DECC

SEVERN TIDAL POWER - SEA THEME PAPER

Physicochemical effects and interrelationships

April 2010

Prepared by
Parsons Brinckerhoff Ltd
Queen Victoria House
Redland Hill
Bristol
BS6 6US

In association with
Black and Veatch Limited

Prepared for
DECC
3 Whitehall Place
London
SW1A 2HD

Report Title	**:**	**Severn Tidal Power - SEA Theme Paper**
Report Status	**:**	**FINAL**
Topic Name	**:**	**Physicochemical Theme**
Date	**:**	**30 April 2010**
Prepared by	**:**	**David Keiller**
Checked by	**:**	**Rob Fraser**
Approved by	**:**	**Tom Matthewson**

Revision	**Status**	**Date Issued**
1	Draft for DECC review	23 Feb 2010
2	Final	30 April 2010

CONTENTS

ABBREVIATIONS

ABBREVIATIONS

The following abbreviations are used in this Environmental Report:

ATT	Admiralty Tide Tables
CCO	Channel Coastal Observatory
CCW	Countryside Council for Wales
CHaMP	Coastal Habitat Management Plan
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
EC	European Commission
EU	European Union
FE	Freshwater Environment & Associated Interfaces
FRLD	Flood Risk & Land Drainage
GCR	Geological Conservation Review
GEBCO	General Bathymetric Chart of the Oceans
GHT	Gloucester Harbour Trustees
GIS	Geographical Information System
GW	Gigawatts
H&G	Hydraulics & Geomorphology
HRA	Habitats Regulations Assessment
IOS	Institute of Oceanographic Sciences
LiDAR	Light Detection And Ranging
m	Metre
Mm^3	Million cubic metres
MTonnes	Million metric tonnes
MW	Megawatts
MWQ	Marine Water Quality
ODPM	Office of the Deputy Prime Minister
PPG	Planning Policy Guidance
PPS	Planning Policy Statements
PSMSL	Permanent Service for Mean Sea Level
PSU	Practical salinity units
PWS	Public Water Supply
RBMP	River Basin Management Plan
SAC	Special Area of Conservation
SEA	Strategic Environmental Assessment
SEFRMS	Severn Estuary Flood Risk Management Strategy
SLR	Sea Level Rise
SMP	Shoreline Management Plan
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
STP	Severn Tidal Power
SWRDA	South West Regional Development Agency
TAN	Technical Advice Note
TWh	Terrawatt hours
UKCP	United Kingdom Climate Projections
WAG	Welsh Assembly Government
WFD	Water Framework Directive
WWTW	Waste Water Treatment Works
1D	One dimensional
2D	Two dimensional
3D	Three dimensional

NON TECHNICAL SUMMARY

NON TECHNICAL SUMMARY

Feasibility Study and Purpose of the SEA

The Government announced a two-year feasibility study on harnessing the renewable energy from the tidal range in the Severn Estuary in January 2008. This work is being carried out by a cross-Government team led from the Department of Energy and Climate Change (DECC). The aim of the Severn Tidal Power (STP) Feasibility Study is to investigate whether Government could support a tidal power scheme in the Severn and, if so, on what terms.

The Feasibility Study has been split into two phases: Phase One examined the scope of work and analysis required to make an evidence-based decision on whether to support a tidal power project in the Severn and what potentially feasible schemes exist for converting this energy. Phase One ended with the publication of the consultation document in January 2009. Phase Two (the current stage) has involved work on environmental, regional, economic, commercial, technical and regulatory issues to inform the study conclusions including whether any of the potential schemes are feasible.

A Strategic Environmental Assessment (SEA) is being carried out in support of the Feasibility Study, in accordance with EU Directive 2001/42/EC (the SEA Directive), implemented in England and Wales through the Environmental Assessment of Plans and Programmes Regulations (SI 2004/1633 and Welsh SI 2004/1656), to predict and analyse the environmental effects of alternative short-listed Severn tidal power options over their entire lifetime, in order to inform decision making at the end of the Feasibility Study.

Purpose of the Theme Papers

The SEA Directive requires that the likely significant effects on the environment and their interrelationships are described (SEA Directive Annex 1 (f)). The theme papers therefore summarise the interrelationships between related SEA topics and thereby ensure that the many complex issues that are not self-contained within a given topic are recognised and their implications understood. Each theme paper also examines the interrelationships between this theme and other themes within the STP SEA. This is the Physicochemical theme paper. This paper covers the:

- Hydraulics & Geomorphology,
- Marine Water Quality,
- Freshwater Environment & Associated Interfaces, and
- Flood Risk & Land Drainage topics**.**

Furthermore, the theme papers also assist the Environmental Report to meet the requirements of the SEA Directive by collating the difficulties (such as technical deficiencies or lack of know-how) encountered in compiling the required information (SEA Directive Annex 1 (h)).

Each theme paper therefore provides an integrated summary across the theme, drawing on information presented in its topic papers. This theme paper also addresses the interrelationships between this theme and the Habitats Regulations Assessment. Each theme paper also considers the likely significant effects on the environment of the variations of alternative options referred to as combination and multiple basin options.

Uncertainty within the Physicochemical Theme

The majority of assessments within the physicochemical theme depend on the outcome of modelling of the key processes involved at a level appropriate for a strategic assessment. The uncertainty associated with the predictions of the effects of alternative options varies with the type of prediction being made.

The predictions of changes in water levels, flows and waves are relatively certain. For these issues, two independent approaches were applied to cross check results and so help to further limit residual uncertainty. For issues where the assessment is primarily dependent on water levels, flows or waves, the uncertainty in the assessment will be more dependent on topic specific uncertainty than on the uncertainty in the model predictions of these parameters. This applies to assessments of effects on geological and geomorphological SSSIs and flood risk and land drainage within the Physicochemical theme.

For predictions of changes in suspended sediment and future water quality there is moderate uncertainty as the reliability of the predictive methods available for these aspects is limited. The reliability of eutrophication predictions are therefore considered to be of high uncertainty as these are based on a combination of predictions of suspended sediment changes and water quality changes. This high uncertainty has implications for topics in the Biodiversity theme and the Habitats Regulation Assessment.

There is high uncertainty about predictions of future morphology as the methods available can only account for some of the processes involved and will be influenced by future events and changes that cannot be reliably predicted. There is also high uncertainty about issues where the assessment is dependent on future morphology such as the extent of erosion protection required for flood defences.

In some cases uncertainty may be reduced by investment to improve the reliability of the methods of assessment. In other cases, particularly those involving long term predictions of changes in complex systems that are subject to multiple processes, such as morphology, the outcome is likely to remain partially unpredictable because future events are unpredictable. In such circumstances the approach adopted needs to be robust enough to support the range of potential outcomes.

Physicochemical Theme Baseline Environment, Significant Effects and Measures to Prevent or Reduce these effects

Baseline Environment

The Severn Estuary has the largest tidal range of any estuary within the European Union. The estuary receives freshwater from many rivers, the largest being the rivers Severn, Wye, Usk and Avon. The estuary is surrounded by a large low lying flood plain that is protected from sea flooding by flood defence embankments. Although drainage of the flood plain is impeded for a short period at high tide, there is sufficient time while the tide is out to effectively drain most of the land by gravity.

The large tidal range in the estuary is associated with wide intertidal foreshores and strong tidal currents that suspend many millions of tonnes of sediment each spring tide period and cause exceptionally high concentrations of suspended sediment during these periods. As a result the bathymetry of parts of the Severn estuary is very dynamic. In other areas there are large areas of bare rock where bathymetry is stable.

The Severn Estuary / Môr Hafren has been designated as a Special Area of Conservation. One of the principal features of the designation is its estuaries designation. This is an overarching designation that includes the form and function of the estuary, its sediments, intertidal foreshores and subtidal sandbanks and its physicochemical characteristics.

Over recent decades, the estuary has benefitted from improved treatment of effluents entering the estuary directly or via the river system. However, the discharge of dissolved inorganic nitrogen, an important plant nutrient, from the catchment is reported to have doubled over the past quarter century. This is one of the main reasons why the whole of the Severn estuary and the Usk, Wye and Parrett estuaries are considered to be of Moderate Ecological Potential or Status under the Water Framework Directive. The difficulty of reducing nitrogen inputs is expected to delay the achievement of Good Potential or Status in these estuaries until 2027.

There are a large number of geological and geomorphological SSSIs on the coastline of the Severn Estuary and Inner Bristol Channel reflecting the geodiversity of the area.

Effects and prevent & reduce measures for the B3 Brean Down to Lavernock Point Barrage (also known as Cardiff to Weston)

The B3 Brean Down to Lavernock Point Barrage reduces the tidal range within the impoundment by around 50% by raising low water levels close to the baseline mean tide level. High tide levels would be reduced by up to 1m on spring tides within the impoundment, though the effect on neap tides is less. Outside the barrage there would be reduced high water levels and raised low water levels. These effects would extend, with reducing effect, as far west as Ilfracombe and the Gower peninsular. Some increases in high tide levels are predicted, however, around the St George's Channel. The extent of the intertidal foreshore would reduce by just over 50%.

The reduced high water levels east of Ilfracombe and the Gower peninsular would benefit flood risk management, since works to raise flood defences to counter sea level rise could be delayed. However, the rise in low water level within the barrage basin would require measures to prevent impeded drainage of around 370km^2 of the tidal flood plain, including parts of Bristol and Newport. The changes in tidal levels are not expected to increase fluvial flood levels behind the Cardiff Bay Barrage. The rise in mean sea level within the basin is expected to raise groundwater levels in coastal towns, especially Weston-super-Mare, and would require measures to prevent or reduce adverse effects on underground infrastructure and basements. The lowermost exposures of ten geological and geomorphological SSSIs within the barrage basin area would experience permanent submergence especially the Otter Hole cave system on the River Wye.

There is a high risk of an increase in high water levels including surge levels along the coast of west Wales especially in the Pwhelli to Barmouth area where increases of 0.2-0.3m are predicted. This would require measures to prevent adverse effects on flood risk over up to 90km of coastline. Increases in high water level of 0.1-0.2m are also predicted for 10 to 20km of the Republic of Ireland coastline between Wicklow and Wexford. Smaller increases in high water levels around the coasts of the Irish Sea are also possible though the extent and magnitude is uncertain.

Tidal currents would reduce within the impoundment and over a large area outside extending, with reducing effect, as far west as Lundy Island. The reduction in tidal currents may change some of the linear sandbank features of the Bristol Channel such as Culver Sands, Nash Bank and Helwick Bank. The reduced tidal currents may reduce the amount of sediment in suspension by up to 90% within the impoundment, and possibly up to 60% outside. Shortly after starting generation, more than half the sediment in suspension would have permanently settled onto the deeper areas of the sea bed within the barrage basin.

Considering the scale of the changes to the tidal regime, the changes to the quality of the water are expected to be generally modest. However, the reduced suspended sediment concentrations during neap tide periods might increase water clarity sufficiently to allow enhanced algal growth for limited periods within the impoundment near to the barrage. As there are sufficient nutrients to support primary productivity this could increase the potential risk of eutrophication in the estuary.

Light penetration is likely to continue to be the limiting factor that restricts primary productivity in the Severn Estuary as suspended sediment concentrations would remain too high during much of the spring neap tidal cycle to allow nutrients to be fully utilised.

Over the long term, the evolution of the estuary is uncertain but modelling indicates that there would be accretion within subtidal parts of the estuary and erosion of many sections of the intertidal foreshores. This erosion is likely over the lifetime of the barrage to require measures to prevent undermining of up to 140km of the flood defences, with the first measures required within 5 to 10 years.

Effects and prevent & reduce measures for the B4 Shoots Barrage

The B4 Shoots Barrage would reduce the tidal range within the impoundment by around 50% by raising low water levels above the baseline mean tide level, reducing high water levels by 0.3m. Outside the barrage there would be a 0.2m increase in high water levels from Newport, extending, with reducing effect, as far west as Swansea. Further west any effects are generally expected to be less than 0.1m. The extent of the intertidal foreshore would reduce by about 10%.

The increased high water level would require measures to prevent adverse effects on flood risk over around 60km of coastline. The rise in low water level within the barrage basin would require measures to prevent impeding the drainage of around 240 km^2 of the tidal flood plain. The lowermost exposures of four geological and geomorphological SSSIs within the barrage basin area would experience permanent submergence, especially the Otter Hole cave system on the River Wye.

Tidal currents are expected to reduce within the impoundment and in the estuary outside as far as Clevedon. The reduced tidal currents may reduce the amount of sediment in suspension by up to 90% within the impoundment, and possibly locally up to 80% outside. Shortly after starting generation some of the sediment in suspension would have permanently settled onto the deeper areas of the sea bed within the barrage basin and outside as far downstream as Portishead.

Considering the scale of the changes to the tidal regime, the changes to the quality of the water are generally modest. While the reduced suspended sediment concentrations may allow some increased primary productivity, strong light limitation is expected to continue to prevent full utilisation of the available nutrients. The risk that the reduced suspended sediment concentrations could increase water clarity sufficiently to cause substantial algal growth is considered to be small.

Over the long term, the evolution of the estuary is uncertain but modelling strongly indicates that there would be much accretion upstream of the barrage which could impair energy generation within the 120 year design life of the scheme and may contain some contaminated sediment. Over the lifetime of the barrage, foreshore erosion is likely to require measures along around 70km of frontage to prevent undermining of the flood defences, with the first measures required after about 5 years.

Effects and prevent & reduce measures for the B5 Beachley Barrage

The B5 Beachley Barrage would reduce the tidal range within the impoundment by almost 50% by raising low water levels above the baseline mean tide level, reducing high tide levels by 0.3-0.4m. Outside the barrage there would be an increase of up to 0.2m in high water levels near Newport, extending, with reducing effect, as far west as Minehead. Further west any effects are generally expected to be less than 0.1m. The extent of the intertidal foreshore would reduce by about 9%.

The increased high water levels would require measures to prevent adverse effects on flood risk over around 95km of coastline. The rise in low water level within the barrage basin would require measures to prevent impeding the drainage of around 70 km^2 of the tidal flood plain. The lowermost exposures of three geological and geomorphological SSSIs within the barrage basin area would experience permanent submergence,

Tidal currents are expected to reduce within the impoundment and in the estuary outside as far as Clevedon. The reduced tidal currents may reduce the amount of sediment in suspension by up to 90% within the impoundment, and possibly up to 60% outside. Shortly after starting generation, some of the sediment in suspension would have permanently settled onto the deeper areas of the sea bed, mainly within the barrage basin.

Considering the scale of the changes to the tidal regime, the changes to the quality of the water are generally modest. While the reduced suspended sediment concentrations may allow some increased primary productivity, strong light limitation is expected to continue to prevent full utilisation of the available nutrients. The risk that the reduced suspended sediment concentrations could increase water clarity sufficiently to cause substantial algal growth is considered to be small.

Over the long term, the evolution of the estuary is uncertain but modelling strongly indicates that there would be much accretion upstream of the barrage which could impair energy generation within the 120 year design life of the scheme and may contain some contaminated sediment. Over the lifetime of the barrage, foreshore erosion is likely to require measures along around 10km of frontage to prevent undermining of the flood defences, with the first measures required within 5 years.

Effects and prevent & reduce measures for the L2 Welsh Grounds Lagoon

The L2 Welsh Grounds Lagoon would reduce the tidal range within the lagoon by 50% by raising low water levels above the baseline mean tide level, but with little change to high tide levels. In the Severn estuary outside the lagoon there would be a small decrease in high water levels, though in the Bristol Channel between Barry and Swansea increases of around 0.1m in spring high level are predicted. Further west any effects are generally expected to be less than 0.1m. The extent of the intertidal foreshore would reduce by about 25%.

The increased high water levels would require measures to prevent adverse effects on flood risk over around 20km of coastline. The rise in low water level within the lagoon would require measures to prevent impeding the drainage of around 50 km^2 of the tidal flood plain.

Tidal currents are expected to reduce within the impoundment and locally in the estuary outside. The reduced tidal currents may reduce the amount of sediment in suspension by up to 90% within the lagoon, and possibly up to 55% outside. Shortly after starting generation, some of the sediment in suspension would have permanently settled within the lagoon.

The concentrations of suspended sediment within the lagoon on neap tides are expected to be sufficiently low to allow algal blooms to occur. However, any algae that grew within the lagoon would be rapidly flushed out and so prevent blooms forming within the lagoon. Outside the lagoon, the suspended sediment concentrations are predicted to remain too high to permit substantial algal growth on any tides. In other respects, the predicted changes to the quality of the water are considered modest.

Over the long term, the evolution of the estuary is uncertain but modelling strongly indicates that there would be much accretion within the lagoon which may start to impair energy generation near the end of the 120 year design life of the scheme. Over the lifetime of the lagoon, foreshore erosion in the estuary outside is likely to require measures along around 20km of frontage to prevent undermining of the flood defences, with the first measures required within 5 to 10 years.

Effects and prevent & reduce measures for the L3 Bridgwater Bay Lagoon

The L3 Bridgwater Bay Lagoon would reduce the tidal range within the lagoon by about 1m by raising low water levels and reducing high tide levels. In the Severn estuary outside the lagoon there would be a small decrease in tide range lowering high tides by about 0.3m and raising low tide levels by a similar amount. These changes should reduce to less than 0.05 west of Port Talbot. Further west any effects are generally expected to be less than 0.1m. The extent of the intertidal foreshore would reduce by about 7%.

The rise in low water level within the lagoon would require measures to prevent impeding the drainage of around 240 km^2 of the tidal flood plain. However, because spring low water levels only rise by around 0.5m this effect is predicted to be relatively minor overall.

Tidal currents are expected to be increased markedly within and close to the lagoon because of the mode of operation, which is likely to lead to local scour of soft sediments. The lagoon is expected to move the existing area of high suspended sediment concentration in the estuary closer to the Welsh shore. The changed tidal currents may reduce the amount of sediment in suspension by up to 40% within the lagoon, and possibly up to 40% outside. Within a month of starting operation, settlement of sediment is anticipated in quiescent areas inside and outside the southern end of the lagoon wall.

The concentrations of suspended sediment within the lagoon on neap tides are expected to be sufficiently low to allow algal growth to occur. However, any algae that grew within the lagoon would be rapidly flushed out and so prevent blooms forming within the lagoon. Outside the lagoon, the suspended sediment concentrations are predicted to remain too high to permit substantial algal growth on any tides. In other respects, the predicted changes to the quality of the water are considered modest.

The dispersion of the thermal plume from Hinkley B nuclear power station is likely to be adversely affected by the lagoon wall near its southern end. Measures to rebuild the cooling water system would be required to prevent this effect. There is a risk that the effluent plume of the Weston Waste Water Treatment Works may be affected by the north end of the lagoon and move closer to the bathing beach. This risk requires further assessment but would potentially require measures to prevent this effect.

Over the long term, the evolution of the estuary is uncertain but modelling indicates that there would be modest accretion within the lagoon though relatively little outside. A particular issue is that muddy sediments are predicted to accumulate in areas of low velocity close to the southern landfall of the lagoon at Hinkley Point which could interfere with the cooling water system of the power station. Over the lifetime of the lagoon, foreshore erosion in the estuary outside is likely to require measures along around 40km of frontage to prevent undermining of the flood defences with the first measures required within 75 to 100 years.

Interrelationships

The Hydraulics and Geomorphology topic provides the key information that predicts how physical conditions in the Severn Estuary and Bristol Channel would change as a result of implementing any of the alternative options. The results of this topic provide essential input to the other topics of this theme; Marine water Quality, Flood Risk and Land Drainage and Freshwater Environment and Associated Interfaces.

The predictions from the Hydraulics and Geomorphology topic, along with those from the Marine Water Quality topic provide essential input to the Biodiversity theme. The other three themes also rely on outputs from the Hydraulics and Geomorphology topic and in some cases the outputs from the three other topics within the Physicochemical theme.

Uncertainties in the results of the Hydraulics and Geomorphology topic inevitably lead to uncertainties in the input information used by the other topics. In many cases, where for example water level or wave information is provided by the Hydraulics and Geomorphology topic, the uncertainty surrounding this information is relatively small and would not degrade the assessments that are made using this information. However, the prediction of future suspended solids concentrations, water quality and long term morphology evolution is subject to medium or high uncertainty which may affect the robustness of assessments carried out by other topics.

For work in the Flood Risk and Land Drainage topic, predictions were taken directly from the Hydraulics and Geomorphology topic. Although high uncertainty surrounds some predictions, the type of change that is expected is more certain than the likely magnitude of change and the rate of change. This has allowed this topic to express the effects of uncertain morphology predictions by uncertain timing of interventions.

The uncertainty in future morphology predictions is also an important contributor to uncertainty in the various topics that make up the Biodiversity theme and the scale of long term changes that are likely to affect the navigation and other sea bed uses topics within the Society and Economy theme.

Measures to as Fully as Possible Offset any Significant Adverse Effects

The implementation of any of the alternative options would cause changes to the estuary form and function that are features of the designation of the Severn Estuary / Môr Hafren European Site. There is no possibility of fully offsetting such changes.

Some of the alternative options would submerge the lowermost exposures of some coastal geological and geomorphological SSSIs. The Geological Conservation Review (GCR) may include other sites that have similar examples of the particular features that may be permanently submerged. In such cases there is a possibility that the geological information lost to research by submergence could be offset by designation of a similar outcrop elsewhere. Conversely, it is also possible that the particular geological and geomorphological features being submerged are unique. In this situation, no offsetting would be possible.

SEA Objective Compliance

The SEA Objectives were drafted and consulted upon as part of the Phase 1 SEA scoping stage. This theme paper identifies any interactions or inconsistencies between topics within this theme with regards to the assessment against SEA Objectives.

As identified during the scoping stage of SEA, SEA objectives were not set for the Hydraulics and Geomorphology topic. Effects on the hydraulics and geomorphology of the estuary have been outlined above.

For the Marine Water Quality topic, SEA objectives are complied with as measures to prevent or reduce adverse effects are proposed. The potential exception is the risk of increased eutrophication effects upstream of the B3 Brean Down to Lavernock Point Barrage. If this risk is realised, the objective ‘To avoid adverse effects on Marine Water Quality in relation to Marine Water Quality standards’ may not be met.

The proposed measures to prevent or reduce adverse effects would allow the SEA objectives for Flood Risk and Land Drainage and for Freshwater Environment and Associated Interfaces to be largely met. One exception is the loss by submergence of Geological and Geomorphological SSSIs, which would require offsetting measures. This particularly affects the B3 Brean Down to Lavernock Point Barrage, but affects to a more limited extent the B4 Shoots Barrage and the B5 Beachley Barrage. Another exception is the effect of the B3 Brean Down to Lavernock Point Barrage on raising groundwater levels in urban areas built on permeable gravels and sands which may damage underground assets of local importance.

Implementation

The theme paper concludes with suggestions on monitoring requirements and further studies required to assess tidal power schemes.

SECTION 1

INTRODUCTION

1 INTRODUCTION

1.1 Background

1.1.1 The Government announced a two-year feasibility study on harnessing the renewable energy from the tidal range in the Severn Estuary in January 2008. This work is being carried out by a cross-Government team led from the Department of Energy and Climate Change (DECC), including representatives of the Welsh Assembly Government (WAG) and the South West Regional Development Agency (SWRDA), taking external advice as necessary and engaging stakeholders and the wider public. The aim of the Severn Tidal Power (STP) Feasibility Study is to investigate whether Government could support a tidal power scheme in the Severn and, if so, on what terms.

1.1.2 Any project to generate power form the tidal range of the Severn Estuary will need to meet the following objectives:

- To generate electricity from the renewable tidal range resource of the Severn Estuary in ways that will have an acceptable overall impact our environment and economy both locally and nationally, will meet our statutory obligations and provide benefit to the UK; and

- To deliver a strategically significant supply of renewable electricity, which is affordable and represents value for money compared to other sources of supply 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.

1.1.3 The Feasibility Study has been split into two phases:

- Phase One: Examining the scope of work and analysis required to make an evidence-based decision on whether to support a tidal power project in the Severn and what potentially feasible schemes exist for converting this energy. Phase one ended with the publication of the consultation document in January 2009.

- Phase Two: Work on environmental, regional, economic, commercial, technical and regulatory issues to inform the study conclusions including whether any of the potential schemes are feasible. This is the current stage.

1.2 Purpose of the SEA

1.2.1 A Strategic Environmental Assessment (SEA) is being carried out in support of the Feasibility Study, in accordance with EU Directive 2001/42/EC (the SEA Directive), implemented in England and Wales through the Environmental Assessment of Plans and Programmes Regulations (SI 2004/1633 and Welsh SI 2004/1656), to predict and analyse the environmental effects of alternative short-listed Severn tidal power options over their entire lifetime, in order to inform decision making at the end of the Feasibility Study.

1.3 Purpose of the Theme Papers

1.3.1 The SEA Directive requires that 'the likely significant effects on the environment, including on issues such as biodiversity, population, human health, fauna, flora, soil, water, air, climatic factors, material assets, cultural heritage including architectural and archaeological heritage, landscape and the interrelationship between the above factors' are described (SEA Directive Annex 1 (f)).

1.3.2 The theme papers therefore summarise the interrelationships between related topics – see Table 1.1 below – and thereby ensure that the many complex issues that are not self-contained within a given topic are recognised and their implications understood. This approach emerged from the SEA scoping phase to allow related topics to interact and interface more effectively. Each theme paper also examines the interrelationships between this theme and other themes within the STP SEA.

Table 1.1 SEA themes and topics

SEA Theme	SEA Topics
Physicochemical	Hydraulics & Geomorphology Marine Water Quality Freshwater Environment & Associated Interfaces Flood Risk & Land Drainage
Biodiversity	Marine Ecology Waterbirds Migratory & Estuarine Fish Terrestrial & Freshwater Ecology
Landscape & Seascape and Historic Environment	Landscape & Seascape Historic Environment
Air & Climatic Factors and Resources & Waste	Air & Climatic Factors (including Carbon Footprint) Resources & Waste
Society & Economy	Communities Navigation Other Sea Uses Noise & Vibration

1.3.3 Furthermore, the theme papers will also assist the Environmental Report to meet the requirements of the SEA Directive by collating the difficulties (such as technical deficiencies or lack of know-how) encountered in compiling the required information (SEA Directive Annex 1 (h)).

1.3.4 Each theme paper therefore provides an integrated summary across the theme, drawing on information presented in its topic papers. Each theme paper presents a review of the environmental baseline and considers the environmental effects for the topics within this theme, taking into account the interrelationships between them and identifying difficulties in compiling the information and uncertainties in the assessment. However, no substantive analysis is undertaken within each theme papers that is not already contained within its topics.

1.3.5 Each theme paper also considers the likely significant effects on the environment of the variations of alternative options referred to as combination and multiple basin options.

SECTION 2

APPROACH

2 APPROACH

2.1 Overall approach adopted in the SEA

2.1.1 The assessment process involved the collection of information and the development of SEA objectives, definition of alternatives and identification of significant environmental effects. Measures to prevent, reduce and as fully as possible offset significant adverse effects on the environment were developed, and proposals reviewed in the light of identified significant environmental effects. A more detailed description of the purpose of each SEA task and the STP SEA approach is given in the Environmental Report (Severn Tidal Power 2010a).

2.2 SEA Objectives

2.2.1 SEA Objectives are a recognised tool for comparing alternative options. SEA Objectives, and associated assessment criteria and indicators were drafted and consulted upon as part of the Phase 1 SEA scoping stage. The Government response to the consultation for the most part confirmed the SEA Objectives and in some cases made some minor modifications (DECC, 2009b).

2.2.2 The SEA Objectives for this theme, as amended in response to the Scoping consultation, are set out in Table 2.1.

2.2.3 No objectives were set for the Hydraulics and Geomorphology topic. However, the results from the hydraulics and geomorphology studies are a major factor affecting achievement of the other SEA objectives.

Table 2.1 SEA Objectives for the Physicochemical theme

SEA Topic	SEA Objective
Hydraulics & Geomorphology	No objectives were set
Marine Water Quality	1. To avoid adverse effects on Marine Water Quality in relation to Marine Water Quality standards 2. To avoid adverse effects on designated marine wildlife sites of international and national importance due to changes in Marine Water Quality 3. To avoid adverse effects on Marine Water Quality which would affect human health, flora and fauna, recreation and other users 4. To avoid adverse effects on inherent water characteristics (temperature, salinity, pH) that could lead to adverse changes in Marine Water Quality 5. To minimise risk of pollution incidents
Freshwater Environment & Associated Interfaces	1. To avoid adverse effects on water quality (whether surface water, groundwater or coastal waters) in relation to water quality standards 2. To avoid adverse effects on water quality which would affect human health, flora and fauna, recreation and other users 3. To avoid adverse effects on water abstractions (whether surface water, groundwater or coastal waters) particularly

SEA Topic	SEA Objective
	those utilised for the Public Water Supply (PWS) 4. To avoid adverse effects to the water regime of designated water-dependent sites of nature conservation interest 5. To avoid adverse effects to buildings and infrastructure 6. To avoid adverse effects to the soil resource 7. To avoid adverse effects on agricultural land currently in use 8. To avoid adverse effects on geological and geomorphological sites of international and national importance 9. To conserve and enhance designated geological and geomorphological site features
Flood Risk & Land Drainage	To avoid an increase in flood risk to property, land and infrastructure where this might otherwise occur as a consequence of the construction and operation of any tidal power structure.

2.3 Alternative Options for Tidal Power

2.3.1 At the beginning of Phase 2, five alternatives for the development of tidal power using the tidal range of the Severn Estuary were identified as the preferred candidates for more detailed study. The five options comprise three tidal barrages and two tidal lagoons (Severn Tidal Power 2010b). These alternative options and key parameters associated with alternative options are set out in Table 2.2.

Table 2.2 Alternative options

Alternative	Location	Length (approx)	Operating mode	Turbine type	No. turbines	Annual energy output	Caissons	Locks
B3: Brean Down to Lavernock Point Barrage	Brean Down to Lavernock Point	16km	Ebb only	Bulb-Kapeller	216 (40MW)	15.1 to 17.0 TWh/year	129	2
B4: Shoots Barrage	West Pill to Severn Beach	7km	Ebb only	Bulb-Kapeller	30 (35MW)	2.7 to 2.9 TWh/year	46	1
B5: Beachley Barrage	Beachley to land directly to the east on the English side	2km	Ebb only	Straflo	50 (12.5MW)	1.4 to 1.6 TWh/year	31	1
L2: Welsh Grounds Lagoon	River Usk to Second Severn Crossing	28km	Ebb only	Bulb	40 (25MW)	2.6 to 2.8 TWh/year	32	1
L3d: Bridgwater Bay Lagoon	Brean Down to Hinckley Point	16km	Ebb & Flood	Bulb-Kaplan	144 (25MW)	5.6 to 6.6 TWh/year	42	1

2.3.2 Variations in the alternative options have also been considered. Whilst at this stage none of these constitute alternative options under the feasibility study, initial consideration has nonetheless been given to their potential effects. The variations considered included multiple basins and combinations of the five short-listed alternative options. Multiple basin variants are configured with the aim of providing continuous power to better align energy yield with peak demand.

2.3.3 Following an evaluation process (considering energy yield, costs, programme and opportunities for optimisation) one multiple basin and two combinations of options were identified for further high level review. This does not constitute the same level of detail as assessment of the short listed alternatives, but if any of the variations are found to have advantages over the alternatives, then further work would be required.

2.3.4 The multiple basin option variant identified for high-level consideration of environmental effects is a double basin version of the L3d Bridgwater Bay lagoon (with pumping). The double basin concept splits the L3d lagoon into a high basin and a low basin using a rockfill dividing wall with its landfall at Berrow. The variant is then configured to provide a continuous cycle of water from the sea to the high basin, from the high basin to the low basin and then from the low basin to the sea. This variant employs two powerhouses, one between the high and low basins and a second between the low basin and the sea. Each basin would experience a tidal range, but the high basin water levels would always be kept above the low basin. Pumping is used to raise water levels in the high basin and lower them in the low basin to increase power output. The option variant would utilise single direction turbines (in contrast to the ebb/flood generation of the standard L3d alternative option).

2.3.5 Both of the potential combinations of options include the standard single basin L3d option, with the assumption that it would be generating in an ebb/flood configuration. A combination of L3d (ebb/flood) with B3 Brean Down to Lavernock Point barrage (ebb only) has been shown to be worthy of further consideration; as has a combination of L3d (ebb/flood) with B4 Shoots barrage (ebb only).

2.3.6 L3d and B3 would be constructed sequentially due to the large amount of resources required to build either of these alternative options. Either option could be constructed first. L3d and B4 could be constructed either sequentially or concurrently. The operating rules and forms of construction for the combined options are assumed for the purpose of this high-level review to be the same as those for the individual alternative option.

2.4 Technical studies within the theme

Sources of information

2.4.1 The technical studies within the physicochemical theme included collection and collation of the considerable volume of information available within each topic covered by the theme. Much of this information was held by the authorities responsible for Navigation, Environmental Management, Flood Risk Management, Surface Water Management and Sewage Disposal. These Authorities willingly provided their information for use in this Assessment. An extensive private archive of information held by Dr Robert Kirby which includes data originally obtained by IOS (Institute of Oceanographic Sciences) was accessed.

2.4.2 The extensive surveys commissioned during the earlier studies for generation of tidal energy from the Severn Estuary, which reported through EP46 (Energy Paper 46, 1981) and EP57 (Energy Paper 57, 1989), were also utilised. A key data set collected to support EP46 was the measurements of tidal currents, salinities and suspended sediment over complete spring and neap tides at 15 sites in the Severn Estuary and Bristol Channel in 1980 (HRS 1981a). This data set provided key information for the Physicochemical Theme on tidal currents and salinity, and important additional information on suspended sediment concentrations. The sites where these data were collected are shown on Figure 2.1.

2.4.3 The Hydraulics and Geomorphology topic (Severn Tidal Power 2010c) and Marine Water Quality topic (Severn Tidal Power 2010d) depended heavily on these sources of information, with the Marine Water Quality topic additionally relying on water quality data gathered by the Environment Agency to support the review of consents affecting the Severn Estuary / Môr Hafren European Site (Environment Agency 2009d).

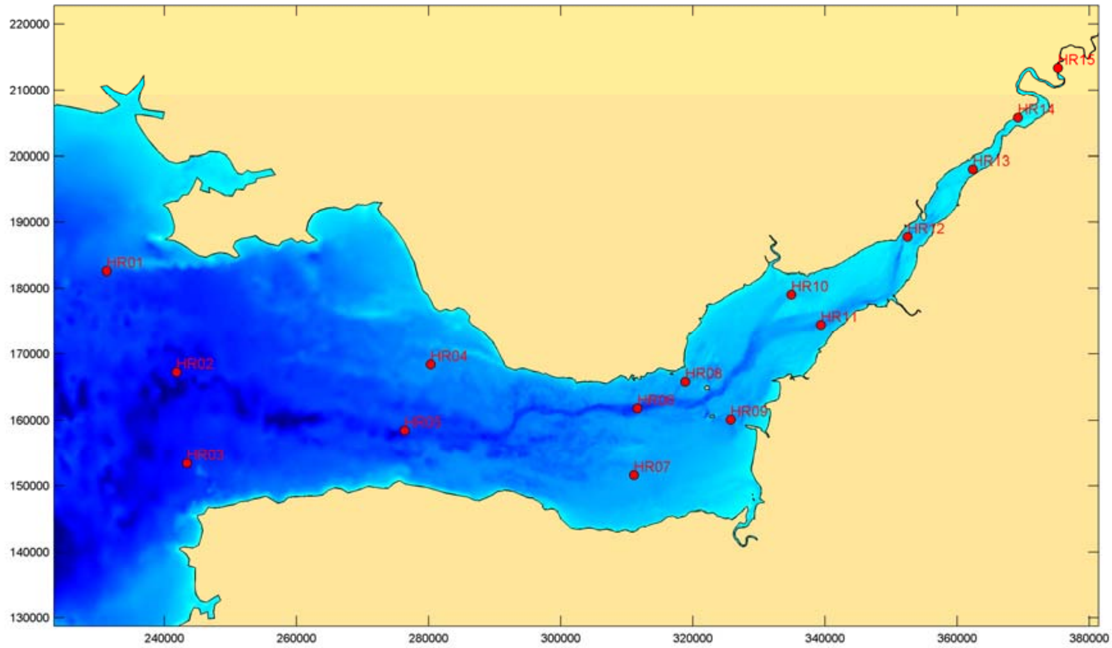


Figure 2.1 **Observations of currents, salinity and suspended sediment in 1980 (HR Wallingford)**

2.4.4 The Flood Risk and Land Drainage topic (Severn Tidal Power 2010e) were granted access to databases and detailed information on flood defence assets, land levels, properties at risk and details of drainage outfall structures. This SEA was carried out concurrently with the review of the Shoreline Management Plan (SMP) for the Severn Estuary and the development of the Severn Estuary Flood Risk Management Strategy (SEFRMS). Emerging findings have been made available by the Environment Agency and these provide useful background to assess the baseline.

2.4.5 The Freshwater Environment and Associated Interfaces topic (Severn Tidal Power 2010f) used a desk-based review of readily available mapping and other data in the public domain supplemented and clarified where necessary by consultation with key stakeholders.

2.4.6 The scoping assessment concluded that despite the considerable volume of information available there were also important information gaps, particularly of contemporary data on tidal levels and currents, suspended sediments, physical details of land drainage outfalls and properties at risk of fluvial flooding due to impeded drainage to the estuary. Much of the available data was linked to the Cardiff Weston (B3) barrage proposals and there was less information available to support some of the other alternative options. However, the conclusion was reached that sufficient existing information was available to support a robust strategic assessment of all alternative options. Suggestions for collecting further information are included in section 7.2.

Overview of models employed

2.4.7 The available data was processed in a variety of ways both to determine baseline conditions and assess the effects of the alternative options. The majority of analyses included development of numerical models to represent baseline conditions and then the application of these models to each of the alternative options. The key models employed represented:

- Tidal water levels and water flow (H&G Annexes 7, 8, 9),
- Waves in the estuary (H&G Annexes 10, 11),
- Suspended sediments and short term deposition of mud (H&G Annex 12),
- Sand transport (H&G Annex 14),
- Intertidal profile evolution (H&G Annex 15),
- Long term geomorphological evolution of the estuary (H&G Annex 16),
- Water salinity (MWQ Annex 2),
- Dilution and dispersal of thermal plumes (MWQ Annex 4),
- Dilution and dispersion of treated sewage effluent (MWQ Annex 8),
- Salinity stratification (MWQ Annex 5), and
- Details of the assessment of increased flood risks due to restriction of land drainage (Severn Tidal Power 2010e Appendix D)

2.4.8 Details of the development, calibration and application of each of these models are contained in the Annexes to the Hydraulics & Geomorphology, Marine Water Quality and Flood Risk & Land Drainage topic papers.

2.4.9 Within the Hydraulics & Geomorphology topic, two models of tidal water levels and flows and two models of wave propagation were developed. The short timescale of the phase 2 SEA studies required the development of the two flow and two wave 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.

2.4.10 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 results from this model were also provided to the Biodiversity and Society and Economy Themes for the use of each of the topics within these other themes.

2.4.11 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. This second model was extended into the tidal reaches of three main tributaries; the River Usk, the River Parrett and the River Avon where salinity and water quality issues were of particular importance. Both models included the tidal reaches of the River Severn between Sharpness and Gloucester.

2.4.12 The wave model developed by ABPmer was primarily intended to provide the wave conditions required for assessment of the Marine Ecology topic in the Biodiversity theme as well as providing the wave conditions required for assessment of tidal flood risk in the Flood Risk and Land Drainage topic of this theme. This model also predicted how wave reflection from the face of the structures of each alternative option might modify the wave climate. This model included the Bristol Channel and Severn Estuary from Lundy Island to the onset of the meanders in the tidal river at Hock Cliff.

2.4.13 The second wave model developed independently by HR Wallingford was primarily intended to characterise the typical wave conditions that determine the processes of sediment transport and intertidal profile evolution within the Severn estuary. This model had a downstream boundary near Lundy Island, but excluded the section of estuary upstream of the River Wye confluence.

The contemporary bathymetry

2.4.14 All the estuary modelling of tides, waves and sediment movement used the same contemporary estuary bathymetry of the Severn Estuary and Bristol Channel. This bathymetry was derived by merging together the most recent survey information and using this bathymetry as input information to all the numerical modelling. The estuary is dynamic and in some areas bathymetry can change on a weekly basis. Because of the time period over which the data were surveyed, the bathymetry does not represent conditions throughout the estuary in a particular month or year but rather provides a typical bathymetry representative as far as possible of contemporary bathymetry. This bathymetry has been supplied to all the other topics and themes for topic specific use.

2.4.15 The methods adopted to splice together the individual datasets are described in the Development of Estuary Bathymetry Report (Severn Tidal Power 2009c). The contemporary bathymetry combined

- Digital versions of estuary navigation charts supplied by DECC, based on SeaZone information,
- Recent intertidal mapping obtained from the Environment Agency LiDAR monitoring of intertidal areas throughout the Severn Estuary and Bristol Channel,
- A survey by the Gloucester Harbour Trustees (GHT) of the bathymetry from Avonmouth to Hock Cliff,

- Survey by the Channel Coastal Observatory (CCO) of the subtidal near shore bathymetry of the English coastline,

- River Severn cross sections surveyed in the late 1970s by Severn Trent Water Authority were used between Hock Cliff and Gloucester as more recent survey information could not be identified.

