d Bridgwater Bay Lagoon on the other hand is constrained by the size of the impoundment and not the installed capacity and hence has a higher energy yield relative to the impounded area.

In Section 9.1 it was noted that the efficiency reduction for turbines in two way operation, modelled at a 2.5% average, could be of the order of a 5% average. The B3 Cardiff to Weston Barrage ebb flood energy yield is less favourable than the ebb equivalent based on 2.5% efficiency reduction and would become more unfavourable if the effect of efficiency reduction has been underestimated. The L2 Welsh Grounds Lagoon and L3d Bridgwater Bay Lagoon ebb flood energy yields are higher than the ebb equivalent and would remain higher if the effect of efficiency reduction has been underestimated but the difference would reduce. It is not considered appropriate to reduce the adopted energy estimates at this stage due to this uncertainty as it is within the 18% range in energy yield estimated in Table 9.1 and requires more detailed optimisation studies with sensitivity testing of efficiency reductions.

Scheme	Operating Mode	Estimated Annual Energy (TWh/yr)	Comments
B3 Cardiff Weston Barrage	Ebb only	15.1 to 17.0	1-D results for modern turbines adjusted to allow for 2-D results
B4 Shoots Barrage	Ebb only	2.7 to 2.9	1-D results for modern turbines adjusted to allow for 2-D results
B5 Beachley Barrage	Ebb only	1.4 to 1.6	Based on 2-D results for 1979 turbine characteristics
L2 Welsh Grounds Lagoon	Ebb only	2.6 to 2.8	1-D results for modern turbines adjusted to allow for 2-D results
L3d Bridgwater Bay Lagoon	Ebb flood	5.6 to 6.6	1-D results for modern turbines adjusted to allow for 2-D results

Table 9.1 Provisional Energy Yields (subject to inclusion of measures to prevent or reduce adverse environmental effects)

Scheme	Estimated Upper Bound Annual Energy Yield (TWh)	Indicative Impounded Area (km^2)	Annual Energy Yield per Unit Area (TWh/km^2)	Comments
B3 Cardiff to Weston Barrage	17.0	550.8	0.031	Capacity constrained by width of deep water
B4 Shoots Barrage	2.9	94.0	0.031	Capacity constrained by width of Shoots Channel
B5 Beachley Barrage	1.6	61.7	0.026	Capacity constrained by width and depth of estuary channel
L2 Welsh Grounds Lagoon	2.8	86.1	0.033	Capacity constrained by width of Newport Deep Channel
L3d Bridgwater Bay	6.6	86.8	0.076	Capacity unconstrained
Note: Indicative impounded area is the surface water area at the highest water level in a sample one year tide cycle.				

Table 9.2 Comparison of Adopted Energy Yields Relative to Impounded Area

9.2.1 Comparison between Energy Estimates Derived by PB and Fleming Energy for the Welsh Grounds Lagoon

The energy yield estimate provided in Table 9.1 is for the scheme concept developed by PB from the scheme originally submitted by Fleming Energy. Section 3.4.4 reported differences between the 1,000MW ebb only scheme concept developed by PB for the Feasibility Study and the 2,000MW ebb only concept developed by Fleming Energy. Based on 1D and 2D modelling carried out independently of the SEA modelling, the Fleming Energy estimates an energy yield of 3.15TWh per year. A 2,000MW installation has not been adopted by PB for the Feasibility Study because adopting an additional 1,000MW capacity for an additional 0.25 to 0.45 TWh per year would lead to a less favourable levelised energy cost. If the lagoon is taken forward beyond the Feasibility Study, detailed optimisation studies would be required to determine the optimal capacity.

9.3 Effect on Energy of Inclusion of Measures to Prevent or Reduce Adverse Effects on the Environment

Section 8 identified measures recommended for inclusion to prevent or reduce adverse effects on the environment and identified those measures likely to affect energy yield. Table 9.3 provides an assessment of the effects of those measures on energy.

Measure Envisaged to Prevent or Reduce Adverse Effects	Effect on Energy Yield				
	B3 Cardiff to Weston Barrage	B4 Shoots Barrage	B5Beachley Barrage	L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
M2 and M8 Sluice Management – sluicing after generation period in ebb only mode (See note 1)	Minor reduction	Minor reduction	Minor reduction	Minor reduction	No Effect
M3 and M9 Topographic Modification (See note 2)	No effect likely	No effect likely	No effect likely	No effect likely	No effect
M4 and M33 Seawater and Freshwater Level Management by Pumping (See note 3)	3% to 10% increase	3% to 10% increase	Not applicable	3% to 10% increase	10% to 20% increase
M15 Operational Management of barrage/lagoon regime by allowing turbines to freewheel during generation so that fewer turbines generate at higher efficiency (See note 4)	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase
M17. Type size number and position of sluices – altering the sluice arrangements to increase permeability of barrage/lagoon (See note 5)	5% to 15% reduction	5% to 15% reduction	5% to 15% reduction	5% to 15% reduction	5% to 15% reduction
Overall Effect on Energy Yield (see note 6)	2% to 5% reduction	2% to 5% reduction	5% to 15% reduction	2% to 5% reduction	Up to 5% increase

Table 9.3 Effects of Inclusion of Measures to Prevent or Reduce Adverse Effects on Energy Yield

Table 9.3 should be read in conjunction with the following notes:

1. Sluicing after generation (measures M2 and M8) will cause some loss of energy by diverting flow from turbines but energy yield towards the end of the generation cycle is a small proportion of overall yield and energy reduction will only be minor

2. Although topographic modification (measures M3 and M9) upstream of a barrage or within a lagoon would reduce the live storage volume, the generating capacity of B3, B4, B5 and L2 is constrained by space available for generating capacity rather than the volume of live storage. L3d is constrained by live storage but no topographic modification is proposed within the lagoon.

3. Earlier studies into the B3 Cardiff to Weston Barrage (ref (v)) have shown that pumping (measures M4 and M33) would augment energy yield by between 3% and 10%. B4 Shoots Barrage and L2 Welsh Grounds Lagoon are likely to benefit by a similar amount, if bulb turbines are adopted. L3d Bridgwater Bay lagoon has a significantly larger installed capacity per unit impounded area than other schemes and it is likely that pumping will be more beneficial in energy terms for L3d than other schemes. Pumping is not possible with Straflo turbines as proposed for B5 Beachley Barrage. Detailed 2D model tests are required to determine the optimal pumping regime and provide greater certainty in the energy effects.

4. Measure M15 would effect a minor increase resulting from improved turbine efficiency.

5. It has been assumed for the purpose of the assessment that the overall permeability of each option could be increased by between 5% and 15% of total flow shared between measures M15 and M17. Diversion of 5% to 15% of flow through sluices would lead to a commensurate reduction in energy. It is not known at this stage how the 5% to 15% flow reduction would be shared between M15 and M17.

6. The upper and lower bound overall effects on energy are assumed to be the aggregate of the upper and lower bound effects of all measures combined.

The overall effect of the measures is to reduce energy yield by up to 5% for all schemes except L3d Bridgwater Bay Lagoon which could benefit in an increase by up to 5% on account of the effect of pumping.

Upper bound, lower bound and mean energy estimates are shown in Table 9.4 taking account of the range shown in Table 9.1 and the range of effects in Table 9.3.

Scheme	Estimated Annual Energy (TWh/yr)		
	Lower Bound	Mean Estimate	Upper Bound
B3 Cardiff Weston Barrage	14.4	15.6	16.7
B4 Shoots Barrage	2.6	2.7	2.8
B5 Beachley Barrage	1.3	1.5	1.6
L2 Welsh Grounds Lagoon	2.5	2.6	2.7
L3d Bridgwater Bay Lagoon	5.6	6.3	6.9

Table 9.4 Energy Yields Following Inclusion of Measures to Prevent or Reduce Adverse Environmental Effects

Assuming the reduction in energy in Table 9.3 would be applied to the 2,000MW Welsh Grounds Lagoon concept proposed by Fleming Energy, the equivalent energy for the Fleming scheme would be 3.0 to 3.1 TWh/yr.

SECTION 10

SCHEME COSTS AND LEVELISED ENERGY COSTS

10 SCHEME COSTS AND LEVELISED ENERGY COSTS

10.1 Introduction

Project cost estimates have been prepared to a common level of detail for the primary variants of all shortlisted schemes defined in Section 3. Cost estimates for the alternative variants have been extrapolated from the primary variant estimates. Operation and maintenance costs were estimated in Section 6.

The levelised energy cost (LEC) of a scheme represents the revenue per unit of electricity (usually expressed in £/MWh) that an investor in the project would need to receive in order for the project to break even (i.e. have a Net Present Value of zero) at a particular discount rate. LECs for Severn schemes are calculated by discounting the stream of costs incurred by a project across its life (including initial capital costs as well as operation and maintenance costs across the whole 120 year design life), and summing this to give a Present Value (PV) of costs. This is then divided by the PV of the energy a scheme produces (calculated in the same way). The approach to the scheme cost estimates and calculation of Severn LECs are set out in the following sections.

All costs are quoted at 1st quarter 2008 prices.

10.2 Optimism Bias

Optimism bias (OB) has not been included in the cost and programme estimates. The suitable OB uplift to apply to the costs and programme estimates, including the cost of measures to prevent and reduce adverse effects and the cost of compensation under the Habitats Regulations, has been determined by DECC, in conjunction with HM Treasury, and reported within the Feasibility Study policy documents (Consultation Document, Impact Assessment, ref xviii).

10.3 Project Cost Estimates

10.3.1 Pre-Construction Costs

Work required for planning and consenting is set out in Section 4.

Estimating the costs for undertaking pre-construction work is challenging and will be highly dependent upon the scoping and consultation outputs as well as the nature of the preferred option itself. Previous studies on the Cardiff Weston Barrage estimated a five year development period and a development phase cost of £190m (1989 prices) which, if escalated to 2008 levels would be approximately £285m. On a pro-rata basis, costs are likely to fall in the range of £50m (for the smaller options) to £300m or more for the Cardiff Weston Barrage option, over a minimum four year period, including allowances for the project management time involved by the promoter of these studies. Table 10.1 indicates the build-up of these costs on an option by option basis.

The pre-construction costs for alternative mode sensitivity tests are assumed to be the same as the primary mode.

Option:	B3 Cardiff to Weston Barrage	B4 Shoots Barrage	B5 Beachley Barrage	L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
Site Investigation, Design and Procurement Costs	90m	20m	10m	35m	50m
Cost of Planning Consent Studies:	150m	30m	30m	25m	70m
Promoter Management Costs	25m	10m	10m	10m	20m
Contingency	25m	10m	10m	10m	20m
Total Costs	290m	70m	60m	80m	160m
Time Period	5 years	4 years	4 years	4 years	4 years
1. All cost estimates exclude optimism bias					

Table 10.1 Pre-Construction Cost Estimates

10.3.2 Civil Engineering Construction Costs

For each option, principal quantities have been estimated for the items listed in Table 10.2.

Item	Item Coverage
Preliminaries	Staff and supervision, site accommodation, welfare and messing, workshops, materials testing, site transport etc. Preliminaries have been assessed as 13.5% of civil engineering costs for schemes over £5bn (B3 Cardiff to Weston Barrage, L2 Welsh Grounds Lagoon and L3d Bridgwater Bay Lagoon) and 15% of civil engineering costs for less costly schemes (B4 Shoots Barrage and B5 Beachley Barrage)
Caissons	Casting yards, dredging for caisson towing, construction, installation and fit-out works. Excludes lock and breakwater caissons.
Embankments	Construction facilities (including branches, sidings and rail heads, rock handling harbour, dolos (precast concrete armouring units required to protect embankments) construction yards and haul roads), construction, fit-out and connection to public roads
Navigation locks	Dredging for shipping channels, precast concrete caisson gates (B3 Cardiff to Weston Barrage only), lock caissons, rubble mound breakwaters (B3 only), breakwater caissons (B3 only), landing area and control buildings, lead-in structures, bascule bridges.
Surface Buildings	Powerhouse buildings, on barrage/lagoon substation buildings, control centre, visitors centre, sundry operations buildings

Table 10.2 Principal Civil Engineering Cost Items

For the lagoons, the cost estimates have been prepared for conventional rockfill construction which, as discussed in Section 3, has been adopted as the base case form of lagoon impoundment construction. The costs have been tested below against the costs estimated for alternative forms of impoundment discussed in Section 3.

10.3.3 Mechanical and Electrical Equipment Costs

For each option, principal quantities have been estimated for the items listed in Table 10.3.

Turbine generator costs have been applied as a cost per MW of installed capacity for each size of turbine included in the scheme descriptions. The costs for turbines intended for ebb flood generation are based on ebb generation but include an additional allowance for a reversible type electrical generator, additional electrical auxiliaries, design modifications and other minor nuances.

Item	Item Coverage
Turbine generators	Turbine generator manufacture, delivery, installation, testing and commissioning, engineers' fees, contractor's oncosts and profit, and contingency. Turbine generator costs include turbine control gates but exclude turbine stoplogs. For B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon, the turbine generator cost includes a £200m allowance for the possible development, maintenance and decommissioning of project turbine manufacturing facilities required to enable delivery of turbines at the rate required to achieve first energy generation in six and five year programmes respectively.
Sluice and Lock Gates	Gate design, manufacture, delivery, installation, testing and commissioning. Gate costs include turbine and sluice stoplogs, stoplog built-in parts, lock filling sluices and design costs. Contractor's oncosts are excluded.
Cranes	Turbine handling gantry cranes, stoplog handling cranes, and design costs. Contractors' oncosts are excluded.
Grid connection	Includes principal transmission equipment components between generator terminals and connection to the sub-station. Includes design fees and contractor's oncosts.

Table 10.3 Principal Mechanical and Electrical Cost Items

10.3.4 Design Costs

Detailed design costs for B3 Cardiff to Weston Barrage and the lagoons have been estimated as 1% of civil works costs (excluding caisson installation and dredging). B4 Shoots Barrage and B5 Beachley Barrage are estimated to have similar design costs to L2 Welsh Grounds Lagoon.

10.3.5 Contractor's Oncosts, Insurances and Profit

Contractor's on-costs, insurances and profit have been allowed at 9.25% of the civil and M&E costs (excluding turbine generators for which these were included in the rate per MW).

10.3.6 Ancillary Works

All options require consideration of ancillary works - works that are necessary as a consequence of the construction of a tidal power facility to mitigate the impact on day to day operation of existing assets. These are in addition to any mitigation works incorporated directly into an energy generation structure such as ship locks, fish passes etc. Such assets include:

- Modification of port facilities as a consequence of reduced high water levels and changes in vessel buoyancy
- Navigational aid requirements
- Pumping systems at tidal outfalls to allow land drainage discharges that would otherwise have been prevented from the reduced tidal range
- Additional flood defence protection from increased erosion due to changed water levels and, for B3 Cardiff to Weston barrage, increased water levels due far field effects.

Ancillary works have been identified within the measures recommended for inclusion to prevent or reduce adverse effects on the environment in Section 8. The costs of the ancillary works measures are provided in Table 10.4.

Ancillary Works	Estimated Present Value Cost (£m)				
	B3 Cardiff to Weston Barrage	B4 Shoots Barrage	B5 Beachley Barrage	L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
Demarcation of high risk areas to reduce risk to commercial navigation due to increase in peak water velocities (measure M36)	Assumed negligible	Assumed negligible	Assumed negligible	Assumed negligible	Assumed negligible
Alterations of port infrastructure (reduction in sill levels and dredging of approach channels (measure M41)	150	-	50	-	150
Reconfiguration of intakes and outfalls at Hinkley B nuclear power station (measure M43 and M44)	-	-	-	-	100
Improved treatment at Weston waste water treatment works (measure M45)	-	-	-	-	Not estimated at this stage due to uncertainty in requirements
Pumping systems to tidal outfalls (measure M49) – costs discounted at 8% over scheme life	171	108	51	16	17
Improvements to tidal or sea defences to reduce effects of raised water levels on peak tides for locations in the estuary and for far field effects. (measure M54)	22 to 44	17 to 31	38 to 48	13	-
Erosion protection measures for tidal defences (measure M56) - costs discounted at 8% over scheme life	37 to 234	17 to 99	33 to 143	14 to 66	Up to 2
Monitoring of flood defences (measure M57) - costs discounted at 8% over scheme life	1	1	1	1	1
Total	381 to 600	143 to 239	173 to 293	44 to 96	268 to 270

Table 10.4 Ancillary Works Costs

10.3.7 Cost of Measures to Prevent and/or Reduce Adverse Effects

Construction cost of measures to prevent and reduce adverse effects

Measures recommended for inclusion to prevent or reduce adverse effects were identified in Section 8 which also identified those measures likely to affect scheme cost. Table 10.5 provides an assessment of the cost of those measures which would have more than a marginal effect on cost.

The estimates ranges of designated inter-tidal habitat loss after the application of topographic modification and other measures to prevent and reduce the loss have been provided in Section 8. There is significant uncertainty in the potential effectiveness of topographic modification and for costing purposes only, the mean of the range of potentially effective topographic modification measures has been used. The mean represents 32.5% of the total opportunity to implement topographic modification. Varying the amount of topographic modification would change the overall scheme costs only marginally.

Additional operating and maintenance costs to prevent and reduce adverse effects of sediment deposition

Accretion during the life of the scheme has the potential to reduce the depth of navigation channels, reduce the fluvial capacity of the river channel and reduce the live storage upstream of barrages or within lagoons causing a reduction in energy yield. Based on a review of accretion rates predicted for each scheme within the hydraulics and geomorphology topic reporting, the following conclusions are drawn on the amount of maintenance dredging required to manage accretion.

B3 Cardiff to Weston Barrage - No maintenance dredging is required to preserve energy yield over the life of the scheme. However, maintenance dredging of around 2 million m^3 per year will be required to maintain port accesses at a cost of £10m per year.

B4 Shoots Barrage – Maintenance dredging of around 1.75 million m^3 per year will be required to maintain navigation channels and fluvial capacity and avoid any loss of live volume within the 120 year design life. This rate of dredging assumes that half the 3 to 4 million m^3 per year predicted in the geomorphology studies needs to be dredged and that the remaining half will accrete below the live volume away from the main river and navigation channels. The annual dredging cost is estimated at £8.75m.

B5 Beachley Barrage – Maintenance dredging of around one million m^3 per year will be required to maintain navigation channels and fluvial capacity and avoid any loss of live volume within the 120 year design life. This rate of dredging assumes that half the two million m^3 per year predicted in the geomorphology studies needs to be dredged and that the remaining half will accrete below the live volume away from the main river and navigation channels. The annual dredging cost is estimated at £5m.

Measure Envisaged to Prevent or Reduce Adverse Effects	Estimated Construction Cost (£m)				
	B3 Cardiff to Weston Barrage	B4 Shoots Barrage	B5Beachley Barrage	L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
M3 and M9 Topographic Modification (see note 1)	520	130	130	163	33
M21 Intertidal habitat creation and enhancement to reduce the loss of individual fish and/or intertidal habitats within the Severn Estuary catchment	5	5	5	5	5
M22 Predator Control	Less than £1m	Less than £1m	Less than £1m	Less than £1m	Less than £1m
M37 Relocation of locks for B4 and B5	-	40	180	-	-
M38 Dredging of approach channels to affected ports to reduce or prevent the effects of short term sediment deposition.	Less than £1m	Less than £1m	-	-	Less than £1m
M40 Dredging of new channel during construction (B3 only)	Included in scheme costs	-	-	-	-
M53 Provision of a flood relief channel for the River Axe (B3 only)	10	-	-	-	-
M62 Delivery of construction materials by alternative routes, e.g. rail or sea (B3 and L3d only)	100	-	-	-	100
M66 Increased drainage through provision of measures additional to those outlined for FRLD (Provisional costs)	100	100	Assumed negligible	100	100
M70 Modifying alignment to prevent adverse effects on existing seabed telecommunications cables (L3d only)	-	-	-	-	100
M73. Beach recharge	15	15	15	15	15
Total Cost	750	290	330	283	353

Table 10.5 Cost of Measures to Prevent or Reduce Adverse Effects on the Environment

L2 Welsh Grounds Lagoon –No maintenance dredging is required to preserve energy yield during a 120 year design life as accretion is generally predicted below the live storage volume and there will be no effects on navigation. At some point beyond 120 years maintenance dredging will be required unless the scheme is decommissioned. The amount of dredging will need to be assessed at the time.

L3d Bridgwater Bay Lagoon –No maintenance dredging is required to preserve energy yield during a 120 year design life as accretion is generally predicted below the live storage volume but a small amount of dredging (less than 0.1 million m^3 per year) will be required to maintain the navigation channel at a cost of £0.3m per year. At some point beyond 120 years maintenance dredging will be required unless the scheme is decommissioned. The amount of dredging will need to be assessed at the time.

Cost of measures to prevent and reduce adverse effects to ports

The cost of providing the B3 Cardiff to Weston navigation locks and associated shipping channels has not been separately itemised as measures to prevent and reduce adverse effects on navigation as locks are an integral part of the schemes as shortlisted. The locks and shipping channels for B3 barrage are estimated at £2.4bn £0.9bn of which is for the shipping channels. It should be noted that the estimated cost of shipping channels is an upper bound provision which would provide for access at all times to the Port of Bristol deep sea container terminal (DSCT), which has recently received consent.

The cost of providing shipping locks and navigation channels for the B4 Shoots Barrage and B5 Beachley Barrage are £222m and £117m respectively. The cost estimates are based on the same lock size but Shoots Barrage requires significantly more dredging for the temporary navigation channel during lock construction.

The navigation lock for L3d Bridgwater Bay lagoon is estimated at £85m.