2.4.16 The density of the raw bathymetry is very variable, being sparse in deep areas away from the Severn Estuary but provided on a 25m grid by SeaZone, for the Severn Estuary and Bristol Channel although the raw soundings are sometimes sparser than this. LiDAR data were provided on a 2m grid by the Environment Agency. The contemporary bathymetry was provided for use on a uniform 25m grid throughout the area shown on Figure 2.2. The various numerical models accessed this bathymetry at each model node at a variable spacing between 12km and 50m, with the greatest density of nodes in the areas of greatest interest.

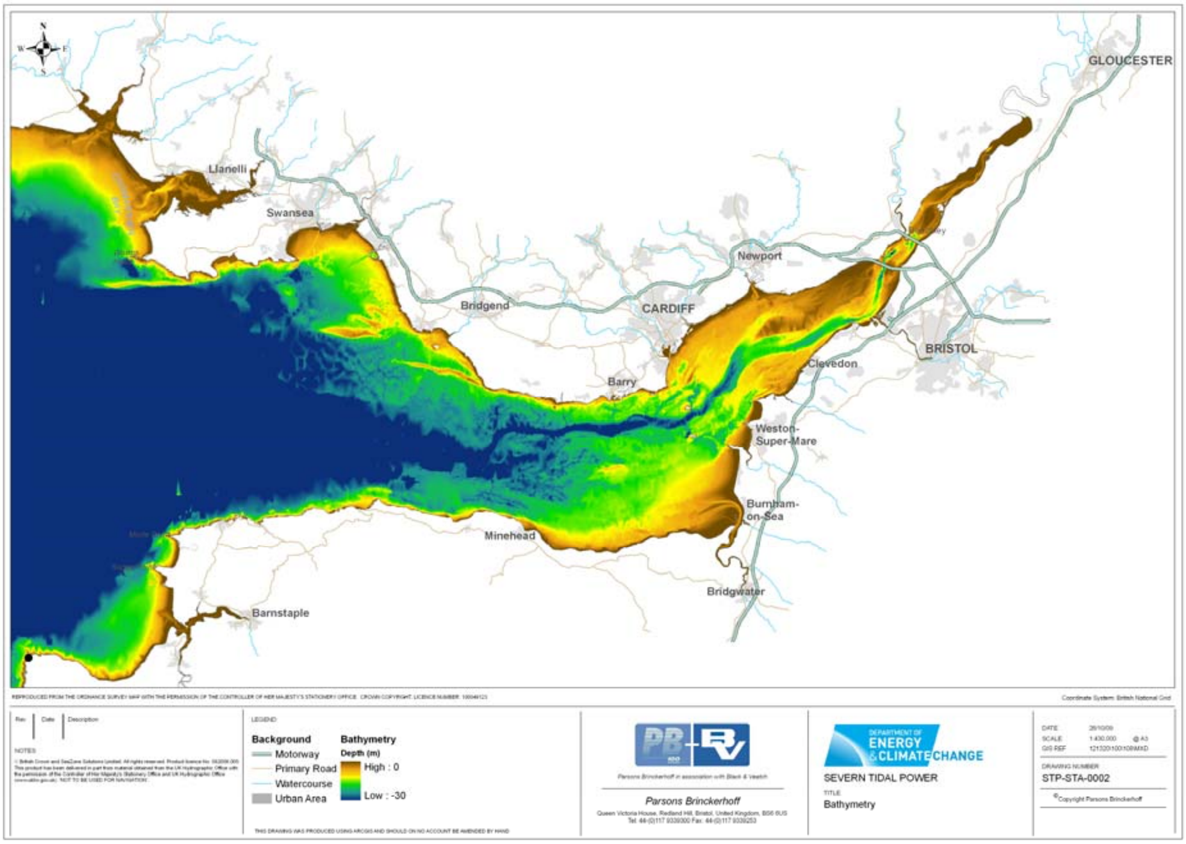


Figure 2.2 **Severn Estuary and Bristol Channel contemporary bathymetry**

2.4.17 The domain of the flow models extended over a much larger sea area than that covered by the contemporary bathymetry. In United Kingdom Waters to the west of the area covered by the contemporary bathymetry, SeaZone digital information used to compile navigation charts was used. In International Waters GEBCO (General Bathymetric Chart of the Oceans) data were used.

2.4.18 The model domain used by the two 2D models extended into the sea areas around the Bristol Channel including the west coast of Wales, the east coast of Ireland and the north western tip of France. The bathymetry used over this extended area is shown in Figure 2.3.

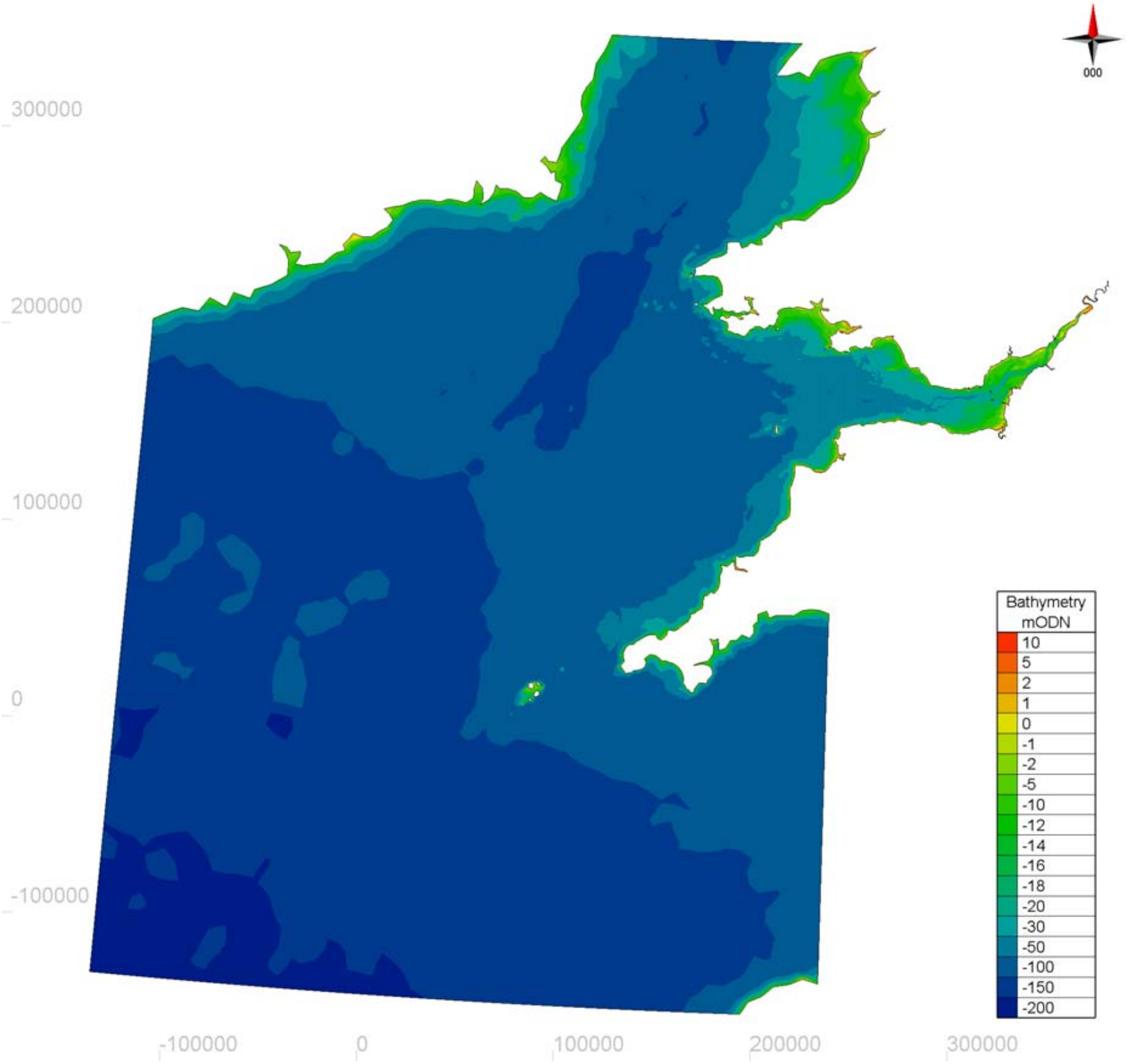


Figure 2.3 **Model domain and bathymetry used for water level and flow modelling**

2.4.19 The mesh for the 2D models was coarse in areas remote from the study area and became more detailed in the inner Bristol Channel and Severn Estuary as shown on Figure 2.4 for the HR Wallingford model. The ABPmer model mesh is similar to the HR Wallingford model mesh. However, the two model meshes differ in detail as the ABPmer model was primarily set up to model wave propagation where changes in slope of the near shore sea bed are of greater importance than for flow and water level modelling.

2.4.20 The tributary models of the River Usk, River Parrett and River Avon were derived from models developed on behalf of the Environment Agency and utilised the interpretation of the original bathymetric data embedded within these models.

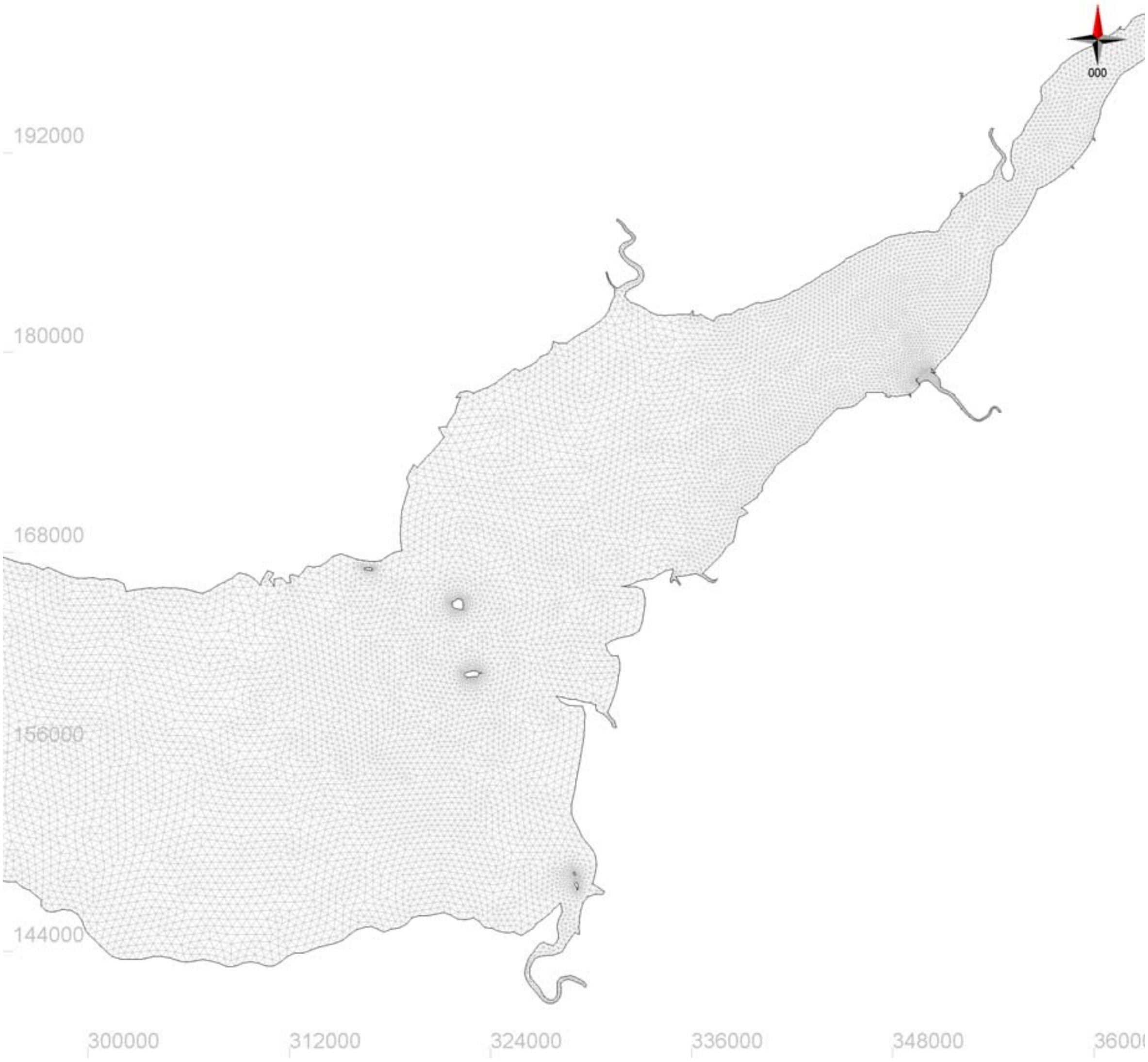


Figure 2.4 **HR Wallingford water level and flow model mesh in the main study area**

2.4.21 In the tidal floodplain of the Severn Estuary, and in areas where the tidal models predicted an increase in water levels, LiDAR data were also used to establish ground levels. This use of LiDAR data both on the estuary intertidal areas and on the adjacent tidal floodplain ensured ground levels in both areas were consistent.

Measurements of tides, currents, waves and suspended sediments

2.4.22 The most extensive and comprehensive measurements of tide levels and water velocities date from 1980. The most extensive measurements of suspended sediment concentrations were obtained in the 1970s and 1980s. Some continuous measurements of tide levels continue and there have been more recent measurements of suspended sediment concentrations including helicopter surveys of surface water quality at high water by the Environment Agency and their predecessors. These measurements have been used to calibrate and validate the numerical models used for the hydraulics and geomorphology studies. The models calibrated using the tidal conditions observed in 1980 have been applied without modification to represent the current baseline.

2.4.23 Some wave data were also obtained in 1980, though since 2007, wave data are available on-line from a buoy at Scarweather in Swansea Bay and since 2008 from a buoy off Hinkley through the WaveNet website (Wavenet website 2009). Since mid-2007 CCO have also started collection of wave data from the English shore of the Bristol Channel and Severn Estuary, though none of these data were used in this study as the times when they were available did not match the times when the WaveNet data were available.

2.4.24 A particular data gap is the absence of recent wave data from the Severn Estuary area. Wave data were collected from the Severn Estuary from 1978-81 (HRS 1981b), using surface mounted instruments. However, because the raw data could not be stored digitally at the time, it is difficult to incorporate this information into assessments using the current generation of wave models. Data from 1980 also predate the availability of offshore wave data from the Met Office wave models used for weather forecasting.

Assessment of effects of climate change

2.4.25 In the context of the Severn Estuary Tidal Power SEA study, the effects of climate change are considered as a secondary perturbation to the existing system compared with the effects of any of the alternative options. For this reason climate change effects have been examined as a sensitivity test which examines the sensitivity of the response of the estuary to one of the alternative options compared with its response without climate change. For this purpose the B3 option, which has the largest effects by far, is the only one where sensitivity to climate change has been considered.

2.4.26 The baseline, or the current state of the environment, has been considered in the same way. The majority of assessments assume existing processes will continue. In addition a sensitivity test considering how these processes might change in the presence of climate change has been carried out and compared with how the B3 option responds to climate change.

2.4.27 The majority of assessments assume climate change follows the medium emissions median outcome scenario set out in UKCP09 (Defra 2009). However in the Flood Risk and Land Drainage topic the assumptions on sea level rise, storminess and river flows included in the Planning Guidance (WAG 2004 and DCLG 2006) were used to ensure compatibility with the Severn Estuary SMP, CHaMP and SEFRMS. The project specific climate change scenarios (Severn Tidal Power 2009e) set out and compare these different scenarios.

2.4.28 In considering the likely evolution of the physicochemical aspects of the environment, sea level rise is the most important aspect of climate change. Additionally for Marine Water Quality temperature change is an important issue. For the Flood Risk and Land Drainage and for the Freshwater Environment and Associated Interfaces topics changes in river flows are also important. The Flood Risk and Land Drainage topic is also concerned with changes in storminess.

2.4.29 The approach adopted in the Hydraulics and Geomorphology and Marine Water Quality topics has been to carry out sensitivity tests to understand how sensitive the effects of the B3 Brean Down to Lavernock Point Barrage are to climate change. If the changes due to climate change are of a much lesser magnitude than those due to the option in the absence of climate change, then the assumption is made that climate change effects are secondary in relation to option effects and may be within the uncertainty of prediction of the scheme effects. In these circumstances there is little to be gained by testing other options to assess their sensitivity to climate change. This approach underpins the effects of sea level rise, temperature rise and changed storminess.

2.4.30 The following assessments have been carried out that include climate change scenarios:

- Effect of a 1.66m rise in sea level on tidal propagation through the UK Continental shelf with a dam in the Inner Bristol Channel (H&G Annex 7),
- Effect of a 1m rise in sea levels on Severn Estuary water levels and energy output with the B3 option (H&G Annex 8),
- Effect of sea level rise of 0.59m derived from UKCP09 (Defra 2009) medium emissions median outcome scenario on wave heights associated with a range of one year return period events (H&G Annex 10),
- Sea levels raised by 0.59m at the time of a surge of around a 1 in 100 year return period to calculate wave heights with around a 1 in 5 year return period (H&G Annex 9 and 10),
- Effect of 2mm/year sea level rise for 120 years on Baseline and effect of UKCP09 (Defra 2009) medium emissions median outcome scenario sea level rise of 3.5mm/year increasing to 5.6mm/year over 120 years on intertidal profiles for Baseline and B3 option (H&G Annex 15),
- Effect of 2mm/year sea level rise for 120 years was included in all long term estuary evolution tests. The effect of the UKCP09 (Defra 2009) medium emissions median outcome scenario sea level rise on long term estuary evolution was also considered for the Baseline and B3 option (H&G Annex 16),
- For the Marine Water Quality studies no specific climate change allowances have been included, though the anticipated changes in temperature have been discussed.
- The Flood Risk and Land Drainage Studies (Severn Tidal Power 2010e) added 0.7m to the water levels predicted by the Hydraulics and Geomorphology topic (H&G Annex 9) to take account of the difference between UKCP09 (Defra 2009) and earlier estimates of sea level rise in Planning Guidance (WAG 2004 and DCLG 2006). No changes were made to the predicted wave heights (H&G Annex 10) calculated assuming 0.59m of sea level rise.
- Qualitative assessments of the effect of climate change on river flows were included within the Freshwater Environment and Associated Interfaces topic (Severn Tidal Power 2010f).

Division of the study area into zones

2.4.31 The study area has been divided into five zones as shown on Figure 2.6. These zones are mainly used to describe broad scale features of the estuary and of the effects of the alternative short listed options.

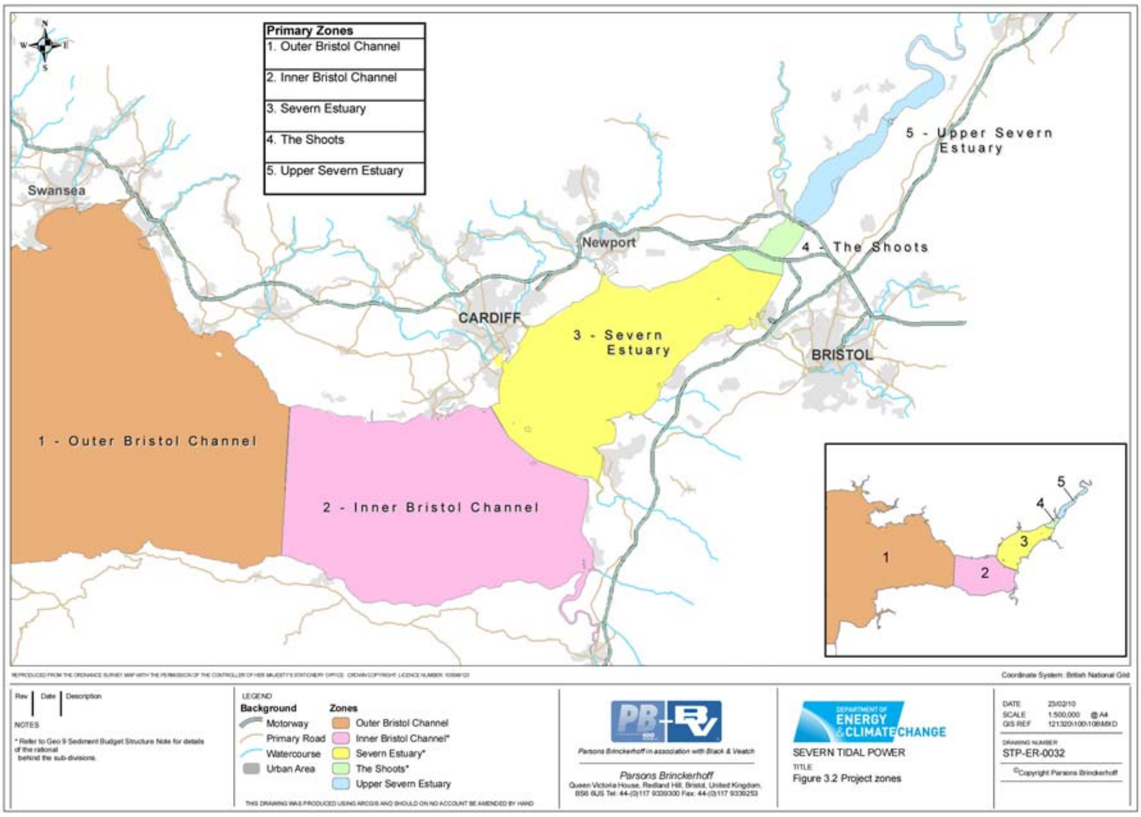


Figure 2.5 Estuary zones within the study area

Difficulties encountered – bathymetry

2.4.32 In a dynamic estuary, there are inevitably inconsistencies between surveys carried out at different times. In developing the contemporary bathymetry shown in Figure 2.2, these differences have been resolved as far as possible by giving priority to LiDAR surveys and the recent surveys by GHT and CCO over the SeaZone data, which is generally at a coarser resolution and has a lower accuracy specification (Severn Tidal Power 2009c).

2.4.33 In some areas it was noticeable that there was not a particularly good match between SeaZone bathymetry derived from navigation charts and LiDAR data obtained at low tide across the intertidal. There are a variety of potential reasons for this including the different survey datum used in the two surveys: Chart Datum for SeaZone and Ordnance Datum for LiDAR. The differences cause 'steps' in the bathymetry at an elevation that is important for nature conservation and wave propagation. Insertion of the CCO data, which broadly agreed with the LiDAR, was beneficial as it allowed the transition between data sets which concentrate on near shore conditions and navigation data to be moved well below spring low water level to an area of less concern for nature conservation and wave propagation. Expansion of the CCO data set to cover the remainder of the coastline, principally within Wales, would help improve the link between near coast and navigation datasets.

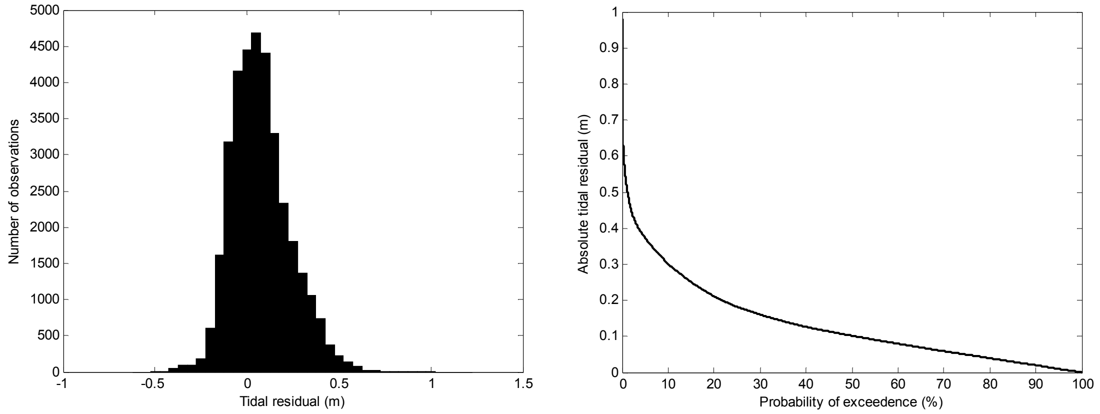
2.4.34 There is a lack of recent survey data from the upper part of the Severn Estuary above Hock Cliff, primarily because this section of estuary is not used for navigation. Surveying of this section of estuary is difficult because of the fast currents and the short high water period. Bed levels change frequently in this section in response to changes in tidal and fluvial conditions.

2.4.35 The project team were unable to identify any surveys of the estuary of the River Wye. If a feasibility study is undertaken in the future of any Severn Tidal Power Scheme that is anticipated to affect conditions in the River Wye estuary, adequate bathymetric and hydrographic survey of this estuary would probably be essential.

Difficulties encountered – water level and flow measurements

2.4.36 The use of hydrographic surveys generally dating from 1980 did not cause particular problems in model calibration when used with the contemporary bathymetry, apart from two features. Low tide levels in the upper Severn Estuary north of The Shoots and especially north of Sharpness were noticeably less well reproduced than elsewhere, as in this part of the estuary low tide levels are particularly sensitive to bathymetry. These difficulties are not surprising as the survey of this part of the estuary was carried out in 2000; 20 years after the water levels were measured. The water velocities measured in 1980 were generally well represented in the model using current bathymetry with the exception of those measured over Cardiff Grounds, a sandbank that has changed notably in the intervening 30 years.

2.4.37 The minimum change in water level that can be reliably measured was considered (H&G Annex 7 Appendix D). Observed water levels at Milford Haven were found to differ from those predicted by more than ±0.1m for about 50% of the time during 2007 as shown in Figure 2.6. The Severn Tidal Power SEA has therefore adopted a threshold for measureable effects on water levels of ±0.1m.



a) Histogram of level differences **b) Exceedance probability plot**

Figure 2.6 Observed and predicted tide levels at Milford Haven in 2007

Difficulties encountered – suspended sediment measurements

2.4.38 The suspended sediment data set collected by IOS in the 1970s remains a key dataset for understanding the three dimensional spatial and temporal variability in suspended sediment concentrations. Collecting this dataset required very considerable investment as it required repeat visits to many sites over a long period using a seagoing vessel. This dataset is critical for the mud modelling discussed below.

2.4.39 This IOS dataset has variable coverage within the Severn Estuary, with fewer surveys in intertidal areas which could not be reached in safety by seagoing vessels. There are also no surveys north of The Shoots where suspended sediment concentrations are known from other datasets to reach their maximum. The need for repeat surveys to cover a range of tidal conditions leads to the tidal and seasonal conditions surveyed at each site being slightly different.

2.4.40 The IOS dataset still provides the best three dimensional descriptions of how suspended sediment concentrations vary around the estuary, how they vary with depth throughout each tide and how they change during the two week neap-spring-neap tidal sequence. Other datasets indicate that in addition river flow, wind and waves can have an important effect on the suspended sediment concentration in some circumstances and in particular areas, though the understanding of these effects is less well developed. The available data were examined and analysed as part of the Hydraulics and Geomorphology topic (H&G Annex 5).

Difficulties encountered – inclusion of a tidal power scheme in numerical models

2.4.41 Baseline models of water levels and flows within the Severn Estuary and Bristol Channel provided few difficulties, and the use of the contemporary bathymetry aided their calibration. The two models closely agreed as discussed in section 3.3.

2.4.42 There were more difficulties with representation of the alternative options in the numerical models. The inclusion of equations to represent the operation of the tidal power scheme requires modifications to the core numerical solution algorithms that represent flows between model cells that are separated by sluices or turbines.

2.4.43 The hydraulic equations used to represent turbines and sluices were developed (Keiller and Thompson 1981) for a one dimensional (1D) model and were utilised in the 1D model developed for energy optimisation (Severn Tidal Power 2009d). These equations represent the conservation of energy on entry and the conservation of momentum on exit from the turbines or sluices. The equations for sluice and turbine discharge assume there is no entrainment of water into the discharge jet because the many neighbouring jets prevent entrainment from the side and there is insufficient space above or below each jet to allow entrainment. The reduction in jet velocity to ambient velocity is balanced by a small rise in local water level that conserves jet momentum but loses a proportion of the kinetic energy that leaves the turbine or sluices.

2.4.44 The same equations were considered to be applicable in the two dimensional (2D) flow models developed by HR Wallingford (H&G Annex 8) and ABPmer (H&G Annex 9) developed for the Hydraulics and Geomorphology topic, provided appropriate modifications were made to account for the two dimensional nature of the models.

2.4.45 These equations could be included into the HR Wallingford model as their model used the TELEMAC system they have developed in collaboration with French and German institutes. With access to the source code they could make appropriate modifications to the numerical algorithms. Since the beginning of 2010 the TELEMAC software is available as Freeware (Telemac 2010), allowing any user to make modifications to meet their requirements.

2.4.46 ABPmer used for their numerical model the MIKE system developed by the Danish Hydraulic Institute. This is proprietary software and users do not have access to the source code. The ABPmer approach was to develop look up tables that quantified the flow through the turbines and sluices for particular conditions of water level either side of the power station.

2.4.47 Comparison of the performance of the two 2D models (Severn Tidal Power 2010g) in Table 2.3 shows that for the Baseline the two models predict similar high and low tide levels throughout the Severn Estuary. Changes in water levels, currents and energy generation can be modelled with reasonably high levels of certainty although these predictions are associated with a set of barrage operating rules. Uncertainty in these rules or how the barrage might be operated in the future would lead to changed predictions of hydrodynamic parameters (H&G Annex 1 and 8).

2.4.48 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 (Severn Tidal Power 2010g and H&G Annex 8). For most circumstances, the agreement between models shown on Table 2.3 indicates that either model may be used to predict water levels.

Table 2.3 Comparison of the results from the two 2D models

	High Water conditions (m)		Low Water conditions (m)	
	Average water level difference	Range of standard deviation	Average water level difference	Range of standard deviation
Baseline **Burnham, Cardiff, Avonmouth** **Sharpness**	0.02 – 0.05 -0.26	0.02 – 0.04 0.24	-0.04 – 0.18 0.49	0.06 – 0.28 0.02
B3-Orig **Burnham, Cardiff, Avonmouth** **Sharpness**	0.14 – 0.15 0.02	0.05 – 0.07 0.10	0.03 – 0.11 0.31	0.10 – 0.20 0.08
B4-V3A **Burnham, Cardiff, Avonmouth** **Sharpness**	0.03 – 0.11 0.53	0.03 – 0.05 0.15	0.05 – 0.18 0.12	0.08 – 0.29 0.16
B5-V7 **Burnham, Cardiff, Avonmouth** **Sharpness**	0.04 – 0.06 0.50	0.03 – 0.04 0.13	0.06 – 0.19 -0.02	0.11 – 0.29 0.20
L2-V8D Burnham, Cardiff, Newport, Avonmouth **Sharpness**	-0.05 – 0.15 -0.24	0.03 – 0.07 0.20	-0.06 – 0.42 0.44	0.04 – 0.27 0.02
L3d-V9 **Burnham, Cardiff, Avonmouth** **Sharpness**	0.02 – 0.07 -0.16	0.06 – 0.11 0.29	-0.02 – 0.04 0.49	0.11 – 0.14[+] 0.03

Note Comparisons based on 22 tides

[+] Excludes 2 outliers at Burnham when ABPmer model turbines did not work correctly

2.4.49 The difference between the two models in the prediction of high water levels at Sharpness for the B4 Shoot Barrage and B5 Beachley Barrage is particularly evident with the HR Wallingford model predicting levels that are 0.5m higher than the ABPmer model. The cause of this difference is because the effectiveness of the sluices in the ABPmer model is noticeably poorer than in the HR Wallingford model or the 1D energy optimisation model (Severn Tidal Power 2010g). The energy optimisation studies indicated that this reduced sluice performance has a relatively small effect on energy output, but a more marked effect on water levels upstream of the B4 Shoots Barrage and the B5 Beachley Barrage.

2.4.50 In contrast, at low tide, the differences between the two models at Sharpness are much reduced especially for the barrage options that impound water at this site. This is probably because the raised low water levels behind the barrages reduce the dependence of Baseline low water levels in the upper estuary on shallow flows over the raised bathymetry.

2.4.51 The outcome of the comparison of results from the two 2D models has been that:

1) Energy outputs derived from the two models have been used as the basis for setting the range of energy outputs quoted for each alternative option. This is done because differences between models cannot be fully explained and there remains residual uncertainty about the mathematical representation of sluices and turbines in a tidal power scheme, and

2) Water levels predicted by the HR Wallingford model take precedence over those calculated by the ABPmer model, though in practice the results of either model may be used except for predicting high water levels upstream of the B4 Shoots Barrage or the B5 Beachley Barrage.

Difficulties encountered – Calculation of intertidal areas

2.4.52 The assessment of intertidal area within the Severn estuary is a cause of uncertainty as there is no reliable method of carrying out the calculation. All calculations have been carried out using the same GIS method to calculate intertidal area and all methods use the same contemporary bathymetry (Severn Tidal Power 2009c) for the Severn Estuary and Bristol Channel provided as spot heights on a 25m grid through out the study area.

2.4.53 The modelling teams used this bathymetry dataset to calculate bed levels within the flow models using triangular cells. The cell dimensions varied throughout the model, but in the study area were typically between 200 and 500m.

2.4.54 The models calculated water levels corresponding to HAT and LAT tide levels throughout the estuary. The position of HAT is generally determined by the presence of flood defences or cliffs and the model grids followed this shape closely. The position of the low water mark is determined by the model's bathymetry and its calculation of low water level. The two flow models predict similar values for low water level as indicated in Table 2.3. Inevitably, the spatial accuracy of the low water mark in the flow models is linked to the size of the model cells. If levels within individual cells are interpolated to find the position of the low water mark, the intertidal area within the study area between HAT and LAT was 27,340 ha in the HR Wallingford model and 26,290 ha in the ABPmer model.

2.4.55 For the Marine Ecology assessment (Severn Tidal Power 2010h), the calculated water levels were applied to the original 25m bathymetry grid to retain the features that were present in that grid, but at too small a scale to be captured in the flow model cells. The model low water levels were applied to the original 25m grid bathymetry, to determine the position of the low water line. When the intertidal area was calculated using the ABPmer water levels, the area between HAT and LAT increased to 30,980 ha, an increase of 18% on the area calculated using the ABPmer model and of 13% on the HR Wallingford model calculation.

2.4.56 Within the Hydraulics and Geomorphology topic paper (Severn Tidal Power 2010c), calculation of changes in intertidal area is required for the morphology receptor. This has been based on the area defined from the HR Wallingford hydrodynamic model. For the Marine Ecology topic paper (Severn Tidal Power 2010h) with its requirement for a more detailed representation of seabed features, the area has been calculated from the more detailed 25m bathymetric grid. Thus areas calculated in the Marine Ecology topic are around 13% larger than those calculated within the Hydraulics and Geomorphology topic. The different values are compared in the baseline environment section.

2.4.57 Although there is uncertainty about the correct intertidal area of the estuary, comparison of the predictions provided using the two methods of calculating area showed agreement within 2% on the percentage reduction in intertidal area associated with each of the shortlisted options. In this theme paper the percentage reductions calculated by the Hydraulics and Geomorphology topic paper (Severn Tidal Power 2010c) and the Marine Ecology habitat modelling annex (Severn Tidal Power 2010h) are both reported.

Difficulties encountered – modelling of suspended sediment concentrations

2.4.58 The behaviour of suspended sediments in the Severn Estuary is an extremely complex three dimensional phenomenon. The concentration of suspended sediments varies spatially throughout the estuary and with depth at each location. The concentration varies vertically during the 12.5 hour period of each tidal cycle and changes dramatically each week as tides modulate between the larger range spring tides and the smaller range neap tides.

2.4.59 During spring tides, much of the sediment is held in suspension. As tides decrease from springs to neaps, the suspended sediment settles to form a layer of extremely high sediment concentration near the bed often referred to as fluid mud. As the tidal range increases again from neaps to springs, peak velocities during each tide cycle increase and this layer of fluid mud is entrained back into the water column.

2.4.60 The approach for the SEA has been to model the dominant processes as simply as possible (H&G Annex 12). The modelling methodology aimed to represent the key behaviour of the system such as the rapid exchange of suspended sediments with near bed high concentration layers and fluid mud. However, the nature of the overall modelling strategy resulted in two important limitations for the mud model.

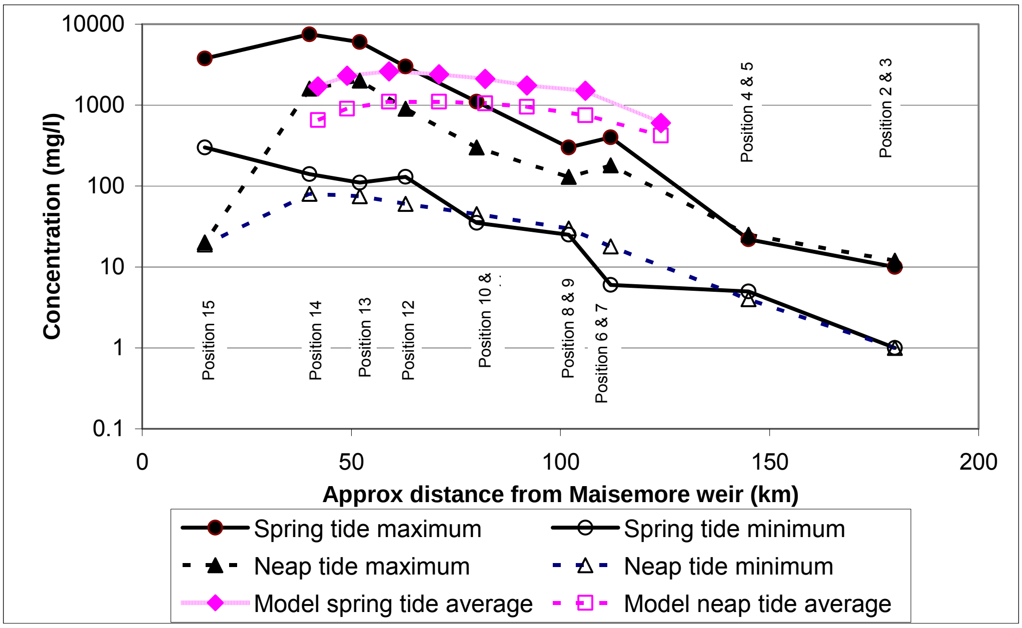
- The use of a 2D flow model to drive the mud transport did not include important 3D forcing factors which affect the distribution of suspended sediments.
- The use of a vertically averaged suspended sediment model did not take account of vertical variations in suspended sediment concentrations. As a result this type of model tends to disperse sediments further than in reality.
- These limitations were addressed by the use of a two-layered bed model.

2.4.61 The model calibration tended to show greater dispersal of sediment than observed in nature, but key erosion and deposition behaviour was reasonably reproduced temporally and spatially. The model was therefore used to predict post scheme sediment concentrations and identify where current suspended sediments might settle permanently.

2.4.62 The uncertainties in modelling should not affect the broad predictions of *where* sediments may settle, but the *amounts* are more uncertain, especially for smaller options because the process may continue for longer than the model run time of two weeks. Correspondingly, moderate uncertainty also resides in the predicted future concentrations of suspended sediments,

2.4.63 In the drive to understand the dominant processes, the mud modelling was simplified to exclude erosion of any existing deposits of settled material. This is not important in most areas where the alternative options only lead to reductions in current speeds over erodible sediments. However, for some alternative options there are increases in predicted current speeds over areas of mobile sediment. The erosion of material this would lead to has not been included in this or other modelling.

2.4.64 The results of the suspended sediment modelling have been compared against measured values (H&G Annex 1 and 12). The model predicts higher concentrations of suspended sediments than observed but this is largely because the model concentrations are depth average concentrations, whilst the measured concentrations relate to near surface values. This is illustrated on Figure 2.7, which compares the range of surface suspended sediment concentrations observed in 1980 (HRS 1981a) with the depth averaged model predictions. In the estuary more than 60km seaward of Maisemore weir in Gloucester close to Position 12 (Figure 2.1) the model predicts higher concentrations than observed. Between 40 and 60km from Maisemore weir the model predictions are within the range observed.



Note: Maximum and Minimum values from HRS 1981a. Values reported in H&G Annex 1 Figure 6.11 are within this range. Model average values from H&G Annex 12 Figures 41 & 42

Figure 2.7 **Comparison of observed (1980) and modelled suspended sediment concentrations**

2.4.65 The period that the mud model is able to simulate is limited to one or two spring neap tide cycles because the vertical variations in suspended sediment concentration and velocity which cannot be included in a depth averaged model begin to have an increasing influence on the results.

Difficulties encountered – long term changes in suspended sediment concentrations

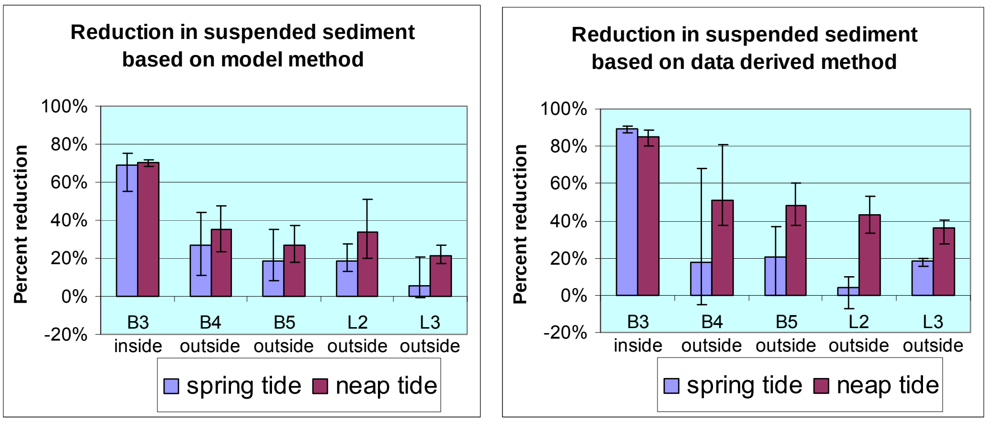
2.4.66 The longer term regimes resulting from the proposed schemes have been evaluated on the basis of looking at the existing data regarding concentrations in the estuary and considering how these concentrations are likely to change under the new hydrodynamic conditions introduced by the schemes. The methodology for inclusion of the effects of the schemes is based on the science related to the effects of turbulent damping of fine sediment mud suspensions (H&G Annex 1, 12 & 15).

2.4.67 This approach seeks to assess how concentrations might vary in the Severn over the longer term following the introduction of one of the alternative options by assuming suspended sediment concentration scales as the cube of the change in tidal range as a surrogate for velocity. This approach described as the ‘data derived method’ (H&G Annex 1, 12 and 15) is recommended by the sediment specialists as the best estimate available of the likely suspended sediment concentrations in the Severn Estuary in the years following introduction of one of the alternative options.

2.4.68 These two methods of assessing sediment concentrations may be compared by considering the percentage reduction provided by each method. This helps remove the effects of spatial differences in baseline concentration in the estuary and also the differences in baseline concentration predicted by each method. The predicted percentage reduction in suspended sediment concentration is very different for each option, but a comparison of the average percentage reduction predicted for all schemes by each method helps illustrate the differences between and similarities of the two methods.

2.4.69 The comparisons available (H&G Annex 1) are for model predictions at five sites and ‘data derived’ predictions at four sites. These sites are all outside the B4 Shoots Barrage, B5 Beachley Barrage and L2 Welsh Grounds Lagoon. All sites, except one model site are outside the L3 Bridgwater Bay Lagoon, while all except one model and one data derived site are inside the B3 Brean Down to Lavernock Point Barrage. In order to help ensure like for like comparisons, the percentage reduction inside the B3 Brean Down to Lavernock Point Barrage is compared with the percentage reduction outside all the other alternative options in Figure 2.8. Error bars are shown on Figure 2.8 to indicate the variability in percentage reduction predicted for each alternative option for each method and tide type.

2.4.70 The predicted percentage reductions in suspended sediment concentrations are greater on neap tides than spring tides with both methods outside the impoundments. Inside the B3 Brean Down to Lavernock Point Barrage, the reductions are very similar on spring and neap tides. The percentage reductions inside the B3 Brean Down to Lavernock Point Barrage are very much greater and less variable than those predicted outside the other four alternative options. The information shown on Figure 2.8 does not indicate whether this is a result of the size of the B3 Brean Down to Lavernock Point Barrage or a result of differences between predictions inside and outside an impoundment.



Note: Bars show the range of percentage reduction values found for each alternative option.

Figure 2.8 **Comparison of different methods for determining percentage reduction in suspended sediment concentration**

2.4.71 The model method predicts for the B3 Brean Down to Lavernock Point Barrage 60 to 70% reduction within the impoundment as shown on Figure 2.8. Review of the model longitudinal suspended sediment profiles for the B4 Shoots Barrage and B5 Beachley Barrage for neap tides (H&G Annex 12 Figure 4.2) indicates that the model method also predicts 60 to 70% reduction in Baseline concentrations within these impoundments.

2.4.72 Predictions for neap tides using the 'data derived' method on Figure 2.8 for the B3 Brean Down to Lavernock Point Barrage, suggest that the long term reduction in Baseline concentrations may be 80 to 90%. For the purposes of this assessment, the assumption has been made that for all barrage options and also the L2 Welsh Grounds Lagoon, there may be a 90% reduction in suspended sediment concentration within the impoundment as indicated on Table 2.4. For the ebb flood Bridgwater Bay Lagoon the suspended sediment percentage reduction would be less and possibly around 40%.

2.4.73 The maximum percentage reductions estimated for neap tides for the various options in the estuary outside the structure using the 'data derived' method varied from 40% to 80% as indicated on Figure 2.8 and in Table 2.4, while the reductions predicted by the modelling method were less, except outside the B3 Brean Down to Lavernock Point Barrage that is not shown on Figure 2.8. For this assessment the largest percentage reduction calculated by either method has been adopted.

2.4.74 The medium uncertainty in modelling suspended sediment concentrations feeds directly into the Marine Water Quality topic of this theme and the Marine Ecology topic of the Biodiversity theme. In both cases the link is through the effects suspended sediment concentrations have on water clarity and dissolved oxygen. Within the Hydraulics and Geomorphology topic, uncertainty in future suspended sediment concentrations affects the assessment of the balance of probability between long term erosion and accretion of the intertidal foreshore, which in turn has knock on effects to many other topics including Flood Risk and those topics such as Marine Ecology and Waterbirds in the Biodiversity theme that are interested in the features of the intertidal foreshore.

Table 2.4 Maximum percentage reduction in suspended sediment concentrations on neap tides for each short listed option

	Max % reduction inside impoundment			Max % reduction outside Impoundment		
For neap tides (spring tides less)	Modelling method	Data derived method	Adopted result	Modelling method	Data derived method	Adopted result
B3-Orig	68%	89%	**90%**	56%	50%	**60%**
B4-V3A	72%	-	**90%**	67%	81%	**80%**
B5-V3	64%	-	**90%**	44%	60%	**60%**
L2-V8	-	-	**90%**	40%	53%	**55%**
L3d-V9	-	38%	**40%**	20%	40%	**40%**

Note: (-) = No data

Difficulties encountered – density of settled sediments

2.4.75 When sediment is in suspension, the quantity is expressed in terms of the mass of sediment within a unit volume of water using units of mg/l or kg/m^3. Such concentrations can be multiplied by the volume of water affected to give the total mass of sediment available, usually expressed as Mtonnes. This approach is used in determining the total mass of sediment in suspension in the estuary during a tide (H&G Annex 5) and the fluvial input of sediment to the estuary (H&G Annex 6). The amount of sediment may also be expressed in volumetric terms often in units of m change in level or Mm^3 of sediment deposited or eroded This is more appropriate when considering erosion or deposition of sediment on the sea bed, whether in subtidal or intertidal areas (H&G Annex 4, 12, 13, 15 and 16).

2.4.76 The mass of sediment in suspension and the settled volume of the sediment are related by the bulk density of the sediment which varies depending on circumstances. The bulk density refers to the mass of sediment within a cubic metre, excluding the mass of water that is also present in the same cubic metre.

2.4.77 In the Hydraulics and Geomorphology modelling, the settled density of newly settled sediments has been assumed to be 200kg/m^3 (H&G Annex 12). This is a medium term density for settled muds, though when these muds are first deposited and before the consolidation process starts, the settled density would initially be less, possibly as low as 50kg/m^3. Over time undisturbed muddy sediments consolidate and in the long term would reach a density of up to 500kg/m^3, reducing the depth of deposition. A settled density of 500kg/m^3 has been assumed in the long term morphology modelling (H&G Annex 15 and 16). In determining the sediment budget (H&G Annex 13), the sediments which were deposited over geological time have had very much longer to consolidate and have a higher bulk density, which may increase with depth below the present surface. Such sediments are assumed to have a bulk density of 850kg/m^3.

Difficulties encountered – modelling long term morphology changes

2.4.78 The detailed models of suspended sediment discussed above and reported on in H&G Annex 12 are not suitable for predicting the long term evolution of estuary morphology over the 120 year design life of the alternative options. For this purpose different approaches were necessary. The main method of providing long term predictions was to use a 'box model' known as ASMITA (Aggregated Scale Morphological Interaction between a Tidal basin and Adjacent coast). This model represents the interactions between tidally averaged conditions in large sections of an estuary or inlet. This type of behaviour model was originally developed by the Dutch, but adapted and enhanced in the UK in recent years where it has been successfully applied to the Humber Estuary, Thames Estuary and Southampton Water to reproduce changes in bathymetry and estuary form documented over periods of up to about 100 years (H&G Annex 1).

2.4.79 In these three cases ASMITA was shown to produce forecasts that closely matched the observed changes over the period. This included sites with long term trends driven by a variety of forces including basin closure, dredging, land reclamation and natural cycles. The range of estuary and tidal basin morphologies and the range of future forcing scenarios considered shows that ASMITA has a strong ability to predict future estuary morphology under a variety of circumstances.

2.4.80 The ASMITA approach has been further developed for this application by extending the schematisation to include multiple channel elements and to represent intertidal flats on the English and Welsh banks as separate model elements (H&G Annex 1 and 16). The cells used to represent the different parts of the Severn Estuary in ASMITA are shown in Figure 2.9. These cell boundaries correspond closely to the study area zones shown on Figure 2.5. The Inner Bristol Channel zone has been subdivided to include a separate zone for Bridgwater Bay, while the Severn Estuary zone has been divided into two at the confluence with the River Usk.

2.4.81 The representation of the Severn Estuary is achieved by dividing the estuary into six major geomorphological units, with each unit having a channel section which is permanently covered and one or two intertidal flat sections which are only submerged for part of each tidal cycle, generally one on each side of the estuary. This representation may be compared with the detail shown in Figure 2.4 for the flow and water level model and the associated wave, mud and sand transport models.

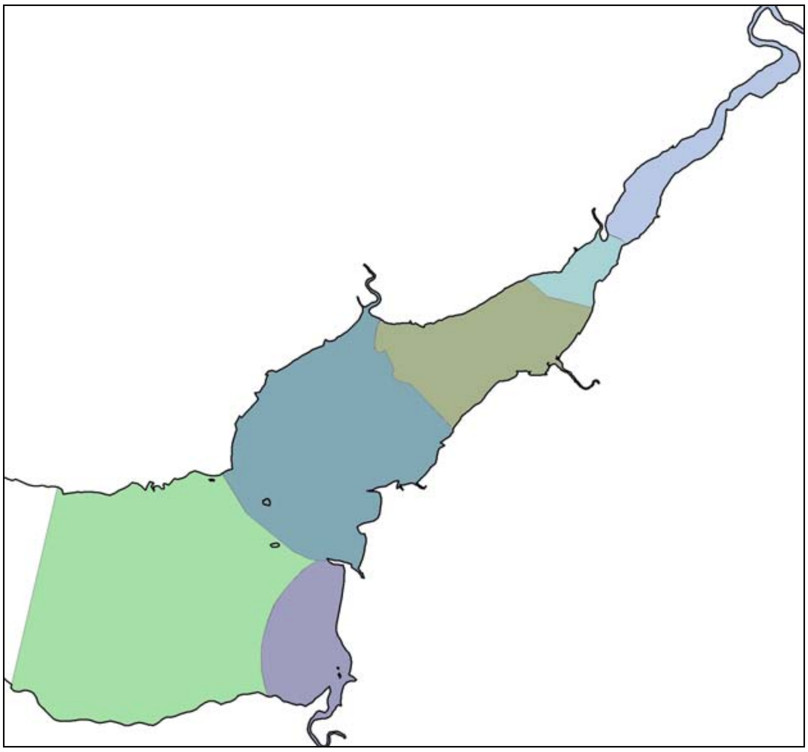


Figure 2.7 **Schematic representation of the Severn Estuary in ASMITA (HR Wallingford)**

2.4.82 On the seaward boundary of the ASMITA model, located along a line connecting Minehead and Aberthaw, a constant concentration of suspended sediment is assumed. This was found to work well for the baseline boundary condition. However, initial runs of the model for some of the alternative options led to concerns as to whether the calculated sediment demands could be supplied by marine sources particularly as the Estuary is currently considered to be a closed sediment system or to export relatively small quantities of sediment.

2.4.83 If further studies of the B3 Brean Down to Lavernock Point Barrage are carried out, extending the ASMITA model further west probably to the Worms Head Morte Point location is recommended. (H&G Annex 1 and 16).

2.4.84 Interpretation of ASMITA results is difficult and requires expert judgement. All estimates of how the geomorphology of an estuary may evolve are subject to considerable uncertainty. Not all the processes are fully understood and others cannot be represented in the simplified models that are used to predict long term evolution. A major issue in setting up a long term model of geomorphology evolution is that in the calibration of such a model, an assumption need to be made about how close the baseline estuary is to dynamic equilibrium. For the Severn Estuary, it has been assumed to be currently close to equilibrium with the forcing processes including a historic sea level rise of 2mm/year during the 20th century.

2.4.85 Several other topics including Flood Risk Management in this theme and Marine Ecology in the Biodiversity theme have used the ASMITA predictions of accretion and erosion of the intertidal flats to estimate how the erosion risk to flood defences and the habitat features of the intertidal foreshore might change. The Navigation topic in the Society and Economy theme have been particularly concerned about how long term predictions of erosion or accretion within channels might affect access to Severn Estuary ports.

2.4.86 Some location specific information on the evolution of intertidal profiles has been provided at selected sites (H&G Annex 15) by Intertidal Profile Modelling. This modelling is location specific, but is able to include more processes than the ASMITA approach. The intertidal profile modelling shows there can be a range of responses over the intertidal depending on wave conditions and water velocities at the site, the existing shape of the intertidal and its sediment properties, and importantly the assumed concentration of sediment in suspension at the profile. Sensitivity testing suggested that this latter factor was the most important determinant of future evolution.

2.4.87 Initially, it was assumed that the effects of sea level rise would be secondary to the effects of the option in determining future morphology. Accordingly accelerated sea level rise has only been tested for the baseline and B3 Brean Down to Lavernock Point Barrage. Both tests show there is likely to be loss of intertidal area as the low water level rises faster than the morphology is predicted to respond. The baseline test suggests greater intertidal erosion occurs with sea level rise, while the test with the B3 Brean Down to Lavernock Point Barrage suggests that the predicted substantial erosion of the intertidal foreshores might reduce. Overall these results confirm that the effects of sea level rise are secondary to the effects of the option in determining future morphology. This difference would be well within the uncertainty of the morphology modelling.

Difficulties encountered – modelling salinity

2.4.88 Modelling of salinity was a key task for the Marine Water Quality topic. Originally this was intended to be carried out using a proprietary water quality module attached to the Mike 2DFM flow model developed by ABPmer. Unfortunately when this module was set up, incompatibilities in the software were identified which prevented accurate transfer of salinity through the turbines and sluices. These incompatibilities were found at a late stage in model development and the topic specialists decided that a 1D model should be used instead of the proposed 2D model (MWQ Annex 2).

2.4.89 The decision to move to a 1D model was not taken lightly as it required that a completely new model be set up and calibrated to give similar results to the 2D flow model for water levels and flows for both the baseline estuary and with option conditions. This model then needed to be calibrated to represent the existing salinity distribution within the estuary. The advantage of the 1D model was that its run times were very much shorter, so the 10 month simulation time required to reach water quality equilibrium could be completed within a few minutes instead of several weeks.

2.4.90 The calibration of the 1D salinity model against salinities measured in 1980 (HRS 1981a) is illustrated on Figure 2.8 from information tabulated in MWQ Annex 2. During the period of observations, in July and August 1980, the freshwater flows in the River Severn varied between 25 and 65m^3/s (MWQ Annex 2) so river flows were fairly typical of low flow conditions. The locations of the sites where salinity was measured are shown on Figure 2.1. Generally the model reproduces the observed range of salinity well, especially the maximum salinities encountered at each position.

2.4.91 The minimum salinity in the model calibration at position 14 on Figure 2.8 reflects the minimum salinity values observed during spring tides (Figure 3.4) but not the lower salinity observed at this position on the neap tide observed in 1980.

2.4.92 Overall the 1D model provides a reasonable level of agreement with observed salinities that are suitable for a strategic study, but would require a more refined calibration in a more detailed study of an individual option. In any salinity modelling a critical feature of the modelling is the assumption made about the dispersion coefficient within the estuary as this determines how the waters of the estuary mix. The magnitude of the dispersion coefficient is set within the model calibration process to reproduce the observed salinity conditions in the estuary and depends on the features of the model that is being used.

2.4.93 After a tidal power scheme is introduced, the estuary velocities and depths change. This is likely to affect dispersion processes. Unfortunately there is little information on how a tidal power impoundment will change dispersion. Previous studies of schemes similar to the B3 Brean Down to Lavernock Point Barrage made different assumptions. In 1980 a 75% reduction in dispersion was assumed for a tidally averaged 1D model, while in 1989 for a 2D model the dispersion coefficient value was assumed to remain unchanged (MWQ Annex 2). For this assessment the value of the dispersion coefficient was assumed to vary with flow, which would generally reduce as a result of a tidal power scheme.

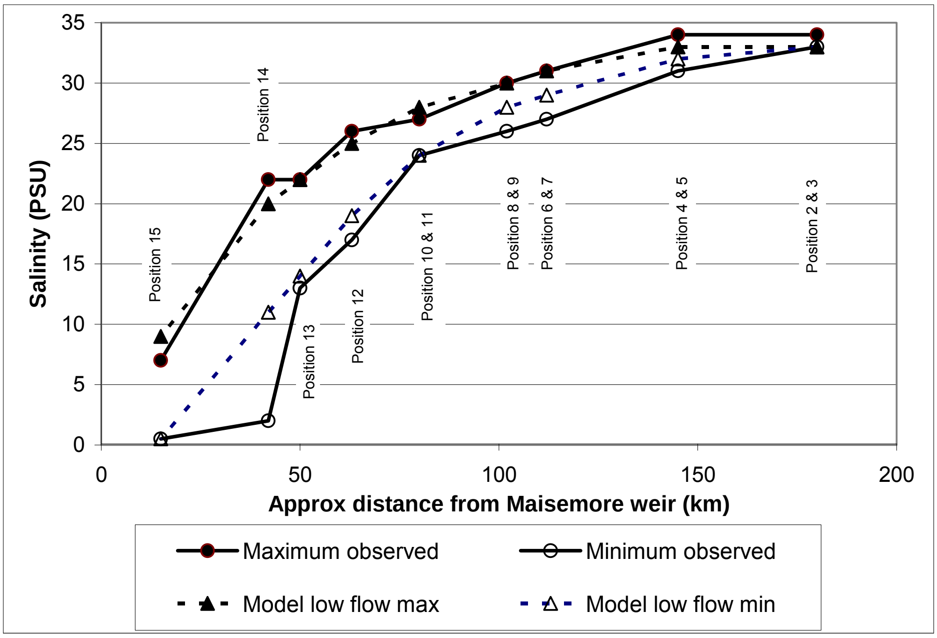


Figure 2.8 Salinity calibration against 1980 observations

2.4.94 The disadvantage of the use of the 1D model is that no information on how cross estuary salinity effects might change as a result of a tidal power scheme could be taken from this work, though cross estuary salinity difference is a known feature of the natural estuary. Further study of any of the options would require the development of a 2D model to assess this effect. Although the mathematics of representing water quality in 2D is well known and included in many models, the very prolonged run times that are required before a large system such as the Severn Estuary reaches equilibrium remain a constraint on how much modelling can be carried out, particularly if a fine resolution mesh is employed to provide good details of flow patterns.

2.4.95 In view of the uncertainties surrounding the appropriate value of dispersion coefficient to use for an operational tidal power scheme and the inability of a 1D model to represent cross estuary variations in salinity, the salinity predictions in this assessment are considered to have medium uncertainty.

Difficulties encountered – modelling thermal and effluent plumes

2.4.96 The ABPmer 2D flow model was used to model the effect of each alternative option on the extent of thermal and treated sewage effluent plumes in the Severn Estuary and Bristol Channel. This modelling used the same software that was intended for use in the salinity modelling. The software problems affecting salinity in theory also affect the results of this modelling. Fortunately none of the effluent plumes are located close to the turbines and sluices for any of the options and so these issues do not affect the majority of these results in any way. There remains some uncertainty for the few cases where an effluent plume is predicted to pass through one or other of the structures, but as this only affects the outer limits of the plume, the effects are considered relatively minor. The modelling of thermal plumes is described in MWQ Annex 4, while the modelling of treated sewage effluent plumes is discussed in MWQ Annex 8.

Difficulties encountered – modelling stratification

2.4.97 A three dimensional (3D) model was utilised to model in a preliminary way the possible development of stratification in the waters upstream of one of the tidal power barrages. This modelling used the proprietary Delft3D software package with the standard estuary bathymetry, but adopted a coarser resolution mesh that had been developed for previous studies by ABPmer. The model was set up with eight vertical layers to allow vertical density differences caused by salinity variations to be represented (MWQ Annex 5).

2.4.98 The limitation on the approach adopted for stratification modelling was that no attempt was made to represent flows through a barrage or lagoon structures (MWQ Annex 5). This limited the modelling to the impounded basin upstream of each barrage, with the barrage being used as a model boundary through which appropriate inflows and outflows passed.

2.4.99 The stratification modelling was limited to the B3 Brean Down to Lavernock Point Barrage, the B4 Shoots Barrage and the B5 Beachley Barrage, as each of these barrages receives major fluvial flows into the impounded basin. The L2 Welsh Grounds Lagoon and L3 Bridgwater bay Lagoon were not modelled as the inflow of freshwater into these lagoons is much smaller than into the barrages, so the risk of stratification occurring is much smaller.

Difficulties encountered – other water quality parameters

2.4.100 No specific modelling of estuary temperature was undertaken for this study. While it would be possible to develop a model for estuary water temperature, a large amount of data would be needed to develop and calibrate such a model, including spatial and temporal water temperature data and an understanding of the influence of insolation on water temperature, both directly and indirectly (through intertidal warming). Such detailed information and understanding was not available to the project and it was not considered appropriate to collect such information for a strategic assessment.

2.4.101 The assessment of changes to estuary temperature are therefore based on the observed correlation in the estuary between salinity and temperature, which reflects the mixing of fresh and marine waters of slightly differing initial temperatures (MWQ Annex 3). The approach adopted means that there is some uncertainty surrounding the likely temperature of water within the lagoon options, where insolation of relatively shallow waters within the lagoon may result in slightly elevated temperatures. However, since a relatively large proportion of the retained volume is flushed on each tide, such an effect is considered to be small in comparison to annual temperature variations.

2.4.102 No specific modelling of nutrient concentrations has been undertaken as the data requirements to parameterize such a model are substantial and this was not considered appropriate for a strategic study. Furthermore such models necessarily make assumptions about important processes such as nitrification, denitrification, biological uptake and excretion. The nature of changes introduced by the alternative options mean that many of these underlying processes may change following implementation of these options. Thus while it may be possible to calibrate a model for a baseline situation, many of the assumptions implicit within the model would not necessarily hold true when applied to the alternative options. The assessment of changes in nutrient concentrations has therefore focused on winter dissolved inorganic nitrogen concentrations which are strongly negatively correlated with salinity (MWQ Annex 6).

Difficulties encountered – Data on land drainage outfall levels and sizes

2.4.103 The land drainage studies that formed part of the Flood Risk and Land Drainage topic (Severn Tidal Power 2010e) identified 762 separate outfalls into the Severn Estuary potentially adversely affected by one or other of the alternative options. These outfalls provided land drainage, surface water drainage, combined sewer overflows or discharges from sewage treatment or water treatment works.

2.4.104 In order to assess how the drainage provided by these outfalls might be adversely affected it was important to know the size and level of each outfall. Exhaustive enquiries were made of the authorities responsible for these outfalls, but this information was only available for 24% of the outfalls with one or other piece of information available for a further 46% of outfalls. That left 30% of outfalls about which no details could be found (Severn Tidal Power 2010e).

2.4.105 The level of recorded information on outfalls was disappointing but was considered sufficient to provide a robust strategic level assessment of the likely effects of each alternative option on land and surface water drainage. For the 59% of outfalls that had no information on outfall level, knowledge of local ground levels from LiDAR mapping provided a useful surrogate as commencement of flooding above ground level is the level where impeded drainage starts to have important effects. Where size was not known, estimates from adjacent similar sites or previous investigations were made. Checks of the available information and further analyses would be required if any of the options were to be taken further.

2.4.106 In the Flood Risk and Land Drainage topic, land drainage outfalls were grouped according to their level compared with tide level and in particular the extent to which the alternative options reduced the time available for free discharge. Simple hydraulic models were used to test typical outfalls for the baseline and to determine the effect on water levels in the flood plain of the alternative options. This approach was in sufficient detail to compare options and to assess the scale of works that would be required to prevent or reduce any significant adverse effects of the options. This analysis was not in sufficient detail to identify the work required at any specific outfall.

Difficulties encountered – Data on underground infrastructure

2.4.107 There is limited information on locally important underground infrastructure. Whilst it is known, for example, that there are areas of Cardiff and Weston-super-Mare that have properties with basements, the number or details of these has not been quantified. The extent and condition of important underground services, such as sewers and communication infrastructure has also not been quantified. Even if this information were available, simplifying assumptions and professional judgement, would still be required because of the large variations that exist within local ground conditions, which are fundamental to understanding the future condition of such assets.

SECTION 3

PHYSICOCHEMICAL THEME BASELINE ENVIRONMENT AND SIGNIFICANT EFFECTS

3 PHYSICOCHEMICAL THEME BASELINE ENVIRONMENT AND SIGNIFICANT EFFECTS

3.1 Introduction

3.1.1 This section summarises the current state, characteristics and evolution of the environment for the topics within this theme.

3.1.2 This section also considers, within this theme, the likely significant effects on the environment for each alternative option and the interrelationships between these effects (SEA Directive Annex 1 (f)). These effects may arise from direct, indirect, far-field, cumulative and consequential development effects during construction, operation and decommissioning phases and may include secondary, cumulative, synergistic, short, medium and long-term permanent and temporary, positive and negative effects (SEA Directive Annex 1 (f)).

3.1.3 This section also considers the difficulties encountered in compiling the required information (SEA Directive Annex 1 (h)) and the level of certainty in the assessment of effects.

3.2 Current state, characteristics and evolution of environment

3.2.1 Baseline information provides the basis for predicting and monitoring environmental effects. Alternative options considered within this Feasibility Study would only be developed several years into the future and would have a long life. It is therefore necessary to project a 'future baseline' against which to compare effects, rather than using the present day baseline.

Baseline environment (up to 2009)

3.2.2 The Severn Estuary is generally regarded as the location with the world's second largest tidal range. The high tidal range is commonly explained by a combination of resonance with the incident North Atlantic tidal wave approaching the Bristol Channel and with further amplification and convergence as the tide moves into the funnel-shaped form of the Severn Estuary.

3.2.3 At the approaches to the Bristol Channel the mean spring tidal range is already in excess of 6m and may be considered hyper tidal (i.e. tidal range in excess of 6m). The tidal range progressively increases in amplitude as it is funnelled into the Severn Estuary, leading to a mean spring tidal range of 12.2m at Avonmouth. The high tidal range within an alluvial flood plain has led to extensive intertidal foreshores around the estuary.

3.2.4 The large amplitude of the progressive tidal wave in the Severn Estuary and the large spatial extent of the estuary generate very strong tidal currents through the main body of the estuary. The strongest currents are confined to the deep channels and the scouring nature of these currents is sufficient to maintain the channels at a more or less fixed depth and in some cases swept clear of sediment.

3.2.5 There is increasing tidal asymmetry as the tide progresses up the estuary: the flood tide period becomes shorter than the ebb tide with distance upstream. This leads to peak flood tide currents that increasingly exceed those occurring on the ebb tide. In the estuary upstream of Beachley the bed rises progressively. This enhances tidal asymmetry and steepens the flood tide phase to such a degree that it leads to formation of a tidal bore (from around Minsterworth) on high spring tides.

3.2.6 The distribution of flows within the estuary strongly influences the distribution of fine and coarse bed sediments through the process of tidal sorting.

Designation of the estuary as an SAC

3.2.7 The Severn Estuary has been designated as a Special Area of Conservation (SAC). The designation of the Severn Estuary / Môr Hafren European Site (NE, CCW and WAG, 2009) is on the basis that it is the largest example of a coastal plain estuary in the UK, has the largest tidal range and supports habitat types and species that are considered important in a European context. The designation includes an overarching estuaries feature within which subtidal sandbanks, intertidal mudflats and sandbanks and hard substrate habitats (rocky shore) are features in their own right along with a range of biological features found in the estuary.

3.2.8 The conservation objectives for the Severn Estuary / Môr Hafren SAC include a wide range of attributes. Within the scope of the physicochemical theme, the conservation objectives require:

- Maintenance of the total extent of the estuary,
- Maintenance of the characteristic physical form, flows and tidal regime of the estuary,
- Maintenance of the range and relative proportions of sediment sizes and sediment budget
- Maintenance of the extent, variety and spatial distribution of estuarine habitat communities including subtidal sandbanks, intertidal mudflats and sandflats and hard substrate habitats
- the Physicochemical characteristics of the water column to support the ecological objectives and
- toxic contamination in the water column and sediment remains below levels that would pose a risk to the ecological objectives.

3.2.9 The other features of the Severn Estuary / Môr Hafren SAC and those of the Severn Estuary / Môr Hafren SPA and Ramsar site are primarily discussed within the Biodiversity theme and associated topic papers, though these other features depend on the physicochemical features discussed in this theme paper. Close liaison has been maintained with topics in the Biodiversity theme to ensure the effects of the proposed options on the many features of the site are treated holistically.

Bathymetry, water levels and flows

3.2.10 The bathymetry adopted for the baseline was the contemporary bathymetry described in section 2.4 and illustrated in Figure 2.2 and 2.3. This bathymetry was used in all the baseline modelling.

3.2.11 The two hydraulic models for flow and water levels were calibrated against the tide levels measured in 1980 and discussed above in section 2.4 (H&G Annex 8 and 9). In both cases the calibration was of high quality in the majority of the estuary, but deteriorated a little upstream of The Shoots. Independently of the calibration process, the tide levels calculated by the two numerical models were compared with each other (H&G Annex 8 Addendum 3) and with the levels published in Admiralty Tide Tables (ATT) 2009 (UK Hydrographic Office 2008).

3.2.12 Both models agree everywhere with the predicted ATT high tide levels on spring and neap tides within ±0.2m between Minehead and Avonmouth, and within ±0.3m at Beachley and Sharpness. The agreement between the two models and ATT low tide levels is not as close with maximum differences of up to 0.6m. Poorer agreement at low water than high water is fairly common, because low water level in shallow areas is sensitive to the details of the local bathymetry, especially where there are narrow low water channels. At the majority of sites, the ATT low water levels are lower than those predicted by either model.

3.2.13 A small sea level rise could be applied to the model tidal levels to raise them from 1980 water levels to conditions representative of 2009. Measurements of annual mean sea level are held by the Permanent Service for Mean Sea Level (PSMSL 2009) at seven long term tide gauges in the SW of the UK between Newlyn, Avonmouth and Fishguard on both shores of the Severn Estuary and Bristol Channel over this period. Examination of these records suggested sea level rose between 1.1 and 7.2 mm/year at these sites over the period 1980-2008. The average rate of sea level rise at the seven sites was 4.3 mm/year. Applying this to the tidal levels used for model calibration would raise high and low tides by 0.13m over this period. This remains within the uncertainty of the modelling and has not been applied as it would not improve the ability of the models to represent current baseline conditions.

3.2.14 Within the Bristol Channel and Severn Estuary, velocities were compared in both models with measurements at up to 14 points surveyed in 1980 from anchored vessels (HRS 1981a and H&G Annex 8 and 9).

3.2.15 Agreement between the model predictions and observations is affected by the 30 years that have elapsed between the measurements and the compilation of the contemporary bathymetry used in the modelling. The agreement is better in the Bristol Channel where the bathymetry is more stable and mean absolute errors of <0.2m/s were found on both the spring and neap tides. In the Severn Estuary where the sea bed is more dynamic, mean absolute errors varied from 0.1 – 0.4m/s. The largest difference between model and observations was reported at Cardiff Grounds, a sandbank that is known to have moved as result of the construction of the Cardiff Bay barrage. At this site the mean absolute error was 0.6m/s on the spring tide and 0.3m/s on the neap tide.

Estuary intertidal area

3.2.16 The various methods of calculating the intertidal area of the estuary in the Inner Bristol Channel and Severn Estuary (zones 2 to 5 on Figure 2.5) are compared in Table 3.1. The estuary survey is closest to a measured intertidal area as the position of the low water contour was mapped during a series of low spring tides (H&G Annex 13). This area, however, is likely to be rather less than the area that would be exposed on a tide that fell to LAT level throughout the estuary. Estimates of this area are provided in Table 3.1 by the two flow models and by the analysis of the bathymetry data for the Marine Ecology topic (Severn Tidal Power 2010h).

3.2.17 There is uncertainty about which assessment better represents the area that would be exposed at a time of LAT tidal conditions in the estuary. For the purposes of this assessment the area calculated for the Marine Ecology topic is considered to take precedence.

Table 3.1 Comparison of calculated baseline intertidal area

Approach	Zone 2 (ha)	Zone 3 (ha)	Zone 4 (ha)	Zone 5 (ha)	Total
Estuary survey on low spring tides (H&G Annex 13)	7730	11840	1280	4270	25120
HR Wallingford model (HAT-LAT)	7750	13940	1700	3950	27340
ABPmer model (HAT-LAT)	7360	13390	1600	3940	26290
Marine ecology 25m grid (HAT-LAT) (Severn Tidal Power, 2010h)	8490	16010	1780	4700	30980

Waves

3.2.18 The wave climate within the Severn Estuary is considered to be largely wind-generated. Exposure to Atlantic swell is limited by the change in direction from the east-west orientated Inner Bristol Channel to the northeast to south-west orientated Severn Estuary which occurs around Flat Holm and Steep Holm. Bridgwater Bay is exposed to swell whilst other important intertidal areas further upstream are less exposed. Sand Bay and Weston Bay are considered to be the limit of Atlantic facing beaches exposed to swell waves.

3.2.19 The wave conditions in the estuary are linked to exposure to the direction of prevailing winds. At high water, fetch lengths can extend over long distances (particularly for westerly and north easterly winds), whereas at low water the intertidal flats and exposed banks can dramatically reduce fetch lengths.

3.2.20 The strong tidal currents within the Severn Estuary can modify local wave properties, depending on the relative direction of wave propagation and current flow. This wave-current interaction can result in modifications to wave height and wavelength. Tidal currents also modify the direction of wave propagation by current refraction.

3.2.21 Two wave models were set up to represent wave processes within the Bristol Channel and Severn Estuary. The results of the comparison of the two models (H&G Annex 10) show very good agreement. The two models are in very good agreement throughout the Severn Estuary though how well this represents observed conditions cannot be verified because of the lack of observed data. The only data available at present is from two sites in the Inner Bristol Channel.

3.2.22 The MIKE-SW wave model provided baseline assessments of one year return period wave conditions throughout the estuary primarily for use in the Marine Ecology topic and five year return period wave conditions calculated at a time of extreme water levels for use in the Flood Risk and Land Drainage topic. The SWAN model results were used to calculate the typical wave conditions that determine typical sediment movements during the course of a year, known as the morphological wave conditions. The morphological wave was used in the sediment transport and intertidal profile evolution assessments of the Hydraulics and Geomorphology topic.

3.2.23 The predictions of this study may be compared with the observed wave climate measured just west of Flat Holm over three years from 1978-81. Analysis of the measured waves, adjusted for differences between the wind climate in the period of observation with the wind climate over the 21 year period 1960-81 indicated a 1 in 1 year wave height of 3.1m with a west wind was appropriate for this site (HRS 1981b). This may be compared with the present study (H&G Annex 10) which predicts a 1 in 1 year wave height of 3.9m in west wind conditions at a similar location just seaward of the B3 Brean Down to Lavernock Point alignment.

3.2.24 The differences between the two estimates were investigated. This found that in the present study, 1 in 1 year west wind conditions were combined with 1 in 1 year wave conditions at the offshore model boundary near Lundy Island. While offshore waves are likely to be important in the Bristol Channel during west wind events, it is unlikely that these events always occur simultaneously. Reconsideration of the probability of these events combining suggests that the wave condition predicted by the present study probably represents a wave condition that might only be experienced around 1 in 5 years. If this were so, it would largely account for the difference as the 1978-81 observed wave data estimated the 1 in 5 year wave height to be 3.8m (HRS 1981b).

3.2.25 A second contributory factor may be decadal variations in the frequency of severe storms (Met Office Hadley Centre, 2009). Over the UK as a whole the period 1960-1980 was a period with unusually few severe storms. The 1990s on the other hand, when many of the storms used to determine the wave and wind conditions appropriate for 1 in 1 year conditions in the present study occurred, had an unusually large but not exceptional, number of severe storms. Overall this suggests that the 1 in 1 year wave height estimate of 3.1m reported from the 1978-81 wave observations should probably be treated as a realistic, but lower bound estimate of a 1 in 1 year wave condition at this site. The upper bound estimate of wave height is likely to be less than the 3.9m reported in this study.

Suspended sediments

3.2.26 Fine sediments (muds, silts and fine sands <63 microns) are highly mobile in the Severn Estuary. Long-term measurements of suspended sediment concentrations have demonstrated that there is a strong correlation between tidal range and tidally averaged suspended sediment concentrations (H&G Annex 5). At the seaward end of the Severn Estuary there appears to be little seasonal influence on this relationship. Further upstream average concentrations in the summer months are found to be lower. This is likely to be in response to the influence of seasonal discharge from the tributaries and the effects of wave action over the intertidal areas. During the summer months the intertidal areas may typically accumulate muddy material which is then removed during winter storms (H&G Annex 4).

3.2.27 The large variation between the mass of suspended sediment that can be maintained in suspension during spring tide periods compared to that during neap tides leads to the formation of mobile suspensions of muddy material (also referred to as fluid mud) in several of the deepest parts of the estuary. Typically the fluid mud forms as the tide range falls towards the neap tide period and is then re-entrained as the tidal range increases towards the spring tide period. The main locations of the mobile suspensions have been mapped for previous barrage studies and are found to be in Bristol Deep, Newport Deep, Kings Road and fronting Bridgwater Bay. The main active sinks for muddy material in the estuary are Newport Deep and the subtidal area fronting Bridgwater Bay.

3.2.28 The longitudinal variability in near surface suspended sediment concentration is indicated in Figure 3.1. This is based on anchored vessel observations on individual spring and neap tides in 1980 at the sites shown on Figure 2.1 (HRS 1981a and H&G Annex 5). The modelled distribution of baseline suspended sediments in the Severn Estuary calculated in H&G Annex 12 is illustrated on Figure 2.7 and mapped on Figure 3.2. This shows the average depth averaged suspended sediment concentration throughout a neap tide in Figure 3.2a and throughout a spring tide in Figure 3.2b. The very much higher baseline spring tide concentrations are evident in both Figures 3.1 and 3.2.

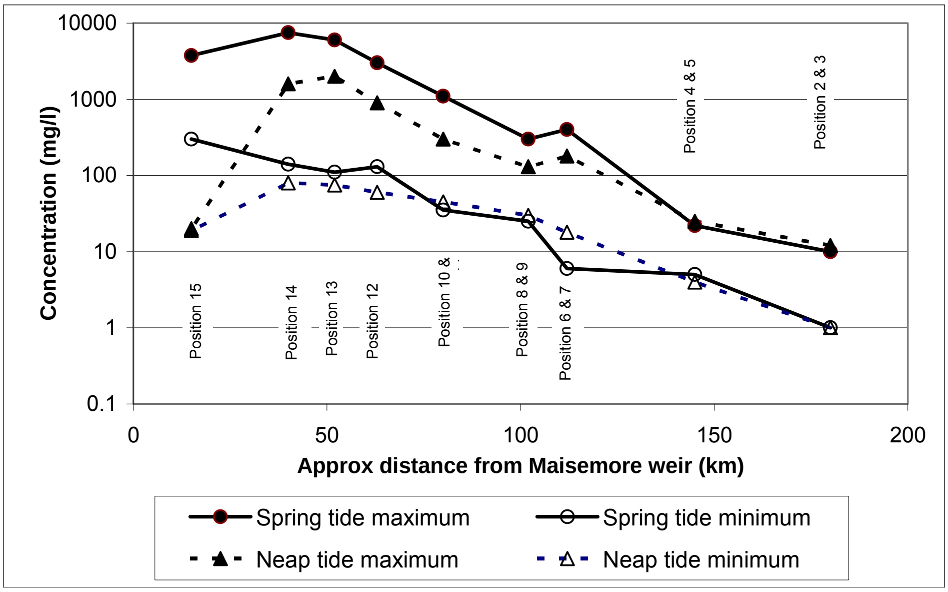
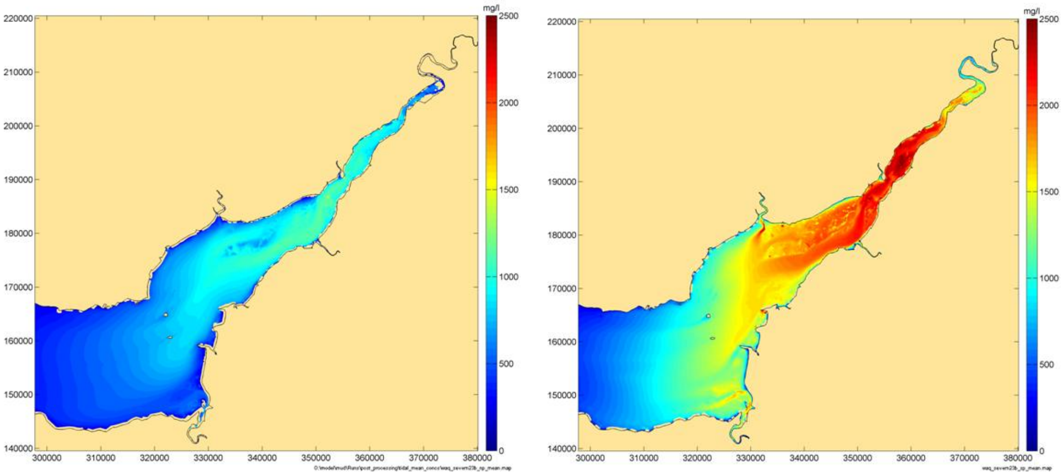


Figure 3.1 **Longitudinal profile of suspended sediment concentration (HR Wallingford)**

3.2.29 On the spring tide, maximum concentrations in the Bristol Channel rose from 10mg/l near Lundy (Positions 2&3) to 400mg/l off Barry (Positions 6&7). In the section upstream of The Shoots (Positions 12 to 15) the peak concentrations are very large in the range 3,000 – 7,500 mg/l. Neap tide peak concentrations are lower in the range 1000 – 2000 mg/l in these sections (Positions 12 to 14), but reduce to low levels once outside the tidal zone for neap tides at Position 15. The minimum values for the two tide types are similar throughout most of the estuary as they occur at slack water, a time when the bulk of the sediment has deposited.