Cost of ebb flood generation as a means of reducing the adverse effects of ebb only generation of B3 Cardiff Weston Barrage and L2 Welsh Grounds Lagoon

Section 8.5 considered the potential for ebb flood generation as a means of reducing the adverse effects of ebb only generation of B3 Cardiff to Weston Barrage and L2 Welsh Grounds Lagoon. Ebb flood generation is not recommended because other measures included in Table 10.5 (M2, M3, M4, M8 and M9) would have less onerous indirect adverse effects. Those other measures would also have less onerous effects on scheme cost. The effects on scheme costs and levelised energy costs are as follows:

- Adopting ebb flood generation for B3 Cardiff to Weston Barrage would add £2.7bn to the scheme cost and effect a 5% reduction in energy yield. Levelised energy costs would increase to between £160 and £170/MWh.

- Adopting ebb flood generation for L2 Welsh Grounds Lagoon would add £0.7bn to the scheme cost and effect a 15% increase in energy yield. Levelised energy costs for ebb flood generation and ebb generation would be similar.

An ebb flood scheme would be more costly than an equivalent ebb generation scheme because ebb flood generation requires longer draft tubes for the water passage through the turbines and the reversible turbine generators would be more costly.

10.3.8 Habitats Directive Compensatory Measures Costs

Compensatory measures for a project are discussed on Section 8. The potential cost of Habitats Directive compensatory measures are considered within the ODR in order to inform the Feasibility Study of the possible contribution they might make to the overall cost of an option. It should be noted that compensation would only apply if an option was able to meet the other Habitats Directive conditions that there were no alternatives and that there were Imperative Reasons of Overriding Public Interest (IROPI) for it to proceed. The ODR presents information that might apply should these other conditions be met but does not make any judgement about whether or not they can be.

Compensation of loss of inter-tidal habitat uses ratios of 1:1, 2:1 and 3:1 to build in sufficient sensitivity analysis to cover likely requirements.

As we are using a range of ratios, we have chosen a single value to represent a plausible average cost for managed re-alignment. In practice, managed realignment is very unlikely to be the only approach taken to deliver compensation measures as topographic manipulation within the Severn Estuary as a means of reducing the effects on habitats could reduce the amount of compensation required.

It should be noted that site based studies show very wide variation in estimating potential unit cost. Site selection criteria may be able to integrate ecological and economic criteria to enable selection of sites within the lower band of cost estimates but that would depend upon which option is selected, what site selection strategy was chosen and other factors.

A unit rate has been derived by DECC from study on managed re-alignment assuming a preference for a low intervention scenario. This scenario assumes the lower range of construction costs and not applying expensive options such as rock armour. Validation of this preference would depend upon the site selection criteria being able to find sufficient areas where the low intervention scenario approach could be implemented.

The unit rate before optimism bias is £45k per hectare. This represents the average of 11 separate desk based studies at three locations covering a range of size of managed re-alignments between 500ha and 11,500ha. This is a test rate for the STP Feasibility Study. There is much uncertainty about what rate would applied when consenting a project. The Commission guidance notes that ratios should be developed on a case by case basis. There are reasonable arguments for supposing that the ratio might be lower or higher when evidence was available.

Annual costs for this measure have not been allocated as there is too great an uncertainty about how they might be treated. If discounted over 120 years the annual costs (and potential replacement costs for new defence structures at 50 year intervals) is unlikely to have significant effect.

The IOAR used a unit cost estimate for inter-tidal habitat creation of £65k per hectare based on a survey of the cost of delivering past schemes with an element of uplift of costs to reflect uncertainty. The updated estimated unit cost based on managed realignment schemes is the cost before consideration of optimism bias and is not therefore comparable with the IOAR estimate. The managed re-alignment study recommended applying an optimism bias of 60% which reflects the experience of Government agencies

A range of topographic modification areas are identified in Table 10.6. For costing purposes, areas of compensation assume that estimate of potential topographic modification will be implemented. Varying the amount of topographic modification would change the overall scheme costs but only marginally. Topographic modification is likely to be most highly prioritised for a B3 Cardiff-Weston Barrage where there is no potential for managed re-alignment within the Severn and losses of inter-tidal supporting habitat for SPA birds would be greatest. If topographic modification was considered acceptable, the optimum balance between topographic modification and managed re-alignment within the Severn and at distance from the Severn would require further investigation as part of the development of an option.

Compensation costs are shown in Table 10.6.

Scheme	Mean of the Estimated Range of Designated Inter-Tidal Habitat Loss after Application of Measures to Prevent or Reduce Significant Adverse Effects (Ha)	Cost of Compensation at £45k/ha (£m)		
		At 1:1 ratio	At 2:1 ratio	At 3:1 ratio
B3 Cardiff to Weston Barrage	14,050	632	1,265	1,897
B4 Shoots Barrage	3,200	144	288	432
B5 Beachley Barrage	2,550	115	230	344
L2 Welsh Grounds Lagoon	7,150	322	644	965
L3d Bridgwater Bay Lagoon	2,100	95	189	284

Table 10.6 Estimates of Inter-Tidal Habitat Loss and Costs of Compensation

Table 10.7 shows the toolkit of other compensatory measures within Commission guidance that has been identified for the purpose of estimating potential costs. These costs are illustrative of the type of cost that might be associated with measures for each option. The main aim of inclusion is to show that future projects would need to develop costs for these categories. Some measures have been conditionally included within the toolkit as they are either uncertain in terms of their effect, or raise points of principle or policy that would need to be addressed before they might be applied.

An indicative treatment of costs for freshwater wetland habitat creation as supporting habitat for SPA birds and for species introduction for shad has been given. An indicative cost for possible new designation of reef features has been included. This would be dependent upon this form of compensation being considered acceptable for features that are not the 'primary reason for SAC selection'. There is insufficient quantitative evidence available to estimate the cost of other possible compensatory measures for fish such as river enhancement and barrier removal at this stage. These could be substantial in the case of options that would lead to extinction of salmon from a river.

The possible cost of compensation for effects on the estuary and sub-tidal sandbanks if required has not been included.

Habitats Directive compensation for any impacts on the SAC sub-features has not been assessed within this strategic study and would need to be developed as part of a project.

There is no basis for costing compensatory measures outside Commission guidance (equal value measures) where these are required and are considered to be acceptable. The treatment of possible further tranches of habitat compensation to respond to future losses of inter-tidal due to erosion and sea level rise may need to be factored in. It might be assumed that these would be so far in the future that they will be heavily discounted and therefore less significant. A further consideration is that by the time such tranches are required the additional habitat created by the application of a compensation ratio may be considered sufficiently functional so as not to require additional compensation for the later losses.

The estimates for the cost of compensation do not include all measures and features for which compensation is likely to be required. This is an unknown cost that is likely to be most significant for those options such as B4, B5 and L2 which have relatively high impacts on migratory fish and comparatively lower loss of inter-tidal habitat. This is an additional source of uncertainty when considering the overall cost of compensation.

Finally, the costs do not include any consideration of the possible need to compensate for effects outside the Bristol Channel which have not been quantified within the current study.

Measure	B3 Cardiff to Weston Barrage	B4 Shoots Barrage	B5 Beachley Barrage	L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
Shad introduction programme with river enhancement and barrier removal, including possible River Tywi enhancements.[1]	£30m	£20m	£20m	£20m	£3m (R Tywi only)
Measures for other migratory fish	Uncertainty about impact prediction for fish and uncertainty about quantification of effects of mitigation and compensation measures does not allow for robust costing This could require a substantial programme of measures to remove factors limiting the population of species such as Atlantic salmon on rivers at distance to the Severn. Such measures would need to be determined as additional to the existing regulatory requirements.				
Freshwater wetland creation and management as alternative supporting habitat for birds. [2]	£12.6m	£4.2m	£2.1m	£2.1m	£2.1m
Sub-tidal sandbank	Predictions are no net loss although uncertain whether compensation would be needed for loss of function due to modification of feature. Costs not included.				
Survey and new notification for Saballaria reef if feasible,	£620k	£620k	n/a	n/a	£620k
Measures for estuary sub-features.	Not covered within strategic study. Would require assessment and costing in the light of detailed development of a project.				
Equal value measures outside Commission guidance	Measure is conceptual level only and no basis for costing is currently available.				

Notes:

1. Assumes that that not all introductions would be successful and cost covers 'failed attempts'. Assumes that objective would be to create one established river population for each lost river population.
2. Notionally based on areas of 6000ha (B3), 2000ha (B4) and 1000ha (B5, L2 and L3d) based on costs from agri-environment schemes with some additional project cost applied for ten years after which designation is assumed. Indicative of scale of cost not of delivery or tenure model applied.

Table 10.7 High level assumptions about cost of non inter-tidal compensatory measures

10.3.9 Contingency

An assessment of the accuracy of scheme cost estimates has been carried out taking into account the level of certainty in the detail of the defined options, the estimates of quantities of materials and components, unit cost rates, costs of construction processes and the costs allowed for items which have not been defined, such as fabrication yards.

The central cost estimates of the civil and mechanical and electrical engineering works contain a risk allowance of between 5% and 10% which reflects the level of conservativism in the estimates. Assessment of the accuracy of the central cost has determined the contingency allowance that should be applied to reflect the accuracy in scheme cost estimates. Contingency has not been separately applied to the cost of Habitats Directive compensatory habitat, ancillary works and measures to prevent and reduce adverse effects. The costs of ancillary works and prevent/reduce measures have been estimated at a high level and have been derived using a precautionary approach. Contingency is built into the rate applied for the cost of compensatory habitat. Risk allowance and contingency have not been separately identified for these cost components but are implicitly contained within the precautionary estimates adopted.

Contingency adjustments are shown in Table 10.8. B3 Cardiff to Weston Barrage has the least contingency because the evidence base available to inform the construction cost estimates is the most robust. Lagoons have the highest contingency allowance to reflect the uncertainty in the cost of their impoundment construction.

Scheme	Contingency Allowance to be Applied to the Central Cost Estimate
B3 Cardiff to Weston Barrage	+15%
B4 Shoots Barrage	+17.5%
B5 Beachley Barrage	+17.5%
L2 Welsh Grounds Lagoon	+20%
L3d Bridgwater Bay Lagoon	+20%

Table 10.8 Contingency Allowances

10.3.10 Scheme Cost Estimates

Estimated scheme costs excluding optimism bias, are provided in Table 10.8 for various ratios of compensation required under the Habitats Directive. The full construction cost estimates are included in Appendix E.

As reported in Section 3.5, scheme cost estimates were based on a preliminary assessment of embankment crest levels and wave heights which have since been reviewed to take account of findings from the hydraulics and geomorphology studies. It is estimated that modifications required to embankments and caissons of B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon to protect against the water levels and wave heights predicted by the hydraulics and geomorphology studies could increase those scheme costs by 0.5% and 3% respectively above the costs reported in Table 10.9.

Scheme	Estimated Scheme Cost (£m)				
	B3 Cardiff to Weston Barrage	B4 Shoots Barrage	B5 Beachley Barrage	L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
Pre-Construction	290	70	60	80	160
Construction (Central Estimate)	17,610	3,260	2,141	4,706	9,161
Construction Contingency	2,641	571	375	941	1,832
Ancillary Works (Upper bound cost)	600	239	293	96	270
Measures to Prevent and Reduce Adverse Effects (Upper bound cost)	750	290	330	283	353
Non Inter-Tidal Compensation Measures	43	25	22	22	6
Inter-tidal habitat Compensation (1:1 ratio)	632	144	115	322	95
Scheme Cost including 1:1 compensatory habitat	22,567	4,599	3,336	6,449	11,877
Scheme Cost including 2:1 compensatory habitat	23,199	4,743	3,450	6,771	11,971
Scheme Cost including 3:1 compensatory habitat	23,831	4,887	3,565	7,093	12,066

Table 10.9 Estimated Scheme Costs

10.3.11 Scheme Costs Estimated by Fleming Energy for the Welsh Grounds Lagoon

The construction cost estimate provided in Table 10.9 is for the scheme concept developed by PB from the scheme originally submitted by Fleming Energy. Section 3.4.4 reported differences between the 1,000MW ebb only scheme concept developed by PB for the Feasibility Study and the 2,000MW ebb only concept developed by Fleming Energy. Table 10.10 provides the estimated scheme cost based on construction costs estimated by Fleming Energy. The estimate has not been adopted for the purpose of the Feasibility because, as explained in Section 3.4.4, the estimate is based on innovations which require further concept development before they can provide the reasonable certainty required for the Feasibility Study.

Scheme	L2 Welsh Grounds Lagoon based on estimates provided by Fleming Energy
Pre-Construction [1]	80
Construction (Central Estimate) [2]	3,201
Construction Contingency [4]	640
Ancillary Works (Upper bound cost) [1]	96
Measures to Prevent and Reduce Adverse Effects (Upper bound cost) [1]	283
Non Inter-Tidal Compensation Measures [1]	22
Inter-tidal habitat Compensation (1:1 ratio) [1, 3]	322
Scheme Cost including 1:1 compensatory habitat [1, 3]	4,644
Scheme Cost including 2:1 compensatory habitat [1, 3]	4,966
Scheme Cost including 3:1 compensatory habitat [1, 3]	5,288

Notes:

1. Taken from Table 10.9
2. Estimate based on caisson and wall/embankment costs provided by Fleming Energy for 2,000MW scheme concept based on innovations which require further concept development to provide reasonable certainty and not adopted for Feasibility Study
3. Compensatory habitat costs as estimated for a 1,000MW scheme. Compensatory habitat costs have not been estimated for a 2,000MW scheme and are likely to be different.
4. Contingency applied as 20% of construction cost, as Table 10.8.

10.10: L2 Welsh Grounds Lagoon Scheme Cost Based on Cost Estimates Submitted by Fleming Energy

10.4 Comparison of Lagoon Impoundment Costs

Section 3 set out the alternatives to the conventional rock fill embankment which has been adopted as the base case for lagoon impoundment construction. Costs of alternative forms of construction have been assessed for Bridgwater Bay lagoon to test the adoption of the base case. Costs of the Fleming wall have not been considered at this stage whilst the discussions over the need for modifications to the design are in progress. The cost associated with the Rubicon technology has not been considered.

10.4.1 Embankments Constructed with Geo-Containers

Principal quantities for the embankment construction using geo-containers have been estimated. The cost of geo-container construction has been prepared with the assistance of specialist contractors and geo-container material suppliers. The comparison of embankment cost for the Bridgwater Bay scheme is ongoing.

For Bridgwater Bay lagoon, initial indications suggest that the cost of the geo-container based embankment construction was found to be 20% higher than conventional rockfill construction.

10.4.2 Halcyon Wall

A reasonably detailed evidence based estimate of the wall cost has been provided by Halcyon. Within the time available, it has not been possible to peer review the wall estimate in detail but a high level summary of the wall cost is provided in Table 10.11.

Cost Component	Halcyon Wall Cost (£m)	Comments
Support Columns	285	Cost supplied by Halcyon
Mini-Caissons	191	Cost supplied by Halcyon
Sealing System	43	Cost supplied by Halcyon
Halcyon Jack-Up Barge Equipment	94	Cost supplied by Halcyon – assumes two barges required
Fabrication Yards	123	Cost excluded from Halcyon estimate; equivalent cost to embankment construction facilities assumed
Total	736	

Table 10.11 Estimated Halcyon Wall Costs

The estimate provided by Halcyon, including an allowance for fabrication yards omitted from the Halcyon estimate is about 50% of the estimated cost of embankment construction. However, it should be noted that the wall costs omit a roadway which would be required on top of the wall to provide access to the powerhouses and locks to be consistent with the lagoon impoundment principles set out in Section 3. The cost also excludes provision for export and communications cable tunnels which would be supported from the roadway structure. Around 10km of roadway would be required, assuming no roadway connection between the two powerhouse structures. No design is available on which to estimate the cost of the roadway and cable tunnels but its cost would close the gap between the wall and embankment estimates.

For Bridgwater Bay, it is concluded that the cost of the Halcyon solution may be competitive with the cost of a conventional embankment but further study is required into the programme for the construction of the Halcyon wall and the cost of providing access to the powerhouses and locks.

10.5 Levelised Energy Costs

10.5.1 Methodology

Project costs are as detailed in section 10.3 and are inclusive of grid connection (from generator to sub-station connections), compensation for loss of habitat under the Habitats Directive, and ancillary works. The costs are exclusive of grid reinforcement costs which are usually borne by National Grid and recovered through tariffs. Tariffs have been in included in operational and maintenance costs. Decommissioning costs have not been included in the levelised energy costs as decommissioning is assumed to occur at some point after the end of the 120 year design life. In discounted cash flow analysis, the present day cost of decommissioning is insignificant. The issue is not the impact that decommissioning will have on cost of energy but to ensure instead that a sinking fund is created at the start of the project to enable the small contribution from energy revenue and the associated interest to accrue over the lifetime of the project to build the decommissioning fund. The cost of such a find has not been included in the levelised energy cost and requires further consideration.

Costs per unit energy have been calculated by distributing the pre-construction costs and construction costs evenly over the respective periods set out in Section 3. 25% of the cost of compensatory habitat has been distributed evenly over the pre-construction programme to allow for site selection, investigation, design, planning, consenting and land purchase options agreements. The remaining costs are distributed evenly over the construction period. The simplified distribution of costs introduces some inaccuracies in the levelised energy costs. Levelised energy costs in the Feasibility Study Impact Assessment (ref xviii) have been derived using a more accurate profiling of construction costs.

Planning and consenting costs are distributed evenly over the pre-construction period. Annual energy yields are as estimated in Section 9. Operation and maintenance costs are as estimated in Section 6 plus the maintenance dredging costs estimated in Section 10.3.

10.5.2 Levelised Energy Costs

Levelised Costs for a single project can vary significantly depending on the rate at which costs and energy are discounted. Ideally, discount rates should capture the rate of return that an 'investor' in the scheme would require, and calculate the per unit revenue the investor would need to receive for the project to break even given this. Given uncertainty around who would invest in a Severn scheme, and the commercial structure to deliver a scheme, we calculate levelised costs using a range of different discount rates as follows:

- 10%: this represents a typical private sector rate of return when the investor is exposed to a significant degree of market price risk;
- 8%: this represents a private sector rate of return under a subsidy mechanism that insulates an investor from market price risk;
- 8% for first 35 years of economic life, then Green Book rates: this represents a rate of return for an investor over a typical private sector appraisal horizon, as well as the 'residual value' (the benefits of the scheme to society after the end of the private sector time horizon).
- Green Book rates: this enables us to calculate 'societal' levelised costs, i.e. if costs and energy were discounted at social discount rates, the per unit price of electricity that would be required for Net Present Value of the project for society as a whole to equal zero.

The levelised energy costs, excluding optimism bias, using the above discount rates and based on the mean energy estimate are shown in Tables 10.12 to 10.15 for various ratios of compensation required under the Habitats Directive. Modifications to embankment and wave wall heights identified in Section 10.3.10 could increase the reported levelised costs for B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon by 0.5% and 3% respectively above the costs reported in Tables 10.12 to 10.15.

Scheme	Levelised Energy Cost (£/MWh)			
	Excluding Compensatory Habitat	Allowing for 1:1 Compensatory Habitat	Allowing for 2:1 Compensatory Habitat	Allowing for 3:1 Compensatory Habitat
B3 Cardiff to Weston Barrage	198	204	211	217
B4 Shoots Barrage	214	221	228	235
B5 Beachley Barrage	274	283	293	303
L2 Welsh Grounds Lagoon	313	331	348	366
L3d Bridgwater Bay Lagoon	244	246	248	250

Table 10.12 Levelised Energy Costs (Mean Energy Estimate, 10% Discount Rate)

Scheme	Levelised Energy Cost (£/MWh)			
	Excluding Compensatory Habitat	Allowing for 1:1 Compensatory Habitat	Allowing for 2:1 Compensatory Habitat	Allowing for 3:1 Compensatory Habitat
B3 Cardiff to Weston Barrage	156	160	165	169
B4 Shoots Barrage	171	176	181	187
B5 Beachley Barrage	218	225	233	240
L2 Welsh Grounds Lagoon	246	259	272	285
L3d Bridgwater Bay Lagoon	193	194	196	198

Table 10.13 Levelised Energy Costs (Mean Energy Estimate, 8% Discount Rate)

Scheme	Levelised energy cost (£/MWh)			
	Excluding Compensatory Habitat	Allowing for 1:1 Compensatory Habitat	Allowing for 2:1 Compensatory Habitat	Allowing for 3:1 Compensatory Habitat
B3 Cardiff to Weston Barrage	70	72	73	75
B4 Shoots Barrage	79	81	83	85
B5 Beachley Barrage	99	102	105	107
L2 Welsh Grounds Lagoon	107	112	116	121
L3d Bridgwater Bay Lagoon	86	87	88	88

Table 10.14 Levelised Energy Costs (Mean Energy Estimate, HM Treasury Green Book Long Term Discount Rates)

Scheme	Levelised Energy Cost (£/MWh)			
	Excluding Compensatory Habitat	Allowing for 1:1 Compensatory Habitat	Allowing for 2:1 Compensatory Habitat	Allowing for 3:1 Compensatory Habitat
B3 Cardiff to Weston Barrage	145	149	153	158
B4 Shoots Barrage	159	164	169	174
B5 Beachley Barrage	203	210	217	224
L2 Welsh Grounds Lagoon	229	241	253	265
L3d Bridgwater Bay Lagoon	180	181	183	184

Table 10.15 Levelised Energy Costs (Mean Energy Estimate, 8% Discount Rates over a 35 Year Finance Period and HM Treasury Green Book Long Term Discount Rates Thereafter)

10.5.3 Energy Yield Sensitivity Tests

Sensitivity tests have been carried out on the upper and lower bound energy yield to determine levelised energy costs for comparison against the levelised costs with the mean energy yield estimate. The sensitivity test has used the 10% discount rate and 2:1 compensation ratio. The results are shown in Table 10.16.