3.2.30 The amount of suspended sediment in motion varies greatly between spring and neap tides. Previous estimates suggest (H&G Annex 5) there is 12.5Mtonnes of sediment in suspension on a representative mean spring tide between Watchet and The Shoots but 4.3Mtonnes of sediment in suspension on a representative mean neap tide. On large spring tides, up to 20Mtonnes of sediment might be in suspension, and this figure could increase 50% if such a tide followed a winter storm that suspended additional material.



a) neap tide average concentration **b) spring tide average concentration**

Figure 3.2 Depth averaged suspended sediment concentration (HR Wallingford)

Intertidal foreshore

3.2.31 Studies of the changes in level of the intertidal foreshores of the Severn Estuary have been made over a variety of timescales from tidal to decadal at a few locations (H&G Annex 4). These studies have found that there is often a seasonal variation of typically 100mm in foreshore level with accretion during the spring and summer and erosion during the winter.

3.2.32 The levels of the intertidal foreshore of the Severn Estuary have been monitored since 2000 by LiDAR surveys. Comparing results from surveys in 2000 and 2006 on the Welsh coast and surveys in 2003 and 2007 on the English coast has allowed an estimate of recent changes in foreshore levels to be made (H&G Annex 4). The differences between the LiDAR surveys suggest there has been accretion over the Welsh shore of around 0.05m/year and erosion on the muddy English shores of around 0.01m/year over these periods. The possibility that these changes might be associated with seasonal factors or with antecedent conditions was considered but no evidence found to support this suggestion.

3.2.33 At a few sites, comparison of surveys separated by several decades has also been possible (H&G Annex 4). On both the Welsh and English shores surveys at eight sites have been compared with the most recent LiDAR surveys. Most of the Welsh surveys were compared over a 20 year period while two made comparisons over more than 80 years. On the English shore the comparison was over 50 years.

3.2.34 These comparisons suggest erosion has occurred on the majority of profiles over these periods, especially on the Welsh shore where erosion rates from 0.01 to 0.04 m/year were recorded at six sites with little change at the other two. On the English shore the long term pattern was more variable, with accretion of up to 0.02m/year found at two sites on Stert Flats in Bridgwater Bay and erosion of 0.01 to 0.04m/year at another five sites, with little change at the final English site. The period covered by these long term measurements includes the period of recent accretion monitored by the LiDAR surveys.

3.2.35 As the number of long term data sets available is fairly limited there is a possibility of bias in the original selection of the measured profiles. Some of the profiles were probably originally measured precisely because they were showing erosion (at a rate which gave rise to concern) while neighbouring accreting or quasi-stationery profiles did not present a problem and therefore did not require measurement.

3.2.36 Overall the longer term surveys suggest that erosion of the intertidal foreshore is the more likely long term trend within the Severn Estuary both on the Welsh and English foreshores. Within this overall trend, there is often seasonal accretion in spring and summer and erosion in winter. Recent surveys suggest that within the longer term trend for erosion, episodes of accretion may persist for several years, implying that there is considerable decadal variability in the behaviour of the intertidal foreshore.

3.2.37 Future LiDAR surveys should in time allow the temporal and spatial variation in patterns of accretion and erosion to be better understood.

3.2.38 There is considerable uncertainty in the estimates of accretion or erosion of the intertidal foreshores of the Severn Estuary. The sediment budget (H&G Annex 13) reports estimates ranging from 1.6Mm^3/year accretion to 2.6Mm^3/year erosion. The former is derived from a comparison of the two LiDAR surveys, while the latter is derived by comparing historic surveys with the most recent LiDAR survey.

3.2.39 The sediment budget (H&G Annex 13) suggests the best estimate of intertidal change to be 1.8Mm^3/year erosion. This estimate is based on a comparison of historic surveys with recent LiDAR that takes account of the area of muddy intertidal foreshore estimated from biotope surveys. This is equivalent to erosion of 1.5Mtonnes/year of muddy sediments based on the limited information that is available on the bulk density of the eroded sediment.

Fluvial input of sediment to the Severn Estuary

3.2.40 The best estimate of the annual fluvial input of sediment to the Severn Estuary is 0.7MTonnes of fine suspended sediment (H&G Annex 6). This estimate is subject to uncertainty in the range 0.3 to 1.0MTonnes/year. Around 70% of this total sediment enters through the Rivers Severn and Wye. A further 10% enters the Cardiff Bay Barrage that impounds the Rivers Taff and Ely, and this may be retained within the impoundment. These estimates suggest fluvial sediments could contribute of the order of 150Mm^3 of deposited sediment during the assumed 120 year life of the tidal power options (H&G Annex 16).

3.2.41 There is no reliable estimate of the quantity of the larger sized bed-load sediments that enter the Severn Estuary each year.

Baseline morphology of the estuary

3.2.42 Analysis of historic charts in the Severn Estuary has shown some long term changes in the estuary over the past 150 years (Severn Estuary Aggregates Working Group 2007 and ABPmer 2007) along with the dynamic variability evident from routine bathymetry surveys carried out to maintain safe navigation in the estuary. These longer term changes may or may not recur. For the purpose of this assessment the contemporary bathymetry is considered to adequately describe the current morphology of the estuary. In addition there are the changes in the intertidal foreshore discussed above.

3.2.43 A key assumption built into the longer term morphology modelling (H&G Annex 16), is that the estuary morphology is close to equilibrium at the present time.

Water Quality baseline

3.2.44 Data describing the water quality of the Severn Estuary and inner Bristol Channel has been collected over a long period since the late 1970s to the present date. This data shows the estuary to be vertically well mixed with a long flushing time of up to 300 days (Severn Tidal Power 2010d). There have been important improvements in estuary water quality since 1980 often as a result of changes in legislation. The one aspect of water quality that is deteriorating is the concentration of dissolved inorganic nitrogen because of increasing loadings in the catchment from diffuse agricultural sources (MWQ Annex 6).

3.2.45 The Environment Agency's Water Framework Directive (WFD) characterisation in the Severn River Basin Management Plan (RBMP) (Environment Agency 2009a) classifies the Severn Estuary as a Transitional Water type TW3 – fully mixed, predominantly polyhaline, macrotidal and sheltered with extensive intertidal areas. The water bodies of the Severn Estuary and Inner Bristol Channel used to determine status under the WFD are shown in Figure 3.3.

3.2.46 The Severn Estuary and the estuaries of the Usk, Avon and Parrett have all been characterised as Heavily Modified Water Bodies. The estuary of the River Wye is the only sub estuary that is not characterised in this way. The Severn and South West RBMPs (Environment Agency 2009a and 2009b) indicates that the Severn, Usk and Parrett estuaries are of 'moderate potential' or 'moderate (uncertain) potential', the Avon estuary is of 'good potential' and the Wye estuary is of 'moderate (uncertain) status'

3.2.47 The Coastal Waters of the Bristol Channel Inner South is classified as a Heavily Modified Water Body of 'moderate (uncertain) potential', while those of Bridgwater Bay are of 'moderate (uncertain) status' (Environment Agency 2009b). The Coastal Waters of the Bristol Channel Inner North are of 'good ecological status' (Environment Agency 2009c).

3.2.48 The Severn Estuary, its sub estuaries and adjacent coastal waters largely fail to meet 'good Ecological Potential or Status' because of dissolved inorganic nitrogen, invertebrates and the absence of mitigation measures. These elements will prevent these water bodies reaching good status by 2015 as improving dissolved inorganic nitrogen is disproportionately expensive or technically infeasible. All the water bodies, requiring assessment meet the requirements for 'good' chemical status or potential.

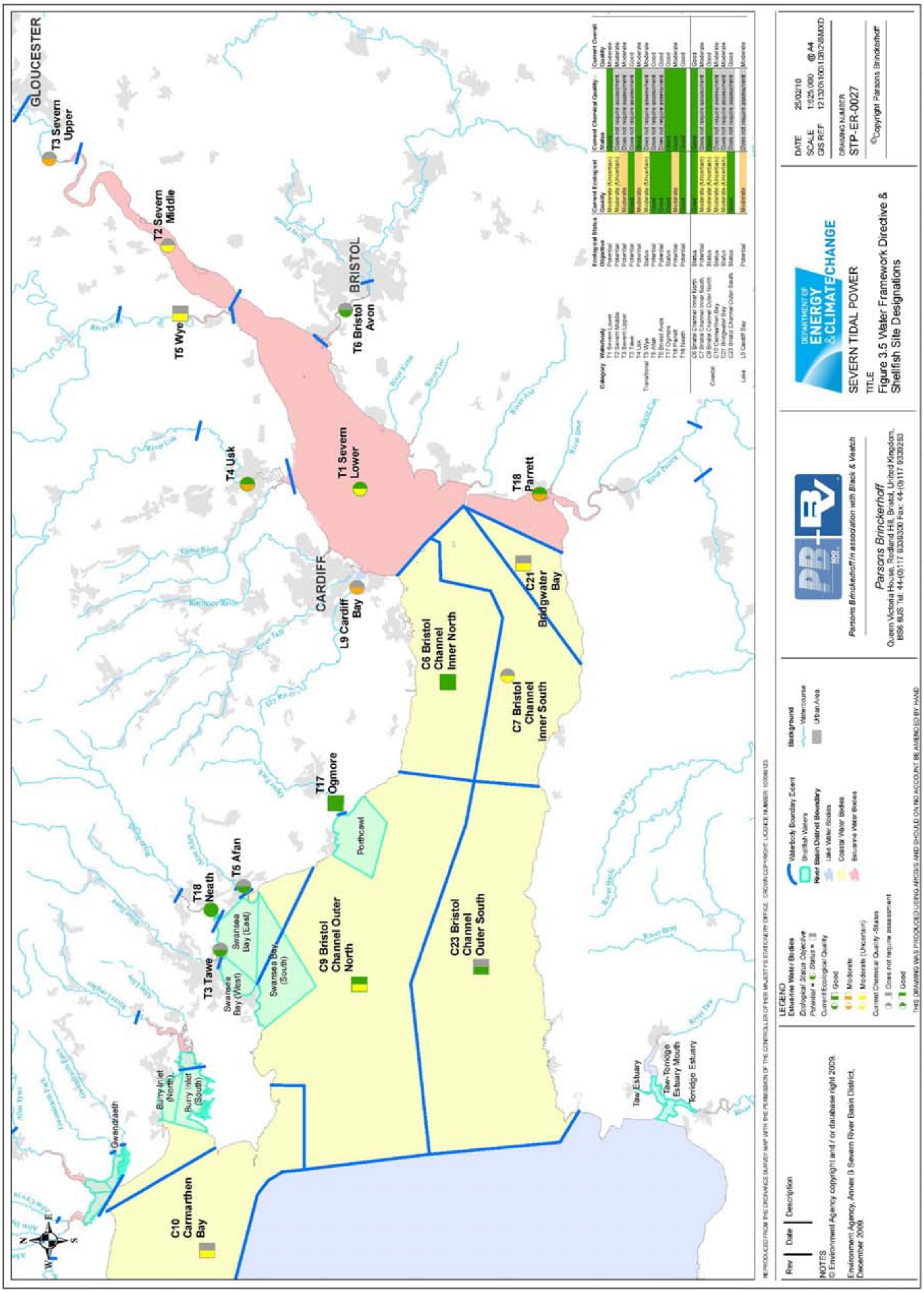


Figure 3.3 Water Body designations under the Water Framework Directive

3.2.49 The longitudinal salinity distribution within the Severn Estuary is illustrated in Figure 3.4 from salinities recorded in 1980 (HRS 1981a and MWQ Annex 2). The locations of the observation positions are shown on Figure 2.1. These salinities were measured during a period of low flows in the summer of 1980 when saline intrusion into the estuary would be greater than during periods of higher flows.

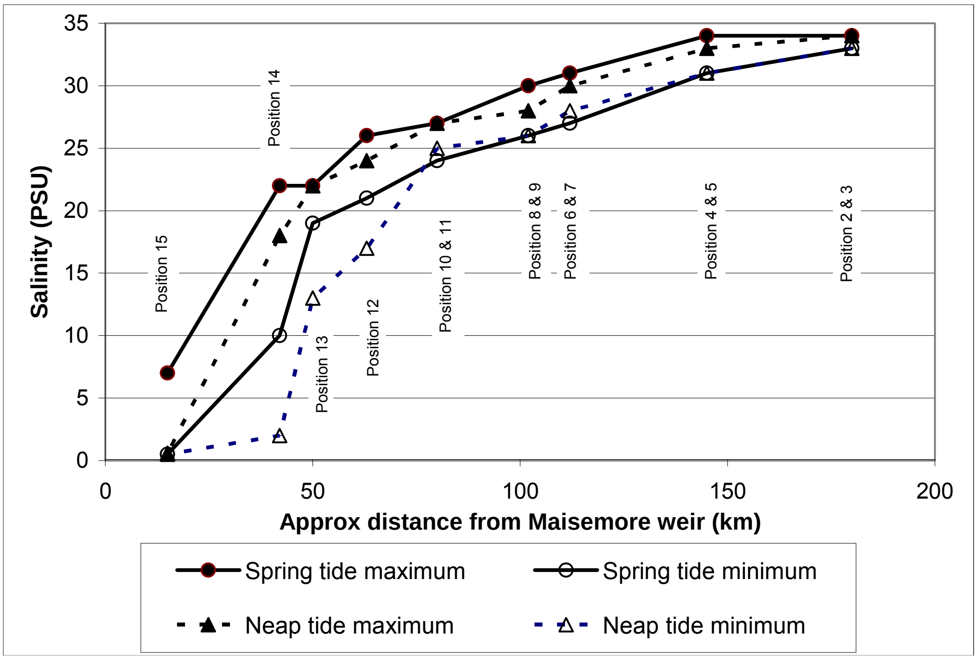


Figure 3.4 **Observed salinity variation during low flow conditions in 1980**

Flood risk and land drainage baseline

3.2.50 The information provided by the Environment Agency and other authorities has allowed the baseline situation for Flood Risk and Land Drainage to be established subject to the difficulties outlined in section 2.4 with establishing the sizes and levels of drainage outfalls.

3.2.51 The emerging findings of the SEFRMS and the SMP review suggest that where there are significant assets being protected there will be a policy of holding the line and adapting the tidal defence system to keep pace with sea level rise. For the purposes of this SEA and to compare the alternative options against the baseline it is not essential to forecast the exact content of these plans. Further details of the methodology are set out in the Flood Risk and Land Drainage topic paper (Severn Tidal Power 2010e).

Freshwater Environment and Associated Interface baseline

3.2.52 There are a large number of licensed abstractions within the study area. Those within 2km of the coastline or floodplain and east of a line from Lavernock Point to Hinkley include:

- Three surface water sources used for the PWS, all associated with Bristol Water's Purton source from the Sharpness Canal;

- 39 licensed abstractions for other uses of surface water;
- Three groundwater sources used for the PWS: Welsh Water's use of the 'Great Well' intercepted by the Severn Railway Tunnel, and Bristol Water's sources at Banwell and Clevedon;
- 36 licensed groundwater abstractions for other uses.

3.2.53 There are a large number of SSSIs designated for their geological and / or geomorphological interest in the study area within 2km of the coastline or floodplain, of which 14 occur east of a line from Lavernock to Hinkley:

- On the Welsh side: - Penarth Coast, Flat Holm, Rhymney River Section, Lower Wye and Otter Hole within Pierce, Alcove and Piercefield Woods SSSI;
- On the English side - Lydney Cliff, Purton Passage, Aust Cliff, Avon Gorge, Portishead Pier to Black Nore, Clevedon Shore, Middle Hope, Spring Cove Cliffs and Brean Down.

3.2.54 These sites are all geological SSSIs with the exception of Lower Wye and Clevedon Shore which are geomorphological.

3.2.55 The variation in soil type within the Study Area is vast and complex. As soil type is related to the underlying geology, soils occurring above the estuarine alluvium and glacial till are generally heavy, clay-rich and poorly drained, whereas those overlying sand and gravel deposits are lighter, more sandy and better drained. Undisturbed peat also has poor drainage characteristics. This simplification makes no allowance for soil improvement that may have taken place as a result of agricultural practices, but is sufficient for this SEA.

3.2.56 The infrastructure considered in this topic includes:

- Nationally important assets, comprising the Severn Railway Tunnel, the M4 and M48 road crossings, and the cable tunnel beneath the estuary operated by National Grid plc; and
- Locally important subterranean infrastructure within urban centres such as basements, sewers and other services. The extent of this is unknown.

<u>Baseline during construction (2014 – 2020)</u>

3.2.57 Most aspects of the baseline up to 2020 including bathymetry and land levels are assumed to remain similar to those reported in 2009, though bathymetry and hence the estuary morphology it represents is expected to continue to vary dynamically from month to month and year to year.

3.2.58 It is unknown whether changes similar to the historic changes in estuary morphology discussed as part of the current baseline may occur. For the purpose of this assessment such changes are assumed not to take place.

3.2.59 Tidal water levels and water velocities are also assumed to remain unchanged though UKCP09 predicts a small rise in mean sea level of around 0.05m from 2009 to 2020. In practice the effects of any changes this causes would be impossible to distinguish from the changes that arise from year to year in a naturally dynamic system such as the Severn Estuary. Such changes cannot be predicted and none have been applied to the tidal models.

3.2.60 Storminess over timescales of a decade is more likely to be influenced by changes in meteorological features such as the North Atlantic Oscillation than by underlying changes in climate (Met Office Hadley Centre, 2009).

3.2.61 There are not predicted to be any changes in the concentration of suspended sediments in the Severn Estuary in the period up to 2020.

3.2.62 There are not anticipated to be major changes in marine water quality in the period up to 2020. Continued investment in improved treatment of point source discharges as various water quality directives are implemented is likely to lead to small improvements in water quality.

3.2.63 The RBMPs (Environment Agency 2009a, 2009b and 2009c) anticipate that waters in the Severn and most of its sub estuaries and the adjacent coastal waters will continue to meet the standard for Moderate Potential or Status throughout this period. Measures to bring these waters up to Good Potential or Status will probably be underway by the end of this period in order to ensure compliance by 2027. The estuary of the Avon is expected to continue to be at Good Potential throughout this period.

3.2.64 The changes in sea level anticipated up to 2020 are unlikely to markedly change the performance of the existing tidal defences. In this period only isolated lengths of defence are at significant risk of failure and it has been assumed that the existing standard of protection will be maintained.

3.2.65 Implementation of the national water resources strategies is expected to maintain the number of licensed abstractions, although the licensed volumes may be reduced in the second round of RBMPs due for publication in 2015.

Baseline during operation (2020 – 2140), Decommissioning and Longer Term Trends

Anticipated effect of climate change on water levels and storminess

3.2.66 UKCP09 (Defra, 2009) predicts an increase in sea levels up to 2140. The median prediction for the medium emissions scenario is that by 2100 sea levels may have risen about 0.5m, which has been extrapolated to an estimated rise of about 0.6m in around 2140 (Severn Tidal Power 2009e). This prediction is considered to have a roughly equal chance of being too low or too high. For the Flood Risk and Land Drainage topic the more precautionary planning guidance of PPS25 (DCLG 2006) and TAN15 (WAG, 2004) has been adopted to provide compatibility with the assumptions underpinning the SEFRMS and the SMP review. This guidance anticipates around 0.9m increase in sea level in 2100.

3.2.67 Assessing the effects of rising sea levels on baseline conditions is a critical issue for the SEFRMS and SMP review and these studies are considering the implications of sea level rise for flood risk and shoreline management. For this SEA of tidal power options, sea level rise and other aspects of climate change affect both the baseline and with option conditions. The critical issue is the difference that the scheme makes to sea level rise effects or other climate change effects. The baseline is anticipated to evolve as the activities that will be included within the SEFRMS and SMP review are implemented.

3.2.68 No new predictions on likely future changes in wind speed has been prepared as part of UKCP09 (Defra, 2009). The planning guidance provided in PPS25 (DCLG 2006) and TAN15 (WAG, 2004) that the sensitivity of proposals to a 10% increase in wave height by the end of the 21st century should be considered has been adopted (Severn Tidal Power, 2009e).

Anticipated morphology changes with and without climate change

3.2.69 The baseline modelling of future morphology of the estuary has assumed continuation of the historic 2mm/year sea level rise experienced during the 20th century. With these rates of sea level rise, long term morphology throughout the inner Bristol Channel and Severn Estuary predicted accretion of up to 0.2m over the next 120 years in some subtidal channels and erosion of around 0.1m in the average levels of intertidal foreshores (H&G Annex 16). These changes are not significant and well within the uncertainty associated with this type of modelling.

3.2.70 The effect of increasing the current rate of sea level rise to 3.5mm/year with a gradual acceleration to 5.5mm/year after 120 years as predicted by the median value of the medium emissions scenario in UKCP09 (Defra, 2009) was also tested for baseline estuary conditions in the long term estuary morphology model (H&G Annex 16). With these assumptions there was increased accretion of up to 0.5m in some subtidal zones and erosion of up to 0.2m in the average levels of intertidal foreshores. Losses of intertidal foreshore were predicted for the inner part of the Severn Estuary zone and the Shoots zone (Figure 2.5) while gains were restricted to the intertidal areas around the inner Bristol Channel zone. These changes are not significant and well within the uncertainty associated with this type of modelling. Despite this the results do reflect the anticipated effects of coastal squeeze associated with sea level rise which predicts a loss of intertidal area fronting flood defences as sea levels rise.

3.2.71 Applying the median value of sea level rise predicted for the UKCP09 medium emissions scenario to the intertidal profile modelling led to a loss of intertidal width over 120 years of between 0 and 15% to the eight profiles modelled (H&G Annex 15). This loss of width was primarily due to the rising low water level. The median reduction in width was 4%. These changes are again consistent with the anticipated effects of coastal squeeze.

Anticipated effects on temperature and water quality

3.2.72 One of the major effects of climate change anticipated by UKCP09 (Defra, 2009) during the 21st century is the rise in sea surface temperatures. The median prediction for the medium emissions scenario is that by 2100 seasonal sea surface temperatures may have risen by 2.5 to 2.8^{O}C in winter, spring and summer and by around 3.5^{O}C in autumn compared with conditions in the period 1961-1990. This prediction is considered to have a roughly equal chance of being too low or too high. These changes in temperature would apply to the baseline and each alternative option.

3.2.73 Irrespective of climate change effects, the requirements of the WFD will continue to affect water quality as changes are made to maintain the Good Ecological Potential or Good Ecological Status of the Transitional and Coastal Waters that make up the Inner Bristol Channel, the Severn Estuary and its sub estuaries.

Anticipated effect of climate change on the freshwater interface

3.2.74 Rising sea level and the anticipated reduction in minimum freshwater inflows would increase the risk that saline intrusion moves upstream where it is not prevented from doing so by a high weir or similar structure. The upstream movement of the saline interface has the potential to adversely affect existing freshwater abstractions close to the tidal limits of rivers discharging to the Severn estuary.

3.2.75 The effects of sea level rise and other changes on geological and geomorphological SSSIs are expected to have an effect on exposure and access in the period up to 2140. These changes apply to the baseline and each alternative option.

3.3 Significant environmental effects

3.3.1 This section considers, within this theme, the likely significant effects on the environment and the certainty of this assessment for each alternative option and the interactions between these effects. The full methodology for identifying these significant environmental effects is set out in the Environmental Report.

3.3.2 Consideration has also been given to the potential effects of combination options and multiple basin options although this has not been subject to the same level of detailed assessment as the individual shortlisted options.

Predicted tide levels associated with each option

3.3.3 One of the key significant changes associated with all of the options is the change in tidal range on spring and neap tides. Table 3.2 compares tidal conditions for each alternative option with baseline conditions. In this table, the water levels for each alternative option based on the use of modern turbines with sluicing at the end of each generation period. The derivation of these levels is discussed in the model comparison report (Severn Tidal Power 2010g). These levels are similar to but not the same as the levels predicted in the detailed testing of each alternative option discussed in the Hydraulics and Geomorphology topic paper (Severn Tidal Power 2010c) and its annexes. The predicted changes arising with each alternative option are discussed below under that option.

Table 3.2 Comparison of predicted tide levels for each alternative option

		Water level (mAOD)					
Location	**Tide**	**Baseline**	**B3-Orig**	**B4-V3A**	**B5-V7**	**L2-V8**	**L3d-V9**
Burnham-on-Sea	HAT	6.8	6.0	7.2	7.0	7.1	5.7
	MHWS	5.9	5.4	6.1	6.1	6.0	5.2
	MHWN	3.1	3.1	3.1	3.2	3.0	2.7
	MLWN	-2.3	-2.1	-2.3	-2.3	-2.3	-2.4
	MLWS	-4.8	-4.7	-4.9	-4.9	-4.8	-4.3
	LAT	-5.7	-5.5	-5.7	-5.7	-5.7	-4.8
Cardiff	HAT	7.2	6.4	7.5	7.4	7.2	6.9
	MHWS	6.1	5.6	6.3	6.3	6.1	5.8
	MHWN	3.1	3.1	3.1	3.2	3.1	2.8
	MLWN	-2.4	-0.4	-2.3	-2.4	-2.3	-2.3
	MLWS	-5.0	0.7	-5.1	-5.0	-5.0	-4.8
	LAT	-5.9	-0.4	-6.0	-6.0	-5.9	-5.6
Newport	HAT	7.6	6.3	7.8	7.7	7.4	7.3
	MHWS	6.4	5.5	6.5	6.5	6.3	6.1
	MHWN	3.2	3.1	3.2	3.2	3.2	2.9
	MLWN	-2.6	-0.6	-2.4	-2.4	-2.4	-2.4
	MLWS	-5.4	0.4	-5.4	-5.4	-5.2	-5.0
	LAT	-6.3	-0.7	-6.4	-6.4	-6.2	-5.9
Avonmouth	HAT	8.2	6.5	8.2	8.2	8.0	7.9
	MHWS	6.8	5.7	6.8	6.9	6.7	6.5
	MHWN	3.3	3.3	3.3	3.4	3.3	3.2
	MLWN	-2.6	-0.8	-2.4	-2.4	-2.4	-2.3
	MLWS	-5.6	0.2	-5.3	-5.4	-5.5	-5.2
	LAT	-6.4	-0.9	-6.3	-6.2	-6.5	-6.1
Sharpness	HAT	8.4	6.9	8.1	8.1	8.6	8.1
	MHWS	7.2	6.3	7.2	7.0	7.2	6.9
	MHWN	3.6	3.8	3.6	3.1	3.5	3.6
	MLWN	-1.4	-0.5	0.2	0.3	-1.4	-1.2
	MLWS	-1.2	-0.2	2.1	1.5	-1.2	-1.3
	LAT	-1.5	-0.6	-0.2	0.2	-1.5	-1.5
Inside L2 lagoon (using Newport for baseline)	HAT	7.6	-	-	-	7.7	-
	MHWS	6.4	-	-	-	6.4	-
	MHWN	3.2	-	-	-	3.1	-
	MLWN	-2.6	-	-	-	0.1	-
	MLWS	-5.4	-	-	-	2.1	-
	LAT	-6.3	-	-	-	-0.1	-

Levels taken from Severn Tidal Power 2010g, Table 14.3

Predicted wave conditions associated with each option

3.3.4 The wave climate is changed by each of the preferred options. The presence of a barrier within the estuary would limit fetch lengths and cause a proportion of the incident wave energy to reflect off the barrier. The changes in water levels either side of the barrier would also affect the fetch length available for wave generation, while changes in the shape of the tide curve would alter the duration that waves can attack various levels of the foreshore. The changes in wave activity feed into the studies of sediment transport and morphology (H&G Annexes 12, 14 and 15) and into the Flood

Risk and Land Drainage topic (Severn Tidal Power 2010e). Details of the wave studies used for sediment transport and morphology are reported in H&G Annex 11, while those affecting the Flood Risk and Land Drainage topic are reported in H&G Annex 10.

Predicted changes in Dissolved Oxygen, pH and contaminants

3.3.5 Assessment of the effects of the alternative options on Dissolved Oxygen was considered by an in depth literature review of the likely effects combined with an interpretation of the available information from the Severn Estuary on those aspects of water quality that contribute to the dissolved oxygen concentration in the water body (MWQ Annex 7). The salinity modelling results were taken into account because of the links between oxygen solubility and salinity. This assessment also took account of predicted changes in sediment oxygen demand as a result of the changed quantities of sediment in suspension. Overall the assessment concluded that changes in dissolved oxygen concentrations were likely to be insignificant in the assessment of each option, although uncertainty remains for the B3 Brean Down to Lavernock Point Barrage which is discussed with the water quality considerations for this option.

3.3.6 A similar but less detailed approach was adopted for consideration of pH (MWQ Annex 1). The less detailed approach was considered appropriate for a strategic level assessment because of the perceived low risk of effects due to the high buffering capacity of seawater. Again this assessment concluded that changes in pH including in those areas adjacent to existing mixing zones for acid or alkaline discharges was not significant for the assessment.

3.3.7 Contamination of sediments and the water column by metals and organic chemicals has been a historic problem in the Severn Estuary. Careful management over many decades has removed most active sources of contamination and the problem now is essentially how the historic contamination, mainly of sediments might be affected by the changes in sediment behaviour predicted for the alternative options. As all alternative options tend to lead to reduced quantities of sediment in motion, these contaminants are more likely to be linked to permanently deposited sediments, though there is a risk contaminated sediments might move to new locations. As most options predict accumulation of settled sediment in subtidal areas of the estuary, these areas are most at risk of increased contamination. The assessment concluded that movement of contaminated sediments was not significant for the assessment.

3.3.8 Overall the assessments of dissolved oxygen, pH and contaminants are considered to have medium uncertainty.

Alternative Option B3: Brean Down to Lavernock Point Barrage

3.3.9 The B3 Brean Down to Lavernock Point Barrage encloses the whole of the Severn Estuary between Brean Down and Lavernock Point. The barrage encloses the estuaries of the rivers Severn, Wye, Usk and Avon as well as several smaller rivers and also the Cardiff Bay Barrage that receives water from the rivers Taff and Ely. Of the principal rivers draining to the Severn Estuary and Inner Bristol Channel, only the River Parrett is outside the B3 Cardiff Weston Barrage.

Water level changes

3.3.10 The operation of the B3 Brean Down to Lavernock Point Barrage would lower spring tide high water levels throughout the impounded basin. The reduction in spring high water level at Avonmouth and Sharpness would be around 1.0m while at Cardiff it would be 0.5m. Spring low water levels would be raised around 5.7m at both Cardiff and Avonmouth, but around 1m at Sharpness where baseline low water levels are increased by the rising bed levels of the upper estuary.

3.3.11 The extent of the intertidal foreshore in zones 2 to 5 of the Inner Bristol Channel and Severn Estuary (Figure 2.5) is predicted to reduce by 53% or 51% (Severn Tidal Power 2010c or 2010h) as a result of the B3 Brean Down to Lavernock Point Barrage.

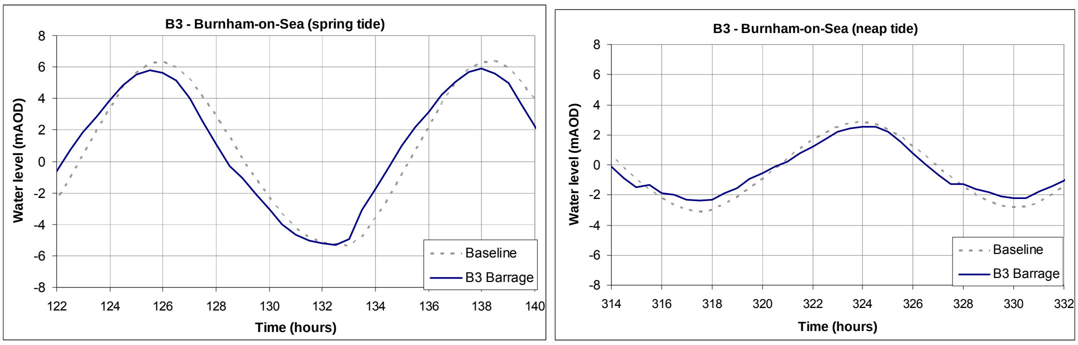
3.3.12 On neap tides the baseline high water level within the impounded basin would be changed by less than ±0.2m by the B3 Brean Down to Lavernock Point Barrage. Neap low tide levels would be raised by l.8 to 2.0m at Cardiff and Avonmouth, though by around 0.9m at Sharpness.

3.3.13 The shape of the tide curve within the impounded basin, which is shown on Figure 3.5b for typical spring and neap tides would feature a flood tide that rises at a slightly slower rate than the baseline. After high water, the high water level would be retained for around two hours before the tide ebbs more slowly than the baseline. A noticeable feature of the tides evident in Figure 3.5b is that the low water level on spring tides would be around 1m higher than the neap tide low water level within the impounded basin. This is unlike the baseline where the spring tide low water level is around 3m lower than neap tide low water level.

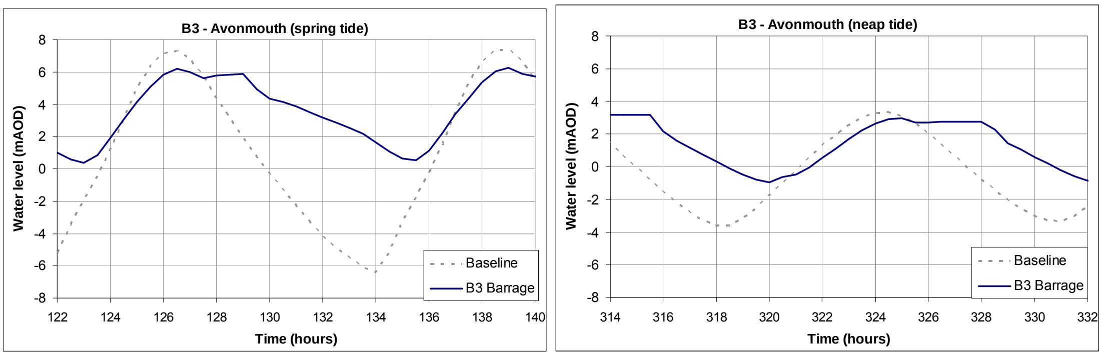
3.3.14 In the inner Bristol Channel outside of the B3 Brean Down to Lavernock Point Barrage, there would be a reduction in spring tidal range that would reduce with distance from the barrage. Spring tide high water levels would be reduced around 0.5m at Burnham on Sea while spring tide low waters would be raised 0.1m as illustrated in Figure 3.5a. Further west the reductions in high water levels and tidal range would decrease and are predicted to be less than 0.1m west of a line joining Ilfracombe with the eastern end of the Gower Peninsular as illustrated in Figure 3.6 (H&G Annex 8).

3.3.15 The tide curves of Figure 3.5a outside the B3 Brean Down to Lavernock Point Barrage show a short stand midway through the ebb of the neap tides. This stand is caused by the flow starting through the turbines which is sufficient to temporarily halt the ebb of the tide near to the barrage on its seaward side. This feature is much less pronounced on the spring tide as the rate of fall of the tide and the flow of water is much greater.

3.3.16 Predictions of the changes in water levels due to the B3 Brean Down to Lavernock Point Barrage are considered reliable with a high degree of certainty.



a) Typical spring tide outside **Typical neap tide outside**



b) Typical spring tide inside **Typical neap tide inside**

Figure 3.5 Water levels inside and outside the B3 Brean Down to Lavernock Point Barrage

3.3.17 In the outer Bristol Channel and along the Cornish and Irish coasts, the predicted changes in spring tide high water levels are less than 0.1m. However, all along the west Wales coast from Milford Haven to the Llŷn peninsular, increases in spring tide high water levels exceeding 0.1m are predicted. These increases are predicted to reach a maximum of 0.2 to 0.3m in Cardigan Bay and along the south coast of the Llŷn peninsular as indicated in Figure 3.6. There is also a 10 to 20km length of the coastline of the Republic of Ireland between Wicklow and Wexford where increases in high water level of 0.1-0.2m are predicted (H&G Annex 1).

3.3.18 The flow modelling carried out for the SEA does not extend north of the Llŷn peninsular so the possibility of effects further north in the Irish Sea cannot be discounted. Effects could occur in either the English or Irish shore, though it seems unlikely their magnitude would exceed those predicted for west Wales.

3.3.19 The far field water level effects predicted by the flow models in St Georges Channel have a lower certainty than the effects predicted within the Bristol Channel and Severn Estuary as the models have not been specifically calibrated for this region. Nevertheless since this type of effect is predicted by both flow models (H&G Annex 8 and 9) and also by the UK continental shelf model used to determine the boundaries of the SEA model (H&G Annex 7), this effect seems likely.

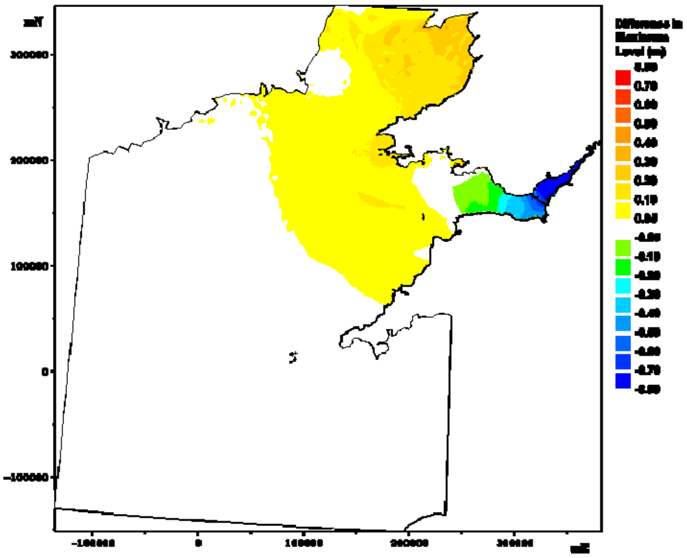


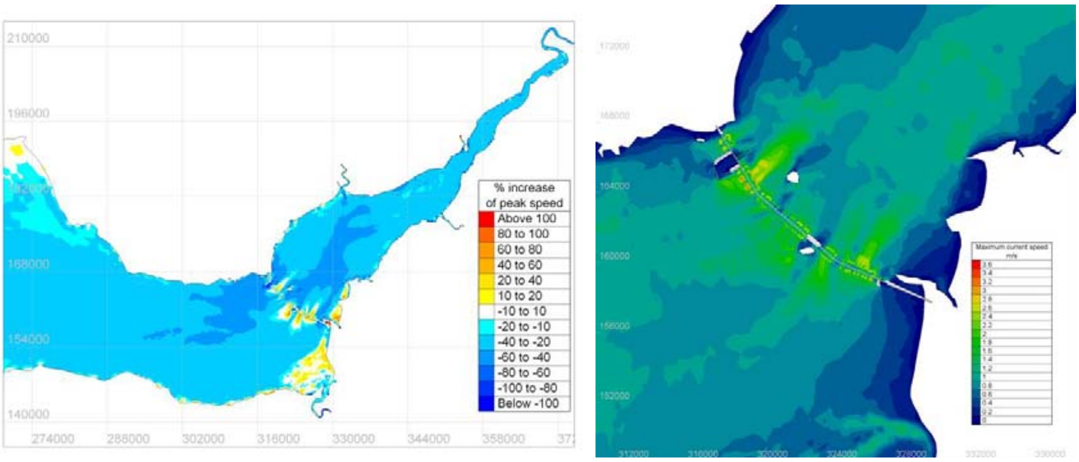
Figure 3.6 **Far field effects associated with the B3 Brean Down to Lavernock Point Barrage (HR Wallingford)**

Changes in water velocities

3.3.20 The predicted changes in peak water velocity associated with the B3 Brean Down to Lavernock Point Barrage are shown in Figure 3.7a. The predicted changes are extensive with reductions of 20-40% compared with baseline conditions over large areas of the Severn Estuary and Bristol Channel. Reductions in baseline velocities in the waters nearer to the barrage would be in the range 40-60%, while in the waters of Swansea Bay, which are more sheltered from the main currents in the Bristol Channel, 10-20% reductions in maximum velocity are predicted. Close to the turbine and sluice caissons and in the sheltered waters of Bridgwater Bay, Weston Bay and Sand Bay some increases in velocity are predicted.

3.3.21 The maximum velocities predicted with the B3 Brean Down to Lavernock Point Barrage remain everywhere below about 2.5m/s as Figure 3.6b shows except very close to the turbine discharges. In Bridgwater Bay, Weston Bay and Sand Bay, although velocities are predicted to rise by 10-20% (Figure 3.7a), the velocities in these areas remains below 0.6m/s as shown on Figure 3.7b.

3.3.22 The predicted changes in water velocity for the B3 Brean Down to Lavernock Point Barrage have a high degree of certainty, though local water velocities are sensitive to changes in bathymetry. As there are very few areas where velocities are predicted to increase there is unlikely to be much erosion of soft sediments during operation that would reduce the predicted velocities.



a) changes in peak velocity **b) Peak velocities on a large spring tide**

Figure 3.7 Peak water velocities due to B3 Brean Down to Lavernock Point Barrage (HR Wallingford)

Short term changes in suspended sediment and bed levels

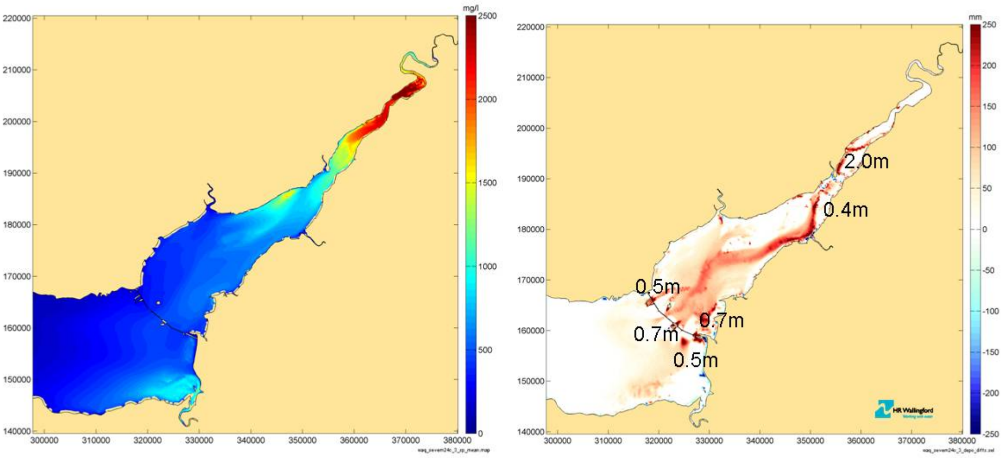
3.3.23 The introduction of the B3 Brean Down to Lavernock Point Barrage would have a major effect on the existing movement and concentration of suspended sediments in the Severn Estuary. The changes in suspended sediment concentration are indicated by comparing the predictions of spring tide concentrations for baseline conditions on Figure 3.2b with those including the B3 Brean Down to Lavernock Point Barrage in Figure 3.8a. The suspended sediment modelling (H&G Annex 12) predicts that the widespread reduction in velocities would lead to a 60 to 70% reduction in average neap tide concentrations (Table 2.4), in all areas within the impoundment except the Upper Severn Estuary zone (Figure 2.5) where suspended sediment concentrations are predicted to increase, especially upstream of Sharpness. In the longer term, within the impoundment a 90% reduction in suspended sediment concentrations is predicted (Table 2.4).

3.3.24 Reductions in concentration outside the B3 Brean Down to Lavernock Point Barrage are likely to be less than those experienced inside. The modelling (H&G Annex 12) suggests around a 60% reduction in suspended sediment concentrations (Table 2.4).

3.3.25 Short term suspended sediment modelling suggests that within the first two weeks after impoundment an additional 9.4Mtonnes of material previously suspended during spring tides would permanently settle (H&G Annex 12). Initially this might take up a volume of around 47Mm^3, consolidating over time to around 19Mm^3. Around 6.9Mtonnes of additional material is predicted to settle within the basin, mainly in the deep water channels all the way from the barrage to about Oldbury, though there is likely to be shallower deposition on lower intertidal areas as indicated on Figure 3.8b. Initially this might take up a volume of around 35Mm^3, consolidating over time to around 14Mm^3. Around 2.5Mtonnes of additional material is predicted to settle outside the barrage in the area offshore from Bridgwater Bay as shown in Figure 3.8b. Initially this might take up a volume of around 12.5Mm^3, consolidating over time to around 5Mm^3.

3.3.26 If around 9.4Mtonnes of suspended sediment settles within the first two weeks after the barrage becomes operational, the existing estimates of the suspended sediment resource suggest (H&G Annex 5) that more than half the available quantity has settled within this period, so the extent of future settlement is likely to be quite limited and the process would largely be complete within about another month. In practice some of these changes may well start to occur in the final stages of construction.

3.3.27 These predictions of future suspended sediment concentrations and short term settlement of sediment are of medium uncertainty.



a) Average spring tide concentration **b) Initial sedimentation**

Figure 3.8 **Spring tide concentration and areas of initial sedimentation with the B3 Brean Down to Lavernock Point Barrage (HR Wallingford)**

Long term changes to sand banks

3.3.28 The B3 Brean Down to Lavernock Point Barrage causes extensive reductions in velocity over the whole of the Severn Estuary and inner Bristol Channel. These large changes lead to a very high risk of change to the English and Welsh Grounds, Culver Sand and Nash Bank. The long term risk of change to Helwick Bank is also considered high because of the reductions in tidal velocities that are predicted for this area (H&G Annex 14).

3.3.29 The tidal forces helping to sustain the baseline profile of all these sand and gravel banks would diminish making them more sensitive to the wave conditions they experience. Wave conditions would not change in the case of the more distant Helwick and Hash Banks, though Culver Sand and the English and Welsh Grounds may experience complex changes in wave exposure as a result of the presence of the barrage and the changes in water levels.

3.3.30 By analogy with the assessment for Culver Sand, the dune systems that surround Bridgwater Bay and Weston Bay are considered likely to have a high risk of long term change as a result of the B3 Brean Down to Lavernock Point Barrage. This aspect has not been investigated in this strategic assessment but should be investigated if a more detailed assessment is carried out.

Long term accretion and erosion

3.3.31 The long term morphology modelling (H&G Annex 16) is very sensitive to the assumptions made about the availability of sediment from the Bristol Channel. The modelling predicts that 140 to 500Mm^3 of sediment may settle within the subtidal areas of the B3 Brean Down to Lavernock Point Barrage basin over 120 years. The predictions also suggest that 25 to 60Mm^3 of sediment may erode from the intertidal flats over this same period.

3.3.32 Although 140 to 500Mm^3 of sediment is predicted to be deposited within the subtidal waters behind the B3 Brean Down to Lavernock Point Barrage, the enclosed basin behind the barrage is so large that the average deposition in the seaward part of the Severn Estuary zone (Figure 2.5) is predicted to be 0.3 to 1.4m (H&G Annex 1), with a maximum of 0.3 to 0.5m of average deposition predicted for zones further from the barrage. This sediment is predicted to fill less than 10% of the available volume below the mean low water level on spring tides.

3.3.33 The average erosion of the intertidal foreshores predicted by the long term geomorphology modelling (H&G Annex 16) inside and outside the barrage over 120 years is sensitive to the assumptions on sediment supply. In the Severn Estuary zone, average erosion of the intertidal in the range 1.4 to 3.1m is predicted over 120 years (H&G Annex 1), if a substantial supply of sediment from the Bristol Channel is available. If these supplies of sediment are very limited, erosion of the Severn Estuary zone intertidal area is predicted to be in the range 0.5 to 1.3m over 120 years,

3.3.34 There is likely to be considerable local variability in the erosion experienced along these shorelines. The intertidal profile modelling (H&G Annex 15) seeks to explore this variability. Of the seven profiles tested; three eroded, two accreted and two showed little overall change. The single profile outside the B3 Brean Down to Lavernock Point Barrage also showed an eroding trend.

3.3.35 The predictions of long term changes to estuary morphology including sand banks and intertidal profiles have high uncertainty.

Water quality changes

3.3.36 The predicted reductions in suspended sediment would increase the water clarity. On spring tides, the assumed 90% reduction in sediment concentrations (Table 2.4) within the impoundment is unlikely to increase clarity sufficiently to permit substantial algal growth. However, on neap tides, this reduction in sediment concentrations might increase water clarity enough to allow enhanced algal growth for limited periods particularly in the Severn Estuary zone (Figure 2.5) near to the barrage. As there are sufficient nutrients to support primary productivity, the presence of the B3 Brean Down to Lavernock Point Barrage could increase the potential risk of eutrophication in the estuary.

3.3.37 Light penetration is likely to continue to be the limiting factor that restricts primary productivity in the estuary as suspended sediment concentrations would remain too high during much of the spring neap tidal cycle to allow nutrients to be fully utilised.

3.3.38 Any increase in primary productivity will lead to an increase in production of organic matter, which consumes dissolved oxygen when it decays. There is a risk that this would have a significant effect on dissolved oxygen concentrations, though the likelihood it will be realised remains uncertain.

3.3.39 The uncertainty in the prediction of long term suspended sediment concentrations makes it uncertain whether the increased risk would be translated into a regular occurrence of nuisance algal blooms within the basin. The uncertainty in the prediction of eutrophication risk is considered high.

3.3.40 The changes in water levels and flows associated with the B3 Brean Down to Lavernock Point Barrage are predicted to slightly reduce the salinity range experienced in the Severn Estuary as illustrated on Figure 3.9 for mean annual freshwater flow conditions of 105m^3/s in the River Severn. The modelling predicts a small increase in minimum salinity and a small reduction in maximum salinity as indicated in Figure 3.9. These changes are not considered significant in water quality terms in view of the natural variability of salinity at each point in the estuary (Severn Tidal Power 2009d and MWQ Annex 2).

3.3.41 In the upper Severn Estuary, during the average flow conditions illustrated on Figure 3.9, there is predicted to be around a 0.5km seaward movement of the 2PSU salinity contour. With a low flow of around 20m^3/s in the River Severn, the saline interface will move upstream. With the B3 Brean Down to Lavernock Point Barrage in operation, the saline interface is predicted to be about 2.5km further seaward than in the Baseline.

3.3.42 The predictions of water quality changes including salinity have medium uncertainty.

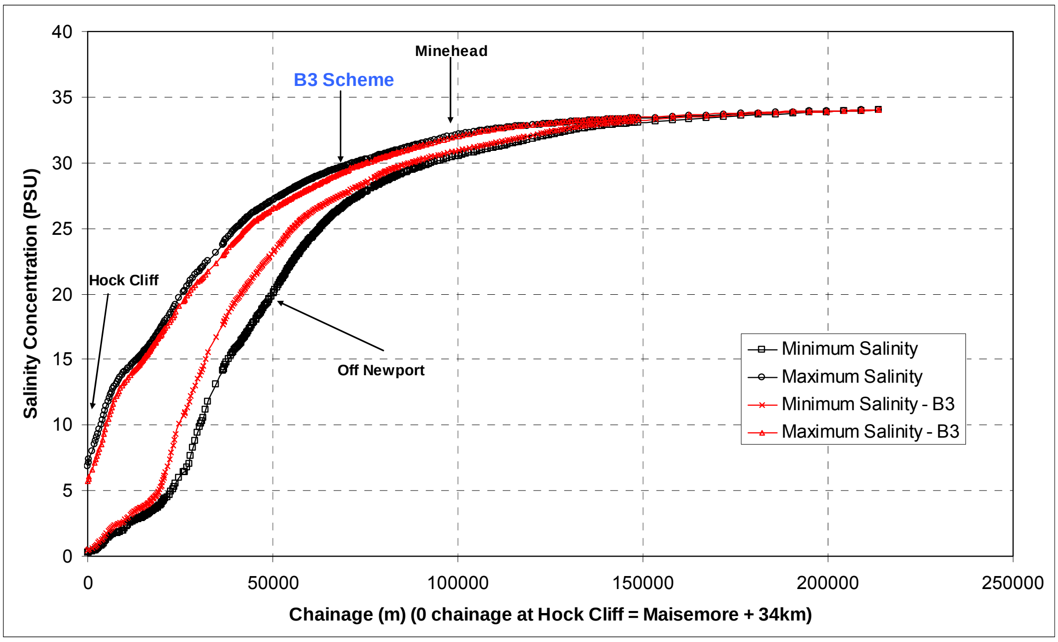


Figure 3.9 **Change in salinity range for mean annual flows for the B3 Brean Down to Lavernock Point Barrage**

Changes to flood risk and land drainage

3.3.43 Throughout the Severn Estuary and inner Bristol Channel, high water levels would reduce as a result of operating the B3 Brean Down to Lavernock Point Barrage so there is no adverse effect on tidal flood risk. The reduced high water levels would benefit around 89,000 properties in the tidal flood plain including 42 critical infrastructure assets by reducing the tidal flood risk to the whole estuary. The effects of the reduced tide levels within the impoundment are equivalent in some locations to over 100 years of sea level rise (Severn Tidal Power 2009e), while outside the barrage, the effects are equivalent to 55 to 75 years of sea level rise.

3.3.44 The increased spring tide water levels predicted for the west Wales coast would have an adverse effect on the standard of protection provided by existing sea defences to around 6,000 properties. The length of defences at risk is estimated to be in the range of 44-87km, with a best estimate of 58km at risk (Severn Tidal Power 2009e). The measures proposed to avoid or reduce this effect are discussed in section 5.

3.3.45 The raised low water level within the B3 Brean Down to Lavernock Point Barrage is predicted to adversely affect the drainage of around 372km^2 of low lying land alongside the estuary containing around 50,500 residential and commercial properties and 28 critical infrastructure assets (Severn Tidal Power 2009e). Low lying parts of Bristol and Newport containing around 13,100 residential and commercial properties and 4 critical infrastructure assets are within the areas affected by raised low water levels. The measures proposed to avoid or reduce this effect are discussed in section 5.

3.3.46 The peak flood levels within the Cardiff Bay barrage would not be raised as a result of the B3 Brean Down to Lavernock Point Barrage. Although estuary low water levels are raised by this option, high tide levels are reduced. Modelling of these changes predicted a reduction in peak flood levels within the Cardiff Bay Barrage during the evacuation of large fluvial floods (Severn Tidal Power 2009e).

3.3.47 Peak fluvial flood levels in the River Severn are predicted to be reduced by the operation of the B3 Brean Down to Lavernock Point Barrage. However, the main reduction is downstream of Epney and in that section of the estuary the tidal levels would be higher than the fluvial levels, in which case there is no additional benefit that can be attributed to the reduced fluvial levels (Severn Tidal Power 2009e).

3.3.48 There is predicted to be erosion of intertidal foreshores fronting the existing flood defences over 67 to 201km of the estuary within 120 years. This erosion is expected to start to adversely affect adjacent flood defences within 5 to 10 years of starting operation (Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5. As these predictions have high uncertainty a large range of effects and timings has been adopted.

Changes to freshwater environment

3.3.49 The B3 Brean Down to Lavernock Point Barrage is not expected to change the natural variation of salinity in the Avon and Parrett estuaries and cause minor changes in the Usk, Wye and Severn estuaries. In the modelling of the highest spring tides at times of low river flow the saline interface was predicted to move seaward by about 2km in the River Usk, 2.5km in the River Severn, and landward by about 0.5km in the River Wye. The changes are not considered significant (Severn Tidal Power 2010f and MWQ Annex 2) for abstraction for public water supply or other uses.

3.3.50 The raised mean sea levels behind the B3 Brean Down to Lavernock Point Barrage would raise groundwater levels alongside the estuary. This would lead to increased soil wetness over about 360km^2 (Severn Tidal Power 2010f) and degradation of the soil resource, but may be advantageous in the longer term in reducing the effects of climate change.

3.3.51 Raised groundwater levels may affect local infrastructure in communities close to the sea. Properties in parts of coastal Weston-super-Mare are likely to be affected, and other low lying urban areas could also be affected including parts of Cardiff, Newport, Caldicot, Avonmouth, Portishead and Clevedon.

3.3.52 The access to the Otter Hole cave system, a SSSI on the banks of the River Wye would be permanently submerged by the raised low water levels upstream of the B3 Brean Down to Lavernock Point Barrage. The western landfall of the barrage embankment would cause direct loss to the southernmost portion of the Penarth coast SSSI. Purton Passage, Lydney Cliff, Aust Cliff, Rhymney River Section, Portishead Pier to Black Nore, Flat Holm, Middle Hope and Brean Down SSSIs would experience loss of access to the lowermost geological exposures during barrage operation (Severn Tidal Power 2010f). Far field effects on tide levels in west Wales may have effects on low lying soft coastal geological and geomorphological features.

Alternative Option B4: Shoots Barrage

3.3.53 The B4 Shoots Barrage impounds the Severn Estuary upstream of the narrow channel known as The Shoots close to the M4 Severn Bridge and the Severn rail tunnel. The impounded basin includes the estuaries of the rivers Wye and Severn.

Water level changes

3.3.54 The operation of the B4 Shoots Barrage would not change spring tide high water levels at Sharpness but raise spring tide low water levels by 3.3m within the impounded basin as shown on Figure 3.10b. On neap tides there would be little reduction in high water level but the increase in low water level would be 1.6m.

3.3.55 The extent of the intertidal foreshore in zones 2 to 5 of the Inner Bristol Channel and Severn Estuary (Figure 2.5) is predicted to reduce by 10% or 11% (Severn Tidal Power 2010c or 2010h) as a result of the B4 Shoots Barrage.

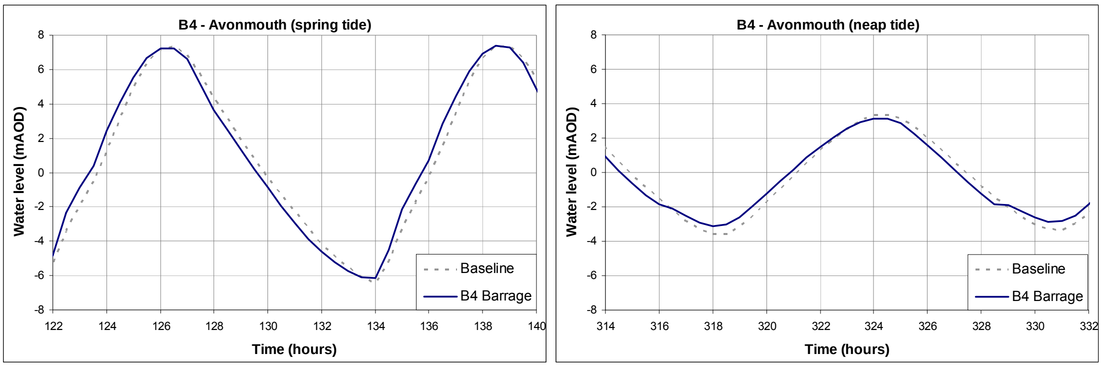
3.3.56 The shape of the tide curve within the impounded basin at Sharpness, which is shown on Figure 3.10b for typical spring and neap tides, would feature a slower rise of the tide than occurs in the baseline, with a prolonged high water stand of two hours on spring tides extending to four hours on neap tides and a steady rate of fall in tide level that would not change between spring and neap tides. The effect of this would be that on spring tides, the tide falls more slowly than the baseline while on neap tides, it falls at a similar rate. A noticeable feature of the tides within the basin evident in Figure 3.10b is that the low water level on spring tides at Sharpness would be around 2m higher than the neap tide low water level. This is a larger difference than experienced at present in the estuary where the spring tide low water level is around 0.2m higher than neap tide low water level.

3.3.57 Outside the B4 Shoots Barrage, high tide levels at Avonmouth illustrated on Figure 3.10a are similar to the baseline, but from Newport to Minehead, spring high water levels and tidal ranges are up to 0.2m higher than baseline as shown on Table 3.1. Neap high tides and low tide levels are similar to the baseline at all ports from Newport to Burnham.

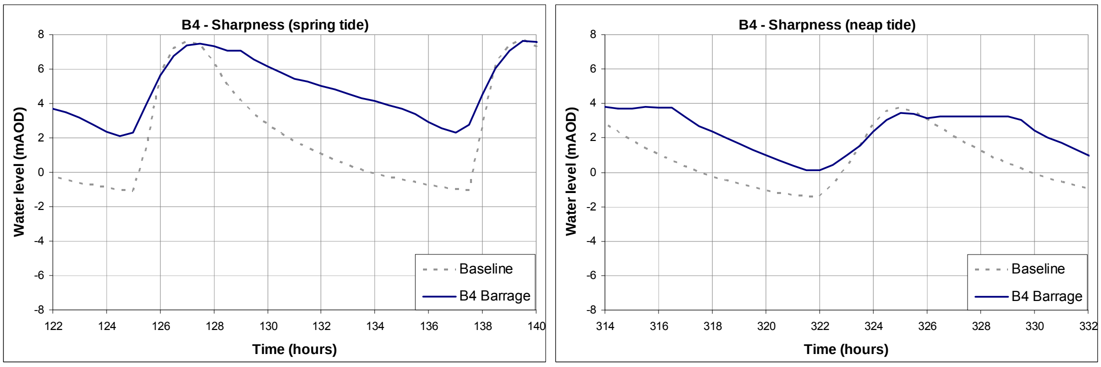
3.3.58 Predictions of the changes in water levels due to the B4 Shoots Barrage are considered reliable with a high degree of certainty.

3.3.59 Far field effects at high tide of the B4 Shoots Barrage shown on Figure 3.11 indicate that changes to high water levels would be less than 0.05m west of Swansea.

Around the west Wales, Irish and Cornish coasts spring high water levels are also generally changed by less than 0.05m. There is an isolated area around the Llŷn peninsular where the model predicts a change of more than 0.1m. This change affects a short length of coastline and since the magnitude is close to the limit of measurable effects, it is not considered significant. (Severn Tidal Power, 2010c and H&G Annex 8).



a) **Typical spring tide outside** **Typical neap tide outside**



b) **Typical spring tide inside** **Typical neap tide inside**

Figure 3.10 Water levels inside and outside the B4 Shoots Barrage

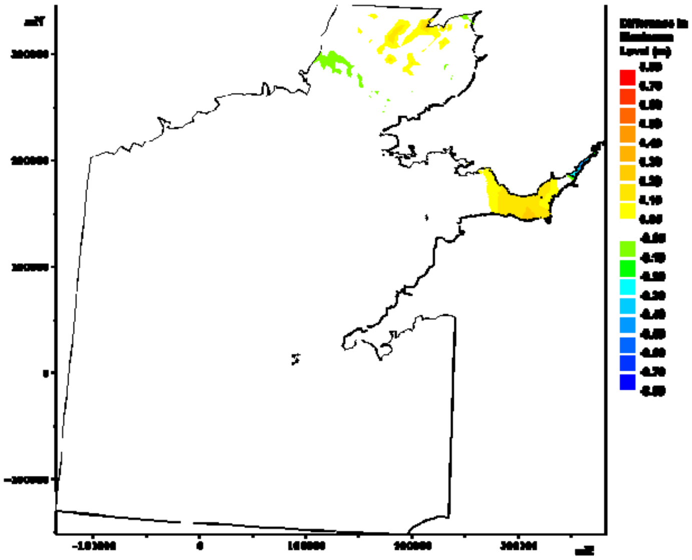


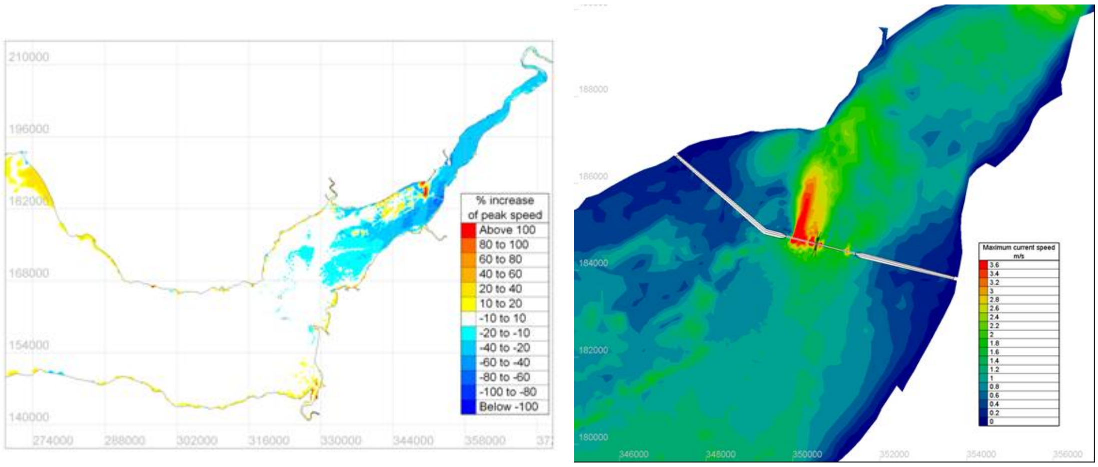
Figure 3.11 **Far field effects associated with the B4 Shoots Barrage (HR Wallingford)**

Changes in water velocities

3.3.60 The changes in peak water velocity associated with the B4 Shoots Barrage are shown in Figure 3.12a. Within most of the impounded basin and also in the estuary outside as far as approximately Clevedon, there is a general 20-40% reduction in maximum velocities with general decreases of more than 40% predicted between Avonmouth and Severn Beach near the English shore. In the outer Severn Estuary south of Sand Point, reductions in peak velocity are generally less than 10%. In low velocity areas in Bridgwater Bay and Swansea Bay local increases of 10-40% are predicted.

3.3.61 Maximum velocities close to the B4 Shoots Barrage are shown in Figure 3.12b. The area of high velocities exceeding 3.5m/s north of the barrage is particularly notable. This is in the discharge jet from the sluices and turbines and implies shallow flows as the basin starts to refill over areas where the bed level is high. Figure 3.12a indicates that the velocities in this area would approximately double. Mapping suggests these areas of high velocity are where gravels overlie bedrock.

3.3.62 The predicted changes in water velocity have a high degree of certainty except in areas where high velocities are predicted over mobile sediments. In these areas, scour would reduce velocities over a relatively short time period to magnitudes where erosion and accretion are in broad balance.



a) changes in peak velocity **b) Peak velocities on a large spring tide**

Figure 3.12 Peak water velocities due to the B4 Shoots Barrage (HR Wallingford)

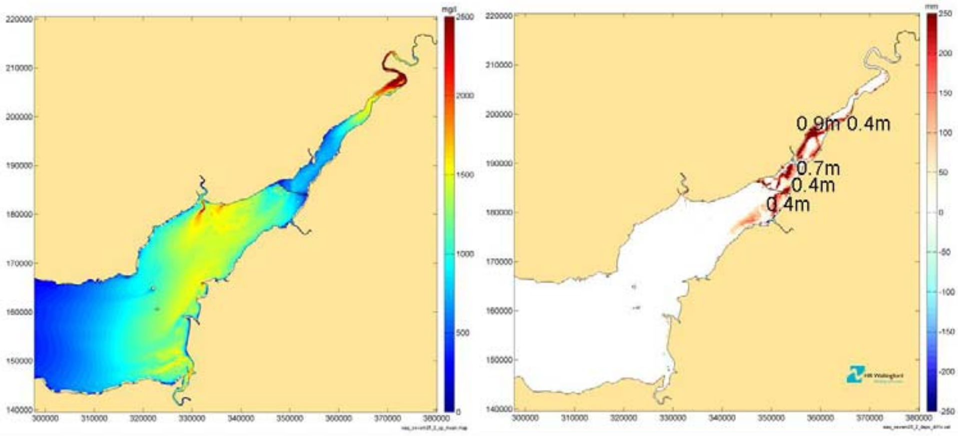
Short term changes in suspended sediment and bed levels

3.3.63 The introduction of the B4 Shoots Barrage would have an important effect on the baseline concentrations of suspended sediments in the Severn Estuary. The changes in suspended sediment concentration are indicated by comparing the predictions of spring tide concentrations for baseline conditions on Figure 3.2b with those including the B4 Shoots Barrage in Figure 3.13a. Within the B4 Shoots Barrage basin, the modelling predicts that the widespread reduction in velocities would lead to a 60 to 70% reduction in average neap tide concentrations (Table 2.4), within the impoundment, except in the estuary upstream of Sharpness where an increased concentration of suspended sediment is predicted. In the longer term, within the impoundment a 90% reduction in suspended sediment concentrations has been adopted (Table 2.4).

3.3.64 Outside the B4 Shoots Barrage, the sediment modelling illustrated by Figure 3.13a predicts a reduction in suspended sediment concentrations of up to 65% in the Portishead and Avonmouth areas, but a 10-30% reduction in the outer part of the Severn Estuary zone (H&G Annex 12). In the longer term, a maximum reduction of 80% in suspended sediment concentration has been adopted for the Portishead and Avonmouth area.

3.3.65 Short term suspended sediment modelling suggests that within the first month after impoundment around 1.3Mtonnes of material previously suspended during spring tides would permanently settle within the B4 Shoots Barrage impoundment (H&G Annex 12). Initially this might take up a volume of around 6.5Mm^3, consolidating over time to around 2.5Mm^3. An additional 0.9Mtonnes is expected to settle outside the B4 Shoots Barrage, primarily in the channels between the barrage and Portishead. Initially this might take up a volume of around 4.5Mm^3, consolidating over time to around 1.8Mm^3. The locations within and outside the barrage where this settlement is anticipated are shown on Figure 3.13b. In practice some of these changes may well start to occur in the final stages of construction.

3.3.66 These predictions of future suspended sediment concentrations and short term settlement of sediment are of medium uncertainty.



a) Average spring tide concentration **b) Initial sedimentation**

Figure 3.13 **Spring tide concentration and areas of initial sedimentation with the B4 Shoots Barrage (HR Wallingford)**

Long term changes to sand banks

3.3.67 The B4 Shoots Barrage leads to a high risk of change to the English and Welsh Grounds, and a medium risk of long term change to Culver Sand and Nash Bank. The risk of change to Helwick Bank is considered small (H&G Annex 14).

3.3.68 By analogy with the assessment for Culver Sand, the dune systems that surround Bridgwater Bay and Weston Bay are considered likely to have a medium risk of long term change as a result of the B4 Shoots Barrage. This aspect has not been investigated in this strategic assessment but should be considered further if a more detailed assessment is carried out.

Long term accretion and erosion

3.3.69 The river Severn and Wye contributes around 0.5Mtonnes/year of sediment to the estuary, around 70% of the total sediment input (H&G Annex 5). This sediment enters the estuary upstream of the B4 Shoots Barrage, and the majority is likely to be trapped by the barrage.

3.3.70 The long term morphology modelling (H&G Annex 16) predicts that around 300Mm^3 of sediment would settle within the subtidal area of the B4 Shoots Barrage over 120 years. The rate of accretion is initially predicted to be around 4Mm^3/year, but to decline to 2Mm^3/year after year 50. This is expected to fill almost two thirds of the total volume available below the level of mean low water of spring tides. The accretion in the section between the barrage and the River Wye confluence is expected to be more rapid and is predicted to fill two thirds of the available volume in this area within around 70 years. Thereafter, there is the likelihood that some of the sediments would settle in intertidal areas and reduce the volume of water that can be stored behind the B4 Shoots Barrage at high tide.

3.3.71 In addition to the long term accretion, there is a possibility of 20 to 30Mm^3 of accretion arising from settlement of a portion of the present estuary suspended load within the B4 Shoots Barrage in the first few years of operation.

3.3.72 The long term morphology modelling predicts erosion of the intertidal foreshores upstream of the B4 Shoots Barrage eroding a predicted 1.5 to 2m of material off the intertidal foreshores between the barrage and the River Wye confluence. This erosion, however, contributes less than 5% of the sediment that is predicted to accumulate in the channels. As the subtidal volume fills with sediment, the distinction between subtidal erosion and subtidal accretion is likely to become less clear cut with accretion dominating the processes in most areas.

3.3.73 The evolution over 120 years of two specific intertidal profiles was modelled within the B4 Shoots Barrage. On one profile, accretion of around 0.6m over the whole intertidal was predicted; on the other, 1m of erosion was predicted over most of the foreshore, though some accretion was predicted close to low water level (H&G Annex 15).

3.3.74 Outside the B4 Shoots Barrage the long term morphology modelling (H&G Annex 16) predicts relatively small changes over the 120 year life of this option. The subtidal areas within the study area are predicted to change by ±0.1m. Intertidal areas outside the impoundment are predicted to change in average level by up to ±0.6m over 120 years, with erosion and accretion predicted in separate areas.

3.3.75 The intertidal profile modelling of sites outside the B4 Shoots Barrage (H&G Annex 15) predicted overall erosion of 0.9m at Woodhill Bay on the English shore especially on the upper intertidal foreshore and overall accretion of 0.2m at Wentlooge on the Welsh shore with accretion of the lower foreshore. The majority of these changes were predicted to occur within 5 years and the profiles stabilised within 20 years, No changes were predicted at the other two profiles that were modelled further away from the barrage. Apart from the profile where major erosion is predicted, these changes in foreshore level are consistent with the predictions of the long term estuary modelling (H&G Annex 16).

3.3.76 The predictions of long term changes to estuary morphology including sand banks and intertidal profiles have high uncertainty.

Water quality changes

3.3.77 The predicted reductions in suspended sediment concentration would increase the water clarity. However, as the B4 Shoots Barrage impounds the most turbid part of the estuary where the baseline suspended sediment concentrations exceed 1000mg/l on neap tides (Figure 3.1), the assumed 90% reduction in sediment concentrations (Table 2.4) within this impoundment is unlikely to increase clarity sufficiently to permit substantial algal growth. Although the adopted maximum percentage reduction in sediment concentrations outside the B4 Shoots Barrage is lower (Table 2.4) than inside, the baseline sediment concentration is also lower. These concentrations are predicted to remain too high to permit substantial algal growth.

3.3.78 While the reduced suspended sediment concentrations may allow some increased primary productivity, strong light limitation will continue to prevent full utilisation of the available nutrients. There may be some reduction of nutrient concentrations compared to the baseline especially during spring and summer, but nutrient concentration would generally be expected to remain high (Severn Tidal Power 2010d and MWQ Annex 6).

3.3.79 The uncertainty in the prediction of long term suspended sediment concentrations makes it uncertain how much the risk of eutrophication will increase within the estuary. The uncertainty in the prediction of the eutrophication risk is therefore considered high.

3.3.80 There is a risk that some of the sediment that settles upstream of the B4 Shoots Barrage may be contaminated and lead to a localised risk of increased concentrations of contaminants in some sediment deposits.

3.3.81 Changes in water levels and flows associated with the B4 Shoots Barrage are predicted to slightly reduce the salinity range experienced in the Severn Estuary as illustrated on Figure 3.14 for mean annual freshwater flow conditions of 105m^3/s in the River Severn. The modelling predicts a small increase in minimum salinity and a small reduction in maximum salinity. These changes are not considered significant in water quality terms in view of the natural variability of salinity at each point in the estuary (Severn Tidal Power 2009d and MWQ Annex 2).

3.3.82 In the upper Severn Estuary, during the average flow conditions illustrated on Figure 3.14, there is not predicted to be any movement of the 2PSU salinity contour. With a low flow of around 20m^3/s in the River Severn, the saline interface will move upstream. With the B4 Shoots Barrage in operation, the saline interface is predicted to be about 1km further seaward than in the Baseline.

3.3.83 The predictions of water quality changes including salinity have medium uncertainty.

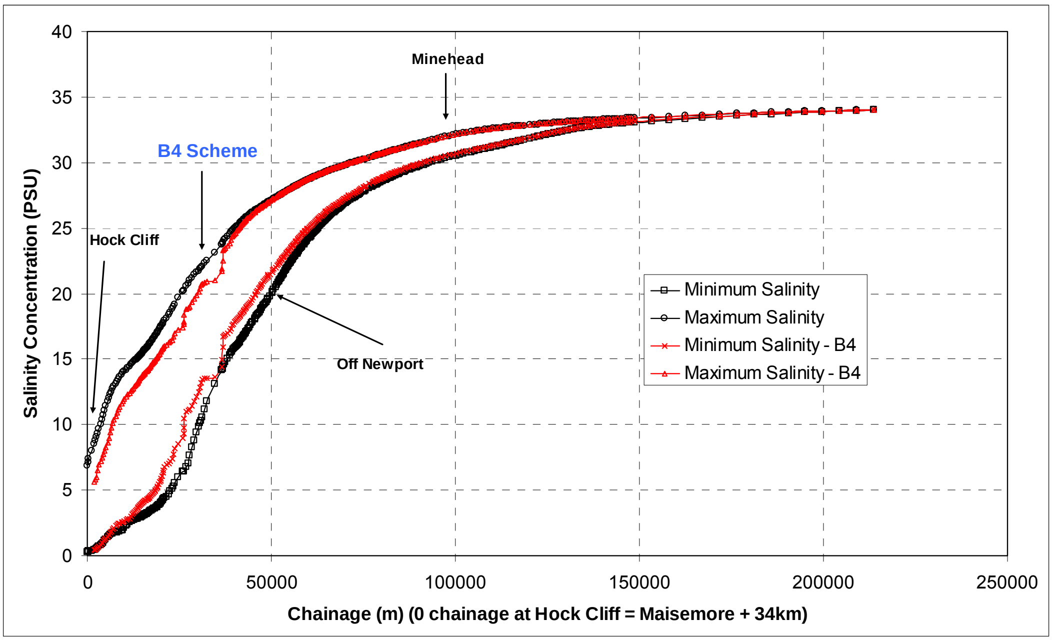


Figure 3.14 Change in salinity range for mean annual flows for the B4 Shoots Barrage

Changes to flood risk and land drainage

3.3.84 The rise in high tide levels outside the B4 Shoots Barrage is likely to have an adverse effect on the standard of protection provided by 62 km of flood defence. This effect is discussed in more detail in the Flood Risk and Land Drainage Topic Paper (Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5.

3.3.85 Within the impoundment of the B4 Shoots Barrage, and for a short distance outside, high water levels would reduce. The reduced high water levels are not however estimated to reduce the tidal flood risk sufficiently to allow a delay in the raising of flood defences that would otherwise be required to combat the effects of rising sea levels (Severn Tidal Power 2010e).

3.3.86 The raised low water levels within the B4 Shoots Barrage is predicted to adversely affect the drainage of $97km^2$ of low lying land alongside the estuary containing around 2400 residential and commercial properties and three items of critical infrastructure (Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5.

3.3.87 There are not predicted to be any significant differences in peak fluvial flood levels within the River Severn immediately following commissioning of the B4 Shoots Barrage. The effect on fluvial flood evacuation of the subtidal siltation predicted within this basin requires further investigation if more detailed studies of this option are proposed.

3.3.88 There is predicted to be erosion of intertidal foreshores fronting the existing flood defences, which would affect 36 to 109km of estuary defences within 120 years. This erosion may start to adversely affect adjacent flood defences within about 5 years of starting operation (Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5. As these predictions have high uncertainty a large range of effects and timings has been adopted.

Changes to freshwater environment

3.3.89 The B4 Shoots Barrage is not expected to change the natural variation of salinity in the Usk, Avon and Parrett estuaries and cause minor changes in the Wye and Severn estuaries. In the modelling of the highest spring tides at times of low river flows the saline interface was predicted to move seaward by about 1km in the River Severn and landward by about 1km in the River Wye. The changes are not considered significant (Severn Tidal Power 2010f and MWQ Annex 2) for abstraction for public water supply or other uses.

3.3.90 The raised mean sea levels behind the B4 Shoots Barrage would raise groundwater levels alongside the estuary. This would lead to increased soil wetness over about $90km^2$ (Severn Tidal Power 2010f) and degradation of the soil resource, but may be advantageous in the longer term in reducing the effects of climate change.

3.3.91 The access to the Otter Hole cave system, a SSSI on the banks of the River Wye would be permanently submerged by the raised low water levels upstream of the B4 Shoots Barrage. Purton Passage, Lydney Cliff and Aust Cliff SSSIs would experience loss of access to the lowermost geological exposures during barrage operation (Severn Tidal Power 2010f).

Alternative Option B5: Beachley Barrage

3.3.92 The B5 Beachley Barrage is the most upstream of all the alternative options, impounding the estuary of the River Severn but none of the other rivers.

Water level changes

3.3.93 High water levels upstream of this option at Sharpness are predicted to reduce by 0.2 to 0.5m as shown on Figure 3.15b. Tidal range would reduce by 50% immediately upstream of the barrage at Beachley, but by lesser amounts at Oldbury and Sharpness (H&G Annex 1) because of the naturally rising baseline low water level.

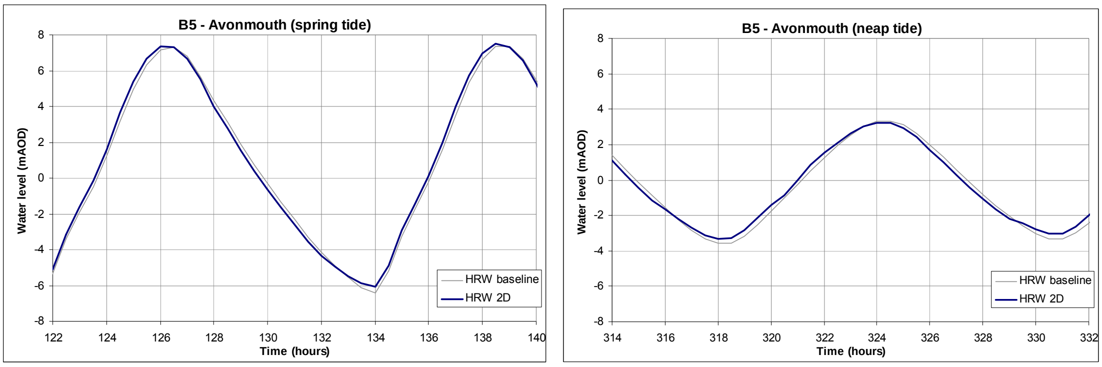
3.3.94 The extent of the intertidal foreshore in zones 2 to 5 of the Inner Bristol Channel and Severn Estuary (Figure 2.5) is predicted to reduce by 9% (Severn Tidal Power 2010c and 2010h) as a result of the B5 Beachley Barrage.