Scheme	Levelised Energy Cost with Upper Bound Energy Yield Allowing for Cost 2:1 Compensatory Habitat (£/MWh)	Levelised Energy Cost with Mean Energy Yield Allowing for Cost 2:1 Compensatory Habitat (£/MWh)	Levelised Energy Cost with Lower Bound Energy Yield Allowing for Cost 2:1 Compensatory Habitat (£/MWh)
B3 Cardiff to Weston Barrage	198	211	226
B4 Shoots Barrage	220	228	237
B5 Beachley Barrage	275	293	339
L2 Welsh Grounds Lagoon	335	348	362
L3d Bridgwater Bay Lagoon	226	248	279

Table 10.16 Sensitivity Tests for Variation in Energy Yield (10% discount rate)

10.5.4 Levelised Energy Costs based on Energy Yields and Scheme Costs Submitted by Fleming Energy

The levelised energy costs shown in Table 10.17 have been calculated for the Welsh Grounds Lagoon scheme concept submitted by Fleming Energy as set out in section 3.4.4, using Fleming Energy's estimate of energy yield (Section 9.3), construction costs (Table 10.10) and 50 month construction programme. These levelised not been adopted for the purpose of the Feasibility because, as explained in Section 3.4.4, the estimate is based on innovations which require further concept development before they can provide the reasonable certainty required for the Feasibility Study.

Discount Rate	Levelised Energy Cost (£/MWh)			
	Excluding Compensatory Habitat	Allowing for 1:1 Compensatory Habitat	Allowing for 2:1 Compensatory Habitat	Allowing for 3:1 Compensatory Habitat
10% Discount Rate Over Whole Life	185	199	212	226
8% Discount Rate Over Whole Life	148	158	169	179
8% Discount Rate Over 35 Year Finance Period; HM Treasury Green Book Long Term Discount Rates Thereafter	139	149	159	168
HM Treasury Green Book Long Term Discount Rates	71	74	78	82
Note: Scheme costs and construction programmes submitted by Fleming Energy are based on innovations which require further concept development to provide reasonable certainty and the levelised energy costs are therefore not adopted for Feasibility Study				

Table 10.17 Levelised Energy Costs for Welsh Grounds Lagoon based on Energy Yield Estimates, Construction Programmes and Scheme Cost Estimates Submitted by Fleming Energy

SECTION 11

COMBINATIONS AND MULTIPLE BASIN OPTIONS

11 COMBINATIONS OF SCHEMES AND MULTIPLE BASIN OPTIONS

11.1 Combinations

11.1.1 Methodology and Assumptions

This section discusses the potential combinations of short listed schemes including their costs and energy yields. A high level assessment of the environmental effects of combinations deemed worthy of further study, if taken forward after the Feasibility Study, is also included. Combinations and multiple basin options have not been studied to the same level of detail as the shortlisted schemes and have not been subject to SEA. The purpose of this section is only to identify those combinations and multiple basin options which would be candidates for more detailed study if the Feasibility Study concludes that individual schemes which could be configured in combination or as multiple basin schemes should be taken forward. The ODR includes a high level evaluation of the environmental effects of those combinations and multiple basin options which would be candidates for further study. Combinations and multiple basin options can not form part of the Government's plan for tidal power development without extending the SEA to include candidate combination or multiple basin options.

There are a number of potential combinations and different permutations in the way combinations could be configured. The comparison of combinations therefore takes a high level view on the scope for individual schemes to be combined. The Interim Options Analysis Report (published in January 2009 as part of the Phase 1 Public Consultation) outlined the possible combinations of options. This was based on the likely interaction between different options in terms of energy yield. For example, a barrage will not readily co-exist with a second barrage located further upstream barrage because of the reduced tidal range within the tidal basin which would reduce energy yields in the upstream barrage. However, lagoons are able to co-exist because their upstream basins are discrete entities. Similarly, lagoons located downstream of barrages can, in theory, co-exist with barrages.

For the shortlisted options, the initial permutations are therefore as follows:

- Shoots or Beachley Barrage with Bridgwater Bay and/or Welsh Grounds Lagoon(s)
- Bridgwater Bay and Welsh Grounds Lagoons
- Cardiff to Weston Barrage and Bridgwater Bay Lagoon

The process that has been applied to the evaluation of combined options has been as follows:

Step 1 Review results from analysis of individual options

Step 2 Consider individual options in combination, assessing energy yield, construction costs, associated effects and review of potential optimisation refinements

Step 3 Identify the combinations which are candidates for further more detailed study beyond the Feasibility Study

Step 4 A high level evaluation of potential environmental effects of combinations

To develop a shortlist of options in combination, each of the permutations has been analysed in terms of Cost of Energy (energy yield, costs, programme) and Opportunities for Optimisation – discussed in section 11.1.2 below. When doing the assessment outlined above, we used the following assumptions:

Cost of Energy:

- The cost of energy from combinations depends on the phasing of their delivery. Given the level of uncertainty in phasing, it is only appropriate to draw broad conclusions on energy costs. It should be noted that the effects of developing schemes in combination on their cost are well within the level of certainty of the individual scheme estimates. Also, as the energy estimates have been extrapolated from results of 2-D modelling of individual schemes, energy and cost of energy estimates should only be used for comparison between schemes constructed in or out of combination rather than absolute estimates of combinations costs.

  Costs of combinations and levelised energy costs have been estimated without optimism bias. Levelised energy costs without optimism bias and without the cost of compensatory habitat have been compared to a threshold levelised energy cost of £170 per MWh has been applied to consider economic viability

  The figure of £170 is derived from the work undertaken by DECC in Phase 1 and represents the upper bound of an estimate of the cost of producing the last percentage point of renewable energy to achieve a 32% renewable electricity contribution to the UK based on an 8% discount rate. Government increased this threshold in Phase 1 of the Severn Study to £200 per MWh to allow options that were marginally more expensive, but had significant environmental benefits, to be included in the shortlist.

Energy Yield

- The energy yield of a combination of schemes is expected to be less than the sum of the individual schemes' energy yields because of the effect that each scheme has on the tidal range downstream of the barrage or outside the lagoon. Energy yield has been estimated by considering the predicted effects that each individual scheme has on the tidal range at the other schemes from 2-D modelling results.

With the key combinations identified, we can then begin to assess the opportunity of selecting operating modes for individual schemes which are advantageous in phasing the tidal range within the impounded area. The principal benefits of this phasing are:

- Phasing the power output to provide more continuous energy which could reduce impacts of schemes on the National Grid and could increase the value of energy. However, comparisons in energy value terms are not quantified due to the speculative nature of energy value forecasts.

- Phasing the exposure of inter-tidal habitats to reduce the inter-tidal effects of individual schemes.

The scope for optimisation focuses on these principal effects.

11.1.2 Scope of potential combinations

Table 1.1 below provides a matrix of the theoretically possible combinations of the shortlisted schemes and an overview of their compatibility:

	B3 Cardiff to Weston	B4 Shoots or B5 Beachley	L2 Welsh Grounds	L3d Bridgwater Bay
Upstream Barrage and Lagoons	×	✓	✓	✓
Lagoons	×	×	✓	✓
Larger Barrage and Lagoons	✓	×	×	✓

Table 11.1 Scope of Potential Combinations

The results of these detailed analyses are presented in the following sections:

Upstream Barrages and Lagoons: Section 11.1.3 (As the effects of combining another scheme with either of the upstream barrages are fairly simple we have grouped our discussion of these options together).
Lagoons: Section 11.1.4
Larger Barrage and Lagoons: Section 11.1.5

The table below provides an overview of the energy yield and capital costs of the potential combinations. Cost of energy assumes that the schemes are constructed concurrently. Costs exclude compensatory habitat.

Combination	Energy Yield (TWh)	Capital Cost (£bn)	Cost of Energy based on 8% discount rate (£/MWh)	Optimisation Opportunities	Combination Favourable (Y/N)?
B5 + L2	3.8 -4 .2	9.4	230 – 250	E/ EF (L2)	N
B5 + L3d	6.9 – 8.5	15.0	180 – 220	E/EF (L3d), EP	N
B5 + L2 + L3d	9.4 – 11.2	21.1	195 – 230	E/EF (L2 & L3d), EP	N
B4 + L2	5.1 – 5.5	10.3 – 10.6	200 – 215	E/ EF (L2)	N
B4 + L3d	8.2 – 9.7	15.9 – 16.2	175 – 205	E/EF (L3d), EP	Y
B4 + L2 + L3d	10.7 – 12.4	22.0 – 22.4	185 – 215	E/EF (L2 & L3d), EP	N
L2 + L3d	7.7 – 9.1	17.7 – 17.9	200 - 240	E/EF (L2 & L3d), EP	N
B3 + L3d	17 - 20	32.9 – 33.7	180 - 210	E/EF/F (L3d)	Y
Key: E – Ebb only generation EF – Ebb flood generation F – Flood only generation EP – Energy phasing (altering the timing of energy generation between schemes)					

Table 11.2 Overview of Combinations

11.1.3 Upstream barrage and one or more downstream lagoons

Energy Yields

The effects of individual schemes on the mean Spring tidal range at the other schemes have been predicted from 2-D modelling and are summarised in Table 11.3 below.

	Effect of B4	Effect of B5	Effect of L2	Effect of L3d
Effect on B4			Negligible	5% reduction
Effect on B5			Negligible	5% reduction
Effect on L2	Small increase (around 1%)	Small increase (around 1%)		5% reduction
Effect on L3d	Small increase (around 1%)	Small increase (around 1%)	Negligible	

Table 11.3 Effects of Individual Schemes on Spring Tidal Range from 2-D Modelling

The effects on tidal range indicate that:

- Energy yield of combinations not including L3d Bridgwater Bay Lagoon are likely to be similar to the sum of the individual scheme yields;
- Energy yield of combinations including L3d Bridgwater Bay Lagoon are likely to be of the order of 5% lower than the sum of the individual energy yields.

Indicative energy yields of combinations are provided in Table 11.4 below. The range takes into account the certainty in individual energy estimates based on 2D modelling.

Combination	Total Energy Yield of Individual Schemes	Indicative Energy Yield of Schemes in Combination	Indicative Energy Yield Reduction In Combination
B4 and L2	5.1 - 5.5	5.1- 5.5	Negligible
B4 and L3d	8.2 - 9.7	7.8 – 9.2	5%
B4, L2 and L3d	10.7 - 12.4	10.2 - 11.8	5%
B5 and L2	3.8 - 4.2	3.8 – 4.2	Negligible
B5 and L3d	6.9 – 8.5	6.6 – 8.1	5%
B5, L2 and L3d	9.4 – 11.2	8.9 – 10.6	5%

Table 11.4 Indicative Energy Yields for Combinations of an Upstream Barrage and One or More Downstream Lagoons

Scheme Costs

Based on a review of the individual upstream barrage (B4 Shoots or B5 Beachley) and downstream lagoon (L2 Welsh Grounds and/or L3d Bridgwater Bay) schemes, combining schemes could have the following effects on individual scheme costs:

- The alignments of L2 Welsh Grounds Lagoon and B4 Shoots Barrage schemes intersect on the Welsh side of the Shoots channel. Depending on which scheme is constructed first, the combination would save either around 3km of embankment from B4 Barrage or around 2.4km of embankment from L2 Lagoon. Only one road connection would be required. This would reduce the scheme cost by either £190m for B4 or £170m for L2 respectively.

- Caisson construction is generally on the critical path of construction programmes and constructing schemes concurrently would require concurrent caisson construction. Each scheme is expected to require 3 or 4 caisson construction yards preferably within the Severn estuary or Bristol Channel. It is doubtful that more than 3 or 4 caisson construction yards could be provided locally and therefore concurrent construction would require yards elsewhere in the UK or Europe, as would be required for B3 Cardiff to Weston Barrage. This would increase the cost of caisson installation. The effect on cost has not been determined.

- If schemes are constructed sequentially, it is possible that caisson fabrication yards constructed downstream of the Second Severn Crossing could be used for other schemes downstream of the Second Severn Crossing. Caisson construction for B5 Beachley Barrage would require yards upstream of the Second Severn Crossing due to navigation restrictions and so would not benefit from yards constructed for other schemes. If yards could be reused, there would be a saving of £200m to a maximum of £240m for a combination of three schemes (i.e. barrage plus both lagoons) but only if sequential construction is planned and the fabrication yards are not decommissioned between schemes.

- All schemes require early build out of embankments from shore. Constructing schemes concurrently would therefore not provide any reduction in the cost of construction facilities for embankments (e.g. rock handling facilities, railheads etc). The cost of the facilities is likely to be similar to the sum of the individual scheme requirements. If the schemes were constructed sequentially with a planned reuse of construction facilities, cost reductions of between £60m and £160m could be available depending on which schemes are constructed first and second. There would be little benefit for B5 Beachley Barrage because its embankments are much smaller.

- Ancillary works required outside the impounded area may be common to all schemes. For example, lowering of lock sills at ports if required as a result of reductions in high water level for one scheme would likely be similar in cost to a combination of two or three schemes. Based on the £50m to £100m cost of ancillary works currently allowed for in the individual scheme estimates, the cost of all but one scheme might be reduced by around £20m.

- There are too many uncertainties to consider the implications of combinations on the cost of compensatory habitat further at this stage.

The effects on caisson construction and installation may have an adverse, beneficial or neutral effect on scheme costs depending on the phasing of construction. These effects are therefore uncertain and not considered further.

The reduction in cost for a combination of three schemes including B4 Shoots Barrage could vary from nil to around £0.4bn. This compares to an aggregate cost of £22.4bn (excluding compensatory habitat) for the three individual schemes (2% reduction), excluding optimism bias. The reduction in cost for a combination of three schemes including B5 Beachley Barrage could vary from nil to around £0.2bn. This compares to an aggregate cost of £21.1bn for the three individual schemes (1%), excluding optimism bias and compensatory habitat.

A combination of B4 Shoots Barrage and a downstream lagoon could result in a cost reduction from nil to around £0.3bn, compared to an aggregate cost of £16.2bn (B4 and L3d Bridgwater Bay Lagoon) or £10.6bn (B4 Shoots Barrage and L2 Welsh Grounds Lagoon), reductions of 2% and 3% respectively.

A combination of B5 Beachley Barrage and a downstream lagoon would be similar to the aggregate cost of the individual schemes.

It should be noted that some reductions assume that construction will be sequential and that operation of the second or third scheme will thus be delayed.

Energy Costs

Levelised energy costs based on an 8% discount and excluding compensatory habitat are shown in 11.2. All levelised energy costs exceed £170 per MWh. The most favourable combination in energy cost terms is B4 Shoots Barrage and L3d Bridgwater Bay Lagoon.

Opportunities for Optimisation

Figure 11.1 compares the generation profiles and water levels of the upstream barrages and lagoons operating individually in the form selected following optimisation of the individual schemes. The comparison shows that on a typical Spring tide, non-generating periods would occur in combinations including L3d Bridgwater Bay Lagoon for around two hours in between every phase of generation. The output of alternate generating phases would vary significantly in magnitude due to the phasing of ebb flood generation from the lagoon and ebb generation from an upstream barrage and L2 Welsh Grounds Lagoon. Non-generating periods in combinations not including L3d Bridgwater Bay Lagoon would be three to four hours between every phase of generation.

Comparing the tidal range effects of the individual schemes, it can be seen that operating L3d Bridgwater Bay Lagoon in ebb flood mode provides periods of inter-tidal exposure at low tide within the lagoon whilst the water levels within L2 Welsh Grounds Lagoon and upstream of B4 Shoots Barrage and B5 Beachley Barrage are generally still rising. Operating one of the lagoons as a single phase flood generation scheme could be advantageous. Compared to two phase ebb flood generation shown for L3d Bridgwater Bay Lagoon in Figure 11.1, the flood generation phases would be longer and would provide a greater continuity of power output from the combination. Figure 11.1 also shows how the tide becomes more asymmetric upstream which may provide the opportunity to optimise a combination so that the power output by L2 Welsh Grounds Lagoon and/or the barrage ramps down later than L3d Bridgwater Bay Lagoon thus providing more continuity.

Optimisation of individual schemes found that upstream barrages operating as ebb flood schemes were unfavourable due to their energy cost and significant impact on upstream tidal range. There is no evidence that developing upstream barrages in combination would increase the prospects for an ebb flood upstream barrage. Similarly, operating barrages as flood generation schemes as part of a combination would not be viable due to energy cost and significant impacts on the upstream tidal range.

Therefore, opportunities for optimising the combinations should focus on comparisons between ebb and ebb flood generation for the lagoons. This should take into account the conclusions from the Feasibility Study on the relative merits of ebb and ebb flood mode for lagoons as stand-alone schemes. Until these conclusions are available, the scope for optimisation of combinations with one or two lagoons is uncertain.

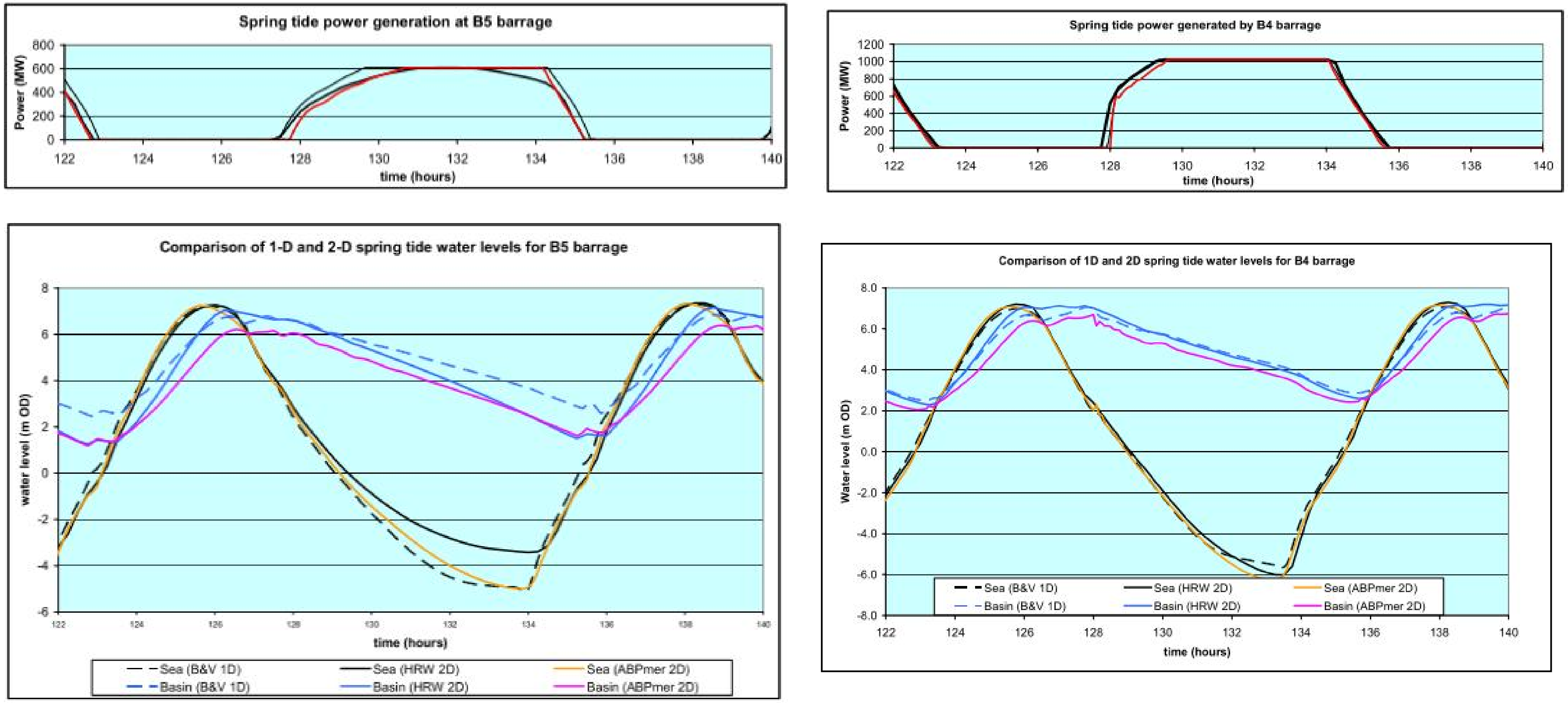


Figure 11.1 Comparison of Generation Profiles and Effects on Tidal Range of B4, B5, L2 and L3d as Stand-Alone Schemes

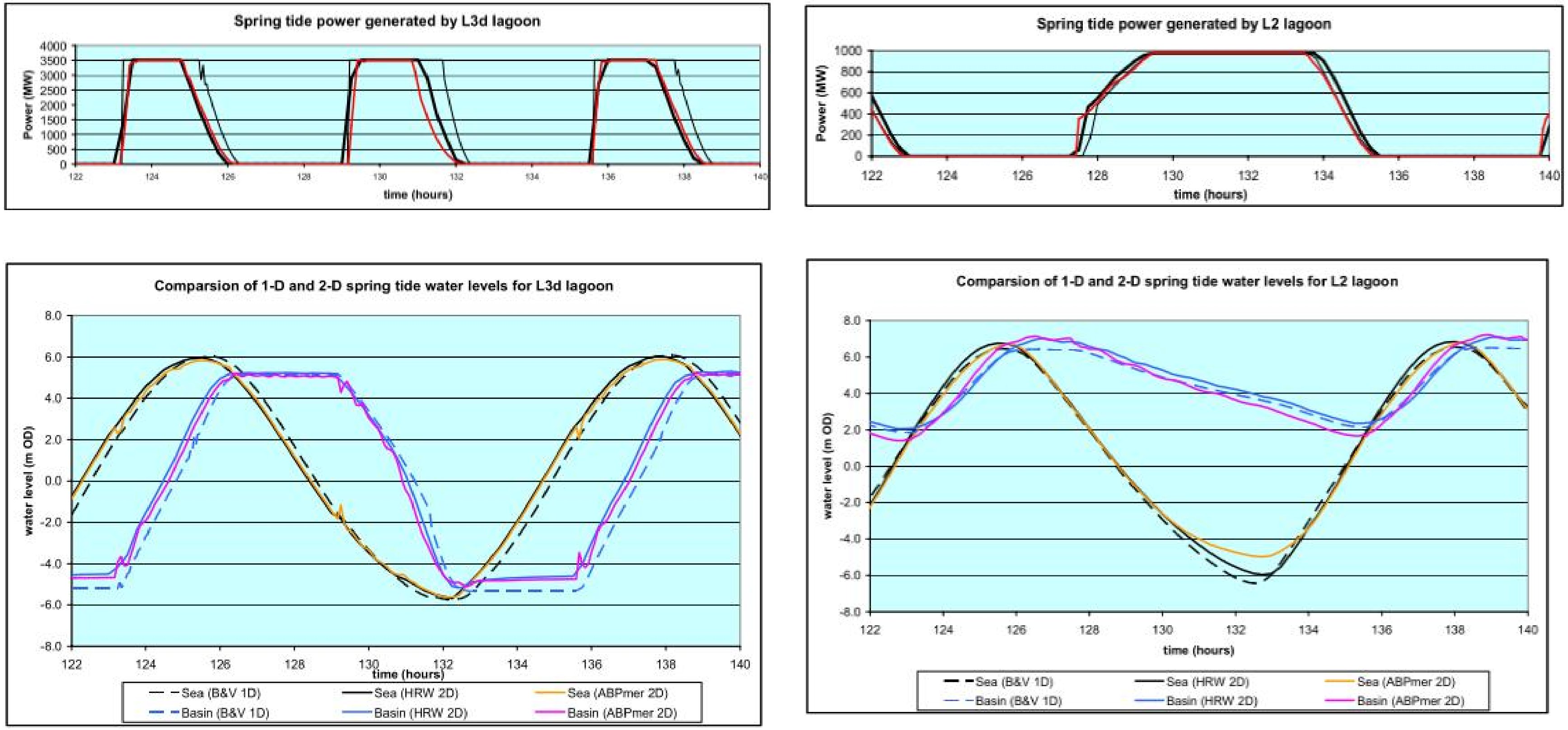


Figure 11.1 cont. Comparison of Generation Profiles and Effects on Tidal Range of B4 Shoots Barrage, B5 Beachley Barrage, L2 Welsh Grounds Lagoon and L3d Bridgwater Bay Lagoon as Stand-Alone Schemes

11.1.4 Combination of two lagoons (L2 Welsh Grounds Lagoon and L3d Bridgwater Bay Lagoon)

Energy Yields

From the results of 2-D modelling, L3d Bridgwater Bay Lagoon causes an approximate 5% reduction in the mean Spring tidal range at the location of L2 Welsh Grounds Lagoon. L2 causes a negligible change in mean Spring tidal range at L3d.

Tidal range effects indicate that the energy yield of a combination of L2 and L3d Lagoons could be of the order of 5% lower than the sum of the individual schemes (7.7 to 9.1TWh/yr compared to 8.1 to 9.6TWh/yr).

Scheme Costs

The effects on cost of combining lagoons with upstream barrages was considered in 11.1.3 above and the main findings can be applied to a combination of lagoons thus:

- The effects on caisson construction and installation may have an adverse, beneficial or neutral effect on scheme costs depending on the phasing of construction. These effects are therefore uncertain and not considered further.

- Constructing schemes concurrently would not provide any reduction in the cost of construction facilities for embankments (e.g. rock handling facilities, railheads etc). The cost of the facilities is likely to be similar to the sum of the individual scheme requirements. If the schemes were constructed sequentially with a planned reuse of construction facilities, a cost reduction of around £160m could be available.

- Based on the £50m cost of ancillary works currently allowed for each individual schemes, the ancillary costs for the combination could be around £20m less than the aggregate cost.

- There are too many uncertainties to consider the implications of combinations on inter-tidal habitats and the associated compensatory habitat requirements.

Ignoring the effect on caisson yard construction costs, the reduction in cost for a combination of two lagoons could vary from nil to around £0.2bn. This compares to an aggregate cost of £16.1bn (excluding compensatory habitat) for the two individual schemes (1% reduction), excluding optimism bias.

Energy Costs

Levelised energy costs based on an 8% discount and excluding compensatory habitat are shown in 11.2. All levelised energy costs exceed £170 per MWh.

Opportunities for Optimisation

Figure 11.1 compares the generation profiles and water levels of the two lagoons operating individually in the form selected following optimisation of the individual schemes. The comparison shows that on a typical Spring tide, non-generating periods would occur for around two hours in between every phase of generation. The output of alternate generating phases would vary significantly in magnitude due to the phasing of ebb flood generation from the lagoon and ebb generation from the barrage.

Figure 11.1 also shows how the tide becomes more asymmetric upstream which may provide the opportunity to optimise a combination so that the power output by L2 Welsh Grounds Lagoon ramps down later than L3d Bridgwater Bay Lagoon thus providing more continuity.

Comparing the tidal range effects of the individual schemes, it can be seen that operating L3d Bridgwater Bay Lagoon in ebb flood mode provides periods of inter-tidal exposure at low tide within the lagoon whilst the water levels within L2 Welsh Grounds Lagoon are generally still rising. This could be advantageous in reducing the effects of the combination of schemes on inter-tidal habitats.

For the reasons provided in 11.1.3, operating one of the lagoons as a single phase flood generation scheme could be advantageous in providing greater continuity of energy and reducing effects on inter-tidal areas but is unlikely to be economically viable.

Therefore, opportunities for optimisation should focus on comparisons between ebb and ebb flood generation for the lagoons. This should take into account the conclusions from the Feasibility Study on the relative merits of ebb and ebb flood mode for lagoons as stand alone schemes. Until these conclusions are available, the scope for optimisation of combinations with one or two lagoons is uncertain.

11.1.5 Larger barrage and downstream lagoon (B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon)

Energy Yields

From the results of 2-D modelling, B3 Cardiff to Weston Barrage causes an approximate 12% reduction in the mean Spring tidal range at the location of L3d Bridgwater Bay Lagoon. L3d causes an approximate 5% reduction in the mean Spring tidal range at L3d.

The schemes will moderate each other's effect on the tidal range but tidal range effects indicate that the energy yield of a combination of B3 Barrage and L3d Lagoon could be of the order of 15% lower than the sum of the individual schemes (17.0 to 20.0TWh/yr) compared to 20.0 to 23.6TWh/yr).

Scheme Costs

It is unlikely that the combination would be constructed concurrently due to the considerable cost of the combination (in excess of £35bn including compensatory habitat) and because it would be more efficient to construct a larger version of the Cardiff Weston Barrage, similar to the B2 Cardiff to Hinkley Barrage which was not shortlisted. Based on a review of the individual lagoon schemes, a combination of B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon could have the following effects on individual scheme costs:

- The alignments of B3 Barrage and L3d Lagoon schemes intersect at Brean Down. The combination would save either around 2km of embankment from the scheme that is constructed second. Only one road connection would be required. This would reduce the scheme cost by around £250m.

- It is possible that caisson fabrication yards could be reused with a reduction in overall cost of around £400m (the cost of facilities for L3d Bridgwater Bay Lagoon) but only if sequential construction is planned and the fabrication yards are not decommissioned between schemes.

- With planned reuse of construction facilities for embankments (eg. rock handling facilities, railheads etc), a cost reduction of around £160m could be available.

- Ancillary works required outside the impounded area may be common to both schemes. For example, lowering of lock sills at ports if required as a result of reductions in high water level for one scheme would likely be similar in cost to the combination. Based on the £50m to £100m cost of ancillary works currently allowed for in the individual scheme estimates, the cost of all but one scheme might be reduced by around £20m.

- The amount, and therefore the cost, of compensatory habitat required for the schemes in combination could be less than the sum of compensatory habitat areas required for the individual schemes depending on how the schemes are optimised, the tidal range effects in combination and the phasing of delivery. If the two schemes are constructed sequentially, then it seems unlikely that the amount of compensatory habitat for the first scheme to be constructed could be any less than if there was no plan for a combination. There are too many uncertainties to consider the implications of combinations on the cost of compensatory habitat.

The combined cost of the schemes could be up to £0.8bn less than the aggregate cost of £33.7bn excluding compensatory habitat (2% reduction), excluding optimism bias.

Energy Costs

The energy cost of the combination depends on the phasing of construction. The only sequence which would provide a levelised energy cost of less than £170 per MWh is if the B3 Cardiff to Weston Barrage was constructed first followed by the L3d Bridgwater Bay lagoon at some point in the future. The actual energy cost of the combination would depend on when the lagoon is actually built.

Opportunities for Optimisation

Figure 11.2 compares the generation profiles and water levels of B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon operating individually in the form selected following optimisation of the individual schemes. The comparison shows that on a typical Spring tide, non-generating periods would occur for around two hours in between every phase of generation. The output of alternate generating phases would vary significantly in magnitude due to the phasing of ebb flood generation from the lagoon and ebb generation from the barrage.

Operating the lagoon scheme as a single phase flood generation scheme could be advantageous. Compared to the two phase ebb flood generation shown in Figure 11.2, the flood generation phases would be longer and would provide a greater continuity of power output. Also, the very high peaks of output on each ebb tide, which could be disadvantageous in terms of compatibility with the National Grid, would be avoided.

Comparing the tidal range effects of the individual schemes, it can be seen that operating the lagoon in ebb flood mode provides periods of inter-tidal exposure at low tide within the lagoon whilst the water levels behind the B3 Cardiff to Weston Barrage are generally falling. This could be advantageous in reducing the effects of the B3 Barrage on inter-tidal habitats depending on the value of the lower part of the inter-tidal area within the lagoon. Evidence considered in the assessment of the stand-alone lagoon scheme indicates that the geomorphological changes may not change the quality of the inter-tidal area within the lagoon but the level of certainty in these results needs to be taken into account in assessing the benefits of operating a combination in this way. As a single phase flood generation scheme, L3d Bridgwater Bay Lagoon could be optimised to increase the exposure time of the inter-tidal areas at low water which could be more advantageous than an ebb flood configuration in reducing the effects of the B3 Shoots Barrage on the inter-tidal areas.

It should be noted that in single phase flood generation mode, the power output of L3d Bridgwater Bay Lagoon would be lower than as a single phase ebb generation or two phase ebb flood generation scheme. In economic terms, L3d Lagoon as a stand-alone scheme would not be viable as a flood generation scheme nor as an ebb flood generation scheme with sluices to provide the flexibility to convert to flood generation in the future. If L3d Lagoon is constructed as an ebb flood scheme followed by the B3 Cardiff to Weston Barrage at some later date, it would be technically possible to convert L3d Lagoon from ebb flood generation to single phase flood generation, by adding sluice gates, if required to reduce the effects of the B3 Barrage on the National Grid and/or inter-tidal habitats. The modification of L3d Lagoon could include topographic modification of the impounded inter-tidal area. The cost, energy, environmental and regional effects of converting L3d Lagoon would need to be studied further in the future as part of the cost of reducing the effects of the B3 Barrage.

11.1.6 Construction Programmes

There is no evidence that a programme of developing schemes concurrently would shorten overall construction programmes. Competition for resources (especially dredging resources, caisson fabrication yards, earthworks materials etc) has the potential to risk increasing construction programmes. This risk could be reduced through planning and the wide sourcing of materials. Turbine availability could be an issue for L3d Bridgwater Bay Lagoon which may require new suppliers to supplement the existing supply chain capacity to achieve a six year programme as a stand alone scheme. Clearly, this becomes a greater requirement for combinations including L3d Lagoon constructed concurrently.

The construction programme of schemes constructed as part of a phased plan may benefit from the construction facilities already constructed for earlier schemes, but only through planned re-use and probably only by a few months.

The choice of which scheme to construct first would largely depend on ease of consent and availability of finance.

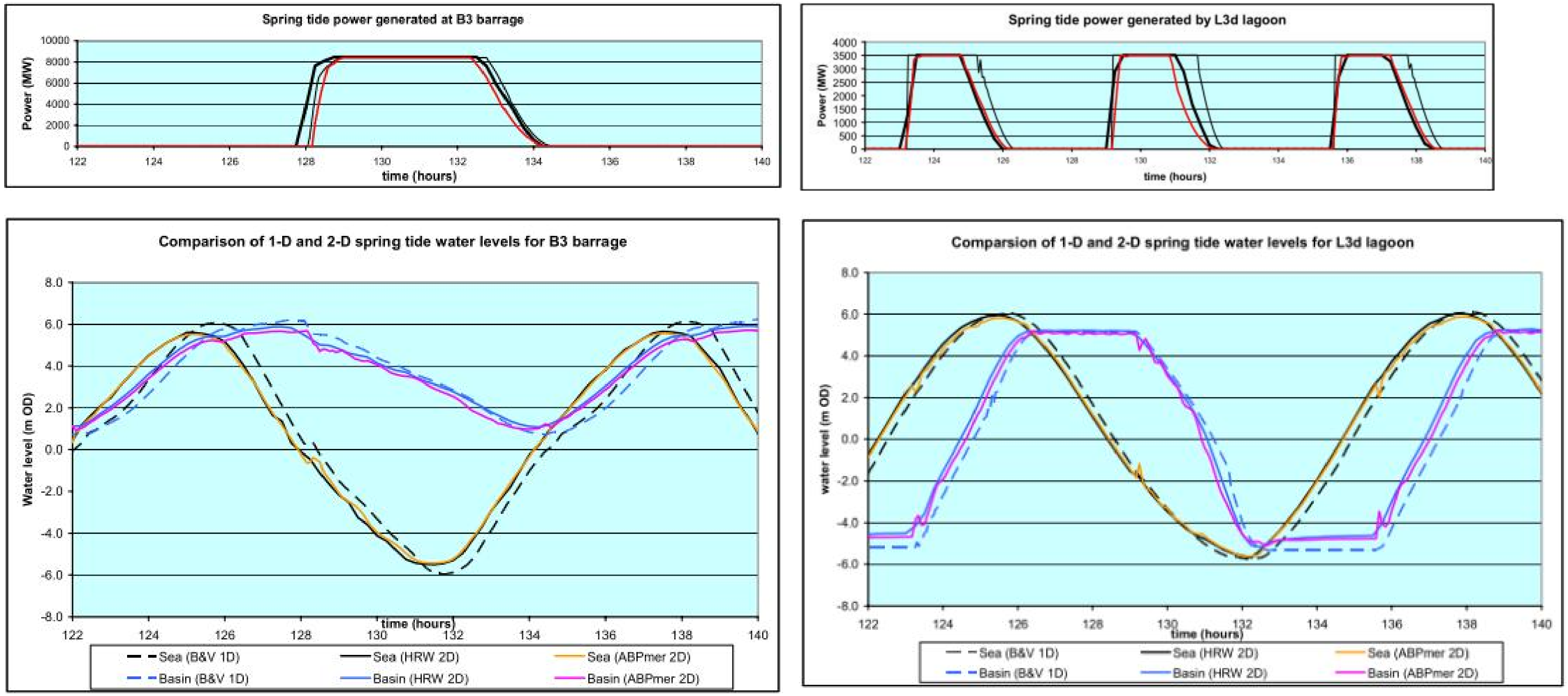


Figure 11.2 Comparison of Generation Profiles and Effects on Tidal Range of B3 Cardiff to Weston Barrage and L3d Bridgwater Bay Lagoon as Stand-Alone Schemes

11.1.7 Conclusions

All combinations if constructed concurrently would exceed the threshold £170 per MWh levelised energy cost at an 8% discount rate, excluding optimism bias and compensatory habitat. Including optimism bias and compensatory habitat would clearly increase costs further above the threshold.

The levelised energy cost of B3 Cardiff to Weston barrage as an individual scheme, with compensatory habitat at a 2:1 ratio and an 8% discount rate, has been estimated at £165 /MWh. It may be possible for a combination of L3d Bridgwater Bay lagoon and B3 Cardiff to Weston barrage to provide a levelised energy cost below the threshold if the lagoon is constructed some time after the barrage but the estimated levelised energy cost of the lagoon alone would still exceed the threshold.

Tidal range effects indicate that the combined energy yield of a Cardiff to Weston Barrage and L3d Bridgwater Bay lagoon could be 17 to 20TWh/year, around 15% less than the aggregate energy yield of the individual schemes.

11.2 Multiple Basin Options

11.2.1 Background

In paragraph 154 of the 2009 consultation document, it was stated that "the Feasibility Study will be examining whether energy production could be optimised to better align with peak demands by … using multiple basins".

Furthermore, the IOAR reported that in phase 2 of the study, "an assessment will be made of the effect on energy yield of …the use of a secondary basin. The possibilities of generating continuous power will also be investigated."

This section therefore examines the shortlisted schemes at a high level to determine whether energy production could be optimised with the use of a secondary basin or multiple basins to better align energy yield with peak demands and provide the possibility of continuous power.

The purpose of this section is not to determine an optimal multiple basin form of each scheme, where relevant, nor to compare multiple basin alternatives with single basin schemes. However, it will identify the scope for optimising multiple basin configurations of the shortlisted schemes which could be subject to further study for those schemes which are taken forward beyond the Feasibility Study.

11.2.2 Methodology and Assumptions

There are many possible permutations of multiple basin configurations. To inform the study into their application to the short listed schemes, multiple basins are first considered in generic terms. Generic illustrations are identified for an appropriate range of operating modes. The potential for pumping is also considered.

A scoping exercise is then carried out to determine the relevance of multiple basin alternatives to each of the shortlisted schemes based on a consideration of their practical application.

Providing more continuous energy could reduce impacts of schemes on the National Grid and could increase the value of energy. However, the possibility of continuous power is only considered qualitatively for the purpose of this study. A quantitative assessment requires an energy value forecast which is not currently available. With smart grids and electrification of parts of the transport sector the demand curve is likely to be smoother with less daily variation in energy value which is likely to impact potential benefits arising from multiple basin schemes

11.2.3 Generic Application of Multiple Basin Solutions

A good account of the application of twin basin (or linked basin) developments is provided in Elements of Tidal Electric Engineering (Clark, 2007). Clark discusses the simple linked-basin concept and more complex double and triple basin schemes. These are described below.

Simple linked-basin concept

The linked basin concept, attributed to Decoeur and discussed in Clark (2007) is shown in Figure 11.3. The scheme is divided into a smaller 'high' basin and a larger 'low' basin, separated by a dyke and powerhouse. Each basin is connected to the sea by sluices. Generation occurs continuously with flow from the high basin to the low basin through one way turbines.

When sea and high basin are both at high water level, the sluices between the high basin and the sea are closed. The high basin then discharges through the turbines to the low basin as the sea level falls. When there is equilibrium between the low basin level and the falling sea level, the sluices between the low basin and the sea open until low water when the sluices are closed. When the falling water levels in the high basin reach the rising sea levels on the flood tide, the sluices between the sea and the high basin open until high water. Then the cycle is repeated.

Double-basin concept

The double basin concept is shown in Figure 11.4. As for the linked basin concept, the scheme is divided into a high basin and a low basin. The scheme is configured to provide a continuous cycle of water from the sea to basin 1, from basin 1 to basin 2, and from basin 2 to the sea.

When sufficient differential head is available between the rising sea level on the flood tide and the water level in the high basin, the sea starts to fill the high basin. When sufficient differential head is available between the high basin and the low basin, the high basin discharges to the low basin. When sufficient differential head is available between the low basin and the falling sea levels on the ebb tide, the low basin discharges to the sea.

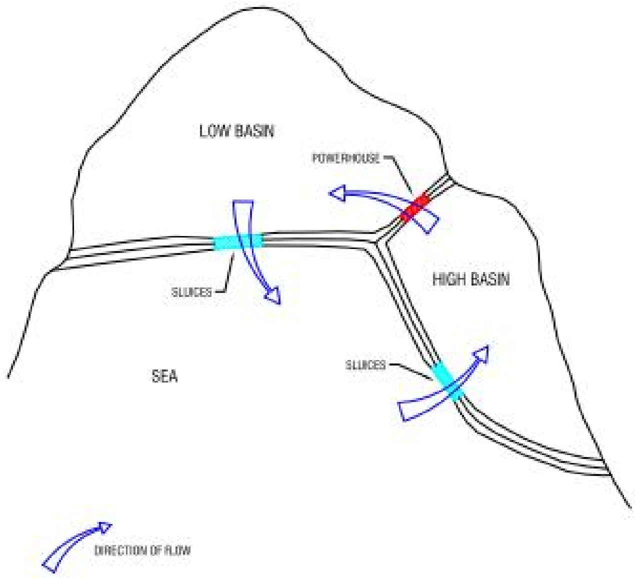


Figure 11.3
Linked Basin Concept
(adapted from Clark, 2007)

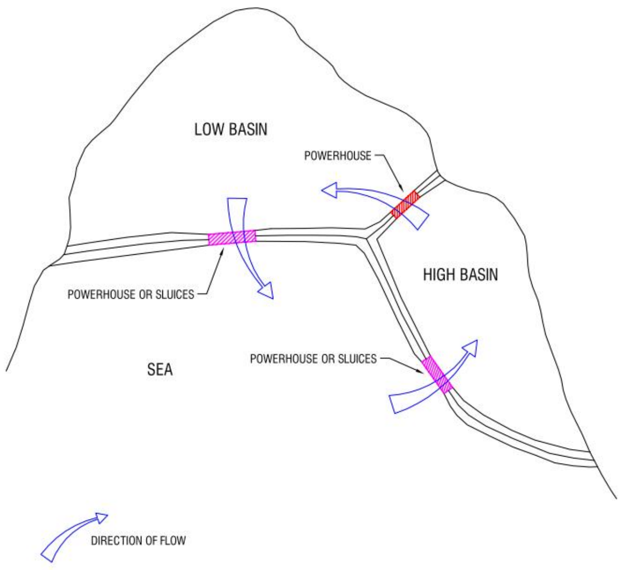


Figure 11.4
Double Basin Concept

Turbine capacities between the two basins and between the basins and the sea are configured to control the cyclical flow and the power output to achieve as smooth a generating profile as possible. Pumping can be used to raise water levels in the high basin and to lower water levels in the low basin to increase the power output of the scheme.