3.3.95 Downstream of the B5 Beachley Barrage, high water levels and the spring tidal range are predicted to be 0.1m higher at Avonmouth, and increase by up to 0.2m further downstream (Table 3.1). West of a line joining Aberthaw and Minehead changes in high water levels and tidal range are predicted to be less than 0.05m (H&G Annex 8).

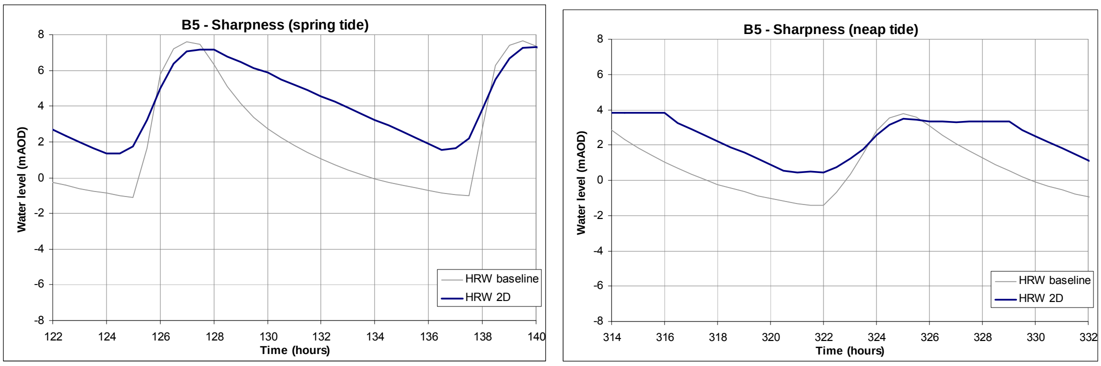
3.3.96 Low water levels upstream of the B5 Beachley Barrage at Sharpness would rise to +1.5mOD on spring tides and +0.3m on neap tides as shown on Figure 3.15b. This is a rise of 2.7m on spring tides and 1.7m on neap tides (Severn Tidal Power 2010g). There would also be a significant change in the shape of the tide curve, which would lengthen the duration of the high water period and considerably reduce the time when water levels are low. Seaward of the B5 Beachley Barrage, the changes in low water level and tide shape would be relatively small as illustrated in Figure 3.15a.

3.3.97 Predictions of the changes in water levels due to the B5 Beachley Barrage are considered reliable with a high degree of certainty.

3.3.98 The high water far field effects of the B5 Beachley Barrage shown on Figure 3.16 indicate that changes to high water levels would be less than 0.05m west of Minehead. Around the west Wales, Irish and Cornish coasts spring high water levels are also generally changed by less than 0.05m. There is an isolated area around the Llŷn peninsular where the model predicts a change of more than 0.1m. This change affects a short length of coastline and since the magnitude is close to the limit of measurable effects, it is not considered significant. (Severn Tidal Power, 2010c and H&G Annex 8).



a) Typical spring tide outside Typical neap tide outside



b) Typical spring tide inside Typical neap tide inside

Figure 3.15 Water levels upstream and downstream of the B5 Beachley Barrage

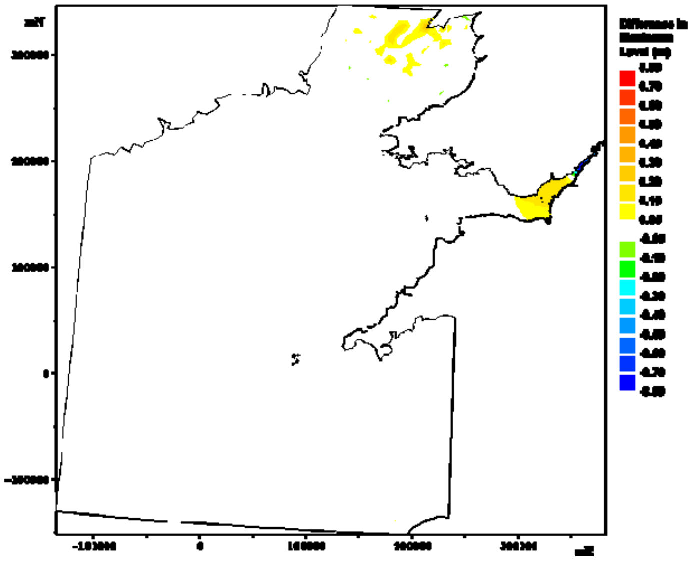


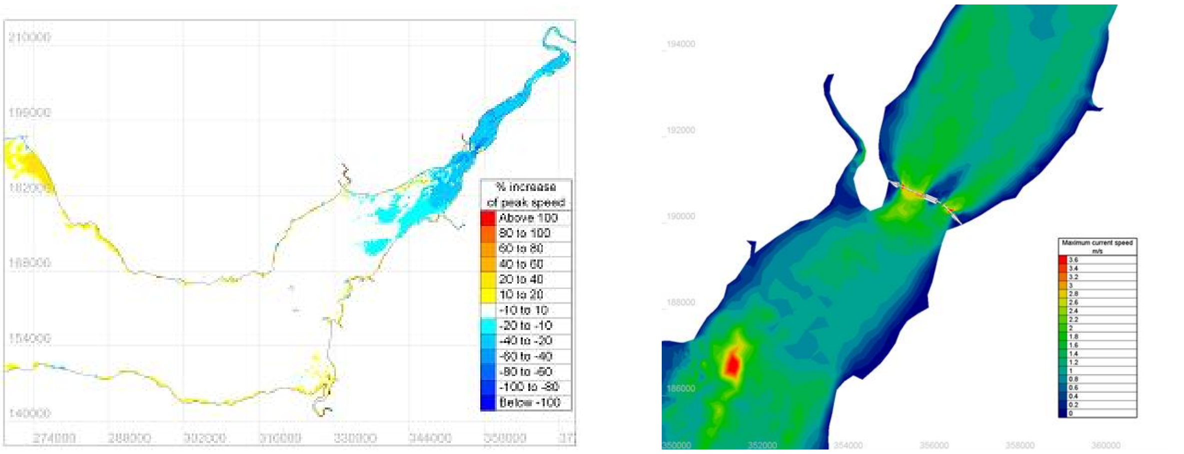
Figure 3.16 Far field effects associated with the B5 Beachley Barrage (HR Wallingford)

Changes in water velocities

3.3.99 The changes in peak water velocity associated with the B5 Beachley Barrage are shown in Figure 3.17a over the whole of the Severn Estuary and Inner Bristol Channel. Reductions in velocity are greater than 10% north of Cleveden. Further seaward there are local increases of 10-20% in the smaller velocities that are found close to the coast and across the intertidal areas of Bridgwater Bay and Swansea Bay. These localised increases are considered likely to have a small effect on sedimentary processes.

3.3.100 In the vicinity of the B5 Beachley Barrage, there is a predicted area of velocities exceeding 3m/s at the northern end of The Shoots channel as indicated on Figure 3.17b. This area of high velocity occurs during the turbine discharge at low tide and arises because of the small size of the channel and causes a rise in low water levels immediately downstream of the B5 Beachley Barrage. Ensuring this channel is correctly represented would be an important component if further modelling of this option occurs.

3.3.101 The predicted changes in water velocity have a high degree of certainty except in narrow channels with high discharges where the confidence is only moderate unless steps are taken to ensure the model mesh correctly reproduces the local bathymetry.



a) changes in peak velocity **b) Peak velocities on a large spring tide**

Figure 3.17 Peak water velocities due to the B5 Beachley Barrage (HR Wallingford)

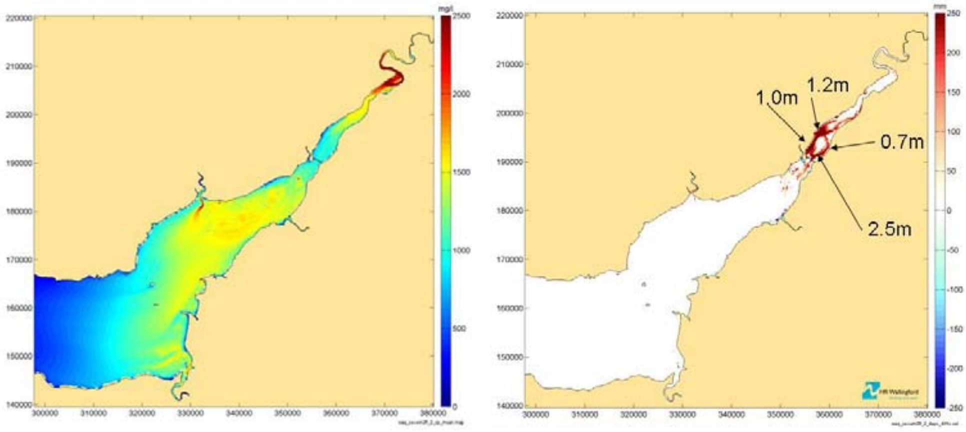
Short term changes in suspended sediment and bed levels

3.3.102 The introduction of the B5 Beachley Barrage would interrupt the existing ebb and flood motion of suspended sediments in the Severn Estuary and tend to trap a proportion of this sediment in the lower velocity zone upstream of the structure where sediment is less likely to erode and pass out of the basin on the ebb tide after settling at high slack water. The modelling predicts that the widespread reduction in velocities would lead to a 60 to 70% reduction in average neap tide concentrations (Table 2.4) within the impoundment, except in the estuary upstream of Sharpness where an increased concentration of suspended sediment is predicted. In the longer term, within the impoundment a 90% reduction in suspended sediment concentrations has been adopted (Table 2.4).

3.3.103 Outside the B5 Beachley Barrage, the sediment modelling illustrated by Figure 3.18a predicts a reduction in suspended sediment concentrations of up to 55% on neap tides in the Avonmouth areas, but a reduction of 20-40% further downstream.

3.3.104 Short term suspended sediment modelling suggests that within the first two weeks after impoundment around 1.3Mtonnes of material previously suspended during spring tides would permanently settle within the basin (H&G Annex 12). Initially this might take up a volume of around 6.5Mm^3, consolidating over time to around 2.5Mm^3.The behaviour during the following months has not been modelled, but some further material seems likely to settle from the supply in suspension outside the basin until a new equilibrium is reached. The locations within the basin where this settlement is anticipated are shown on Figure 3.18b. This figure also shows that immediate settlement is expected in the section between the structure and The Shoots. In practice some of these changes may well start to occur in the final stages of construction.

3.3.105 These predictions of future suspended sediment concentrations and short term settlement of sediment are of medium uncertainty.



a) Average spring tide concentration **b) Initial sedimentation**

Figure 3.18 Spring tide concentration and areas of initial sedimentation with the B5 Beachley Barrage (HR Wallingford)

Long term changes to sand banks

3.3.106 The sand and gravel banks of English Grounds and Welsh Grounds are considered to have a medium risk of long term change as a result of the B5 Beachley Barrage. The risk of change to Culver Sand, Nash Bank and Helwick Bank is considered low (H&G Annex 14).

3.3.107 By analogy with the assessment for Culver Sand, the dune systems that surround Bridgwater Bay and Weston Bay are considered likely to have a low risk of long term change as a result of the B5 Beachley Barrage. This aspect has not been investigated in this strategic assessment but should be considered further if a more detailed assessment is carried out.

Long term accretion and erosion

3.3.108 The River Severn contributes around 40% of the total sediment input to the estuary (H&G Annex 6). This sediment enters the estuary upstream of the B5 Beachley Barrage, and the majority is likely to be trapped by the barrage. The long term morphology modelling (H&G Annex 16) predicts that around 150Mm^3 of sediment would settle in the basin over 120 years in the subtidal zone. The rate of accretion is initially predicted to be around 2Mm^3/year, but is predicted to slow after 50 years once around 100Mm^3 of sediment has been deposited, which is expected to raise the average level of the subtidal area by around 2m. The areas where initial settlement occurs are likely to be similar to those shown on Figure 3.18b. Accretion in the shipping channel is likely to adversely affect navigation to Sharpness within a few years.

3.3.109 As the volume upstream of the B5 Beachley Barrage below the future MLWS level is calculated to be 173Mm^3, the predicted accretion would fill two thirds of this volume after around 70 years and around 90% of the available volume by 120 years. As MLWN is lower than MLWS, it is anticipated that the live storage of this basin may begin to reduce sometime around 50 years after commissioning.

3.3.110 The subtidal deposition may be enhanced by a small volume of erosion from the intertidal areas within the basin. This erosion is expected to lower average intertidal levels within the basin by less than 0.5m over 120 years.

3.3.111 Outside the B5 Beachley Barrage the long term morphology predictions (H&G Annex 16) anticipate accretion of around 60Mm^3 of sediment between the barrage and The Shoots causing a 1.5 to 2m increase in average bed levels over 120 years. The spatial distribution of this accretion would vary, with the turbine discharge channel likely to remain sufficiently free of sediment to allow discharge but with greater accumulations in other areas. The areas at most risk of accretion are indicated on Figure 3.18b.

3.3.112 Further downstream predicted changes are relatively small, being less than ±0.5m over the remainder of the Severn Estuary and Inner Bristol Channel.

3.3.113 The modelling of the evolution of specific intertidal profiles suggested some local changes, especially in the first 20 years (H&G Annex 15). At Welsh Grounds the modelling suggested erosion of up to 1.5m on the upper intertidal over 10 years though the length of this profile was not changed. On the English shore at Severn Beach overall erosion of 3.2m was predicted with more than 6m of erosion of the upper intertidal foreshore predicted especially in the first 20 years. At the other sites the B5 Beachley Barrage is predicted to cause little change to profile lengths or levels. The erosion predicted at Welsh Grounds and Severn Beach differs from the accretion predicted by the long term morphology model in this area indicating the inherent uncertainty in long term morphology predictions.

3.3.114 The detailed predictions of long term morphology changes are considered uncertain. However, the direction of the major changes is clear and certain. There is a high likelihood that there would be considerable accretion upstream of the B5 Beachley Barrage and between this structure and The Shoots, with the likelihood that the live storage volume of the basin would begin to diminish during the 120 year design life of this option.

3.3.115 The predictions of long term changes to estuary morphology including sand banks and intertidal profiles have high uncertainty.

Water quality changes

3.3.116 The predicted reductions in suspended sediment concentration would increase the water clarity. However, as the B5 Beachley Barrage impounds the most turbid part of the estuary where the baseline suspended sediment concentrations exceed 1000mg/l on neap tides (Figure 3.1), the assumed 90% reduction in sediment concentrations (Table 2.4) within this impoundment is unlikely to increase clarity sufficiently to permit substantial algal growth. Although the adopted maximum percentage reduction in sediment concentrations outside the B5 Beachley Barrage is lower (Table 2.4) than inside, the baseline sediment concentration is also lower. These concentrations are predicted to remain too high to permit substantial algal growth.

3.3.117 While the reduced suspended sediment concentrations may allow some increased primary productivity, strong light limitation will continue to prevent full utilisation of the available nutrients. There may be some reduction of nutrient concentrations compared to the baseline especially during spring and summer, but nutrient concentration would generally be expected to remain high (Severn Tidal Power 2010d and MWQ Annex 6).

3.3.118 The uncertainty in the prediction of long term suspended sediment concentrations makes it uncertain how much the risk of eutrophication will increase within the estuary. The uncertainty in the prediction of the eutrophication risk is therefore considered high.

3.3.119 There is a risk that some of the sediment that settles upstream of the B5 Beachley Barrage may be contaminated and lead to a localised risk of increased concentrations of contaminants in some sediment deposits

3.3.120 Changes in water levels and flows associated with the B5 Beachley Barrage are predicted to slightly reduce the salinity range experienced in the Severn Estuary as illustrated on Figure 3.19 for mean annual freshwater flow conditions of 105m^3/s in the River Severn. The modelling predicts a small increase in minimum salinity and a small reduction in maximum salinity. These changes are not considered significant in water quality terms in view of the natural variability of salinity at each point in the estuary (Severn Tidal Power 2009d and MWQ Annex 2).

3.3.121 In the upper Severn Estuary, during the average flow conditions illustrated on Figure 3.19, there is predicted to be a 1km seaward movement of the 2PSU salinity contour. With a low flow of around 20m^3/s in the River Severn, the saline interface will move upstream. With the B5 Beachley Barrage in operation, the saline interface is predicted to be about 3km further seaward than in the Baseline.

3.3.122 The predictions of water quality changes including salinity have medium uncertainty.

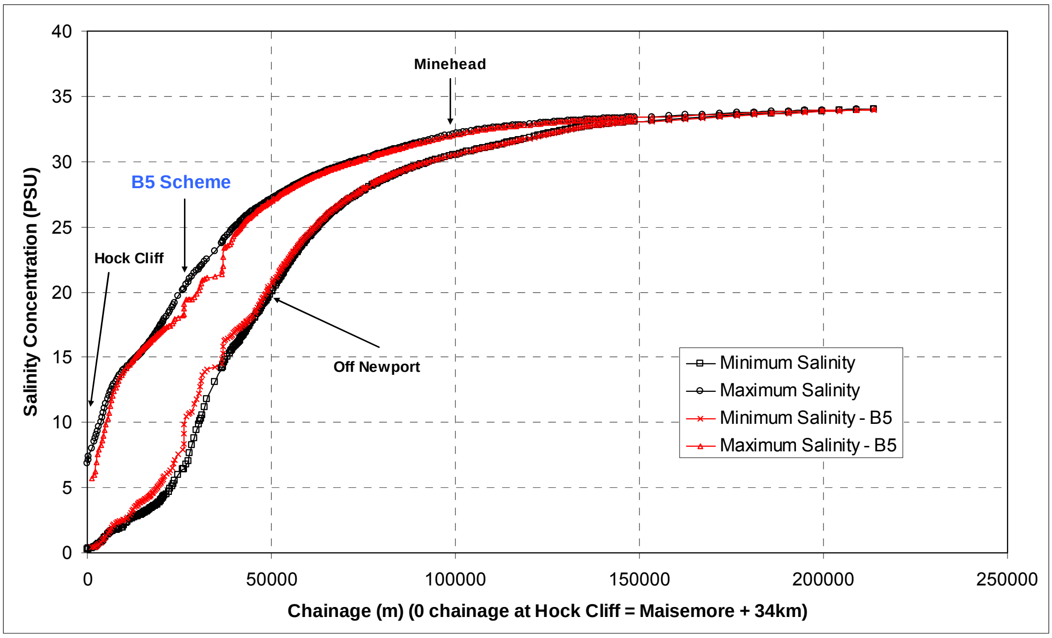


Figure 3.19 Change in salinity range for mean annual flows for the B5 Beachley Barrage

Changes to flood risk and land drainage

3.3.123 The rise in high tide levels outside the B5 Beachley Barrage is likely to have an adverse effect on the standard of protection provided by about 97 km of flood defence (Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5.

3.3.124 Within the impoundment of the B5 Beachley Barrage, and for a short distance outside, high water levels would reduce. The reduced high water levels are not however considered to reduce the tidal flood risk sufficiently to allow a delay in the raising of flood defences that would otherwise be required to combat the effects of rising sea levels (Severn Tidal Power 2010e).

3.3.125 The raised low water levels upstream of the B5 Beachley Barrage are predicted to adversely affect the drainage of 73km^2 of low lying land alongside the estuary containing around 1000 residential and commercial properties (Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5.

3.3.126 There is not predicted to be any significant difference in peak fluvial flood levels within the River Severn immediately following commissioning of the B5 Beachley Barrage. The effect on fluvial flood evacuation of the subtidal siltation predicted within this basin would require further investigation if more detailed studies of this option are proposed.

3.3.127 There is predicted to be erosion of 8 to 23 km of intertidal foreshores fronting the existing flood defences downstream of the barrage within 5 years of commissioning of the B5 Beachley Barrage. Erosion of around 41km of foreshore is also predicted upstream of the barrage, but as the rates upstream of he barrage are relatively slow, this is unlikely to become an issue until around 100 years after commissioning

(Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5. As these predictions have high uncertainty a large range of effects and timings has been adopted.

Changes to freshwater environment

3.3.128 The B5 Beachley Barrage is not expected to change the natural variation of salinity in the main sub-tributaries which are all outside the impoundment. In the modelling of the highest spring tides at times of low river flows the saline interface within the River Severn was observed to move seaward by about 3km. The changes are not considered significant (Severn Tidal Power 2010f and MWQ Annex 2) for abstraction for public water supply or other uses

3.3.129 The raised mean sea levels behind the B5 Beachley Barrage would raise groundwater levels alongside the estuary. This would lead to increased soil wetness over about 73km^2 (Severn Tidal Power 2010f) and degradation of the soil resource, but may be advantageous in the longer term in reducing the effects of climate change.

3.3.130 The eastern landfall of the B5 Beachley Barrage embankment is close to the Aust Cliff SSSI which is at risk of suffering some permanent direct loss of its lowermost exposures during barrage construction. . Purton Passage, Lydney Cliff and Aust Cliff SSSIs would experience loss of access to the lowermost geological exposures during barrage operation (Severn Tidal Power 2010f).

Alternative Option L2: Welsh Grounds Lagoon

3.3.131 The L2 Welsh Grounds Lagoon encloses a large mainly intertidal area on the Welsh side of the Severn estuary between the rivers Usk and Wye. The lagoon itself does not impound any of the principal rivers that drain to the Severn estuary, though it receives drainage from the low lying hinterland of the Caldicot levels.

Water level changes

3.3.132 High water levels within the lagoon are predicted to be similar over the whole lagoon area at a level similar to the baseline level at Newport and 0.4m below the baseline level at Avonmouth. This is in contrast to the baseline where high water levels rise along the shore of the Caldicot Level (Severn Tidal Power 2010g). Tidal range would be reduced by 50% inside the lagoon, though this reduction would only be fully experienced in the small portion of the lagoon that remains covered at low tide.

3.3.133 The extent of the intertidal foreshore in zones 2 to 5 of the Inner Bristol Channel and Severn Estuary (Figure 2.5) is predicted to reduce by 25% or 23% (Severn Tidal Power 2010c or 2010h) as a result of the L2 Welsh Grounds Lagoon.

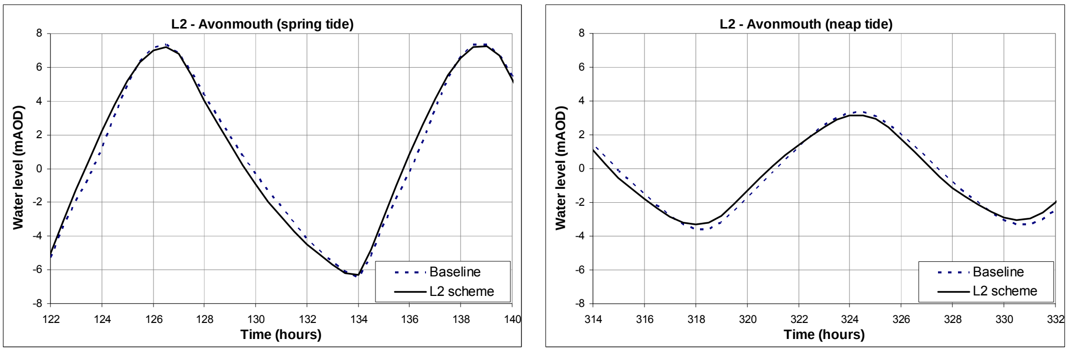
3.3.134 Outside of the L2 Welsh Grounds Lagoon, spring high water levels and the spring tidal range are predicted to reduce by 0.1 and 0.3m respectively at Avonmouth and Newport. Elsewhere in the Severn estuary the reductions are predicted to be up to 0.1m. In the inner Bristol Channel between Barry and Swansea on the Welsh coast and corresponding portions of the English coast increases of around 0.1m in spring high tide levels are predicted. Further west the changes in high water levels are predicted to be less than 0.05m (H&G Annex 8).

3.3.135 Low water levels within the L2 Welsh Grounds Lagoon would rise to +2.1mOD on spring tides and +0.1mOD on neap tides (Severn Tidal Power 2010g). There would also be a significant change in the shape of the tide curve as indicated on Figure

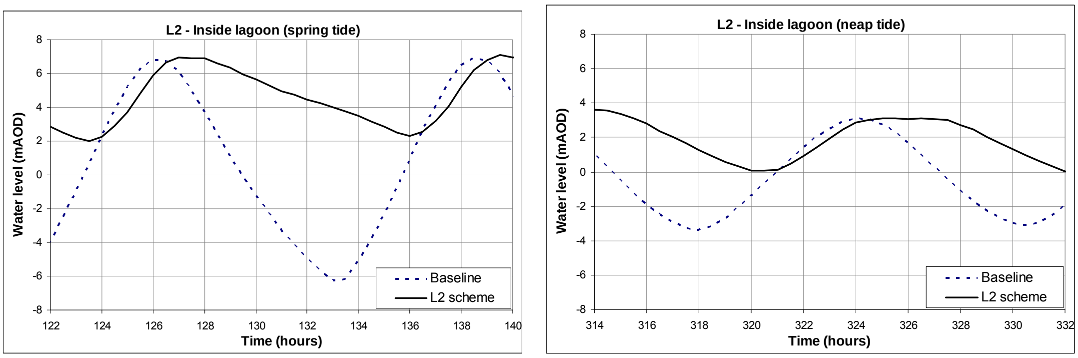
3.20b, which would lengthen the duration of the high water period and considerably reduce the time when water levels are low. Outside the L2 Welsh Grounds Lagoon, the changes in low water level and tide shape would be relatively small as illustrated for Avonmouth in Figure 3.20a.

3.3.136 Predictions of the changes in water levels due to the L2 Welsh Grounds Lagoon are considered reliable with a high degree of certainty.

3.3.137 The high water far field effects of the L2 Welsh Grounds Lagoon shown on Figure 3.21 indicate that changes to high water levels would be less than 0.05m west of the Gower Peninsular and Ilfracombe. Around the west Wales, Irish and Cornish coasts spring high water levels are also generally predicted to change by less than 0.05m. There is an isolated area around the Llŷn peninsular where the model predicts a change of more than 0.1m. This change affects a short length of coastline and since the magnitude is close to the limit of measurable effects, it is not considered significant. (Severn Tidal Power, 2010c and H&G Annex 8).



a) Typical spring tide outside **Typical neap tide outside**



b) Typical spring tide inside **Typical neap tide inside**

Figure 3.20 Water levels inside and outside the L2 Welsh Grounds Lagoon

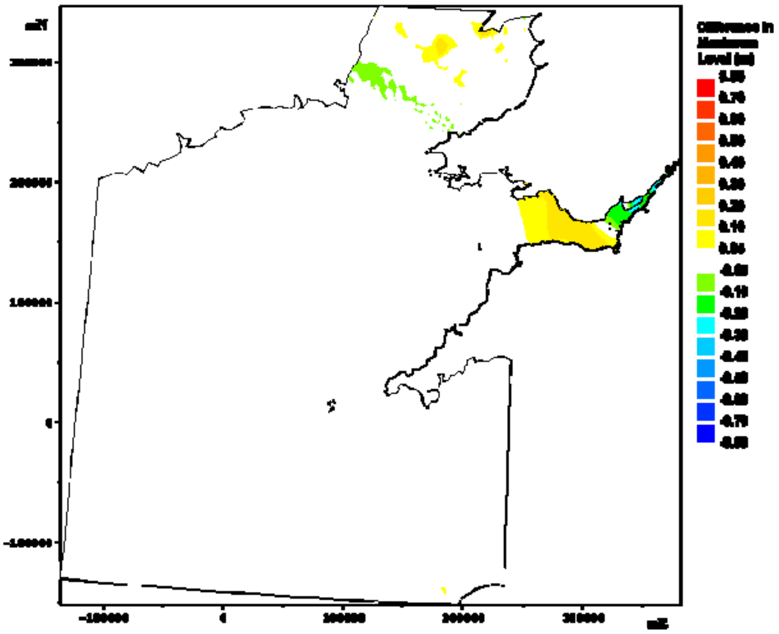


Figure 3.21 **Far field effects of the L2 Welsh Grounds Lagoon (HR Wallingford)**

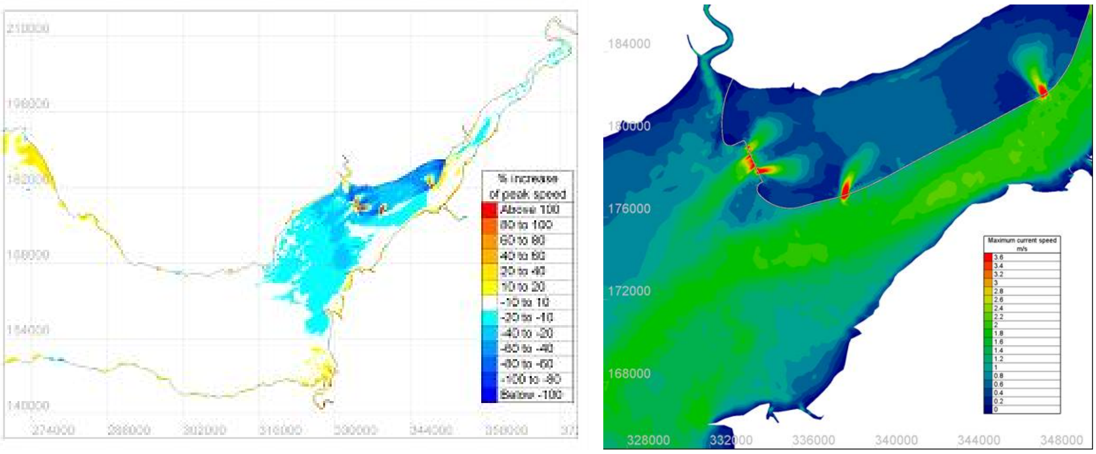
Changes in water velocities

3.3.138 The changes in peak water velocity associated with the L2 Welsh Grounds Lagoon are shown in Figure 3.22a over the whole of the Severn Estuary and Inner Bristol Channel. There are predicted reductions in velocity of 10-20% over the Severn estuary downstream of the lagoon. There are some reductions in maximum velocity predicted adjacent to the lagoon and also in some areas to the north of the lagoon where increases of 10-20% are predicted. Further away in the intertidal areas of Bridgwater Bay and Swansea Bay, the predicted localised increases are considered likely to only have a small effect on sedimentary processes.

3.3.139 In the vicinity of the L2 Welsh Grounds Lagoon there are predicted areas of velocities exceeding 3m/s around each of the groups of sluices and the turbine block as indicated on Figure 3.22b. This area of high velocity occurs during the turbine discharge at low tide and the sluice discharge on the flood tide.

3.3.140 Within the L2 Welsh Grounds lagoon large reductions in velocity are predicted over most of the area except close to the turbine and sluice structures. Reductions of 40-60% are predicted in the central part of the lagoon with 60-80% reductions at either end.

3.3.141 The predicted changes in water velocity have a high degree of certainty except in narrow channels with high discharges where the confidence is only moderate unless steps are taken to ensure the model mesh correctly reproduces the local bathymetry.



a) changes in peak velocity **b) Peak velocities on a large spring tide**

Figure 3.22 Peak water velocities due to the L2 Welsh Grounds Lagoon (HR Wallingford)

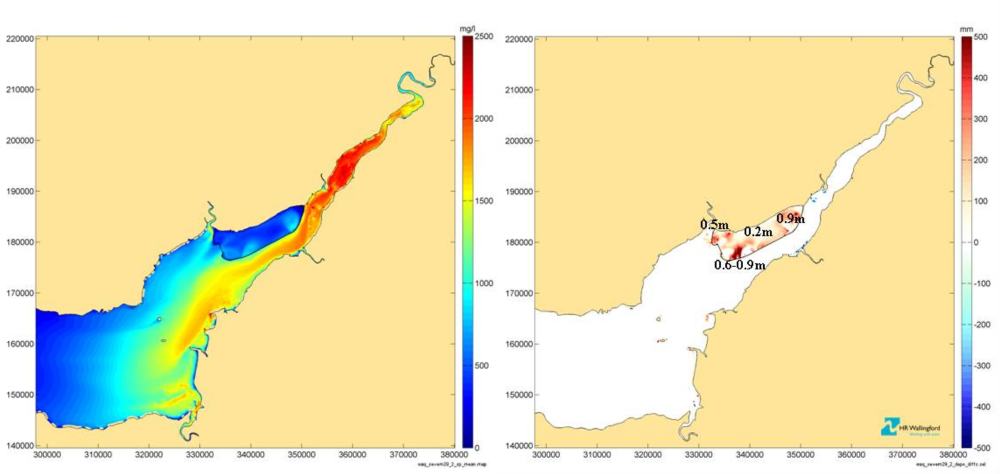
Short term changes in suspended sediment and bed levels

3.3.142 The introduction of the L2 Welsh Grounds Lagoon would have an effect on the existing ebb and flood motion of suspended sediments in the Severn Estuary by reducing the width of the estuary and providing an area of lower velocity within the lagoon where sediments may settle. There are no quantitative predictions of the reduction in average neap tide concentrations within the lagoon. In the longer term, within the lagoon a 90% reduction in suspended sediment concentrations has been adopted (Table 2.4).

3.3.143 The sediment modelling illustrated by Figure 3.23a suggests that in the Inner Bristol Channel and Outer Severn Estuary, the effect of the L2 Welsh Grounds Lagoon is fairly small on spring and neap tides with a likely reduction of up to 20% compared with baseline suspended sediment concentrations. In the inner Severn Estuary, Figure 3.23a indicates that high suspended sediment concentrations would remain upstream of Avonmouth. In the longer term, a maximum 55% reduction in suspended sediment concentrations has been adopted for neap tides outside the lagoon (Table 2.4).

3.3.144 Short term suspended sediment modelling suggests that within the first two weeks after impoundment around 0.8Mtonnes of material previously suspended during spring tides would permanently settle within the basin (H&G Annex 12). Initially this might take up a volume of around 4Mm^3, consolidating over time to around 1.6Mm^3. This amount continues to increase in the model as the tide range reduces towards neaps because the L2 Welsh Grounds Lagoon is acting like a sediment trap. The behaviour during the following months has not been modelled, but further material seems likely to settle from the supply in suspension outside the basin until a new equilibrium is reached. The locations within the basin where this settlement is anticipated are shown on Figure 3.23b. This figure also shows that little settlement is anticipated outside the lagoon. In practice some of these changes may well start to occur in the final stages of construction.

3.3.145 These predictions of future suspended sediment concentrations and short term settlement of sediment are of medium uncertainty.



a) Average spring tide concentration **b) Initial sedimentation**

Figure 3.23 Spring tide concentration and areas of initial sedimentation with the L2 Welsh Grounds Lagoon (HR Wallingford)

Long term changes to sand banks

3.3.146 The sand and gravel banks of English Grounds and Welsh Grounds are considered to have a high risk of long term change as a result of the L2 Welsh Grounds Lagoon. The risk of change to Culver Sand is considered medium, while the risk of change for Nash Bank and Helwick Bank is considered low (H&G Annex 14).

3.3.147 By analogy with the assessment for Culver Sand, the dune systems that surround Bridgwater Bay and Weston Bay are considered likely to have a medium risk of long term change as a result of the L2 Welsh Grounds Lagoon. This aspect has not been investigated in this strategic assessment but should be considered further if a more detailed assessment is carried out.

Long term accretion and erosion

3.3.148 The long term morphology modelling (H&G Annex 16) predicts that around 300Mm^3 of sediment would settle in the L2 Welsh Grounds Lagoon over 120 years. The rate of accretion is initially predicted to be around 3Mm^3/year, but is predicted to gradually decline to 2Mm^3/year over this period. This is expected to raise levels by an average of 3.4m and fill approximately two thirds of the available volume in the lagoon below the new level of mean low water of spring tides. The areas where initial settlement occurs are likely to be similar to those shown on Figure 3.23b, indicating that this accretion would affect intertidal portions of the lagoon as well as subtidal areas.

3.3.149 Outside the L2 Welsh Grounds Lagoon the long term morphology predictions (H&G Annex 16) anticipate accretion of around 65Mm^3 of sediment in the channels adjacent to the lagoon and upstream as far as the River Wye confluence and also on the intertidal flats opposite the lagoon on the English shore causing a 0.5 to 1m increase in average bed levels in these areas over 120 years. In the subtidal area of the Severn Estuary south and west of the L2 Welsh Grounds Lagoon erosion of around 170Mm^3 of bed material is anticipated reducing bed levels by an average of 0.5 to 1m. The spatial distribution of this erosion would vary, with the Newport Deep which receives the turbine discharge being particularly likely to experience erosion.

3.3.150 The modelling of the evolution of specific intertidal profiles suggested local variability in the response within and outside the L2 Welsh Grounds Lagoon, especially in the first 5 or 10 years (H&G Annex 15). At the Welsh Grounds profile at the northern end of the lagoon, the modelling suggested accretion of around 1.5m over the whole intertidal over 5 years extending the length of this profile by around 400m. At the Gold Cliff profile, near the southern end of the lagoon, accretion of 0.3m was predicted.

3.3.151 Outside the lagoon on the English shore the predicted response of the intertidal profiles varies from erosion of 1.8m at Severn Beach over the whole length of the profile to accretion of 0.7m at Clevedon, principally towards low water. The other profiles, more distant from the Welsh Grounds Lagoon predicted much smaller changes (H&G Annex 15).

3.3.152 The predictions of long term changes to estuary morphology including sand banks and intertidal profiles have high uncertainty.

Water quality changes

3.3.153 Within the L2 Welsh Grounds Lagoon, concentrations of suspended sediment on spring tides would be expected to limit light penetration enough to prevent algal blooms but on neap tides concentrations are expected to be sufficiently low to allow blooms to occur (MWQ Annex 6). However, the studies on flushing (MWQ Annex 1) suggest that the entire volume of the lagoon would be exchanged daily. This means that even if algal growth occurred within the lagoon, the algae would be rapidly flushed out to prevent blooms becoming established within the lagoon.

3.3.154 Outside the L2 Welsh Grounds Lagoon the predicted percentage reductions in suspended sediment concentration are lower with a maximum of 55% adopted in Table 2.4. These concentrations are predicted to remain too high to permit substantial algal growth on neap tides. Strong light limitation would therefore be expected to continue to prevent full utilisation of available nutrients within the estuary. Nutrient concentrations would be expected to remain high, though some reduction in spring and summer nutrient concentrations might be observed. (Severn Tidal Power 2010d and MWQ Annex 6).

3.3.155 The uncertainty in the prediction of long term suspended sediment concentrations makes it uncertain how much the risk of eutrophication will increase within the estuary. The uncertainty in the prediction of the eutrophication risk is therefore considered high.

3.3.156 Changes in water levels and flows associated with the L2 Welsh Grounds Lagoon are predicted to slightly change the salinity range experienced in the Severn Estuary as illustrated on Figure 3.24 for mean annual freshwater flow conditions of 105m^3/s in the River Severn. The modelling predicts an increase in both minimum and maximum salinities in the estuary upstream of the lagoon. There is also predicted to be an increase in minimum salinity within the lagoon, but little change to the maximum salinity. While within the estuary, the range of salinity increases at locations upstream of the lagoon, these changes are not considered significant in water quality terms (Severn Tidal Power 2009d and MWQ Annex 2).

3.3.157 In the upper Severn Estuary, during the average flow conditions illustrated on Figure 3.24, there is predicted to be a 3km seaward movement of the 2PSU salinity contour. With a low flow of around 20m^3/s in the River Severn, the saline interface will move upstream. With the L2 Welsh Grounds Lagoon in operation, the saline interface is predicted to be about 4.5km further seaward than in the Baseline.

3.3.158 The predictions of water quality changes including salinity have medium uncertainty.

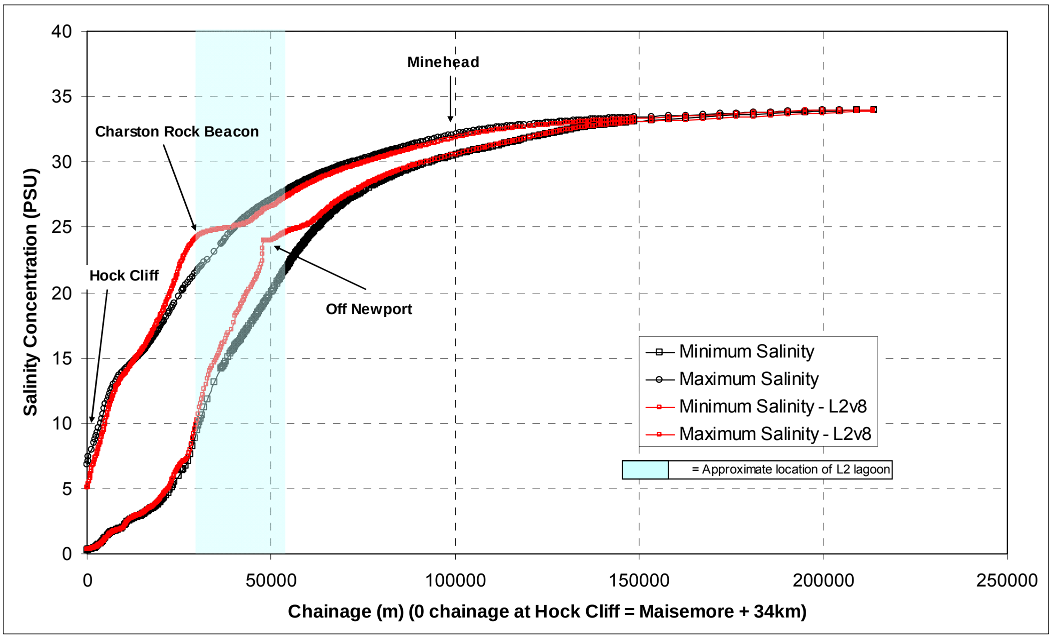


Figure 3.24 **Change in maximum salinity at low flows for the L2 Welsh Grounds Lagoon**

Changes to flood risk and land drainage

3.3.159 Within the Severn Estuary, high water levels do not rise so there is no adverse effect on tidal flood risk. There is therefore no effect on the timing of the raising of flood defences that would otherwise be required to combat the effects of rising sea levels (Severn Tidal Power 2010e).