Where insufficient depth of water is available between the sea and either one of the basins, sluices could be exchanged for the powerhouse but at the expense of a less regular power output and a reduction in pumping capacity.

Triple Basin Concept

The triple basin concept is very similar to the double basin concept but the scheme is divided into three basins. The advantage of three basins over two is to achieve a more uniform supply of energy. As with the double basin concept, pumping can be used to raise water levels in the highest basin and lower water levels in the lowest basin to increase the power output of the scheme. More than three basins would offer little, if any, advantage, primarily because it is possible to generate continuous power with three basins, although the maximum continuous power output would be dictated by the size of the smallest basin.

11.2.4 Practical Application of Multiple Basin Solutions

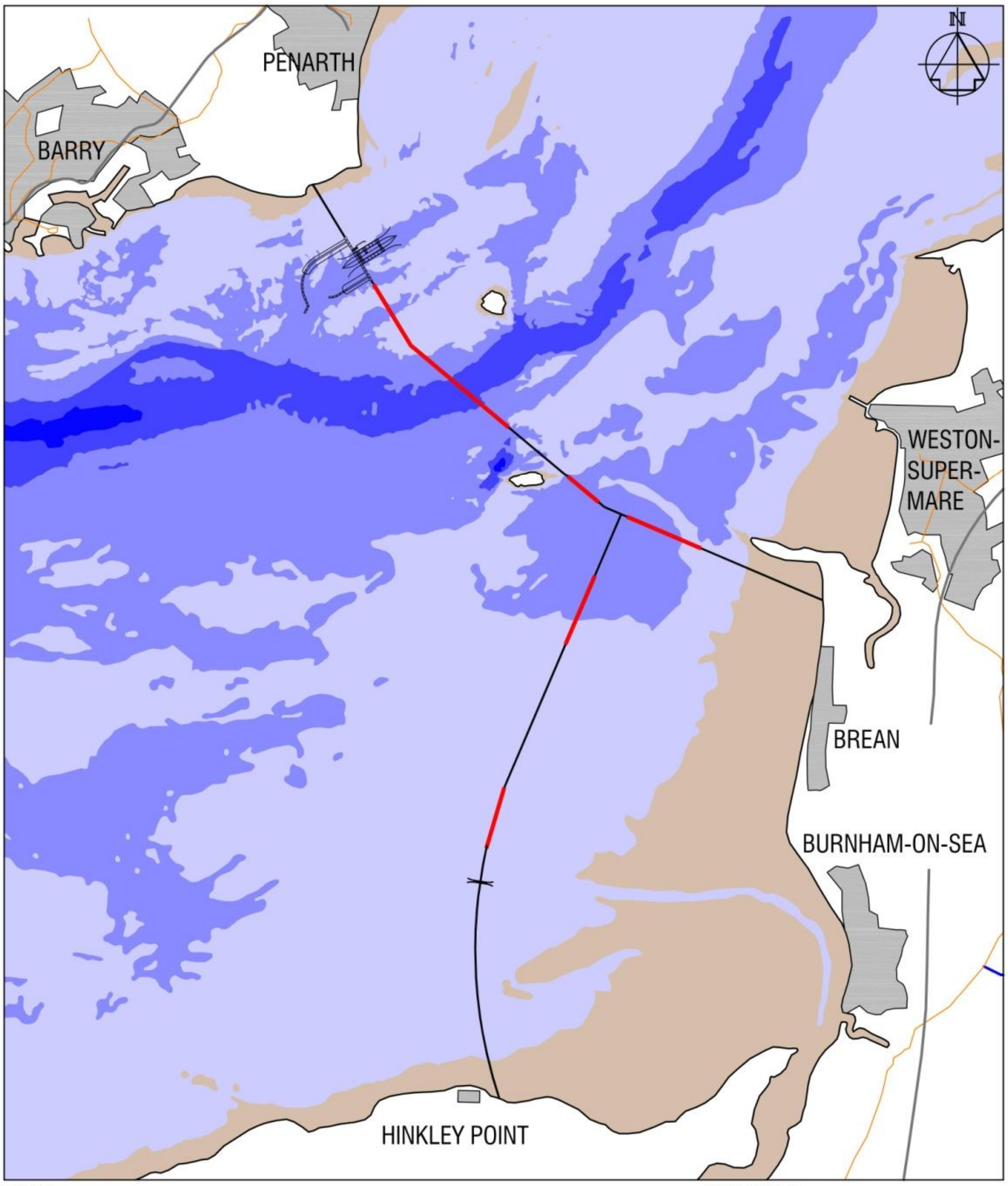
The application of multiple basin solutions depends on a number of practical factors:

- Ideally, double and triple basin concepts require sufficient depth of water for two powerhouses between the basins and the sea;
- For double and triple basin concepts, and the linked-basin concept, sufficient depth of water is required for powerhouses along the dykes dividing the basins;
- Multiple basin alternatives require more civil engineering than equivalent single basin schemes and therefore the shape of the scheme should lend itself to minimising the length, height and therefore the cost of the additional civil engineering;
- The requirement for shipping locks needs to be accommodated to provide access in and out of the basins.

These issues are considered, where relevant, in relation to the five shortlisted schemes.

B3 Cardiff to Weston Barrage

Multiple basin alternatives to a single basin B3 Cardiff to Weston Barrage scheme would be expected to require a significant length of additional embankment and/or caisson structures to provide continuity of power output. In 2007, the SDC Research Report 3 supporting their "Turning the Tide" publication reviewed two multiple basin schemes using the Cardiff to Weston barrage alignment. These were:



• LEGEND

Turbine Caisson

Parsons Brinckerhoff in association with Black & Veatch

• CLIENT/PROJECT

DEPARTMENT OF ENERGY & CLIMATE CHANGE

SEVERN ESTUARY TIDAL STUDY

• TITLE

B3 CARDIFF WESTON BARRAGE
AND L3D BRIDGWATER BAY LAGOON
COMBINED AS A DOUBLE BASIN SCHEME

• DATE
11.12.09

• SCALE
1:125,000 at A4

• FIGURE NUMBER

FIGURE 11.5

- Dr Shaw's two basin pumped storage scheme which included a large offshore lagoon attached to a barrage between Cardiff and Weston. This was based on a low head pumped storage method of operation to increase useful energy yield during the day. Pumping occurred at night for use during the next day. The capital cost was estimated to be approximately £1900/kW at 1980 prices, approximately double the cost of an equivalent high head non-tidal pumped storage scheme.

- The two basin ebb and flood generation scheme considered by Bondi which included a stage 1 barrage between Cardiff and Weston and a stage 2 barrage between the stage 1 structure and Minehead. The costs of the stage 2 structure were estimated to be 85% of the Cardiff Weston barrage using Bondi's estimates. Assuming the ratio remained similar, the equivalent capital cost would be in excess of £35bn using cost outputs from the current Feasibility Study with an additional 5.2TWh of energy.

As the above studies show, a multiple basin scheme based on B3 Cardiff to Weston Barrage requires significant lengths of additional embankment and caissons. Consequently they are considerably more expensive than the single basin alternative and unlikely to be affordable as a stand alone scheme.

Section 11.1 concluded that a combination of L3d Bridgwater Bay lagoon and B3 Cardiff to Weston Barrage could be viable if the lagoon is built first. In combination, the two schemes could function as a linked or double basin scheme if the alignment of L3d Lagoon is modified to provide for the future provision of a powerhouse between the two basins, as illustrated in Figure 11.5.

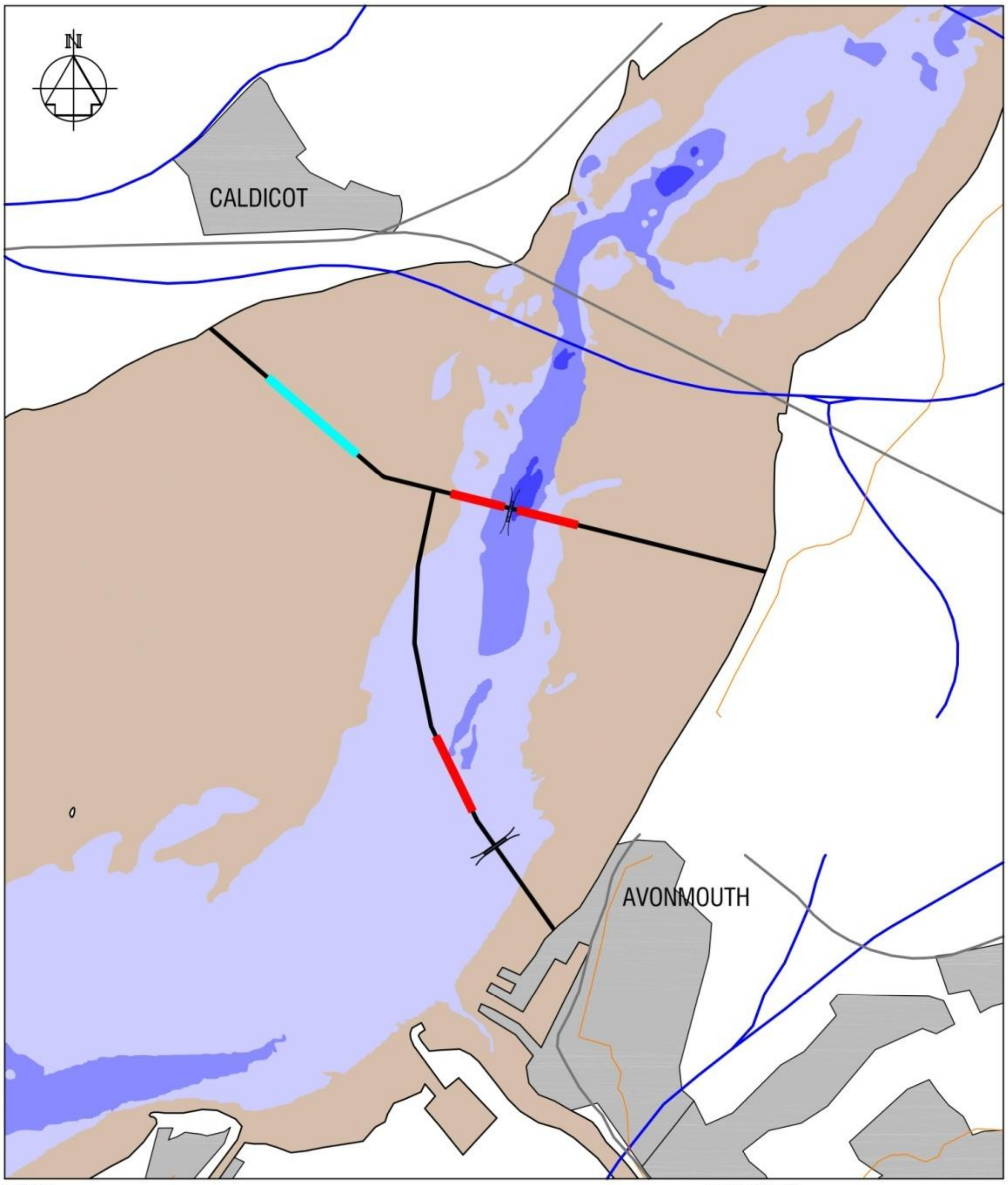
Specific issues that would have to be addressed in considering this approach would include the following:

- Revised costs of the modified combination of B3 Barrage and L3d Lagoon
- Determining the optimal operating regime - whether it is more optimal for L3d Lagoon to discharge to B3 Barrage or vice versa, or whether there is any merit in flexible operation
- Revised energy yield of the modified combination – reduced energy yield (albeit generated over a longer period) from a two basin scheme will increase the cost of energy
- Consideration of environmental impacts resulting from change of operation (operation of L3d Lagoon and B3 Barrage as a two basin scheme will be different from the schemes operating individually or in combination)
- Consideration of regional economic impacts resulting from change of operation.

<u>B4 Shoots Barrage</u>

B4 Shoots Barrage depends on the depth of the Shoots channel to accommodate the turbines. Either side of the Shoots channel, bed levels are shallower. A linked or double basin scheme for B4 Barrage would need to retain the Shoots channel as the location of the powerhouse between the basins. A second ‘high’ basin could be provided downstream of the barrage, by constructing an impoundment structure between the Welsh embankment of the barrage and Avonmouth (Figure 11.6). The impounded area behind the Shoots barrage would be the low basin. This arrangement could either act as a linked basin scheme or a double basin scheme with two powerhouses, one at the Shoots channel and one in deep water near Avonmouth.

However, this arrangement does not lend itself to minimising the length, height and therefore the cost of the additional impoundment structure. Cost of energy would therefore increase and ratio of additional energy yield to capital cost is likely to be less favourable than the B3 Cardiff to Weston Barrage double basin option because of the topographical constraints in this part of the Severn Estuary. Furthermore, although environmental and regional effects of this proposal have not been considered in detail, there would appear to be some significant issues. Acting as a low basin, the impounded area behind the barrage would cause significant issues for navigation to Sharpness and cause a significant impact on inter-tidal areas. The two powerhouses would also seem likely to increase the risk of the barrage to fish. Therefore, this proposal is not considered further.



• LEGEND

Turbine Caisson
Sluice Caisson

Parsons Brinckerhoff in association with Black & Veatch

• CLIENT/PROJECT

DEPARTMENT OF ENERGY & CLIMATE CHANGE

SEVERN ESTUARY TIDAL STUDY

• TITLE

B4 BARRAGE WITH SECOND BASIN

• DATE 11.12.09

• SCALE 1:60,000 at A4

• FIGURE NUMBER

FIGURE 11.6

B5 Beachley Barrage

Beachley Barrage provides similar constraints to the development of a second basin alternative as B4 Shoots Barrage and multiple basin alternatives are not considered further.

L2 Welsh Grounds Lagoon

A double basin alternative could comprise a second 'high' basin between Cardiff and Newport, connecting to the Welsh Grounds lagoon with flow between the two basins via the Newport Deep powerhouse (Figure 11.7). The 'low' Welsh Grounds basin could discharge through a third powerhouse at the Northeast corner of the lagoons. However, this arrangement does not lend itself to minimising the length, height and therefore the cost of the additional impoundment structure leading to a higher energy cost than the already relatively high cost of the single basin Welsh Grounds scheme.

Dividing the Welsh Grounds lagoon into two or three basins is not considered practical due to the shallow depths available.

Multiple basin options for Welsh Grounds are not considered further.

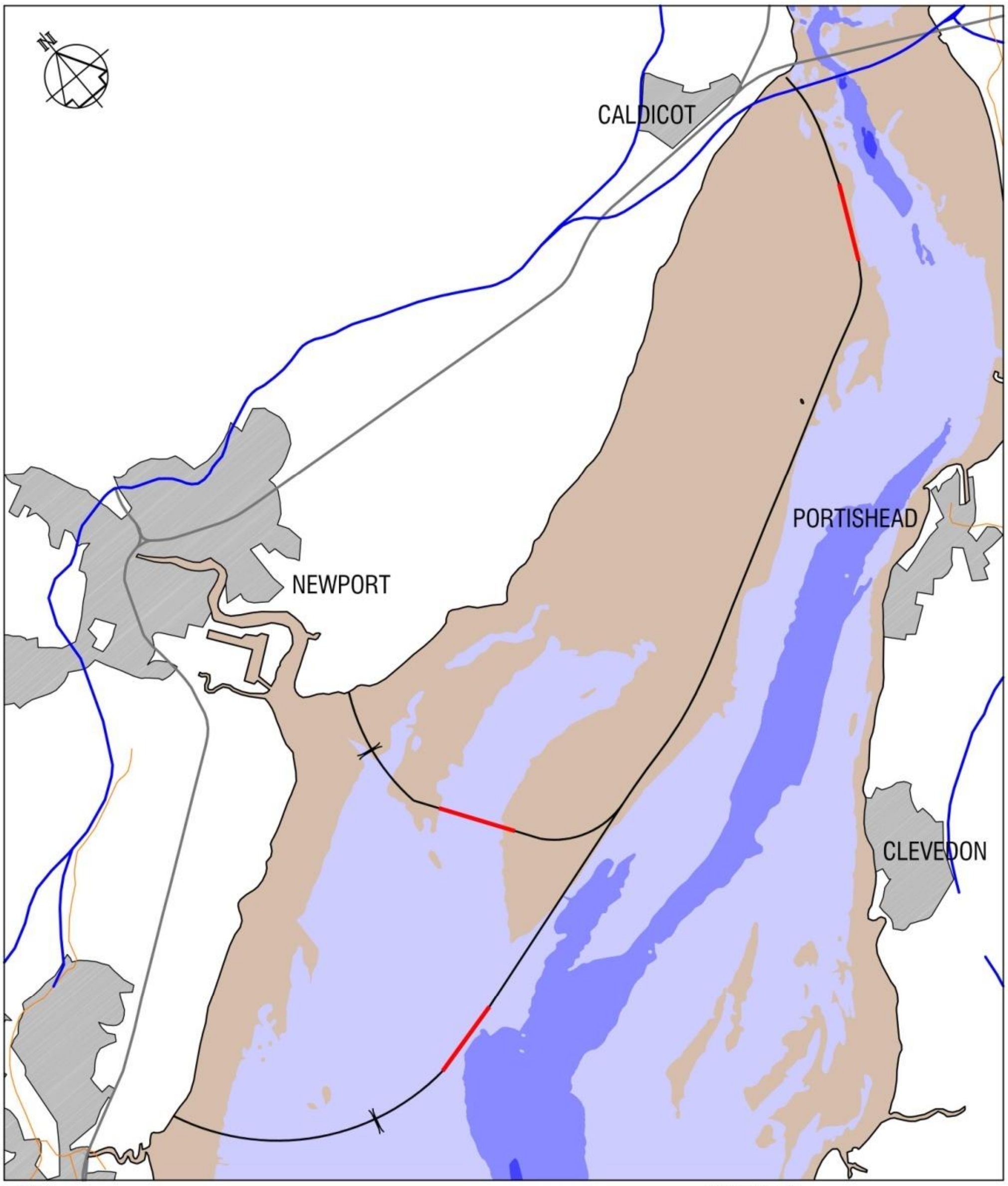
L3d Bridgwater Bay Lagoon

L3d Bridgwater Bay Lagoon and B3 Cardiff to Weston Barrage acting together as a multiple basin scheme has been considered under B3 Barrage above.

The geometry of Bridgwater Bay lagoon lends itself to modification as a double basin scheme with a dyke constructed from a point between the two powerhouses and Berrow. Dividing the lagoon into three basins is unlikely to be practical.

The double basin concept employs a powerhouse between the high and low basin (Powerhouse A) and a second powerhouse between the low basin and the sea (Powerhouse B). The high basin is charged by the sea on the flood tide via sluices. The high basin discharges to the low basin via Powerhouse A. The low basin discharges to the sea on the ebb tide via Powerhouse B. Each basin therefore experiences a tidal range but the high basin levels are always kept above the low basin.

Figure 11.8 shows a double basin arrangement. The high basin would be operated to minimise reduction in high water levels as it would be beneficial in energy terms and also beneficial for navigation on the Parrett. Water flows continuously from the high basin to the low basin so that Powerhouse A generates continuously. Water flows from the low basin to the sea when there is sufficient head across Powerhouse B. Discharging the low basin also preserves head across Powerhouse A.