3.3.160 Within the inner Bristol Channel there is expected to be a small rise in high water levels which would have an adverse effect on about 25 km of flood defence (Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5.

3.3.161 The raised low water levels within the L2 Welsh Grounds Lagoon is predicted to adversely affect the drainage of 47km^2 of low lying land alongside the estuary containing around 275 residential and commercial properties (Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5.

3.3.162 There is not predicted to be any significant difference in peak fluvial flood levels within the River Severn following commissioning of the L2 Welsh Grounds Lagoon.

3.3.163 There is predicted to be erosion of intertidal foreshores fronting the existing flood defences over around 9 to 28 km of the estuary outside the lagoon. Around half this length is expected to adversely affect adjacent flood defences within 5 to 10 years of starting operation. The remaining length would start to adversely affect the flood defences after about 50 years of operation (Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5. As these predictions have high uncertainty a large range of effects and timings has been adopted.

3.3.164 Within the lagoon, erosion of the existing flood defences is not anticipated to be an issue.

Changes to freshwater environment

3.3.165 The L2 Welsh Grounds Lagoon is not expected to change the natural variation of salinity in the Avon and Parrett estuaries and cause minor changes in the Usk, Wye and Severn estuaries. In the modelling of the highest spring tides at times of low river flows the saline interface was predicted to move seaward by about 3km in the River Usk, 1km in the River Wye and 4.5km in the River Severn. These changes are not considered significant (Severn Tidal Power 2010f and MWQ Annex 2) for abstraction for public water supply or other uses.

3.3.166 The raised mean sea levels inside the L2 Welsh Grounds Lagoon would raise groundwater levels alongside the estuary. This would lead to increased soil wetness over about 47km^2 (Severn Tidal Power 2010f) and degradation of the soil resource, but may be advantageous in the longer term in reducing the effects of climate change.

3.3.167 Raised groundwater levels may affect local infrastructure in communities close to the lagoon particularly in Caldicot and Llanwern and the parts of Newport closest to the lagoon.

3.3.168 There is a risk of increased erosion at Aust Cliff and Portishead Pier to Black Nore SSSIs. The risk is not sufficient to be considered a significant effect (Severn Tidal Power 2010f).

Alternative Option L3d: Bridgwater Bay Lagoon

3.3.169 The L3d Bridgwater Bay Lagoon encloses the majority of Bridgwater Bay between Brean Down and Hinkley Point. The lagoon encloses the estuary of the River Parrett and the other rivers that drain the low lying Somerset Levels.

Water level changes

3.3.170 The ebb flood operation of the L3d Bridgwater Bay Lagoon would lower spring tide high water levels by around 0.7m and raise spring tide low water levels by 0.5m within the lagoon.

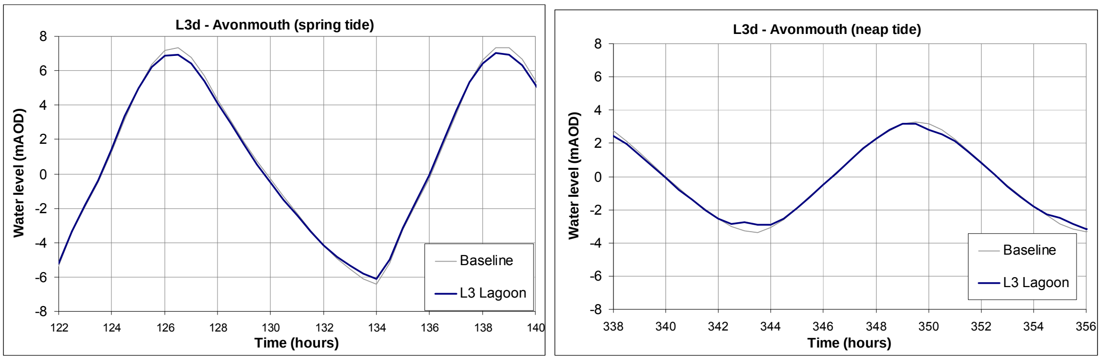
3.3.171 The extent of the intertidal foreshore in zones 2 to 5 of the Inner Bristol Channel and Severn Estuary (Figure 2.5) is predicted to reduce by 7% or 8% (Severn Tidal Power 2010c or 2010h) as a result of the L3d Bridgwater Bay Lagoon.

3.3.172 On neap tides the reduction in tidal range would be less (Severn Tidal Power 2010g). The shape of the tide curve within the lagoon, which is shown on Figure 3.25b for typical spring and neap tides would feature a more rapid rise and fall of the tide than occurs in the baseline separated by prolonged high and low water stands which would have the combined effect of introducing an approximate two hour delay in the rise of the tide and a three hour delay in the fall of the tide.

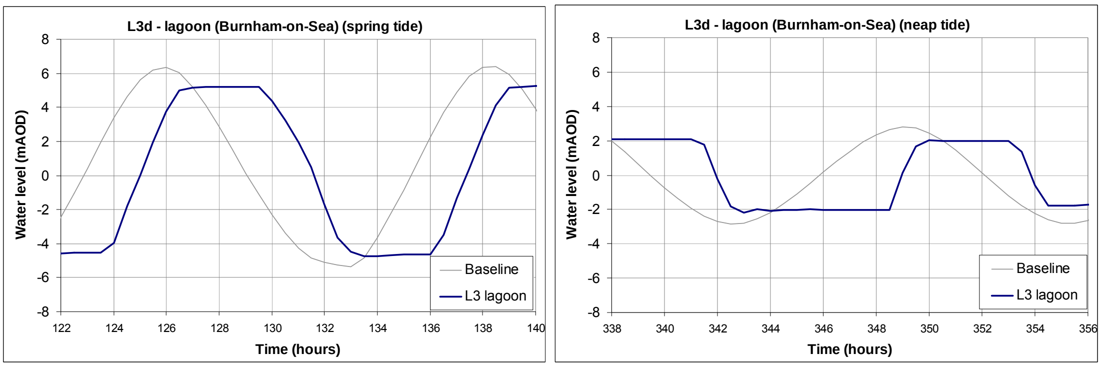
3.3.173 Outside of the L3d Bridgwater Bay Lagoon, there would be a consistent reduction in tidal range on all tides of 0.6m reducing high water levels by around 0.3m and raising low water levels by around 0.3m throughout the Severn Estuary, illustrated for Avonmouth in Figure 3.25a.

3.3.174 Predictions of the changes in water levels due to the L3 Bridgwater Bay Lagoon are considered reliable with a high degree of certainty.

3.3.175 The high water far field effects of the L3d Bridgwater Bay Lagoon shown on Figure 3.26 indicate that changes to high water levels would be less than 0.05m west of Port Talbot. Around the west Wales, Irish and Cornish coasts spring high water levels are predicted to generally change by less than 0.05m. There is an isolated area around the Llŷn peninsular where the model predicts a change of more than 0.1m. This change affects a short length of coastline and since the magnitude is close to the limit of measurable effects, it is not considered significant. (Severn Tidal Power, 2010c and H&G Annex 8).



a) **Typical spring tide outside** **Typical neap tide outside**



b) **Typical spring tide inside** **Typical neap tide inside**

Figure 3.25 **Water levels inside and outside the L3d Bridgwater Bay Lagoon**

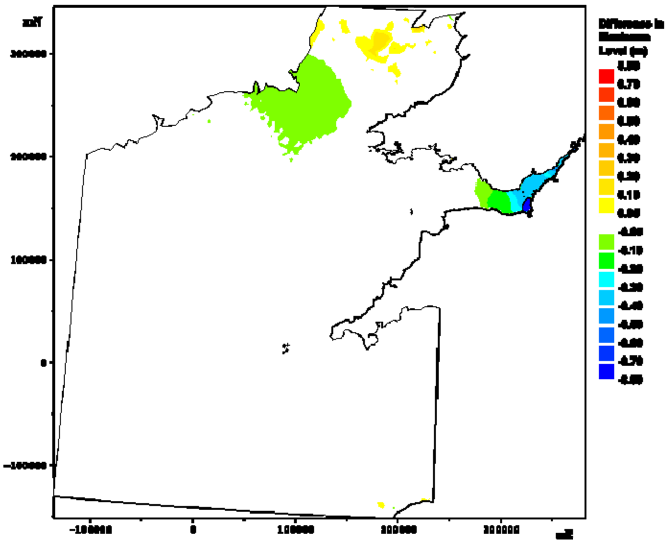


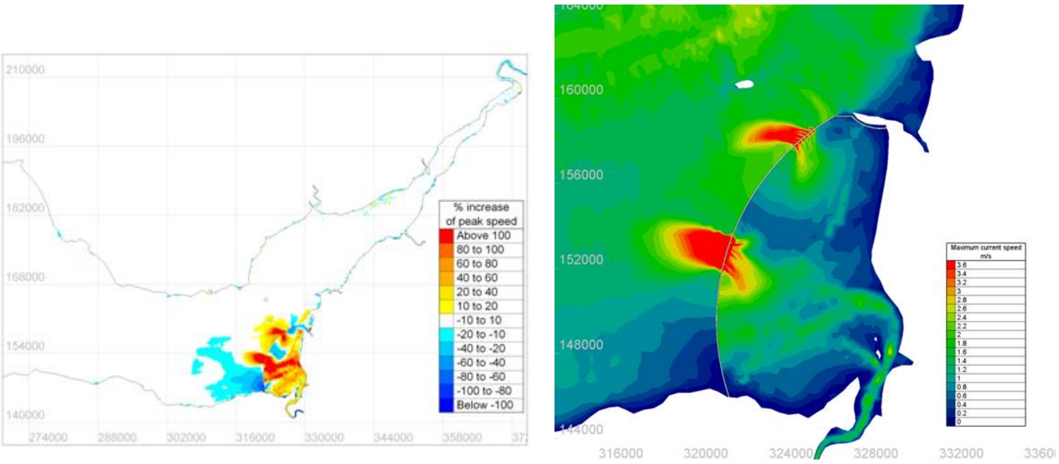
Figure 3.26 **Far field effects of the L3d Bridgwater Bay Lagoon (HR Wallingford)**

Changes in water velocities

3.3.176 The changes in peak water velocity associated with the L3d Bridgwater Bay Lagoon are shown in Figure 3.27a. The changes are relatively localised with considerable increases in velocity within the lagoon, especially in the area adjacent to the turbines, where maximum speeds more than double (>100% increases) are expected, though over much of this area, as Figure 3.27b shows, velocities remain fairly low. In the mouth of the Parrett estuary velocities are 10-40% higher. Maximum velocities are also more than doubled in the areas where the turbines discharge outside the lagoon. In the area immediately outside of the lagoon close to Hinkley Point there is a 60-80% reduction in maximum velocity. The area of lower velocity extends about 15km from the lagoon towards Culver Sands. Away from the area around the lagoon, changes in peak velocity are less than 10%.

3.3.177 In the vicinity of the L3d Bridgwater Bay Lagoon there are predicted areas of velocities exceeding 3.5m/s around both turbine blocks extending for about 2km from the lagoon as indicated on Figure 3.27b. This area of high velocity outside the lagoon occurs as the lagoon empties through the turbines at low tide and the area of high velocity inside the lagoon occurs when the turbines start to generate on the incoming tide, when levels in the lagoon are at their minimum. These high velocities are across areas of soft sediments that would be scoured away which would reduce the maximum velocities over time.

3.3.178 The predicted changes in water velocity have a high degree of certainty except in areas where high velocities are predicted over soft sediments. In these areas, scour would reduce velocities over a relatively short time period to values where erosion and accretion are in broad balance.



a) changes in peak velocity **b) Peak velocities on a large spring tide**

Figure 3.27 Peak water velocities due to the L3d Bridgwater Bay Lagoon (HR Wallingford)

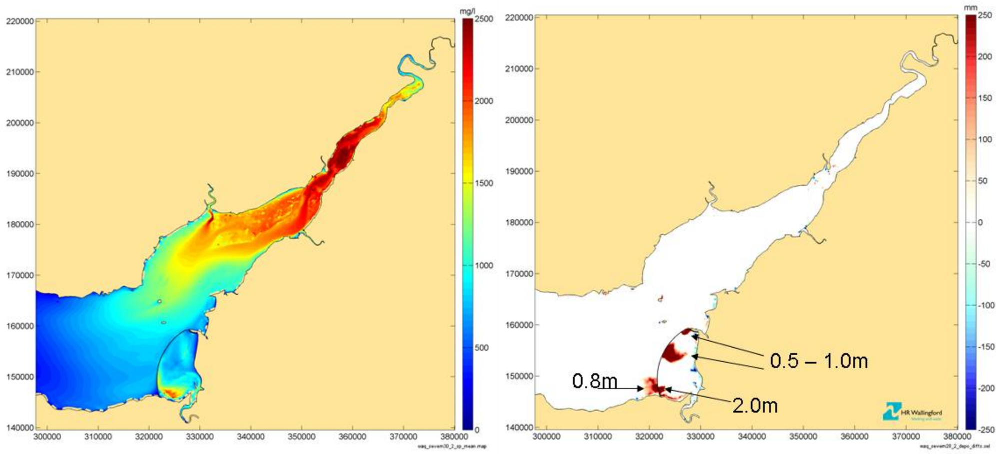
Short term changes in suspended sediment and bed levels

3.3.179 The introduction of the L3d Bridgwater Bay Lagoon would have an effect on the existing ebb and flood motion of suspended sediments in the Severn Estuary by moving the areas of maximum concentration away from the English shore between Clevedon and Weston and closer to the Welsh shore between Newport and Cardiff. Suspended sediment concentrations within the lagoon are expected to diminish at the northern end but may increase near the southern end. The changes in suspended sediment concentration are indicated by comparing the predictions of spring tide concentrations for baseline conditions on Figure 3.2b with those including the L3d Bridgwater Bay Lagoon in Figure 3.28a. Within the lagoon, the modelling predicts suspended sediment concentrations would reduce to around 60-70% of baseline concentrations. In the longer term, within the lagoon a 40% reduction in neap tide suspended sediment concentration has been adopted (Table 2.4).

3.3.180 The sediment modelling illustrated by Figure 3.28a suggests that the effect of the L3d Bridgwater Bay Lagoon is small outside the lagoon on spring tides with a likely reduction of up to 20% in current average suspended sediment concentrations. The percentage reduction on neap tides is expected to be rather greater at up to 40% (Table 2.4).

3.3.181 Short term suspended sediment modelling suggests that within the first two weeks after impoundment around 0.7Mtonnes of material previously suspended during spring tides would permanently settle within the basin (H&G Annex 12). Initially this might take up a volume of around 3.5Mm^3, consolidating over time to around 1.4 Mm^3.The behaviour during the following months has not been modelled, but some further material may settle from the supply in suspension outside the basin until a new equilibrium is reached. The locations within and outside the basin where this settlement is anticipated are shown on Figure 3.28. There is notable settlement within the lagoon in the area between the two turbine blocks and also close to the southern shore. Outside the lagoon, close to Hinkley Point, there is another area of settlement adjacent to the lagoon wall. In practice some of these changes may well start to occur in the final stages of construction.

3.3.182 These predictions of future suspended sediment concentrations and short term settlement of sediment are of medium uncertainty.



a) Average spring tide concentration **b) Initial sedimentation**

Figure 3.28 Spring tide concentration and areas of initial sedimentation with the L3d Bridgwater Bay Lagoon (HR Wallingford)

Long term changes to sand banks

3.3.183 The L3d Bridgwater Bay Lagoon leads to a medium risk of change to the English and Welsh Grounds, Culver Sand and Nash Bank. The risk of change to Helwick Bank is considered small (H&G Annex 14).

3.3.184 Since the L3d Bridgwater Bay Lagoon encloses the dune system of Bridgwater Bay, there would be large changes to tidal flows and wave climate within the lagoon that have the potential to affect the sand transport processes that feed these dunes, posing a high risk of long term change. Outside the lagoon, where changes in hydrodynamic conditions would be less dramatic, by analogy with the assessment for Culver Sand, the dune systems are considered likely to have a medium risk of long term change. This aspect has not been investigated in this strategic assessment but should be investigated if a more detailed assessment is carried out.

Long term accretion and erosion

3.3.185 The long term morphology modelling (H&G Annex 16) predicts that around 45Mm^3 of sediment would settle in the L3d Bridgwater Bay Lagoon over 120 years. The rate of accretion is initially predicted to be around 3Mm^3/year, but is predicted to decline to 1Mm^3/year between years 10 and 20, and thereafter sediment is predicted to accrete at around 0.1 Mm^3/year or less. This is sufficient to fill around 30% of the storage available below low water of spring tides.

3.3.186 The modelling of the evolution of specific intertidal profiles suggested that within the L3d Bridgwater Bay Lagoon there was likely to be accretion of 1.3m on the upper foreshore with a steepening mid shore and erosion of the lower intertidal during the first 10 years (H&G Annex 15). It is likely, considering these results that a proportion of the sediment settling within the L3d Bridgwater Bay Lagoon would settle within the intertidal area and reduce the storage volume available to support energy generation.

3.3.187 Outside the L3d Bridgwater Bay Lagoon the long term morphology predictions (H&G Annex 16) predict relatively small changes over the 120 year life of this option. The subtidal areas within the study area are predicted to accrete by between 0 and 0.3m with the greatest accretion predicted for the inner Bristol Channel and Outer Severn zones closest to the L3d Bridgwater Bay Lagoon. Intertidal areas outside the lagoon are predicted to change in average level by up to ±0.5m over 120 years, though in most areas modest erosion seems more likely than modest accretion.

3.3.188 Outside the L3d Bridgwater Bay Lagoon the intertidal profile modelling (H&G Annex 15) predict very small changes in foreshore level in agreement with the predictions of the long term estuary modelling (H&G Annex 16).

3.3.189 The turbine discharges are expected to bring considerable quantities of muddy sediments into suspension in the early years of operation. This aspect has not been studied within this strategic assessment but would require investigation if this option is taken forward. The areas where this sediment would settle have not been established, but less energetic areas, especially to the west of the lagoon seem a likely location.

3.3.190 A particular issue is that muddy sediments are predicted to accumulate in areas of low velocity close to the southern landfall of the lagoon at Hinkley Point (Figure 3.28b). This settlement could interfere with the cooling water system of the power station.

3.3.191 The predictions of long term changes to estuary morphology including sand banks and intertidal profiles have high uncertainty.

Water quality changes

3.3.192 Within the L3d Bridgwater Bay Lagoon, concentrations of suspended sediment on spring tides would be expected to limit light penetration enough to prevent algal blooms but on neap tides concentrations are expected to be sufficiently low to allow blooms to occur (MWQ Annex 6). However, the studies on flushing (MWQ Annex 1) suggest that the entire volume of the lagoon would be exchanged daily. This means that even if algal growth occurred within the lagoon, the algae would be rapidly flushed out to prevent blooms becoming established within the lagoon.

3.3.193 Outside the L3d Bridgwater Bay Lagoon the predicted percentage reductions in suspended sediment concentration are lower with a maximum of 40% adopted in Table 2.4. These concentrations are predicted to remain too high to permit substantial algal growth on neap tides. Strong light limitation would therefore be expected to continue to prevent full utilisation of available nutrients within the estuary. Nutrient concentrations would be expected to remain high, though some reduction in spring and summer nutrient concentrations might be observed (Severn Tidal Power 2010d and MWQ Annex 6).

3.3.194 The uncertainty in the prediction of long term suspended sediment concentrations makes it uncertain how much the risk of eutrophication will increase within the estuary. The uncertainty in the prediction of the eutrophication risk is therefore considered high.

3.3.195 Changes in water levels and flows associated with the L3d Bridgwater Bay Lagoon are predicted to slightly change the salinity range experienced in the Severn Estuary as illustrated on Figure 3.29 for a mean annual freshwater flow of 105m^3/s in the River Severn. The modelling predicts a small increase in both minimum and maximum salinities in the estuary upstream of the lagoon. There is also predicted to be a small increase within the lagoon, similar to the increase outside shown on Figure 3.29. Although the range of salinity increases at locations upstream of the lagoon, these changes are not considered significant in water quality terms (Severn Tidal Power 2009d and MWQ Annex 2).

3.3.196 In the upper Severn Estuary, during the average and low flow conditions, there is predicted to be no movement of the 2PSU salinity contour compared with the Baseline.

3.3.197 The predictions of water quality changes including salinity have medium uncertainty.

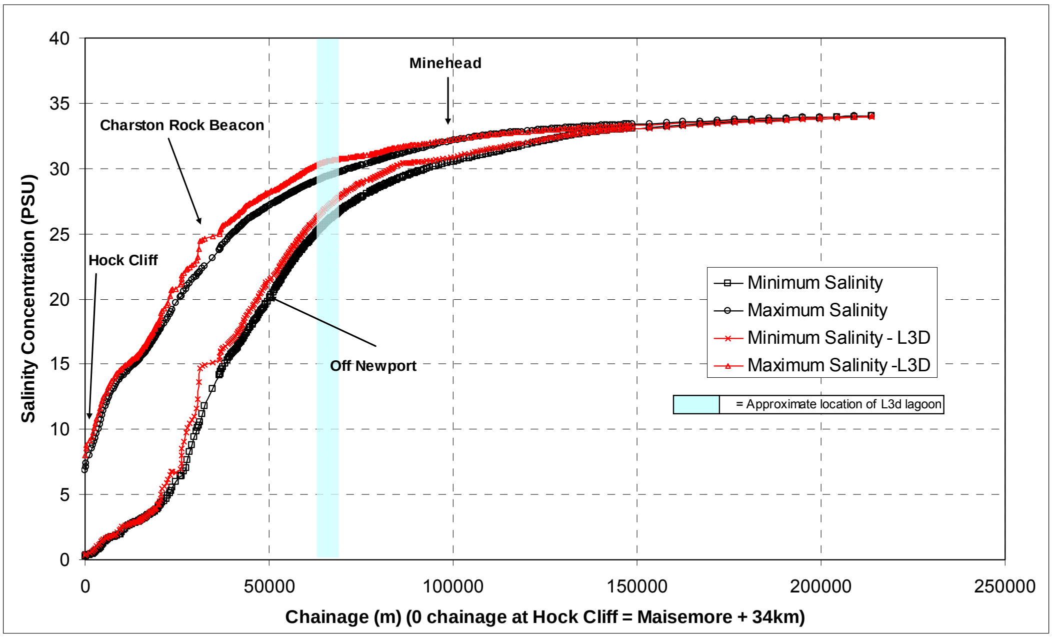


Figure 3.29 **Change in salinity range for average flows for the L3d Bridgwater Bay Lagoon**

3.3.198 The alignment of the L3d Bridgwater Bay Lagoon has potential effects on two users of Severn estuary water. One affected user is the Hinkley Point B nuclear power station which continuously withdraws a large flow of water from the estuary that is returned to the estuary foreshore after cooling the power station. The second user that is potentially affected is the Weston Waste Water Treatment Works which discharges tertiary treated sewage effluent to the Severn estuary at the mouth of the River Axe immediately north of Brean Down.

3.3.199 The intake and outfall for the Hinkley Point power station are close to the southern landfall of the lagoon in an area which would become quiescent as a result of lagoon construction and operation. The modelling predicts that these quiescent conditions would lead to considerable heat build up in the estuary unless these structures or the lagoon wall are relocated (Severn Tidal Power 2010d and MWQ Annex 4). The measures proposed to avoid or reduce this effect are summarised in section 5.

3.3.200 The presence of the L3d Bridgwater Bay Lagoon on the southern side of Brean Down affects the tidal current on the north side of the peninsular which receive the treated effluent from Weston Waste Water Treatment Works (WWTW). The changed tidal currents move the plume from the WWTW north and towards the bathing beach at Weston. The risk this poses to the bathing waters is discussed in Severn Tidal Power 2010d and MWQ Annex 8). The measures proposed to reduce or avoid this effect are discussed in section 5.

Changes to flood risk and land drainage

3.3.201 Throughout the Severn Estuary and inner Bristol Channel, high water levels would reduce as a result of operating the L3d Bridgwater Bay Lagoon so there is no adverse effect on tidal flood risk. The reduced high water levels would reduce the tidal flood risk to the whole estuary. This reduction would be equivalent to around 100 years of sea level rise inside the lagoon and 40 years outside (Severn Tidal Power 2010e).

3.3.202 The raised low water levels within the L3d Bridgwater Bay Lagoon are predicted to adversely affect the drainage of around 243km^2 of low lying land alongside the estuary containing around 1150 residential and commercial properties and one item of critical infrastructure (Severn Tidal Power 2010e). Although the area of land potentially affected by impeded drainage is large, the rise in low water levels at 0.5m is relatively small. This indicates the overall adverse effect on land drainage would be relatively minor. The measures proposed to avoid or reduce this effect are discussed in section 5.

3.3.203 There is not predicted to be any significant difference in peak fluvial flood levels within the rivers Severn or Parrett following commissioning of the L3d Bridgwater Bay Lagoon.

3.3.204 There is predicted to be erosion of intertidal foreshores fronting the existing flood defences affecting 18 to 56km of the estuary outside the lagoon. This erosion is not expected to adversely affect adjacent flood defences until 75 to 100 years after starting operation (Severn Tidal Power 2010e). The measures proposed to avoid or reduce this effect are discussed in section 5. As these predictions have high uncertainty a large range of effects and timings has been adopted.

Changes to freshwater environment

3.3.205 The L3d Bridgwater Bay Lagoon is not expected to change the natural variation of salinity in the River Severn and its major sub-estuaries, with the exception of the River Parrett which is enclosed by the L3 Bridgwater Bay Lagoon. The saline interface in the Parrett estuary was predicted to move landward by about 2.5km at a time of high spring tides during a period of low river flows. This change is not considered significant (Severn Tidal Power 2010f and MWQ Annex 2) for abstraction for public water supply or other uses.

3.3.206 The 0.4m rise in mean sea levels inside the L3d Bridgwater Bay Lagoon would slightly raise groundwater levels alongside the lagoon. Although this could affect an area of about 200km^2, the small change in water level is likely to limit its effects (Severn Tidal Power 2010f).

3.3.207 Raised groundwater levels may affect local infrastructure in communities close to the lagoon especially along the shoreline of Bridgwater Bay.

3.3.208 There are unlikely to be significant changes to any geological or geomorphological SSSIs as a result of the L3d Bridgwater Bay Lagoon.

Multiple basins

3.3.209 As discussed in section 2.3, a two basin variant of the L3d Bridgwater Bay Lagoon has been developed with one part of the lagoon held at a high level and the other part at a low level. This Multiple Basin scheme has not been modelled and the assessment is a high level review of anticipated effects. If this proposal were to be considered in more detail, suitable modelling of all aspects would be required.

3.3.210 In terms of the remainder of the estuary, the effects of this multiple basin scheme are likely to be broadly similar to the effects of the ebb/flood scheme described above. The main difference is that the flows through the turbines connecting the lagoon to the remainder of the estuary would be different and probably smaller.

3.3.211 Within the two basins comprising the lagoon, the effects would be very different from those described above for the ebb flood scheme. With one basin held at a high level and the other at a low level, the tidal ranges in both basins would be around half those in the ebb flood scheme. The high level basin which receives inflows from the estuary would be the area where sediment drawn in from the estuary is likely to settle leading to long term accretion. As the upper basin is never drawn down, the water velocities in this basin are likely to be moderate and only likely to transfer a small amount of sediment from the upper to the lower basin. The quantity of sediment transferred from the lower basin into the estuary is likely to be small after an initial period when the sediments in the lower estuary adjust to the new lower tidal levels. As a result this multiple basin scheme is likely to accumulate considerable quantities of sediment, especially in the high level basin.

3.3.212 Prediction of the effects on Marine Water Quality are of high uncertainty. Any basin that contains water with good clarity because of low concentrations of suspended sediment is likely to have a high risk of eutrophication. This risk would be mitigated if the water in each basin were regularly flushed. The few details available of basin operation and geometry do not allow this assessment to be made.

3.3.213 The effects of the multiple basin variant on Flood Risk and Land Drainage would be very different in the two basins. In the upper basin high tide levels may exceed those occurring in the baseline because of pumping. This may have effects on flood risk management unless pumping is abandoned at times of surge tides. Nevertheless the prevention of large swell waves reaching the shoreline would still provide a benefit to this coastline. In the lower basin flood risk would cease to be an issue.

3.3.214 Effects on drainage of the Parrett estuary are sensitive to which basin it drains into. If the Parrett drains into the upper basin, high tide levels would be maintained, but the impedance the high low water levels would place on fluvial flood discharge is likely to have a significant adverse effect on the standard of flood protection provided to the Somerset Levels. If the Parrett drained to the lower basin, high and low water levels would be much lower and problems with land drainage would be avoided.

3.3.215 The major effect of the multiple basins variant on Freshwater Environment and Associated Interfaces is the effect on the groundwater levels along the adjacent coastline. Behind the high basin, groundwater levels would rise with the risk of water-logging and flooding of basements and subsurface infrastructure, while behind the lower basin there would be a fall in the groundwater levels with the risk of drying out wetlands. The effects on groundwater would extend along the Parrett estuary, depending on whether it drained to the high or low basin.

Combinations

3.3.216 Two combinations are considered worthy of consideration. These are a combination of B4 Shoots Barrage with the L3d Bridgwater Bay Lagoon and a combination of the B3 Brean Down to Lavernock Point Barrage with the L3d Bridgwater Bay Lagoon. The effects of these combinations have not been modelled and this assessment is based on a qualitative review of the individual options. If these combinations were to be considered in more detail, suitable modelling of the combined effects would be required.

3.3.217 Within the Physicochemical theme the effects of the combinations on water levels are likely to be larger than with either scheme on its own. The simultaneous presence and operation of the L3d Bridgwater Bay Lagoon and the B4 Shoots Barrage is likely to result in a small reduction in high-water levels and a small raising of low water levels throughout the Severn Estuary. This would drive the effects on the Flood Risk and Land Drainage topic and on the Freshwater Environment and Associated Interfaces topic.

3.3.218 The effects on morphology of either combination are likely to be broadly similar to the sum of the individual options, especially taking note of the uncertainty surrounding morphology predictions.

3.3.219 The effects on Marine Water Quality are likely to be broadly similar to the sum of the individual options. In particular the effects of the L3d Bridgwater Bay Lagoon on the Hinkley Point B power station cooling water system are unlikely to change with either combination. Similarly for the combination of the B4 Shoots Barrage with the L3d Bridgwater Bay Lagoon, the effects of the L3d Bridgwater Bay Lagoon predicted for the Weston WWTW are likely to remain.

3.3.220 There is a high probability that for the B3 Brean Down to Lavernock Point plus L3d Bridgwater Bay Lagoon combination the effects on the Weston WWTW would be similar to those predicted for the B3 Brean Down to Lavernock Point Barrage rather than those predicted for the L3d Bridgwater Bay Lagoon. However, if the L3d Bridgwater Bay Lagoon were constructed first, the effects on the Weston WWTW would still occur in the years between completion of the lagoon and completion of the barrage.

3.3.221 As there is a risk of enhanced algal growth in both the B3 Brean Down to Lavernock Point Barrage and the L3d Bridgwater Bay Lagoon, the combined risk of eutrophication might be greater, especially if suspended sediments in the estuary outside this combined scheme had lower suspended sediments than the options individually.

3.3.222 There is unlikely to be any additional eutrophication risk associated with the B4 Shoots Barrage and L3d Bridgwater Bay Lagoon combination as the schemes are physically well separated.

3.3.223 There are likely to be opportunities for savings in flood risk costs with sequential construction if the L3d Bridgwater Bay Lagoon was constructed before the B4 Shoots Barrage, compared to the sum of the individual costs of managing flood risk if the two alternative options were built in isolation. This is because, if built first, the L3d Bridgwater Bay Lagoon would be likely to reduce the water levels within the Estuary to the degree that the flood risk works associated with the B4 Shoots Barrage would no longer be needed. However, if the B4 Shoots Barrage was built first then the works would still be needed and there would be no relative savings.

SECTION 4

INTERRELATIONSHIPS

4 INTERRELATIONSHIPS

4.1.1 The SEA Directive requires that the interrelationships between likely significant effects are described (SEA Directive Annex 1 (f)). This theme paper therefore summarises the interactions between related topics and thereby ensures that the many complex issues that are not self-contained within a given topic are recognised and their implications understood. Each theme paper also examines the relationships between this theme and other themes within the STP SEA.

4.1.2 An illustration of the interrelationships between topics of the physicochemical theme and other topics is included in Table 4.1. This table demonstrates that the great majority of topics depend directly on the output from the Hydraulics and Geomorphology Topic. The Communities Topic depends indirectly on hydraulics and geomorphology through other topics in the physicochemical theme, while the Air and Climatic Factors and Noise and Vibration topics depend indirectly on hydraulics and geomorphology through topics in other themes. The results from the Marine Water Quality and Flood Risk and Land Drainage topics are also widely used as source information by the other topics.

Table 4.1 Interrelationships between Physicochemical theme topics and other topics

	Physicochemical theme topics			
Topic	Hydraulics and Geomorphology	Marine Water Quality	Flood risk and Land Drainage	Freshwater Environment & Associated Interfaces
Hydraulics and Geomorphology				
Marine Water Quality	√			
Flood risk and Land Drainage	√			
Freshwater Environment and Associated Interfaces	√	√	√	
Marine Ecology	√	√		
Waterbirds	√	√		
Migratory & Estuarine Fish	√	√		
Terrestrial & Freshwater Ecology	√	√	√	
Landscape & Seascape	√		√	√
Historic Environment	√		√	

	Physicochemical theme topics			
Topic	Hydraulics and Geomorphology	Marine Water Quality	Flood risk and Land Drainage	Freshwater Environment & Associated Interfaces
Air & Climatic Factors				
Resources & Waste	√	√	√	
Communities		√	√	
Navigation	√			
Other Sea Uses	√	√		
Noise & Vibration				

4.2 Interrelationships between topics within the Physicochemical theme

Interrelationships within the Physicochemical theme

4.2.1 The Marine Water Quality topic depends critically on output from the Hydraulics and Geomorphology topic. This inter-relationship is primarily that flows and water levels calculated within the Hydraulics and Geomorphology topic are required to assess how water quality would change.

4.2.2 Within the Hydraulics and Geomorphology topic the ABPmer 2D flow model was specifically set up to provide the information required by the Marine Water Quality topic. This 2D model was extended to represent the sub-estuaries of the tributary rivers where water quality changes are likely to be especially important because the towns of Bristol and Newport are located on the banks of the estuaries of the rivers Avon and Usk respectively.

4.2.3 The determination of the salinity limits for each tributary estuary was a specific analysis included in the interpretation of the ABPmer 2D flow model. This was needed to satisfy requirements of the Freshwater Environment and Associated Interfaces topic.

4.2.4 The other important contribution from the Hydraulics and Geomorphology topic to the understanding of Marine Water Quality was the assessment of changes in suspended sediment concentration as a result of each alternative option. Changes in suspended sediment affects water clarity which provides an important contribution in the assessment of the likelihood of effects of eutrophication occurring and determining the rate of die-off of bacteria discharged with treated sewage effluent.

4.2.5 Within the Flood Risk and Land Drainage topic, the change in the shape of the tide curve, determined by the HR Wallingford 2D flow model affected the drainage of low lying land. The critical factor for the assessment was the change in the time that the tide was below the level of the lowest lying land in the catchment.

4.2.6 Changes in tidal mean water level determined how groundwater levels in the adjacent coastal strip changed as a result of one of the alternative options. With most alternative options the rise in mean tide level and hence groundwater level was an issue of importance for the Freshwater Environment and Associated Interfaces assessment.

4.2.7 Changes in extreme water levels and wave conditions as a result of the alternative options affect the tidal flood and erosion risk along the banks of the estuary; this forms an important component of the Flood Risk and Land Drainage topic. This information was primarily provided by specific model tests in the ABPmer 2D flow and wave models, supplemented by the modelling of long term estuary morphology and intertidal profile evolution which contributed particularly to the assessment of erosion risk within this topic.

4.2.8 There were no areas where the results from the Marine Water Quality, Flood Risk and Land Drainage or Freshwater Environment and Associated Interfaces topics were used in the Hydraulics and Geomorphology topic. The scope of this topic was, however, influenced by the requirements of these other topics.

Transfer of uncertainty between topics in the Physicochemical theme

4.2.9 Uncertainties in the results of the hydraulics and geomorphology topic inevitably lead to uncertainties in the data used for the other topics. In many cases where for example water level or wave information is provided by the Hydraulics and Geomorphology topic, the predictions are considered reasonable certain and would not degrade the assessments that are made using this information.

4.2.10 A particular issue that has needed careful management is the difference in water level predictions between the two 2D models for two of the alternative options in part of the estuary. As discussed in section 2.4, either result could be used in most parts of the estuary, though high water levels within the B4 Shoots Barrage and B5 Beachley Barrage needed to be based on the somewhat higher predictions of the HR Wallingford 2D model (Table 2.3) as providing the best estimate of water levels. This decision caused particular issues with the Flood Risk and Land Drainage topic where assessments of the change in flood risk were primarily based on the ABPmer 2D model. A correlation between the two sets of results was made and extrapolated to estimate surge tide levels within these impoundments.

4.2.11 Predictions of suspended sediment concentrations following implementation of one of the alternative options are subject to medium uncertainty. To better assess the implications of this two alternative prediction methods were developed as discussed in section 2.4. In the Marine Water Quality topic analyses were undertaken using the prediction method that gave the greatest increase in water clarity. The predictions of changes in water clarity are a key consideration in the assessment of eutrophication risk, an assessment that itself is subject to medium uncertainty even if water clarity is well understood. As a consequence the assessment of eutrophication risk is considered to have a high uncertainty in this assessment.

4.2.12 Predictions of future water quality have not been as amenable to modelling of the physical processes as those in the hydraulics and geomorphology topic and the assessments have of necessity relied on simple models of the processes such as the 1D salinity modelling and for other aspects placed considerable reliance on literature reviews and on expert judgement.

4.2.13 The prediction of long term morphology evolution is subject to high uncertainty. For work in the Flood Risk and Land Drainage topic, these predictions were taken directly from the Hydraulics and Geomorphology topic.

4.2.14 To account for high uncertainty in long term morphology predictions a range of sensitivity tests were carried out in the Flood Risk and Land Drainage topic varying the anticipated length of coastline affected by erosion with each alternative option and also varying how rapidly this erosion might undermine the flood defences. The results were expressed in the topic paper and in this theme paper as a range of length and timings. The high estimate halved the time before works were required and doubled the length affected, while the low estimate did not change the timing of the works, but halved the length requiring protection on the best estimate from the morphology modelling.

4.2.15 Far field water level changes are also subject to moderate uncertainty. Again within the Flood Risk and Land Drainage topic, the length of coastline that might be affected and the cost of the works was varied in sensitivity testing to cover this uncertainty.

4.3 Interrelationships between the Physicochemical and other themes

4.3.1 The Physicochemical theme, and in particularly the Hydraulics and Geomorphology topic, provided key information to all the other themes, but did not rely on information from these other themes.

4.3.2 Some of the key recipients of information from the Physicochemical theme were the Marine Ecology and Freshwater Environment topics within the Biodiversity theme. These two topics relied on the Marine Water Quality and Flood Risk and Land Drainage topics as well as the Hydraulics and Geomorphology topic.

4.3.3 The majority of the other topics primarily required water level information from the Hydraulics and Geomorphology topic, though several topics were also interested in the predicted changes in wave climate or long term morphology changes.

4.3.4 The change in water levels calculated within the Hydraulics and Geomorphology topic leads directly to an assessment of the change in intertidal area by identifying where the predicted water levels intersect the bathymetry. This assessment was carried out initially within the Hydraulics and Geomorphology topic paper (Severn Tidal Power 2010c) using bathymetry defined within the hydraulic model. The analysis was subsequently repeated for the Marine Ecology topic (Severn Tidal Power 2010h) using the detailed contemporary bathymetry (Severn Tidal Power 2009c) to assess how the change in intertidal area would change the extent of each intertidal habitat.

4.3.5 A comparison of the two methods of analysis is included in this theme paper. The definitive assessment of changes in intertidal area is reported through the Marine Ecology topic to avoid the confusion that might arise if different values were reported in different reporting streams. .

SECTION 5

MEASURES TO PREVENT, REDUCE AND AS FULLY AS POSSIBLE OFFSET ANY SIGNIFICANT ADVERSE EFFECTS

5 MEASURES TO PREVENT, REDUCE AND AS FULLY AS POSSIBLE OFFSET ANY SIGNIFICANT ADVERSE EFFECTS

5.1.1 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 (SEA Directive Annex I). These measures are considered within this theme paper in terms of the interrelationships between topics within this theme.

5.1.2 In this SEA, and in line with UK practice, these measures are split into those to prevent or reduce effects and measures to as fully as possible offset any significant adverse effects on the environment. Offsetting measures make good for loss or damage to the environment, without directly reducing that loss/damage.