• LEGEND

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• CLIENT/PROJECT

DEPARTMENT OF ENERGY & CLIMATE CHANGE

SEVERN ESTUARY TIDAL STUDY

• TITLE

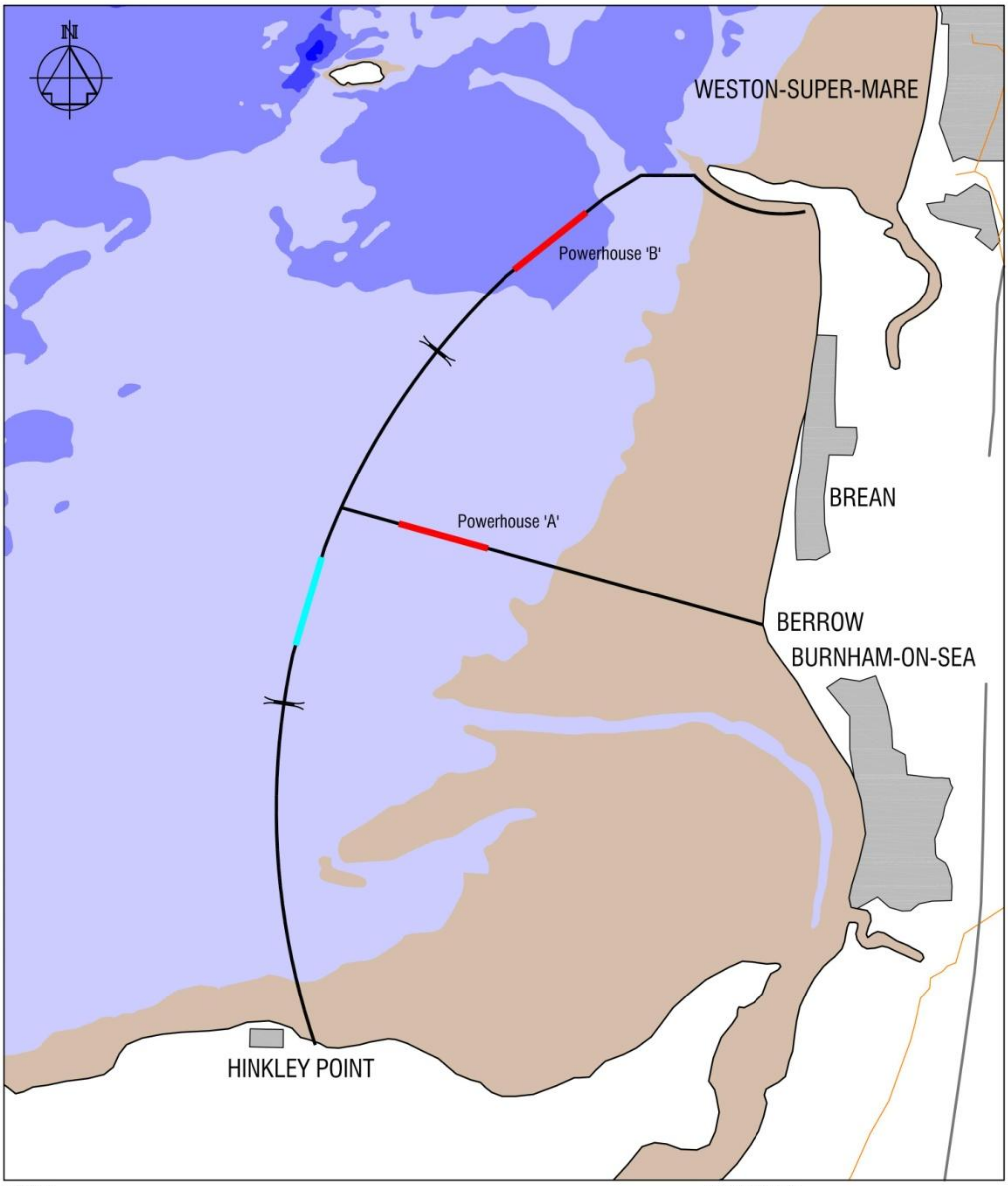
L2 WELSH GROUNDS LAGOON WITH A SECOND BASIN

• DATE 11.12.09

• SCALE 1:125,000 at A4

• FIGURE NUMBER

FIGURE 11.7



• LEGEND

Turbine Caisson

Sluice Caisson

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• CLIENT/PROJECT

DEPARTMENT OF ENERGY & CLIMATE CHANGE

SEVERN ESTUARY TIDAL STUDY

• TITLE

L3D BRIDGWATER BAY LAGOON
AS A DOUBLE BASIN SCHEME

• DATE
11.12.09

• SCALE
1:80,000 at A4

• FIGURE NUMBER

FIGURE 11.8

An additional lock would be required for maintenance access into the low basin.

0-D analysis has been carried out of the Bridgwater Bay lagoon to derive indicative water levels and an indicative output profile as shown in Figures 11.9 and 11.10.

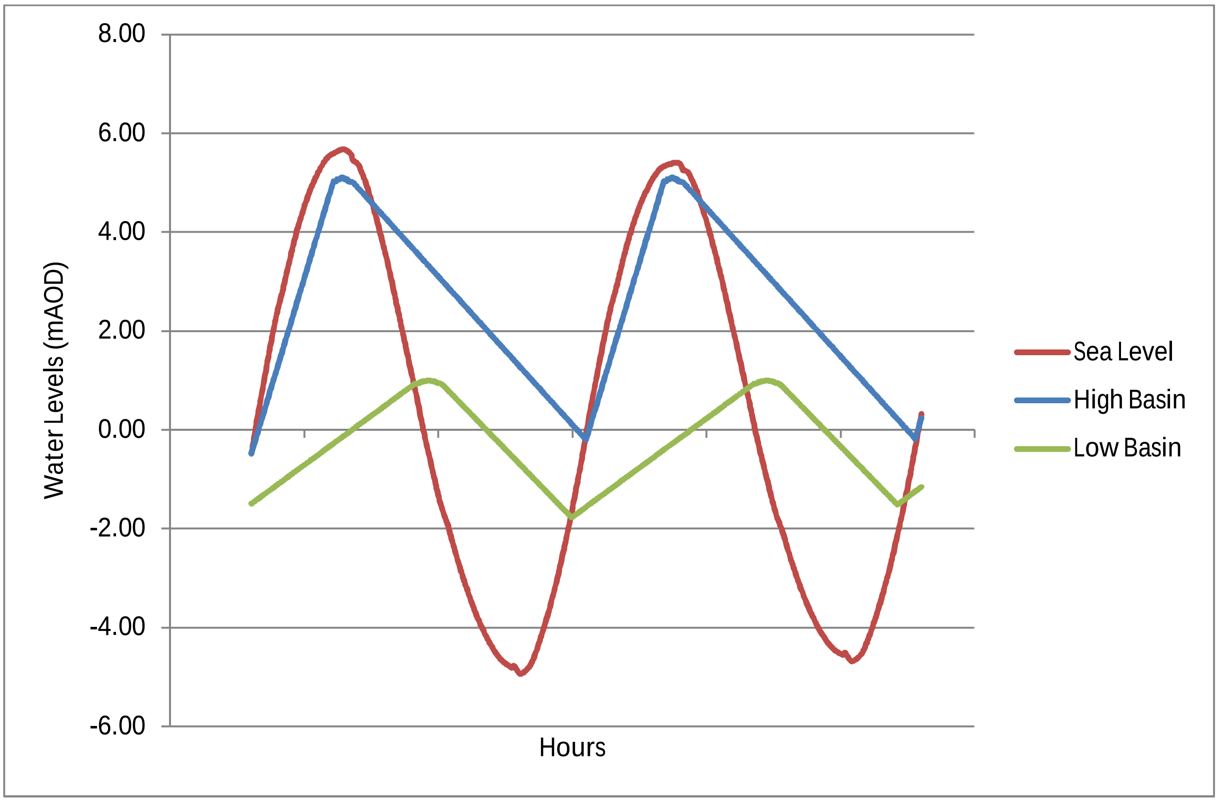

Figure 11.9 L3d Bridgwater Bay Double Basin Lagoon - Indicative Spring Tide Water Levels

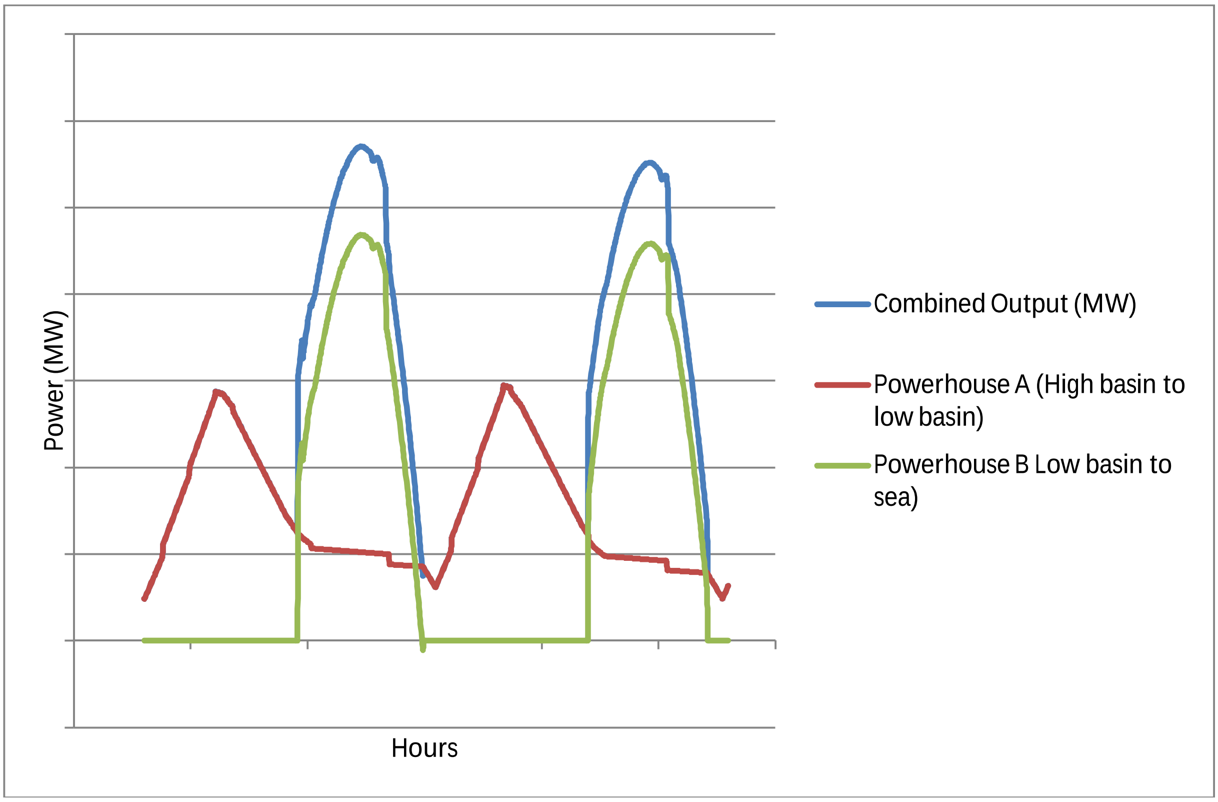

Figure 11.10 L3d Bridgwater Bay Double Basin Lagoon - Indicative Power Output Profile

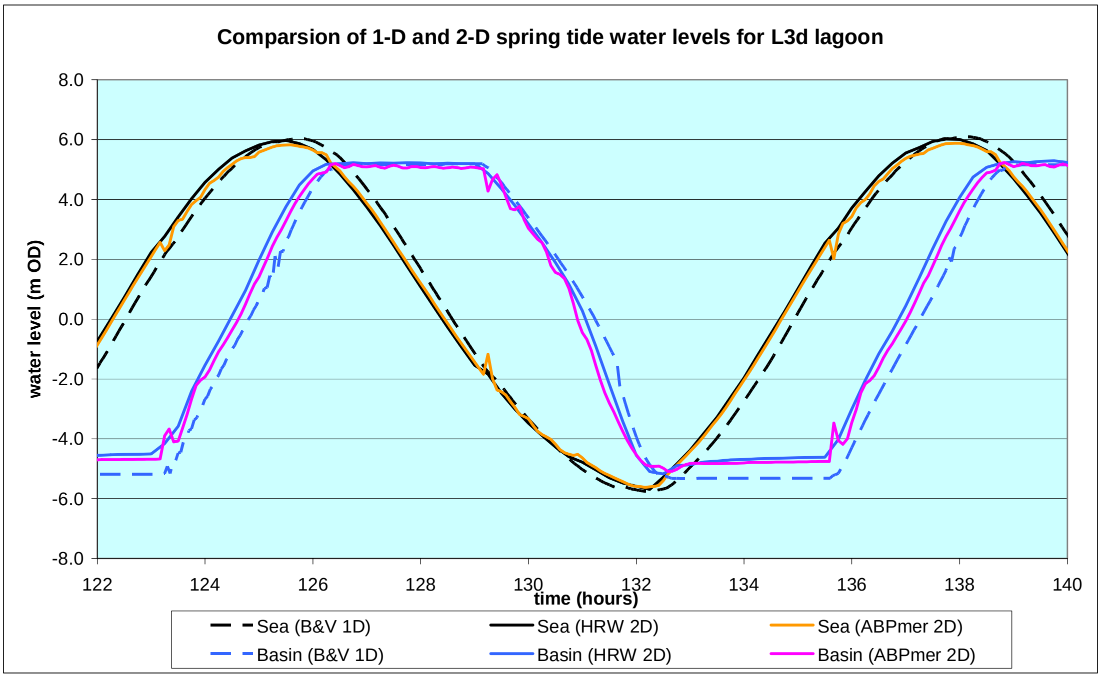

Figure 11.11 L3d Bridgwater Bay Single Basin Lagoon – Water Levels from 1-D and 2-D modelling

For comparison purposes, water levels for the single basin scheme from 1-D and 2-D modelling are shown in Figure 11.11.

It should be noted that the indicative charts of water levels and power output in Figures 11.9 and 11.10 have not been optimised. However, 0-D modelling tests have indicated that the total output from the lagoon would be significantly less than the output from a single basin scheme due to a combination of smaller flow rates and lower heads. Flow rates would be smaller because it would not be possible to exchange as much water between the lagoon and the sea as could be achieved with the single basin scheme as the live storage capacity of the lagoon is limited by the tidal ranges within the high and low basins. Operating heads would also be lower than a single basin scheme as can be seen by comparing water levels in Figures 11.9 and 11.11.

Power output could be increased by closing the turbine gates at Powerhouse A when water level in the high basin reaches high water level to increase the differential head across Powerhouse A. However, energy output would become intermittent and would still be less than the output from a single basin scheme.

A double basin scheme would use pumping to raise the high basin levels and lower the low basin levels to increase the flow through the lagoon and increase the operating head between the high and low basin. However, it is unlikely that pumping would mitigate for the lower heads and smaller flows compared to the single basin option.

More detailed optimisation and modelling are required to quantify the energy yield that could be obtained. However, provisional optimisation of the single basin scheme and the further refinement of the single basin scheme costs and energy yields have shown that it is necessary to maximise the energy yield from the lagoon for it to be economically viable. With the additional cost of the dyke separating the two basins combined with a lower energy yield, it is concluded that the cost of energy from the double basin scheme would be more expensive than the single basin option.

An advantage of the double basin scheme is that the lower output would reduce the effects on the National Grid, therefore requiring less costly reinforcement works.

11.2.5 Conclusions

Conclusions on the potential application of multiple basin solutions is summarised in Table 11.5.

Option	Potential Multiple Basin Option	Assessment Conclusion
B3 Cardiff to Weston Barrage	Could be configured in combination with L3d as a linked or double basin scheme	Worthy of further study if the L3d and B3 combination is taken forward after the Feasibility Study
B4 Shoots Barrage	Second basin theoretically possible between Shoots channel and Avonmouth	Incremental energy cost over single basin alternative would not be favourable. Potentially significant implications for navigation and upstream tidal range. Not considered further.
B5 Beachley Barrage	Not identified as issues similar to B4 Barrage.	Not considered further.
L2 Welsh Grounds	Second basin theoretically possible between Newport and Cardiff.	Would lead to a higher energy cost than the already relatively high cost of the single basin Welsh Grounds scheme. Not considered further.
L3d Bridgwater Bay	Potential to divide lagoon internally into two basins. See also B3 above.	Would lead to lower energy yield and a significantly higher energy cost compared to the single basin alternative. Worthy of further study if L3d is taken forward after the Feasibility Study.

Table 11.5 Multiple Basin Conclusions

11.3 High Level Evaluation of Potential Environmental Effects of Combinations and Multiple Basins

This section provides a high level evaluation of the environmental effects of those combinations and multiple basin options which have been identified in Sections 11.1 and 14.2 as candidates for further study if any of the schemes are taken forward after the Feasibility Study. These variants were not assessed within the SEA topics following the SEA methodology. If taken further, they will need to be considered within an updated SEA before they can form part of the Government’s plan for Severn tidal power development.

11.3.1 Combination of L3d Bridgwater Bay Lagoon and B3 Cardiff Weston Barrage

A high-level assessment has been undertaken of the combination of the L3d Bridgwater Bay lagoon with the B3 Cardiff Weston Barrage.

During construction and decommissioning, a combination of L3d and B3 is likely to largely have the same effects upon the environment as the sum of the individual effects of the construction of both alternative options in isolation. During operation, there is likely to be a reduction in high-water levels throughout the Severn Estuary and a greater far field effect when compared to B3 alone. There are also likely to be greater effects on the local landscape and seascape and communities, due to the presence of both alternative options in close proximity. There are likely to be greater effects upon waterbird and fish populations than the sum of the effects from operating the individual alternative options in isolation.

11.3.2 L3d Bridgwater Bay as a Double Basin Lagoon

During construction and decommissioning, a double basin L3d Bridgwater Bay Lagoon is likely to largely have the same significant effects as a single basin L3d lagoon. During operation, there are likely to be differences in the effects on the hydraulics and geomorphology of the Estuary, most notably, a greater loss in intertidal area which will have further effects on waterbirds and marine ecology.

SECTION 12

APPLICATION OF PHASE 2 FINDINGS TO OPTIONS EXCLUDED FROM THE SHORTLIST (FEEDBACK LOOP)

12 APPLICATION OF PHASE 2 FINDINGS TO OPTIONS EXCLUDED FROM THE SHORTLIST (FEEDBACK LOOP)

12.1 Introduction

In phase 1, the fair basis evaluation of long listed options was based on the application of a common set of principles and assumptions behind the derivation of energy and cost estimates. The fair basis evaluation and outcomes are covered in Section 2.1 and the complete process is reported in the Interim Options Assessment Report (IOAR). The fair basis evaluation informed the Government's selection of the shortlisted schemes for further study in phase 2.

In phase 2, further study into the shortlisted options has led to changes to the estimates of their energy yields and costs. In this section, the findings which have affected energy yield and cost are applied to some of the schemes excluded from the shortlist to update their estimated energy yields and costs. The purpose of this high level feedback exercise is to enable the Feasibility Study to decide whether some excluded schemes could be feasible in light of the evidence now available. The updated energy yields and costs of the excluded schemes do not have the same level of accuracy as those of the shortlisted schemes reported in the ODR and are only to be used as an update to the phase 1 fair basis comparison of the energy yield and cost estimates.

12.2 Excluded Options Reviewed

The phase 2 findings have been applied to the excluded schemes which were based on mature technologies. These are:

B1 Outer Barrage from Minehead to Aberthaw
B2 Middle Barrage from Hinkley to Lavernock Point
L3a Land Connected Lagoon Concept (English Grounds)
L3c Land Connected Lagoon Concept (Peterstone Flats)
L3e Offshore Lagoon Concept (Bridgwater Bay)

The findings of the phase 2 study into the L2 Welsh Grounds Lagoon are directly applicable to the L3b Land Connected Lagoon Concept (Welsh Grounds).

Findings have not been applied to the excluded schemes based on emerging technologies (F1 Tidal Fence and R1 Tidal Reef) because the findings of the phase 2 study into barrage and lagoon concepts are of limited application to those schemes. Emerging technologies have been separately studied under the Severn Embryonic Technologies Scheme.

The U1 Severn Lakes is a scheme between Cardiff and Weston which envisages revenue streams from energy and other development uses. The findings of the phase

2 study are of limited application to the Severn Lakes scheme and therefore the Severn Lakes scheme is excluded from the feedback exercise.

A map showing all long listed options is shown in Figure 12.1 (taken from the IOAR).

12.3 Application of Phase 2 Findings to Excluded Barrage Options

The B1 Outer Barrage was not shortlisted by Government as it was not considered feasible on the grounds of affordability. The B2 Middle Barrage from Hinkley to Lavernock Point was not considered feasible due to the additional cost and greater scale of habitat loss for the extra energy generated compared to the B3 Cardiff Weston Barrage.

Phase 2 study work has informed an update to the B3 Cardiff Weston Barrage cost and the updated costs can be used to verify the phase 1 conclusions. The phase 1 and phase 2 cost estimates for B3 Barrage are compared in Table 12.1.

Adjustments to the B3 Cardiff to Weston Barrage cost estimates between phase 1 and 2 have been applied to B1 Outer Barrage and B2 Hinkley to Lavernock Point Barrage in Table 12.2 either by applying an absolute or percentage increase depending on the cost item.

It is not possible to reliably update the cost of habitat compensation or include the additional cost for measures to prevent and reduce adverse effects as the excluded barrage options have not been subject to environmental assessment.

B3 Barrage scheme costs (excluding compensatory habitats and measures to prevent and reduce adverse effects) have increased from phase 1 to phase 2 by around 16%. This is mainly due to increases in the estimated cost of the locks and, to a lesser extent, ancillary works and caissons.

Updated B1 Outer Barrage and B2 Hinkley to Lavernock Point Barrage costs have each increased by 12%. The % increase is less than B3 Barrage as the cost of both schemes is less sensitive to the increased lock costs than B3 owing to the higher overall cost of the schemes.

The updated cost estimate of B1 Outer Barrage indicates that it is likely to be more expensive than estimated in phase 1 and therefore no more affordable.

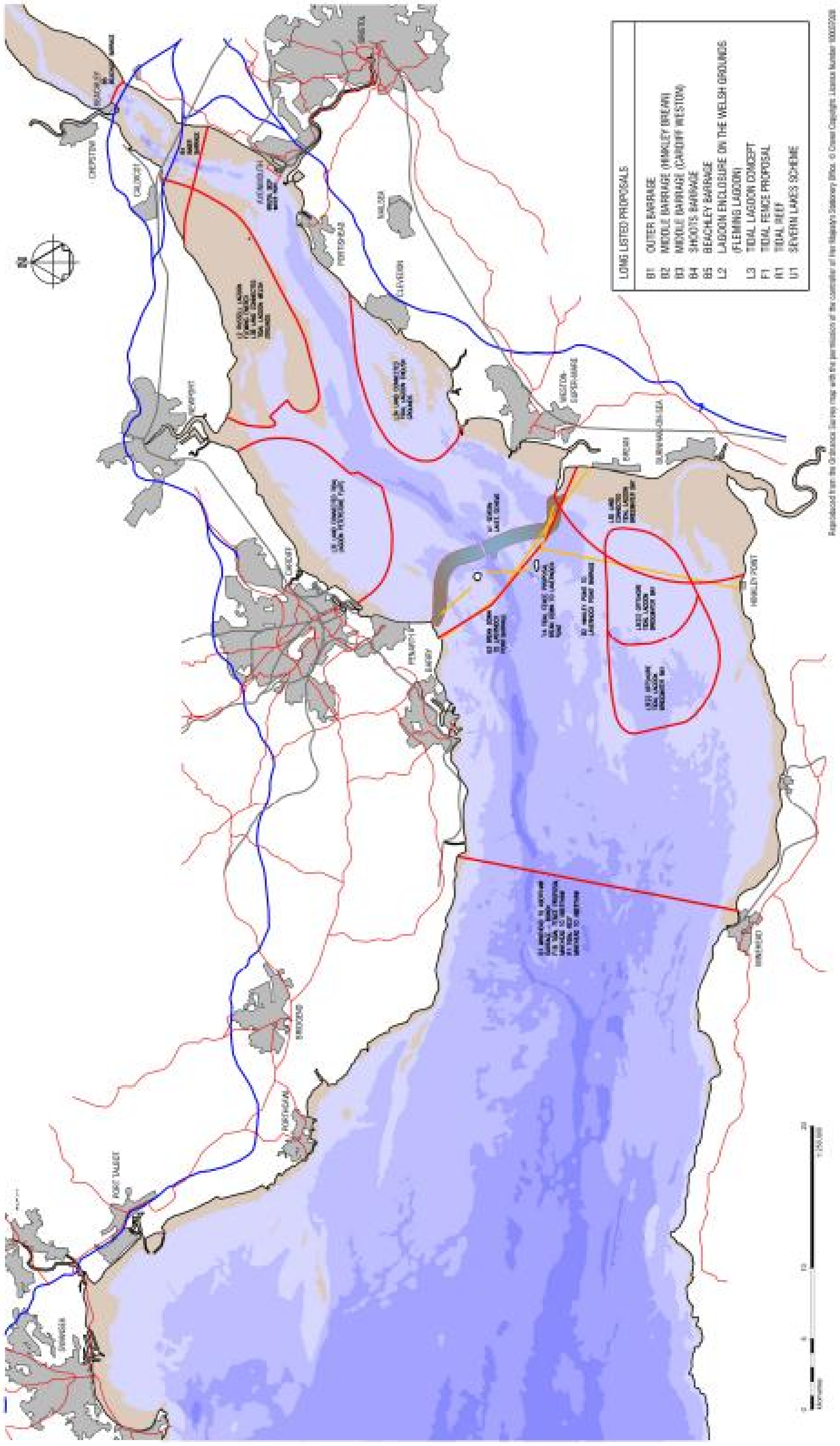

Figure 12.1 Location Map of Long Listed Options (from IOAR)

Table 12.1 B3 Cardiff to Weston Barrage - Comparison of Phase 1 and Phase 2 cost Estimates					
Item	Phase 1 IOAR Cost (£m)	Phase 2 ODR Cost (£m)	Cost Difference (£m)	Cost Difference %)	Comment
Pre-Construction	209	290	81	39%	Updated estimate for phase 2. Refer to Section 4 for updated costs.
Preliminaries and Site Overheads	1,036	1,178	142	14%	Preliminaries and site overheads revised from 15% of civils works (phase 1) to 13.5% of civils works (phase 2)
Caissons	5,314	5,874	560	11%	Updated estimate for phase 2.
Embankments	505	416	(89)	(18%)	Updated estimate for phase 2.
Navigation Locks	1,002	2,383	1,381	138%	More precise estimate in phase 2 based on updated lock design concept. Phase 1 lock estimate was based on a very high level extrapolation from the cost of locks originally included in B3 designs before the Feasibility Study to the updated lock sizes now included.
Surface Buildings	83	54	(29)	(35%)	Updated estimate for phase 2
Turbine Generators	5,841	4,841	(1,000)	(17%)	Updated estimate for phase 2. Phase 1 estimate includes contingency. Phase 2 estimate excludes contingency (see below).
Gates and Cranes	1,160	1,276	116	10%	Updated estimate for phase 2.
Grid Connection	500	485	(15)	(3%)	Updated estimate for phase 2. Phase 1 estimate includes contingency. Phase 2 estimate excludes contingency (see below).
Sub-Totals	15,650	16,797	1,147	(8%)	
Design	272	64	(208)	(76%)	Updated estimate for phase 2.
Site Investigation	4	4	0	0%	

Table 12.1 B3 Cardiff to Weston Barrage - Comparison of Phase 1 and Phase 2 cost Estimates					
Item	Phase 1 IOAR Cost (£m)	Phase 2 ODR Cost (£m)	Cost Difference (£m)	Cost Difference %)	Comment
Contractor's On-Costs and Profit	746	1,034	288	39%	Applied as a 9.25% of civils works (excl preliminaries and site overheads), gates and cranes in phase 1. Applied as a 9.25% of civils works (incl preliminaries and site overheads), gates and cranes in phase 2.
Ancillary Works	300	599	299	100%	Updated estimate for phase 2 based on SEA topic studies of effects on other infrastructure
Total (excluding Contingencies)	16,972	18,498	1,526	9%	
Contingencies	1,210	2,641	1,431	118%	Applied as 15% of civils works (excl preliminaries and site overheads), gates and cranes in phase 1. Applied as 15% of total construction cost (excl ancillary works) in phase 2.
Total (including Contingencies)	18,182	21,139	2,957	16%	

Table 12.2 B1 Outer Barrage and B2 Hinkley to Lavernock Point Barrage – Updated Cost Estimates					
Item	B1 Outer Barrage		B2 Hinkley to Lavernock Point Barrage		Comment
	Phase 1 IOAR Cost (£m)	Updated Cost (£m)	Phase 1 IOAR Cost (£m)	Updated Cost (£m)	
Pre-Construction	317	441	272	378	39% increase applied
Preliminaries and Site Overheads	1,516	1,668	1,355	1,430	Updated to 13.5% of civils works cost
Caissons	8,708	9,666	5,645	6,266	11% increase applied
Embankments	311	255	2,303	1,889	18% reduction applied
Navigation Locks	1,002	2,383	1,002	2,383	Updated B3 cost adopted
Surface Buildings	83	54	83	54	Updated B3 cost adopted
Turbine Generators	10,005	8,304	6,084	5,050	17% reduction applied
Gates and Cranes	2,384	2,622	1,255	1,381	10% increase applied
Grid Connection	868	868	557	557	Phase 1 estimate adopted for updated cost
Sub-Totals	25,194	26,261	18,556	19,388	
Design	426	102	334	80	76% reduction applied

Table 12.2 B1 Outer Barrage and B2 Hinkley to Lavernock Point Barrage – Updated Cost Estimates

Item	B1 Outer Barrage		B2 Hinkley to Lavernock Point Barrage		Comment
	Phase 1 IOAR Cost (£m)	Updated Cost (£m)	Phase 1 IOAR Cost (£m)	Updated Cost (£m)	
Site Investigation	4	4	9	9	Phase 1 estimate adopted for updated cost
Contractor's On-Costs and Profit	1155	1,539	952	1,240	Applied as a 9.25% of civils works (excl preliminaries and site overheads), gates and cranes in phase 1. Applied as a 9.25% of civils works (incl preliminaries and site overheads), gates and cranes in phase 2.
Ancillary Works	400	699	350	749	Phase 2 B3 increase of £299m applied. An additional £100m has been added to B2 to provisionally allow for modifications to Hinkley outfalls and intakes.
Total (excluding Contingencies)	27,179	28,505	20,201	21,466	
Contingencies	1,873	4,105	1,543	3,051	Applied as 15% of civils works (excl preliminaries and site overheads), gates and cranes in phase 1. Applied as 15% of total construction cost (excl ancillary works) in phase 2.
Total (including Contingencies)	29,052	32,610	21,744	24,517	

In phase 1, B2 Hinkley to Lavernock Point Barrage was estimated to have a 20% increase in cost for a 15% increase in energy yield compared to B3 Cardiff to Weston Barrage. Using the updated costs, the cost difference reduces to 16% mainly because the increase in the estimated cost of shipping locks has a relatively smaller effect on B2 than B3. Therefore, mainly due to the increased cost of shipping locks, the B2 barrage becomes relatively more favourable than was the case in phase 1. If the B3 barrage is taken forward, further consideration could be given to modifying its alignment along the B2 line but further study would be needed to compare their effects on the environment, including far field effects which could be more onerous with B2. Further study would also be required into the effects of a higher installed capacity on the National Grid.

12.4 Application of Phase 2 Findings to Excluded Land Connected Lagoon Options

L3a English Grounds Lagoon and L3c Peterstone Flats Lagoon were excluded from the shortlist because their levelised costs were higher than the land connected L3d Bridgwater Bay Lagoon and their energy yields were lower. L3d Bridgwater Bay Lagoon was considered to be the better candidate for further study.

Table 12.3 below compares the installed capacity, operating mode, cost, construction period, energy yield and levelised energy costs of the shortlisted land connected lagoons estimated in phase 1 and phase 2.

The above comparison indicates that the phase 1 study into land connected lagoons may have underestimated the optimal installed capacity and energy yield but may also have underestimated scheme costs, construction periods and levelised energy costs.

12.4.1 Operating Mode, Installed Capacity and Energy Yield

Preliminary optimisation and subsequent 2D modelling of the L3d Bridgwater Bay lagoon led to the following conclusions:

- The 1,360MW capacity assumed in phase 1 was not extracting the maximum energy available from the lagoon;
- Ebb flood operation would achieve higher energy output than ebb only mode; and
- It is necessary to maximise energy output to achieve a lower bound levelised energy cost.

Preliminary optimisation and subsequent 2D modelling of the L2 Welsh Grounds lagoon led to the following conclusions:

- A capacity of around 1,000MW was reasonably optimal in energy yield terms;

- Ebb flood operation could achieve around a 10% increase in energy but at additional capital cost indicating that ebb only mode is likely to be more optimal; and
- The installed capacity and energy yield are limited by energy losses caused by a backwater effect on discharge possibly caused by the capacity of the Newport Deep Channel to convey the flow.

Option		L2 Welsh Grounds Lagoon	L3d Bridgwater Bay Lagoon
Installed Capacity (MW)	Phase 1 IOAR	1,360	1,360
	Phase 2 ODR	1,000	3,600
Operating Mode	Phase 1 IOAR	Ebb only	Ebb only
	Phase 2 ODR	Ebb only	Ebb flood
Scheme Cost including compensation at 2:1 ratio (£m)	Phase 1 IOAR	4.0	3.7
	Phase 2 ODR	6.7	11.9
Construction Period	Phase 1 IOAR	5 years	5 years
	Phase 2 ODR	5 years to 1st energy generation 6 years to full energy generation	5 years to 1st energy generation 6 years to full energy generation
Energy Yield (TWh/yr)	Phase 1 IOAR	2.31	2.64
	Phase 2 ODR	2.5 to 2.7 (ebb only generation)[1]	5.6 to 6.9 (ebb flood generation)[2]
Levelised energy cost including compensation at 2:1 ratio; 8% discount rate (£/MWh)	Phase 1 IOAR	187	156
	Phase 2 ODR	272	196

Notes:

1. Sensitivity tests indicated that L2 energy yield in ebb flood mode is likely to be around 10% higher than in ebb only mode
2. Sensitivity tests indicated that L3d energy yield in ebb only mode is likely to be around 25% lower than in ebb only mode

Table 12.3 L2 Welsh Grounds Lagoon and L3d Bridgwater Bay Lagoon – Comparison of Phase 1 and Phase 2 Findings

Comparing the shape of the two lagoons and the form of the topography, it appears that the higher energy yield achieved for Bridgwater Bay may be attributable to the following factors:

a) The form of the topography in the vicinity of the turbines does not lead to the energy losses experienced at the Welsh Grounds Lagoon

b) The broader shape of the lagoon basin, compared to the narrower shape of the Welsh Grounds lagoon basin, may be associated with a more efficient exchange of water volume between the lagoon and the sea.

The relative effects of the above factors have not been studied but it is considered likely that the form of topography has the greater effect.

To apply the phase 2 findings, it is first necessary to consider these two factors in the L3a English Grounds lagoon (Figure L3a) and L3c Peterstone Flats lagoon (Figure L3c).

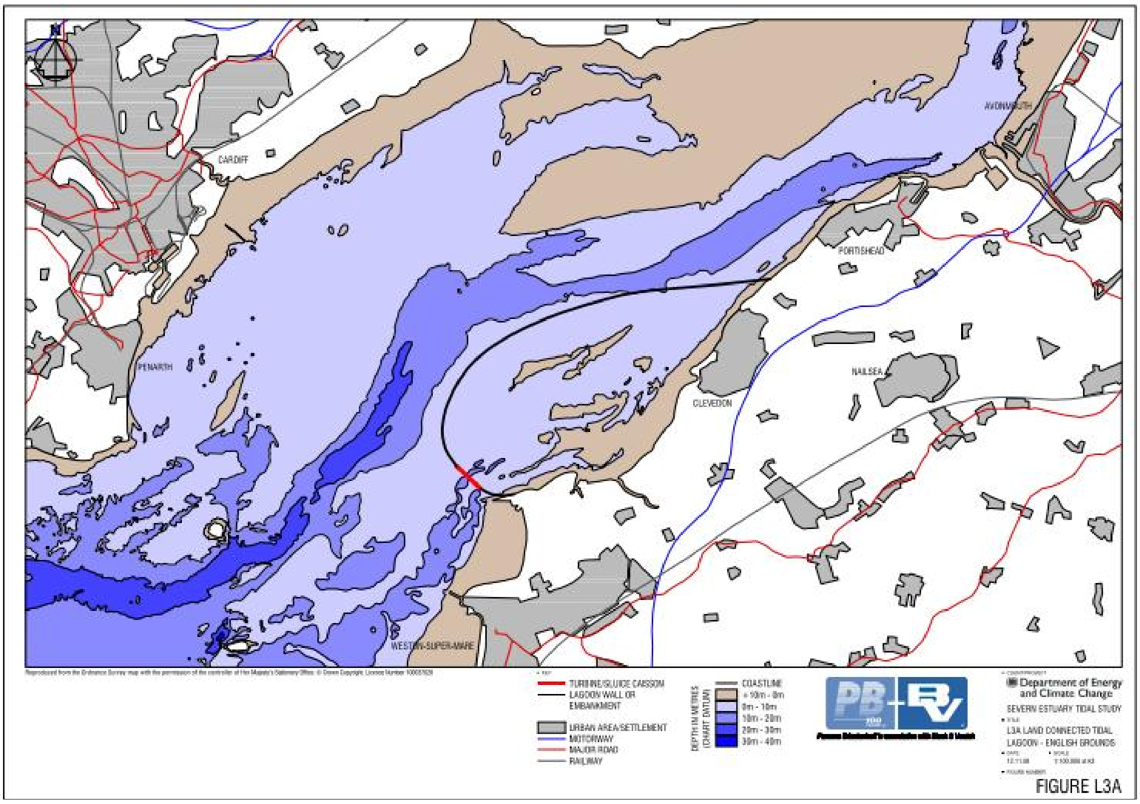

Figure L3A English Grounds Lagoon (from IOAR)

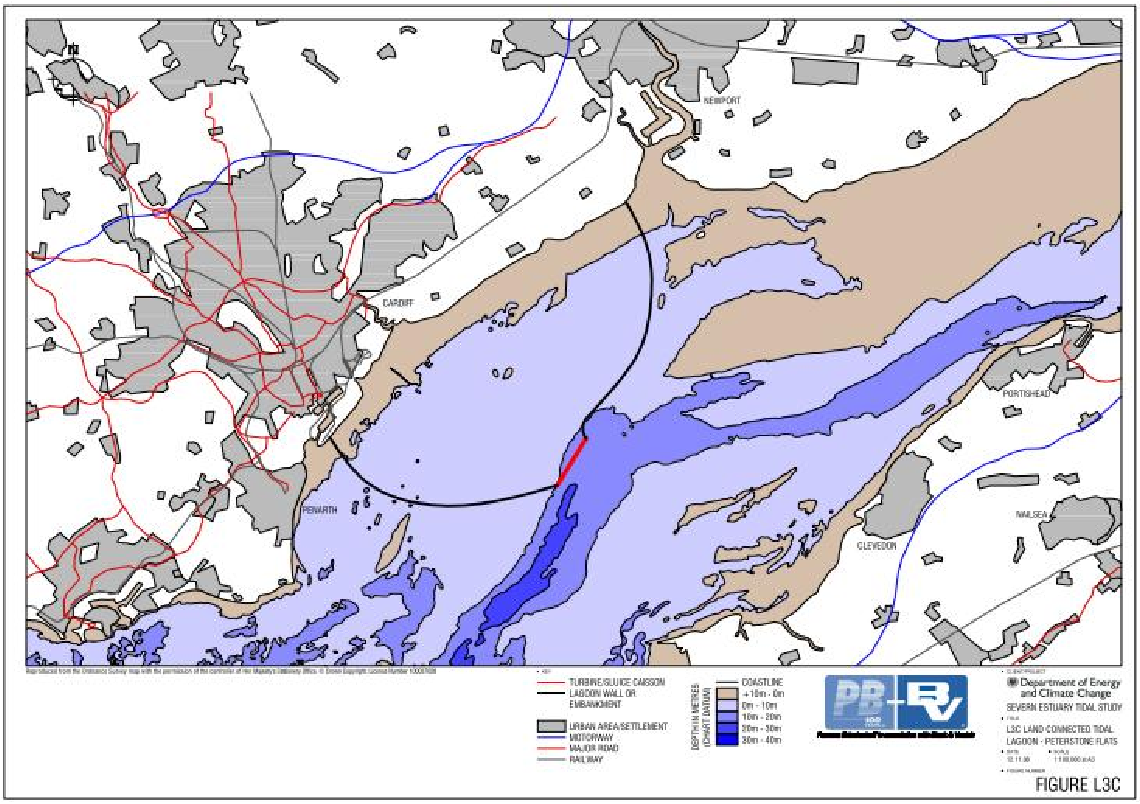

Figure L3C Peterstone Flats Lagoon (from IOAR)

By observation of the topography, it appears that either lagoon could probably be configured to discharge to areas of the Estuary where the topography would not lead to the energy losses experienced at the Welsh Grounds lagoon. The shapes of the two lagoons are more similar to Bridgwater Bay than Welsh Grounds, though both lagoons may benefit from optimisation of the powerhouse location, particularly the English Grounds lagoon.

Therefore, it is concluded that the English Grounds and Peterstone Flats lagoons are likely to behave more similarly to Bridgwater Bay lagoon than Welsh Grounds Lagoon and therefore likely to be more optimal as ebb flood schemes than ebb only schemes.

Table 12.4 provides a comparison between the impounded areas of the Bridgwater Bay, English Grounds and Peterstone Flats lagoons.

Lagoon	Impounded Area (km^2)
L3a English Grounds Lagoon	50
L3c Peterstone Flats Lagoon	76
L3d Bridgwater Bay Lagoon	87[1]
Note: 1. Updated from 89 km^2 estimated in phase 1	

Table 12.4 Lagoon Impounded Areas

During preliminary optimisation, 1D modelling tests were performed on a 52 km² and an 87 km² land connected lagoon at Bridgwater Bay. Figure 12.2 shows the energy yield per unit area impounded for each lagoon for a range of installed capacities in ebb and flood mode.

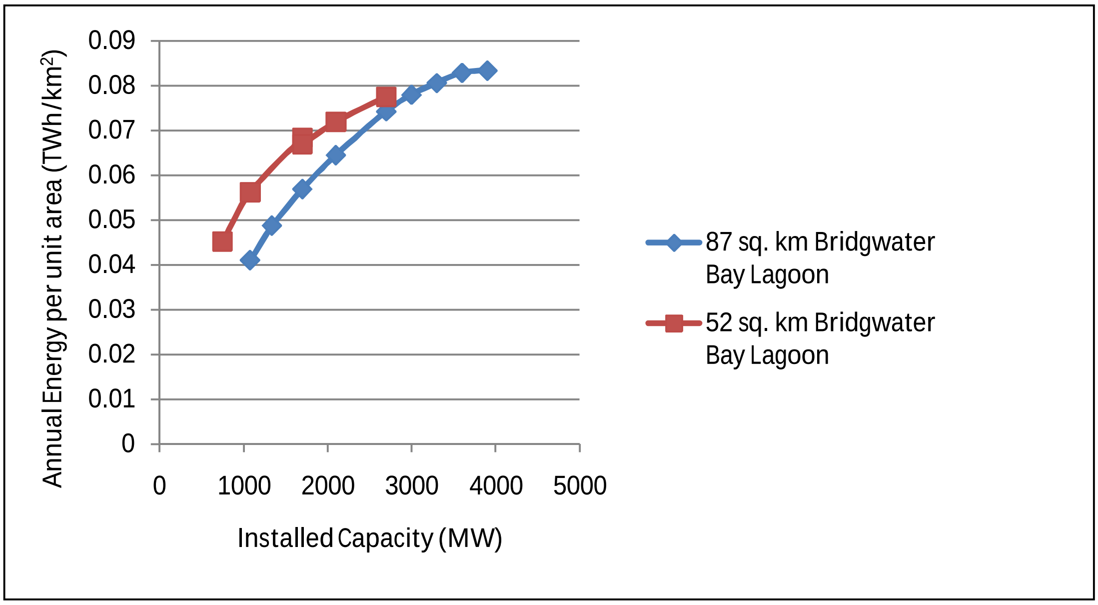

Figure 12.2 Energy Yield per Unit Area for Bridgwater Bay Land Connected Lagoons

For lower installed capacities, the smaller lagoon achieved a higher annual energy yield per unit area but at around 2,700MW, the lagoons start to converge on around 0.08TWh per km². Tests on capacities higher than 2,700MW were not carried out for the 52 km² lagoon but a maximum annual energy output of 0.078 to 0.083 TWh/km² appears to be a reasonable range which could be applied to a 50 km² and 76km² lagoon. A reduction of 5% is required to allow for outages giving a range of 0.074 to 0.079 TWh/km². To obtain a potential energy yield, the energy estimates have been modified to allow for adjustments to the Bridgwater Bay energy yield to take account of 2D modelling results, effects of modern turbines and effects of measures to prevent and reduce adverse effects. The energy yields are derived in Table 12.5.

Figure 12.3 shows load factor against installed capacity from the same tests that produced the data shown in Figure 12.2.

Option	1D Modelling Estimate (1979 Turbine Characteristics) (TWh/yr)	1D Modelling Estimate Adjusted to Allow for 2D Modelling Results and 2008 Turbine Characteristics (TWh/yr)	Adjustment to Allow for Effect of Measures to Prevent and Reduce Adverse effects (Including Pumping) (TWh/yr)	Estimated Energy Yield Range (TWh/yr)
L3d Bridgwater Bay Lagoon	6.7	5.7 to 6.3	0% to 5%	5.7 to 6.6
L3a English Grounds Lagoon ($50km^2$)	3.7 to 4.0	3.1 to 3.8	0% to 5%	3.1 to 4.0
L3c Peterstone Flats Lagoon ($76km^2$)	5.6 to 6.0	4.8 to 5.6	0% to 5%	4.8 to 5.9

Table 12.5 Updated Lagoon Energy Yields

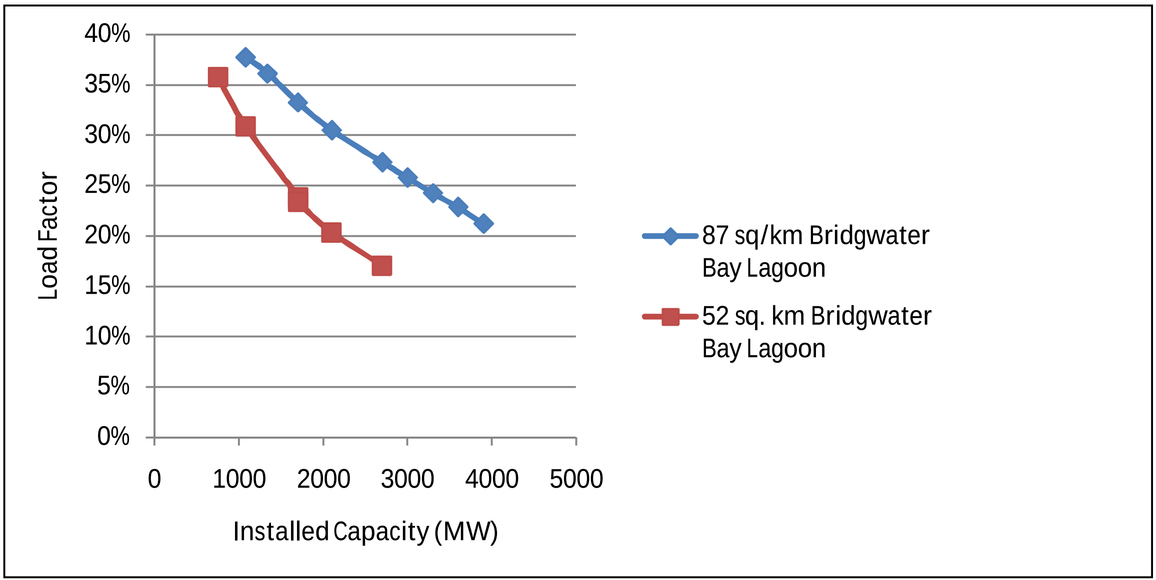

Figure 12.3 Load Factors for Bridgwater Bay Land Connected Lagoons

Test results show that the smaller Bridgwater Bay lagoon tended to have a lower load factor than the larger lagoon indicating that the load factor for a $50km^2$ and $76km^2$ lagoon may be in the region of 15% and 20% respectively. Based on this assumption and using upper bound energy yield, typical installed capacities for the English Grounds and Peterstone Flats lagoons could be around 3,000MW and 3,400MW respectively. More detailed study would be required to determine whether these capacities are optimal.

12.4.2 Scheme costs, Construction periods and Levelised Energy Costs

The key features of the Bridgwater Bay Lagoon, English Grounds Lagoon and Peterstone Flats Lagoon are shown in Table 12.6.

Option	Assumed Capacity	Enclosure Length	Average Embankment Height
L3a English Grounds Lagoon	3,000 MW	18km	23 m
L3c Peterstone Flats Lagoon	3,400 MW	21km	22 m
L3d Bridgwater Bay Lagoon	3,600 MW	16km	22 m

Table 12.6 Land Connected Lagoons - Key Features

Based on the above comparison, it is possible to update at a very high level, the phase 1 scheme costs for the L3a and L3c lagoons by making the following assumptions:

- Although the embankment volume is proportional to the square of the height, the majority of embankment cost is in the protection to the embankment side slopes which is proportional only to the height. Therefore embankment costs are assumed to be roughly proportional to height. This is a simplification which will lead to an underestimate in the updated embankment cost.
- Mechanical and electrical costs and caisson costs are proportional to installed capacity.

Updated scheme costs are derived in Table 12.7. The costs do not include compensatory habitat required under the Habitats Directive and measures to prevent and reduce adverse effects because it is not possible to compare these costs with the Bridgwater Bay lagoon without an equivalent level of environmental assessment. It should be noted though that the cost of compensatory habitat for the Bridgwater Bay lagoon is only around 1% of scheme cost.

Construction programmes should be assumed to be 5 years to first energy generation (76%) and 6 years to full energy generation.

Levelised energy costs, without compensation costs, based on an 8% discount rate and assuming the same operation and maintenance costs for all three schemes are shown in Table 12.8.

Option	Levelised Energy Cost for Upper Bound Energy Estimate (£/MWh)	Levelised Energy Cost for Lower Bound Energy Estimate (£/MWh)
L3a English Grounds Lagoon	271	339
L3c Peterstone Flats Lagoon	207	254
L3d Bridgwater Bay Lagoon	176	217

Table 12.8 Land Connected Lagoons – Levelised Energy Costs

As shown in Table 12.8, the updated levelised costs of L3a English Grounds Lagoon and L3c Peterstone Flats Lagoon exceed £200 per MWh, omitting the cost of compensatory habitat and measures to prevent or reduce adverse effects. Allowing for these costs would increase the cost of energy.

Therefore, there is no case for adding the excluded land connected lagoons to the shortlisted schemes.

Item	L3d Bridgwater Bay Lagoon (£m)	L3a English Grounds Lagoon (£m)	L3c Peterstone Flats Lagoon (£m)	Comment
Pre-Construction	160	160	160	Costs assumed the same for all options
Preliminaries and Site Overheads	600	570	650	Preliminaries and site overheads estimated as 13.5% of civils works
Caissons	2,756	2,300	2,600	Pro-rata adjustment based on installed capacity
Embankments	1,565	1,800	2,100	Pro-rata adjustment based on product of enclosure length and height
Navigation Locks	85	85	85	Costs assumed the same for all options
Surface Buildings	37	37	37	Costs assumed the same for all options
Turbine Generators	3,034	2,500	2,900	Pro-rata adjustment based on installed capacity
Gates and Cranes	303	250	290	Pro-rata adjustment based on installed capacity
Grid Connection	247	247	247	Costs assumed the same for all options
Sub-Totals	8,787	7,949	9,069	
Design	38	38	38	Costs assumed the same for all options
Site Investigation	2	2	2	Costs assumed the same for all options
Contractor's On-Costs and Profit	494	466	533	Applied as a 9.25% of civils works (incl preliminaries and site overheads), gates and cranes
Ancillary Works	273	173	173	Costs for L3a and L3c are as L3d less £100m which is specific to effects of L3d on Hinkley Point.
Total (excluding Contingencies)	9,594	8,628	9,815	
Contingencies	1,832	1,659	1,896	Applied as 20% of total construction cost (excl ancillary works)
Updated Phase 2 Total (including Contingencies)	11,426	10,287	11,711	
Phase 1 Total (including Contingencies)	3,000	2,600	3,300	

Table 12.7 Land Connected Lagoons – Updated Scheme Cost Estimates

12.5 Application of Phase 2 Findings to the Excluded Offshore Bridgwater Bay Lagoon Option

The L3e Bridgwater Bay Offshore Lagoon was not shortlisted because its levelised energy cost exceeded the threshold set at £200 per MWh.

Table 12.3 above provides a comparison between the phase 1 and phase 2 energy yields, scheme costs, construction programmes and levelised energy costs of the shortlisted lagoons. The comparison indicates that the phase 1 study into offshore lagoons may have underestimated the optimal installed capacity and energy yield but may also have underestimated scheme costs.

12.5.1 Operating Mode, Installed Capacity and Energy Yield

Based on the phase 2 preliminary optimisation of the L3d land connected Bridgwater Bay lagoon, there is reasonable certainty that ebb flood mode would be optimal for an offshore lagoon in energy yield and energy cost terms. Phase 2 findings also indicate that an offshore lagoon will be optimal in energy terms if it is configured to maximise energy output.

Extrapolating the energy modelling results from the land connected lagoons to the offshore lagoons is unlikely to give a reliable updated energy yield because an offshore lagoon, being beyond the inter-tidal zone, has a larger live storage volume per unit area than a land connected lagoon.

Therefore, 1D model tests have been carried out for the 90km^2 offshore lagoon, L3e (i), to incrementally increase installed capacity in ebb flood mode to determine the limiting energy yield. The smaller L3e (ii) lagoon has not been tested as the phase 1 offshore lagoon study and the preliminary optimisation of the land connected lagoons in phase 2 both concluded that smaller enclosures are significantly less economic than larger enclosures.

The results of the 1D modelling tests shown in Figure 12.4 indicate that the optimal installed capacity in energy terms is likely to be around 3,750MW. Applying a reduction of 5% for outages, the 1D modelling gave an estimated energy yield of 8.5TWh/yr.

Allowing for the adjustment to the 1D model results based on comparisons between 1D and 2D modelling, and allowing for the effects of measures to prevent and reduce adverse effects and pumping, the energy estimate has been reduced by between 7% and 20%. This gives an energy yield range of 6.8 to 7.9TWh per year.

12.5.2 Scheme Cost, Construction Period and Levelised Energy Cost

Updated scheme costs allowing for the increase in installed capacity are determined below by comparison with the L3d Bridgwater Bay land connected lagoon cost.

Powerhouse caissons and turbine, gate and crane costs have been based on the Bridgwater Bay lagoon costs adjusted in direct proportion to installed capacity.

Further study on the optimal form and cost of embankment for the Bridgwater Bay land connected lagoon has concluded that a rockfill embankment is the most appropriate form of impoundment construction on which to base the land connected lagoon costs. In phase 1, lagoon impoundment construction costs for the land connected and offshore lagoon were provisionally based on an embankment constructed of geo-containers, but in phase 2 further study into the feasibility of that form of embankment has concluded that it has no advantage over rockfill construction but may increase construction time. The adoption of a rockfill embankment in phase 2 has led to an increase in lagoon construction costs.

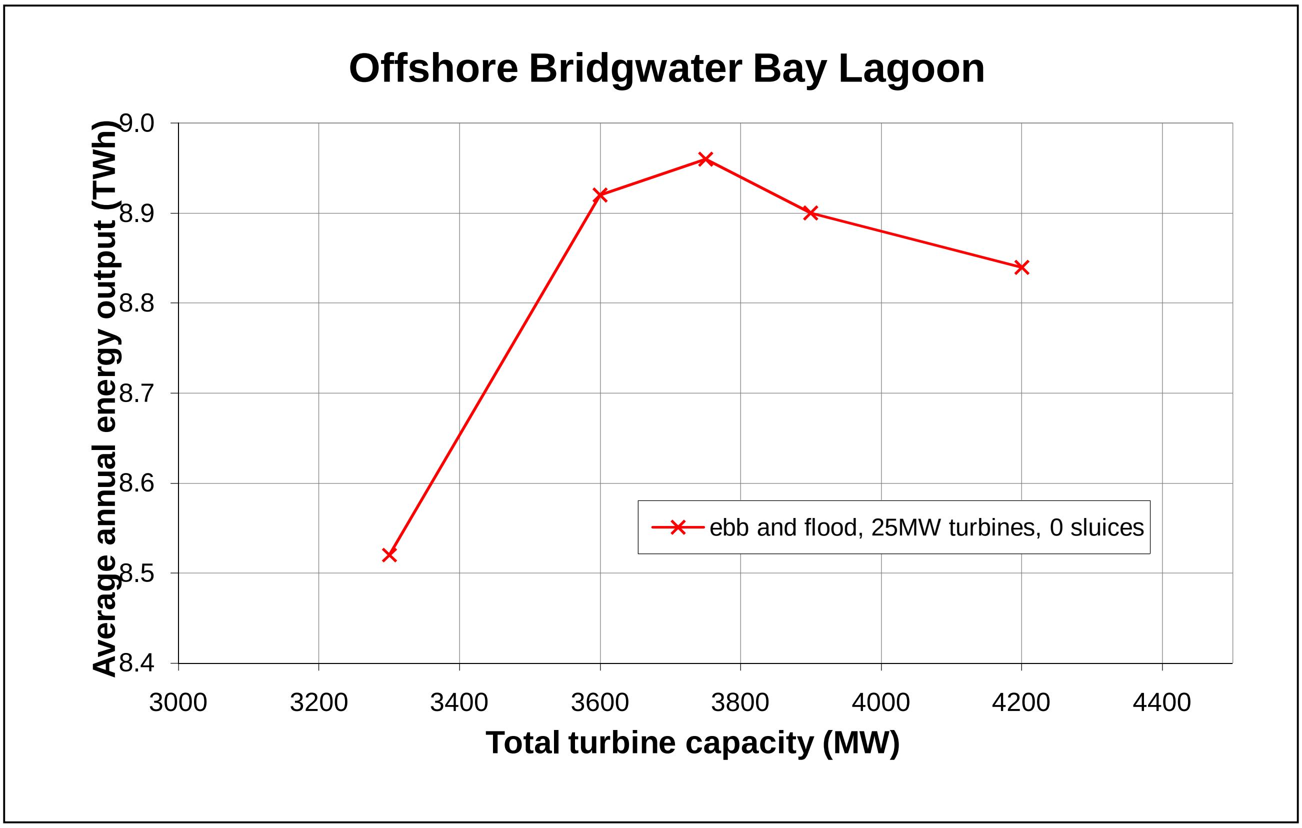

Figure 12.4 Offshore Bridgwater Bay Lagoon – 1D Model Results

Further study into embankment construction using geo-containers has been carried out in phase 2 and reported in Section 3. Geo-container construction was found to have no advantage over conventional rockfill construction in terms of the cost of rock armouring. Geo-container construction was also found to be more suited to embankments with shallower side slopes due to the accuracy of placing the geo-containers. Geo-container construction is likely to be slower to construct than conventional rockfill construction and more sensitive to adverse weather. The evidence suggests that geo-container construction would not be optimal for an offshore lagoon construction.

A provisional assessment of an updated impoundment construction cost is provided in Table 12.8 based on the L3d Bridgwater Bay embankment cost. For an offshore lagoon, plain caissons may be a more suitable alternative to rockfill construction but requires further study before any conclusions can be drawn.

Updated costs do not include compensatory habitat and measures to prevent and reduce adverse effects because it is not possible to compare these costs with land connected lagoons without an equivalent level of environmental assessment. It should be noted though that the cost of compensatory habitat for the Bridgwater Bay lagoon is only around 1% of scheme cost.

Updated scheme costs are provided in Table 12.9.

Scheme Component	L3d Bridgwater Bay Lagoon Conventional Rockfill Embankment	Comments
Length of construction	12,200m	
Construction cost per m	£0.17m	Unit cost for a 25m high conventional embankment
Construction cost for 36,000m offshore impoundment	£6,120m	
Fabrication/construction facilities	£500m	Provisional allowance
Embankment Fit Out Costs	£428m	Provisionally assumed as 7% of embankment construction cost
Total Impoundment Construction Cost	£7,048m	

Table 12.8 Offshore Lagoon Impoundment cost Update

Item	L3d Land Connected Bridgwater Bay Lagoon (£m)	L3e Offshore Bridgwater Bay Lagoon (£m)	Comment
Pre-Construction	160	160	Cost assumed the same for both options
Preliminaries and Site Overheads	600	1,355	Estimated as 13.5% of civils works
Caissons	2,756	2,870	Pro-rata adjustment based on installed capacity
Enclosure Construction	1,565	7,048	From Table 15.8
Navigation Locks	85	85	Cost assumed the same for all options
Surface Buildings	37	37	Cost assumed the same for all options
Turbine Generators	3,034	3,160	Pro-rata adjustment based on installed capacity
Gates and Cranes	303	316	Pro-rata adjustment based on installed capacity
Grid Connection	247	300	Provisional estimate
Sub-Totals	8,787	15,331	
Design	38	38	Cost assumed the same for both options
Site Investigation	2	6	Phase 1 cost estimate adopted
Contractor's On-Costs and Profit	494	1,083	Applied as a 9.25% of civils works (incl preliminaries and site overheads), gates and cranes
Ancillary Works	273	173	Cost for L3e is as L3d less £100m which is specific to effects of L3d on Hinkley Point.
Total (excluding Contingencies)	9,594	16,631	
Contingencies	1,832	3,260	Applied as 20% of total construction cost (excl ancillary works)
Updated Phase 2 Total (including Contingencies)	11,426	19,891	
Phase 1 Total (including Contingencies)	3,000	5,800	

Table 12.9 Offshore Bridgwater Bay Lagoon – Updated Scheme Cost

Phase 2 study into the L3d Bridgwater Bay land connected lagoon has led to an update in the estimated construction period. Construction of the land connected lagoon enclosure was found to be critical to the overall programme and inevitably that would also be the case for an offshore lagoon. A rate of construction of 50m per month was used for the land connected lagoon programme and for the purpose of this update can be assumed for the offshore lagoon. However, the more exposed conditions could lead to a slower rate of construction. The phase 1 study anticipated a 6 year construction period. The offshore lagoon would require some 36,000m of embankment construction and to achieve closure by 6 years would require 10 working fronts. This would be a significant logistical challenge and the costs estimated in this update may not fully reflect the scale of construction facilities and construction equipment required. Nevertheless, for the purpose of the update, 6 years to full energy generation has been assumed.

Levelised energy costs, without compensation costs, based on an 8% discount rate and assuming the same operation and maintenance costs for the land connected and offshore lagoon schemes are shown in Table 12.9.

Option	Levelised Energy Cost for Upper Bound Energy Estimate (£/MWh)	Levelised Energy Cost for Lower Bound Energy Estimate (£/MWh)
L3e Bridgwater Bay Offshore Lagoon	265	312

Table 12.9 L3e Offshore Lagoon – Updated Levelised Energy Costs

As shown in Table 12.9, the updated levelised costs of the offshore lagoon exceed £200 per MWh omitting the cost of compensatory habitat and measures to prevent or reduce adverse effects. Allowing for these costs would increase the cost of energy.

Therefore, there is no case for adding the excluded offshore lagoon to the shortlisted schemes.

REFERENCES

REFERENCES

(i) Energy Paper 46: Tidal Power from the Severn Estuary Volume 2, HMSO 1981,

(ii) Severn Barrage Project Detailed Report, Volumes 3A and 3B: Civil Engineering including Site Investigations – Contractor, Severn Tidal Power Group - ETSU TID 4060-P3A and P3B, 1989

(iii) Severn Barrage Report SBP3: 2D Plan Hydrodynamic Modelling of the Bristol Channel and Severn Estuary with and without Barrage - Water Research Centre, May 1989

(iv) Tidal Barrage Caisson Emplacement Model Tests, Phase 2 – ETSU TID 4115 Contractor, ABP Research & Consultancy Ltd, Southall, Middlesex, 1993

(v) Severn Barrage Project Detailed Report, Volume 2: Electrical and Mechanical Engineering, including Energy Capture and Value – Contractor, Severn Tidal Power Group - ETSU TID 4060-P2, 1989

(vi) Severn Tidal Power Supply Chain Survey Report, DECC, November 2009

(vii) Severn Tidal Grid Impact Report, National Grid, November 2009

(viii) The Hooker Barrage: A new proposal for Tidal Power from the Severn Estuary. March 1990. MRM Consulting Engineers in association with A V Hooker.

(ix) Elements of Tidal-Electric Engineering, Robert H Clark, March 2007

(x) Research Report 3 – Severn Barrage Proposals, Sustainable Development Commission, September 2007

(xi) Interim Options Analysis Report, Parsons Brinckerhoff, November 2008

(xii) GEO6 Investigations of Changes to Hydraulics for Short-Listed Options, H R Wallingford and ABPmer, 2009

(xiii) Severn Tidal Power Strategic Environmental Assessment 1-D Mathematical Modelling Phases 1 and 2, Black & Veatch 2009

(xiv) Comparison of Results from 1D and 2D Mathematical Modelling, Black & Veatch, February 2010

(xv) Severn Tidal Power – SEA Environmental Report, Parsons Brinckerhoff in association with Black & Veatch, April 2010

(xvi) Report to Inform a Stage 2 (Appropriate Assessment) Habitats Regulations Assessment, Black & Veatch, April 2010

(xvii) Tidal Power, A C Baker, 1991

(xviii) Impact Assessment, DECC, April 2010