5.2 Measures to prevent or reduce significant adverse effects

5.2.1 During an initial optimisation phase a range of different configurations of each short listed option were considered at a high level to develop a preferred version for detailed testing that provided a reasonable balance between competing beneficial and adverse effects. This process, described in the Option Definition Report (Severn Tidal Power 2010b), considered changes in alignment, turbine numbers and design, sluice numbers, power station operating regime (ebb generation or ebb and flood generation).

5.2.2 The schemes shortlisted were all based on turbine performance characteristics developed for the UK Government by turbine manufacturers in 1980, though updates to performance were made based on generic improvements in technology. The outcome was the preferred versions of each short listed option that have been subjected to the detailed analysis described in each topic paper and its technical annexes.

Use of modern turbines and freewheeling at the end of the generation period

5.2.3 After these preferred versions were defined, information came available that allowed better definition of the potential relationships between turbine head, flow and efficiency that could be achieved with a 21st Century turbine design. These improvements are described in the model comparison report (Severn Tidal Power 2010g). These improvements indicated that

- high efficiency operation could be sustained with modern designs over a wider range of head and discharge than was possible in 1980, though the improvements in peak efficiency achieved over the previous three decades had already been factored in,

- Minimum head requirements for generation have been enforced more rigorously for the modern designs and in consequence were higher than those permitted with the previous designs. These requirements required generation to cease at around 2m head compared with around 1m head previously, and

- The modern design suggested that less flow could be passed through a modern turbine while freewheeling than the older design anticipated.

5.2.4 The major change arising from including modern turbine design in the effects of the different options was the increase in the minimum head for generation. This raised low water levels within ebb generation impoundments and reduced the tidal range within the ebb and flood generation option. These were seen as being significant adverse effects of employing modern turbines, which would offset the benefits of the higher efficiency operation that was seen as beneficial in limiting fish damage.

5.2.5 The selected method chosen to prevent or reduce these effects on tidal range within the impoundment was to allow flow through the turbine passages with the machines allowed to freewheel in the flow with their blades feathered whenever the head difference was too small to permit generation. The discharge during this period through the turbine passages was sufficient to restore the low water levels achieved with the original turbine design, while possibly further reducing the risks of fish damage.

Operational measures

5.2.6 For a scheme design containing specific hardware, there is a range of operational measures that can be employed regularly or intermittently to meet a range of specific requirements. This envelope of operational freedom has not been investigated. The assumption has been made in this strategic assessment that the hardware is operated at all times to maximise energy output. Other measures available include:

- Utilising fewer than the full number of sluices or turbines on particular occasions,
- Reducing or increasing the starting head for generation,
- Allowing sluices (in addition to turbines) to discharge during the ebb tide once heads are too small to permit generation. This measure is not available for the L3d Bridgwater Bay Lagoon as it contains no sluices.

5.2.7 All these measures would change the water levels and flow velocities inside and outside the impoundment, whenever they are employed, which in turn would affect suspended sediment concentrations. If such measures are used over a prolonged period this would affect the water quality and morphology of the estuary.

Measures to avoid or reduce effects on hydraulics and geomorphology

5.2.8 No specific measures have been identified to reduce specific effects on hydraulics and geomorphology. Many of these effects are inevitable as a result of extracting tidal energy from the Severn Estuary. However, as part of the detail design of a chosen scheme construction and engineering details can be modified to avoid or reduce some effects if that was the most effective way of managing these issues. In this assessment the assumption has been made that the topic area suffering an adverse effect would take the necessary measures and these have been costed.

5.2.9 Examples of measures that might be considered include:

- Caisson and embankment design modified to reduce wave reflection,
- Modification of construction sequence to avoid adverse geomorphology effects,
- Provision of additional scour protection to avoid adverse geomorphology effects,

- Improved design of sluice and turbine passages to limit sediment transport into the smaller ebb schemes (B4 Shoots Barrage, B5 Beachley Barrage, L2 Welsh Grounds Lagoon),

5.2.10 These measures have not been costed or included in this assessment but would need to be considered in more detail if a preferred scheme is identified.

5.2.11 For the small ebb only schemes (B4 Shoots barrage, B5 Beachley Barrage and L2 Welsh Grounds Lagoon), one of the key physicochemical effects is the considerable depths of sediment deposition predicted within the impoundment during the lifetime of the scheme. Some dredging is proposed to maintain navigation, but if sediment accumulation is still considered likely to pose a threat to the viability of the scheme or to fluvial flood evacuation beyond the official lifetime of the scheme, consideration should be given to regular flushing of the impoundment by keeping the sluices open through occasional spring tides to empty the basin to a level as close to existing low water levels as is practical. This would flush accumulated sediment back into the estuary and increase the life of the storage, but at a significant penalty in lost energy generation. Unfortunately such a policy is likely to require flushing from an early stage in the life of the scheme to be effective.

Measures to avoid or reduce effects on flood and erosion risk

5.2.12 All the ebb generation schemes (B3 Brean Down to Lavernock Point Barrage, B4 Shoots Barrage, B5 Beachley Barrage and L2 Welsh Grounds Lagoon) are identified as causing adverse effects to flood risk by raising surge tide levels along some length of coastline. These threats to the existing standard of flood defence would require raising of the affected defences before operation starts. The lengths of defence that are predicted to require raising for each option are set out in the Flood Risk and Land Drainage Topic Paper (Severn Tidal Power 2010e).

5.2.13 All the options pose the threat that erosion of the intertidal foreshore fronting flood defences would erode and risk undermining the defences. The timescale over which this threat fully materialises varies greatly around the estuary for each option, though for all the ebb generation schemes (B3 Brean Down to Lavernock Point Barrage, B4 Shoots Barrage, B5 Beachley Barrage and L2 Welsh Grounds Lagoon) some works to protect the flood defences from erosion are anticipated within 5 to 10 years of starting operation. For the L3d Bridgwater Bay Lagoon works to protect flood defences against erosion are unlikely to be required for several decades.

5.2.14 There will need to be a commitment to monitor rates of erosion and to intervene with appropriate measure once the risk that the defences would be undermined reaches an agreed threshold. The period before intervention is needed and the scale of intervention required are subject to considerable uncertainty. The range of anticipated measures (length and depth affected) and the timing of first intervention are set out in the Flood Risk and Land Drainage Topic Paper (Severn Tidal Power 2010e).

Measures to avoid or reduce effects on land drainage and groundwater levels

5.2.15 The change in tidal conditions within the impoundments formed by each of the short listed options is predicted to have some adverse effects on land drainage. The measures adopted would vary depending on the local circumstances and the severity of the effect. In all cases the improvements in land drainage would need to be implemented before the option starts operation. For the purposes of assessing the cost of the measures needed to avoid the adverse effect on land drainage, construction and operation of an appropriate land drainage pumping stations has generally been assumed in the Flood Risk and Land Drainage Topic Paper (Severn Tidal Power 2010e). The exception is the diversion of the River Axe around Brean Down which is expected to be a more cost effective measure for the B3 Brean Down to Lavernock Point Barrage than pumping. .

5.2.16 Land drainage pumping stations have been used as a generic solution because they can be implemented in almost all rural situations, though they are likely to be more costly than alternative solutions such as storage, enlargement of outfalls, or diversion or amalgamation of drainage lines in some situations. The feasibility of these other approaches can only be determined from specific local studies for each affected drainage area once a preferred option has been chosen.

5.2.17 In the urban areas of Bristol and Newport, the B3 Brean Down to Lavernock Point Barrage is predicted to have adverse effects on urban drainage outfalls. Provision of measures to avoid these effects in urban areas is usually more costly than in rural areas because of severe constraints on land availability (Severn Tidal Power 2010e). Measures to avoid effects on these outfalls have been costed separately at a higher rate appropriate for urban areas. The other options are not predicted to have significant adverse effects on urban drainage.

5.2.18 Measures to avoid effects on land drainage would also avoid the majority of effects associated with rising groundwater levels around the estuary. Residual affects associated with rising groundwater levels affecting properties and buried local infrastructure in the coastal strip may require additional local measures as discussed in the Freshwater Environment and Associated Interfaces Topic Paper (Severn Tidal Power 2010f).

Measures to avoid or reduce effects on water quality

5.2.19 One measure to avoid or reduce the adverse effects of the B3 Brean Down to Lavernock Point Barrage on eutrophication risk would be reduction of nutrient inputs to the estuary from the Severn catchment. A reduction could be made to point sources of nutrients but there would also be a need to reduce diffuse nutrient sources from the catchment. This measure has the potential to be effective, but its dependence on changes in practices over which the project would not have control and the timescales required for implementation make confidence in its implementation and effectiveness low. As the requirement for such measures is currently uncertain it would need to be a key focus for further studies if this option is pursued.

5.2.20 The L3d Bridgwater Bay Lagoon is predicted to have adverse effects on the water quality surrounding the cooling water intake and outfall from the Hinkley Point B power station. There is also a risk that this lagoon would also have an adverse effect on the water quality surrounding the Weston Waste Water Treatment Works.

5.2.21 The adverse effects on Hinkley Point B power station would require physical modification to the cooling water system to ensure that the intake is thermally separated from the outfall and free from siltation risks and that the thermal plume from the outfall continues to comply with Environment Agency Water Quality Objectives and Consent Conditions. In addition to thermal effects, predicted settlement of muddy sediment in the vicinity of the cooling water intake and outfall may require modifications to the arrangement of the lagoon and its turbines in this area to maintain effective operation of the system. The costs of these works are included in the Marine Water Quality Topic Paper (Severn Tidal Power 2010d).

5.2.22 If further study confirms that the adverse effects on the Weston WWTW treated effluent plume are sufficient to infringe Bathing Water Quality at Weston beach or any other Environment Agency Consent Conditions, measures would be required to avoid this risk. In this strategic assessment the assumption is made these measures would be required and the cost of an improvement to treatment processes or moving the outfall has been included in the Marine Water Quality Topic Paper (Severn Tidal Power 2010d).

Measures to avoid or reduce effects on geological SSSI

5.2.23 The raised low water levels in the impoundment behind the B3 Brean Down to Lavernock Point Barrage and the B4 Shoots Barrage are predicted to permanently submerge the entrance to the Otter Hole cave system on the tidal reach of the River Wye and lead to permanent loss of safe access. Provision of alternative safe access to this system could be considered as a measure to reduce the effect on this site as discussed in the Freshwater Environment and Associated Interfaces Topic Paper (Severn Tidal Power 2010f).

5.2.24 The risk of loss to Penarth coast SSSI from the B3 Brean Down to Lavernock Point Barrage landfall and to the Aust Cliff SSSI from the B5 Beachley Barrage landfall could be avoided or reduced by minor adjustment to the alignment of these options, subject to consideration of effects on other topic areas.

5.2.25 The B3 Brean Down to Lavernock Point Barrage, the B4 Shoots Barrage and B5 Beachley Barrage would permanently submerge the lower exposures of geological and geomorphological SSSIs behind these impoundments. This loss cannot be prevented and would need to be offset.

5.3 Measures to as fully as possible offset significant adverse effects

5.3.1 The implementation of any of the alternative options would cause changes to the estuary form and function that are features of the designation of the Severn Estuary / Môr Hafren European Site (NE, CCW and WAG, 2009). There is no possibility of fully offsetting such changes.

5.3.2 The B3 Brean Down to Lavernock Point Barrage, the B4 Shoots Barrage and B5 Beachley Barrage would submerge the lowest exposures of coastal geological and geomorphological SSSIs within the area of the impoundment. The Geological Conservation Review (GCR) may include other sites that have similar examples of the particular features that may be permanently submerged by these options. In such cases there is a possibility that the geological information lost to research by submergence of an SSSI outcrop could be offset by designation of a similar outcrop elsewhere. In this instance, providing that designation could be secured, and that there was access for observation and study, very little additional offsetting requirements would be necessary. Conversely, it is also possible that particular geological or geomorphological features at risk of submergence are unique. In this situation, no offsetting would be possible.

5.3.3 The feasibility of offsetting discrete geological outcrops that may be affected by the alternative options is outside the scope of this strategic study because of the level of detail required, however, it would need to be considered at a later planning stage.

SECTION 6

SEA OBJECTIVE COMPLIANCE

6 SEA OBJECTIVE COMPLIANCE

6.1 Compliance with SEA objectives

6.1.1 The SEA Objectives which were drafted and consulted upon as part of the Phase 1 SEA scoping stage are set out in Section 2.2. This theme paper identifies any interactions or inconsistencies between topics within this theme with regards to the assessment against SEA Objectives.

6.1.2 In line with the outcome of Phase 1 SEA Scoping, no SEA objectives were set for the Hydraulics and Geomorphology topic.

Alternative Option B3: Brean Down to Lavernock Point Barrage

Marine Water Quality topic

6.1.3 The B3 Brean Down to Lavernock Point Barrage is expected to meet Objectives 3, 4 and 5 for the Marine Water Quality topic. There is anticipated to be an uncertain or minor negative performance against SEA Objectives 1 (Avoid adverse effects on Marine Water Quality in relation to Marine Water Quality Standards) and 2 (Avoid adverse effects on designated marine wildlife sites of international and national importance due to changes in water quality). This uncertain or minor adverse performance against both objectives is due to the enhanced risk of eutrophication effects with this alternative (Severn Tidal Power 2010d).

Flood Risk and Land Drainage topic

6.1.4 The B3 Brean Down to Lavernock Point Barrage is expected to meet the SEA objective for the Flood Risk and Land Drainage topic with a major positive performance (Severn Tidal Power 2010e). This major positive performance is due to the delay in the need to invest in measures to raise flood defences to counter rising sea levels that would occur if this alternative is implemented.

Freshwater Environment and Associated Interfaces topic

6.1.5 The B3 Brean Down to Lavernock Point Barrage is expected to meet Objectives 2, 3 and 6 for the Freshwater Environment and Associated Interfaces topic. Objective 4 is being considered as part of the Freshwater Environment topic within the Biodiversity theme and Objective 7 is being considered as part of the Communities topic within the Society and Economy theme. There is anticipated to be a negative performance against Objectives 1, 5, 8 and 9 (Severn Tidal Power 2010f).

6.1.6 There is anticipated to be a minor negative performance against Objective 1 (Avoid adverse effects on water quality (whether surface waters, groundwater or coastal waters) in relation to water quality standards) in relation to groundwater. This is a consequence of increased saline intrusion into gravels and beach sand deposits around Cardiff and Weston-super-Mare.

6.1.7 There is anticipated to be a major negative performance against Objective 5 (Avoid adverse effects to buildings and infrastructure). This is due to the effects of the rise in groundwater level on infrastructure in urban areas alongside the estuary, particularly in Weston-super-Mare.

6.1.8 There is anticipated to be a major negative performance against Objectives 8 (Avoid adverse effects on geological and geomorphological sites of international and national importance) and 9 (Conserve and enhance geological and geomorphological features). This is due to the permanent loss of access to the lowermost exposures at nine sites.

Alternative Option B4: Shoots Barrage

Marine Water Quality topic

6.1.9 The B4 Shoots Barrage is expected to meet all Objectives for the Marine Water Quality topic (Severn Tidal Power 2010d). However, the assessment for SEA Objective 2 (Avoid adverse effects on designated marine wildlife sites of international and national importance due to changes in water quality) is considered uncertain because of the risk of localised future concentrations of contaminants in sediment deposits.

Flood Risk and Land Drainage topic

6.1.10 The B4 Shoots Barrage is expected to meet the SEA objective for the Flood Risk and Land Drainage topic (Severn Tidal Power 2010e).

Freshwater Environment and Associated Interfaces topic

6.1.11 The B4 Shoots Barrage is expected to meet Objectives 1, 2, 3, 5 and 6 for the Freshwater Environment and Associated Interfaces topic. Objective 4 is being considered as part of the Freshwater Environment topic within the Biodiversity theme and Objective 7 is being considered as part of the Communities topic within the Society and Economy theme. There is anticipated to be a negative performance against Objectives 8 and 9 (Severn Tidal Power 2010f).

6.1.12 There is anticipated to be a minor negative performance against Objectives 8 (Avoid adverse effects on geological and geomorphological sites of international and national importance) and 9 (Conserve and enhance geological and geomorphological features). This is due to the permanent loss of access to the lowermost exposures at four sites.

Alternative Option B5: Beachley Barrage

Marine Water Quality topic

6.1.13 The B5 Beachley Barrage is expected to meet all Objectives for the Marine Water Quality topic (Severn Tidal Power 2010d). However, the assessment for SEA Objective 2 (Avoid adverse effects on designated marine wildlife sites of international and national importance due to changes in water quality) is considered uncertain because of the risk of localised future concentrations of contaminants in sediment deposits.

Flood Risk and Land Drainage topic

6.1.14 The B5 Beachley Barrage is expected to meet the SEA objective for the Flood Risk and Land Drainage topic (Severn Tidal Power 2010e).

Freshwater Environment and Associated Interfaces topic

6.1.15 The B5 Beachley Barrage is expected to meet Objectives 1, 2, 5 and 6 for the Freshwater Environment and Associated Interfaces topic. Objective 4 is being considered as part of the Freshwater Environment topic within the Biodiversity theme and Objective 7 is being considered as part of the Communities topic within the Society and Economy theme. There is anticipated to be a positive performance against Objective 3 and a negative performance against Objectives 8 and 9 (Severn Tidal Power 2010f).

6.1.16 There is anticipated to be a minor positive performance against Objective 3 (Avoid adverse effects on water abstractions, particularly those utilised for the PWS). This is due to the reduction in potential for saline intrusion affecting the Purton off-take on the Sharpness Canal, although the benefits may reduce with time.

6.1.17 There is anticipated to be a minor negative performance against Objectives 8 (Avoid adverse effects on geological and geomorphological sites of international and national importance) and 9 (Conserve and enhance geological and geomorphological features). This is due to the permanent loss of access to the lowermost exposures at two sites.

Alternative Option L2: Welsh Grounds Lagoon

Marine Water Quality topic

6.1.18 The L2 Welsh Grounds Lagoon is expected to meet all Objectives for the Marine Water Quality topic (Severn Tidal Power 2010d).

Flood Risk and Land Drainage topic

6.1.19 The L2 Welsh Grounds Lagoon is expected to meet the SEA objective for the Flood Risk and Land Drainage topic (Severn Tidal Power 2010e).

Freshwater Environment and Associated Interfaces topic

6.1.20 The L2 Welsh Grounds Lagoon is expected to meet the seven relevant Objectives for the Freshwater Environment and Associated Interfaces topic (Severn Tidal Power 2010f). The remaining two Objectives are being considered within other topics. Objective 4 is being considered as part of the Freshwater Environment topic within the Biodiversity theme and Objective 7 is being considered as part of the Communities topic within the Society and Economy theme.

Alternative Option L3d: Bridgwater Bay Lagoon

Marine Water Quality topic

6.1.21 The L3 Bridgwater Bay Lagoon is expected to meet all Objectives for the Marine Water Quality topic (Severn Tidal Power 2010d).

Flood Risk and Land Drainage topic

6.1.22 The L3 Bridgwater Bay Lagoon is expected to meet the SEA objective for the Flood Risk and Land Drainage topic with a minor positive performance (Severn Tidal Power 2010e). This minor positive performance is due to the delay in the need to invest in measures to raise flood defences to counter rising sea levels that would occur if this alternative is implemented.

Freshwater Environment and Associated Interfaces topic

6.1.23 The L3 Bridgwater Bay Lagoon is expected to meet Objectives 2, 3, 5, 6, 8 and 9 of the Freshwater Environment and Associated Interfaces topic. Objective 4 is being considered as part of the Freshwater Environment topic within the Biodiversity theme and Objective 7 is being considered as part of the Communities topic within the Society and Economy theme. There is anticipated to be a negative or uncertain performance against Objective 1 (Severn Tidal Power 2010f).

6.1.24 There is anticipated to be a minor negative performance against Objectives 1 (Avoid adverse effects on water quality (whether surface waters, groundwater or coastal waters) in relation to water quality standards) in relation to groundwater. This negative effect is a consequence of the predicted saline intrusion into higher permeability deposits near the Bridgwater Bay coastline.

SECTION 7

IMPLEMENTATION

7 IMPLEMENTATION

7.1 Proposals for monitoring

7.1.1 The SEA Directive requires that measures to monitor the significant environmental effects are described within the environmental reporting. Monitoring allows the actual significant environmental effects of implementing a Severn Tidal Power alternative option to be tested against those predicted.

7.1.2 This section sets out suggestions for the framework for the monitoring of the plan against the predicted significant effects within this theme which can be applied to all of the Severn Tidal Power Schemes under consideration. Table 7.1 includes a brief summary of monitoring proposed for this theme and identifies any interactions or inconsistencies between the topics within this theme.

7.1.3 The monitoring requirements for the elements of the plan within this theme are largely a continuation and increased systematisation of existing monitoring, especially in the case of water levels, subtidal bathymetry, intertidal foreshore levels and marine water quality parameters. For water levels and water quality the sites where monitoring is carried out may need to be modified compared to current monitoring arrangements to take account of anticipated effects of the option. These monitoring programmes would be more intensive in early years to ensure the scheme complies with consent conditions and to compare actual changes with those predicted in the EIA for a preferred scheme.

7.1.4 Specific monitoring of post scheme compliance, that would not need to continue would be required to check compliance of effluent discharges against their consent conditions, which may change as result of scheme implementation.

7.1.5 The monitoring of foreshore erosion to determine when investments in measures to protect flood defences against undermining are required would be a long term requirement of the preferred scheme. The monitoring would determine when conditions that trigger a decision to invest in these measures had been reached.

Table 7.1: Potential Monitoring Summary for Theme Reporting

Monitoring proposal for significant environmental effects	Receptor	Topics covered	Comment
Measure water levels at key locations in the Severn Estuary continuously	water levels	Hydraulics and Geomorphology, Flood Risk and Land Drainage. Key information for other topics in other themes	Key information on the performance and actual effects of a Severn Tidal Power Scheme
Measure bathymetry of the estuary at decade intervals	long term morphology	Hydraulics and Geomorphology. Information for other topics in other themes	This is primarily considering subtidal changes in estuary bathymetry. Intertidal changes considered

Monitoring proposal for significant environmental effects	Receptor	Topics covered	Comment
			below.
Measure foreshore levels of the estuary using LiDAR at decade intervals	long term morphology	Hydraulics and Geomorphology, Flood Risk and Land Drainage. Information for other topics in other themes	This is to measure accretion and erosion of the intertidal foreshore inside and outside a Severn Tidal Power Scheme.
Measure surface concentrations of suspended sediment and other water quality parameters including nutrient and chlorophyll	suspended sediments, nutrients and other water quality receptors	Hydraulics and Geomorphology, Marine Water Quality. Information for other topics in other themes	Continuation of water quality sampling programme with additional measurements to cover specific anticipated effects.
Post scheme compliance monitoring of effluent dispersal	Temperature and pathogens	Marine Water Quality	Monitoring of effectiveness of measures undertaken to avoid adverse effects on thermal and sewage effluent dispersal
Monitor effects of foreshore erosion on adjacent flood defences to determine when measures are required	People and property protected from tidal flood risk	Flood Risk and Land Drainage	Determination of when investment should be made to avoid undermining of existing flood defences.
Post scheme compliance monitoring of effluent dispersal	Temperature and pathogens	Marine Water Quality	Monitoring of effectiveness of measures undertaken to avoid adverse effects on thermal and sewage effluent dispersal
Detailed information on Geological exposures	Geological and geomorphological SSSIs	Freshwater Environment and Associated Interfaces	Identification of exposures that are at risk of submergence if an alternative option is implemented
Water table elevation around buildings and services considered at risk’	Basements and underground assets	Freshwater Environment and Associated Interfaces	The type of ground and its connectivity to surface water drainage would also require assessment.
Water table elevation in rural areas considered at risk’	Soils	Freshwater Environment and Associated Interfaces	The type of ground and its connectivity to surface water drainage would also require assessment.

7.2 Suggestions for further studies

7.2.1 This section includes some suggestions for research to support further consideration of tidal power in the Severn Estuary, prior to the implementation of a preferred scheme.

Hydraulics and Geomorphology

7.2.2 Suggestions on further data gathering and model developments that are desirable to support further Hydraulics and Geomorphology work on Severn Tidal Power schemes have been set out (Severn Tidal Power 2010c and H&G Annex 1). These suggestions are in some cases relevant for all the alternative options, though there are specific suggestions that only apply to certain options.

7.2.3 The following represent some of the key data gaps. Data collection in some or all of these areas is suggested to inform the next phase of development:

1. Wave data should be collected along the sides of the Severn Estuary and where possible over intertidal areas of interest. Measurements of waves and currents should also be made at one fixed location in an upper estuary main channel.
2. A single one-off bathymetric survey of the estuary should be commissioned, including refined data close to the site of the proposed scheme, but with more coarsely spaced transects covering the whole of the estuary from the Bristol Channel up to Beachley. A survey of the Upper River Severn should be commissioned, to tie in with the recent Gloucester Harbour Trustees survey. An understanding of which areas change and over what timescales is also required. For example, changes over a tide, annual changes or changes per lunar nodal cycle. Port of Bristol data clearly showed large changes between spring tidal cycles.
3. A bathymetric survey of the main tributaries to the Severn Estuary, particularly the River Wye should be commissioned. The survey should extend to the tidal limit where this is possible;
4. Flow and water level and sediment load data should be collected in the upper reaches of the estuary.
5. Knowledge of the proposed turbine structures should be improved and fed back into the models.
6. Suspended sediment, intertidal morphology, and subsurface intertidal data should be collected over sensitive areas of intertidal.
7. Analogues should be broadened to include changes to intertidal profiles caused by anthropogenic activities, and not limited to tidal power schemes as for this study.
8. The analysis of the long-term record of intertidal morphological change should be extended through further LiDAR monitoring approximately every five years for the foreseeable future and at estuary wide scale.

7.2.4 The following suggestions have been made for modelling studies as a result of the modelling assessments carried out for this strategic assessment.

1. The offshore northern boundary of the flow model should be extended to at least the Mull of Kintyre, and that far-field effects predicted by POL should be refined over the full wider area for the proposed detailed tidal power scheme now that the options have been clarified further. Note that this is only necessary for the B3 Brean Down to Lavernock Point Barrage.

2. The effects of construction and decommissioning activities on the hydraulic, sediment and morphology regime should be quantified and, where possible, mitigated, and that a final operational design, functioning after a few years, should be tested.

3. The next assessment should focus on a single preferred scheme, allowing high model resolution to be used in all of the areas of interest, with a more detailed definition of the scheme, approaching bed slopes, and ship locks, and with appropriate reduction in resolution in areas of lesser interest.

4. The use of 3D flow modelling to support requirements for more detailed sediment modelling should be considered.

5. The use of 3D sediment modelling should be considered on the assumption that suitable validation data is available.

6. The use of physical models during the design stage, particularly to aid in the development of the construction process, should be considered.

7. A detailed scour assessment should be undertaken to inform the further development of the design.

8. The science of intertidal morphology change and changes to suspended sediments including biological effects (the feedback between both of these study areas) as applicable in the Severn Estuary post scheme should be improved.

9. The siting of the L3V9 Bridgwater Bay Lagoon turbine blocks should be re-evaluated if this scheme is taken forward for further assessment.

10. If the B3 Brean Down to Lavernock Point Barrage is taken forward, the ASMITA boundary should be extended seawards.

11. If the B4 Shoots Barrage or B5 Beachley Barrage are taken forward, measures to seek to minimise the predicted accretion immediately upstream of these barrages should be further investigated (e.g. layout and modes of operation for sluice and turbine blocks, and/or any capital or maintenance dredging plans).

12. The management of sediment, and the predicted ongoing deposition, should be considered.

Marine Water Quality

7.2.5 A series of major water quality studies have been suggested (Severn Tidal Power 2010d) as part of an environmental impact assessment of a preferred option to improve confidence in the predictions of water quality effects and to refine the requirements for measures to avoid or reduce adverse effects.

1. A detailed water quality survey of the estuary and tributaries (linked to physical process studies) should be undertaken to provide robust baseline data on water

and sediment quality which could support water quality model development and wider water quality assessment studies.

2. A more detailed estuary-wide 2-D salinity model (including tributaries) should be developed to better resolve lateral salinity gradients and the effects of changes in water circulation on those gradients. The suggested scope for this model is set out below.

3. Further modelling and assessment of estuary-wide changes in suspended sediment concentrations (including tributaries) should be commissioned to better quantify the spatial extent and magnitude of potential changes.

4. Development of an estuary-wide nutrient model (including tributaries) should be encouraged that takes account of biological transformation processes to evaluate spatial and temporal changes in nutrient concentrations linked to eutrophication risk.

5. Development of an estuary wide dissolved oxygen model (including tributaries) should be encouraged to evaluate potential changes in dissolved oxygen.

6. Detailed scenario modelling of bathing water compliance risks at relevant bathing waters should be undertaken.

7. Development of a temperature model to evaluate changes in temperature within lagoon options should be encouraged if a lagoon option were to be pursued.

8. Detailed modelling of thermal plume issues is suggested.

9. Laboratory studies of potential changes in biogeochemical cycling of contaminants in response to changes in sediment stability, sediment composition, organic carbon, bioturbation, remineralization and estuary flushing are suggested.

7.2.6 In order to address the potential changes in salinity concentration within the Severn Estuary as part of a more detailed investigation of a scheme the following suggestions are made about the scope of such modelling.

1. Investigate the potential changes in dispersion coefficient to improve understanding of the changes arising from a tidal power scheme.

2. 2D or 3D model investigation of the lateral and longitudinal salinity dispersion within the estuary. Giver the high velocity low shear environment it seems more likely that a 2D approach would be preferred.

3. Near field changes in salinity adjacent to tidal power structures should be considered taking into account the likely areas of extremely low flow or complete blockage.

4. The main tributaries (Severn, Usk, Avon, Wye, Parrett and Tone) should be included in the 2/3D model and extend up to the respective tidal limits.

5. The model should be run under a series of specified conditions:
    - Low river flow
    - High river flow
    - Average annual river flow

- Real river flow

7.2.7 Detailed salinity data for model calibration and validation should be captured along the length of the estuary with particular detail within the areas of largest gradient change (approximately Sharpness to Cardiff). Sufficient information should be available spatially, temporally and vertically through the water column particularly if a 3D model approach is adopted. Furthermore, the tidal condition should also be recorded to ensure that the period of investigation can be accurately represented in the modelling investigation.

Flood Risk and Land Drainage

7.2.8 Before the design of any of the alternative options could be undertaken, there are a number of assessments described in this paper which should be refined with further modelling or analyses to reduce and uncertainties. These should be put in place at an early stage if there is a decision to pursue any of the options. These include:

- Further modelling of tributaries for surge tides and fluvial floods.
- Detailed modelling of far field effects for surge tide conditions.
- Modelling of individual outfalls to determine the extent of tide-lock effects and to determine the most appropriate measure to reduce the effects (whether additional storage or duplication of outfalls would be preferable to a pumping station).
- Modelling to improve the estimated erosion risks which could affect tidal or sea defences.
- Modelling to confirm the accretion upstream of the smaller barrages in the long term and to determine whether there are any significant effects which would require measures to reduce these to an acceptable level.

Freshwater Environment and Associated Interfaces

7.2.9 An increased level of understanding in the following areas would be advantageous in reducing the levels of uncertainty associated with the assessment of the Freshwater Environment and Associated Interfaces topic. In all cases the scope of the further studies should be linked to the anticipated effects of the alternative option being selected for further study. Some studies may not be required for all alternative options.

Geological / Geomorphological SSSIs

- Further baseline detail on geological/geomorphological SSSI designations
- The feasibility and associated cost of providing an alternative access into Otter Hole;
- The feasibility of off-setting significant effects to geological and geomorphological SSSIs, through other GCR sites.

Subterranean Assets

- Further baseline information regarding subterranean assets, within low-lying land near the coastal fringe especially in the vicinity of Weston-super-Mare, as well as other urban centres near the coast. In low-lying Cardiff, much of this information should already be available from the Cardiff Bay scheme.

- A high-level review should be made of the post-closure closure monitoring information available from the Cardiff Bay scheme to identify actual versus predicted effects from the impoundment on subterranean infrastructure.

- Further information on the Quaternary and recent deposits adjacent to the Severn estuary, in which infrastructure sits, including its physical and hydraulic characteristics and ground elevations.

- The distribution and nature of Made Ground deposits should be reviewed, as well as its potential influence on groundwater quality within the coastal margin.

Soils

- Further baseline information on the distribution of the different soil types, their current condition and quality, and vulnerability to changes in soil moisture.

7.2.10 Further details about the suggestions for further research are contained within the Freshwater Environment and Associated Interfaces topic paper (Severn Tidal Power 2010f).

SECTION 8

GLOSSARY

8 GLOSSARY

Term	Definition
Alluvial	Material that is transported by rivers
Appropriate Assessment	A process required by the Habitats Regulations (SI 1994/ 2716) to avoid adverse effects of plans, programmes and projects on Natura 2000 sites and thereby maintain the coherence of the Natura 2000 network and its features.
Ancillary development	Other works beyond a Severn Tidal Power scheme but are needed to build or operate the scheme, including measures to prevent, reduce or as fully as possible offset significant environment effects, e.g. dredging, bypasses etc.
ASMITA	A behaviour – based model that describes morphological interaction between a tidal basin and it adjacent coastal environment. ASMITA is typically used to examine the long term morphological evolution in estuaries.
Barrage	A manmade obstruction across a watercourse to retain a head of water on the rising tide, and then run the water through turbines when the tide level drops.
Bristol Channel	The area seaward of the headlands at Lavernock Point on the Welsh coast and Brean Down on the English coast (see Severn Estuary and also Inner Bristol Channel and Outer Bristol Channel)
Bulb Kapeller type turbines	The Kapeller Bulb turbine is a turbine regulated only by its adjustable runner blades (single regulation). It has fixed wicket gates. It is adaptable to pumping as well as generation but only suited to one way generation. Kapeller Bulb turbine technology has largely been superseded by Bulb Kaplan turbines.
Bulb Kaplan turbines	The Kaplan turbine is a propeller-type water turbine that has adjustable blades and adjustable wicket gates (double regulation). It is adaptable to pumping as well as generation. Kaplan turbines are now widely used throughout the world in high-flow, low-head power production. The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. The Kaplan turbine is suited to one or two way generation.
Bulb turbines	The generator is mounted in a bulb on the main turbine axis upstream of the runner blades for one way generation. Bulb turbines can be used for one or two way generation depending on the type (see above).
Caissons	Prefabricated concrete units used to construct parts of a barrage, lagoon or other offshore structures. Caissons can be used to house turbines, sluices or to construct navigation locks, or they may just be plain units used for impoundment construction.
Coalfield river	A river draining a coalfield valley
Coastal Squeeze	Process whereby the coastal margin is squeezed between a fixed landward boundary and the rising sea level.

Term	Definition
Compensation	Measure which makes good for loss or damage to an SAC or SPA feature, without directly reducing that loss/damage. Only used in relation to the Habitats Directive (see offsetting, below).
Consequential development	It is conceivable that a major tidal power scheme will facilitate or attract other developments, which may themselves pose significant environmental effects. These developments are described as ‘consequential developments’.
Cumulative effects	Effects arise, for instance, where several developments each have insignificant effects but together have a significant effect, or where several individual effects of the plan have a combined effect.
Direct effects	The original effect as a result of an option (see indirect effects)
Ebb	When the sea or tide ebbs, it moves away from the coast and falls to a lower level.
Ebb mode	One way generation on ebb tides only i.e. during the period between high tide and the next low tide in which the sea is receding.
Ebb and flood mode	Two way generation during the ebb and flood tides
Effect	Used to describe changes to the environment as a result of an option (see also direct effects, indirect effects, far-field effects and cumulative effects)
Eutrophication	An increase in chemical nutrients (compounds containing nitrogen or phosphorus). This in turn can lead to ‘eutrophication effects’ – an increase in an ecosystem’s primary productivity (excessive plant growth and decay), and further effects including lack of oxygen and severe reductions in water quality, fish, and other animal populations.
Far-field effects	Effects that are felt outside the Severn Estuary study area.
Flood	The inward flow of the tide - This is the opposite of ebb. This refers to a mode of operation for a STP alternative option.
Future baseline	Baseline during construction (2014-2020) and operation (2020-2140), decommissioning and longer term trends.
Geomorphology	The study of the changing form of the estuarine environment and its components in relation to physical forcing.
Hydrodynamics / hydraulics	The science of physical forces acting on the water.
Hypertidal	A tidal range in excess of 6m.
Impoundment	A body of water, such as a reservoir, made by impounding
Indicator	A measure of variables over time, often used to measure achievement of objectives.

Term	Definition
Indirect effects	Those effects which occur away from the original effect or as a result of a complex pathway.
Inner Bristol Channel	The downstream limit extends from Nash Point in Wales to the west of Minehead along the English coast. The upper limit extends from Swanbridge on the Welsh coast to Brean Down along the English coast.
Irreversible	An effect that cannot be reversed. If the timescale for a receptor's return to baseline condition is greater than 50 years then it will be considered irreversible.
Lagoon(s)/ Land-connected lagoons	A man-made enclosed body of water that retains a head of water on the rising tide and then runs the water through turbines when the tide level drops. A land connected lagoon uses the shoreline to make the enclosure.
Long-listed options	All options identified in the SDC report, Call for Proposals and other strategically selected proposals as well as the Interim Options Analysis Report.
Measures to prevent or reduce effects	Measures to prevent, or reduce any significant adverse effects on the environment
Natura 2000	Natura 2000 is the European Union-wide network of protected areas, recognised as 'sites of Community importance' under the EC Habitats Directive (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora). The Natura 2000 network includes two types of designated areas: Special Areas of Conservation (SAC) and Special Protection Areas (SPA).
Negative effects	Changes which are unfavourable for a receptor. Can sometimes be referred to as 'adverse'.
Offsetting	Measures to as fully as possible offset any significant adverse effects on the environment. Such measures will aim to make good for loss or damage to an environmental receptor, without directly reducing that loss/damage. Not used in relation to the Habitats Directive (see compensation, above).
One way generation	The operating mode whereby power is generated on only one phase of the tidal cycle. For Severn tidal power, one way generation is typically ebb mode.
Original scheme	The form of the scheme when it was shortlisted at the end of phase 1.
Outer Bristol Channel	The outer limit extends from St. Govans Head in Pembrokeshire to Hartland Point in Devon, which traditionally defines the lower limit of the Bristol Channel. The upper limit extends from Nash Point in Wales to the west of Minehead along the English coast.
Permanent effect	An effect which will last at least for 50 years.
Phase 1	The current stage of the STP Feasibility Study - i.e. the Decision Making Assessment Framework (to develop a short-list of options) and SEA Scoping.
Phase 2	The second stage of the STP Feasibility Study - i.e. short-listed options appraisal and main assessment stage of the SEA.

Term	Definition
Positive effects	Changes which are favourable for a receptor. Can sometimes be referred to as ‘beneficial’.
Pumping	Operating turbines in reverse to pump water from lower to higher levels. Pumping can be used during one way generation to raise impounded water levels so that more energy can be generated when the ebb tide is receding.
Ramsar site	Ramsar sites are designated under the International Convention on Wetlands of International Importance 1971 especially as Waterfowl Habitat (the Ramsar Convention).
Receptor	An entity that may be affected by direct or indirect changes to an environmental variable.
Reversible	An effect that can be reversed. If the timescale for a receptor’s return to baseline condition is less than 50 years then it will be considered reversible.
Scoping	The process of deciding the scope and level of detail of an SEA, including the environmental effects and alternatives which need to be considered, the assessment methods to be used, and the structure and contents of the Environmental Report.
SEA objective	A statement of what is intended, specifying the desired direction of change in trends.
Seabed	The areas permanently covered by the sea, i.e. Lowest Astronomical Tide. Sometimes referred to as sub-tidal.
Severn Estuary	This is the physical extent of the Estuary and does not reflect the Study Area (see below) or nature conservation designations. Downstream limit - headlands at Lavernock Point on the Welsh coast and Brean Down on the English coast passing through the small island features of Flat Holm and Steep Holm. Upstream limit – Haw Bridge, upstream of Gloucester on the River Severn (based on 1 in 100 year flood risk area and also used by Shoreline Management Plan (SMP) (Gifford, 1998) and Coastal Habitat Management Plan (CHaMP) (ABPmer 2006)). N.B. The tidal limit, which for the Severn is at Maisemore (West Parting) and Llanthony (East Parting) weirs, near Gloucester.
Severn Tidal Power Study Area	The general study area used for the project broadly extends downstream on the Estuary as far as Worm’s Head to Morte Point. It includes the landward fringe and tributaries such as the River Wye and the River Usk. Study areas for individual topics for Phase 2 may extend beyond this area and these are defined separately according to topic.
Short-listed options	Options screened from long-listed options, to be taken forward for analysis in the SEA following the public consultation conducted in 2009.
Significant	Effects on the environment which are significant in the context of a plan or

Term	Definition
environmental effects	programme. Criteria for assessing significance are set out in Annex II of the SEA Directive (2001/42/EC).
Site of Special Scientific Interest (SSSI)	Designated under the Wildlife and Countryside Act 1981, any land considered by Natural England to be of special interest because of any of its flora, fauna, or geological and physiographical features.
Sluice caissons	Prefabricated concrete structures placed into the water to house a sluice.
Special Area of Conservation (SAC)	Strictly protected site designated under the EC Habitats Directive 92/43/EEC. Article 3 of the Habitats Directive requires the establishment of a European network of important high-quality conservation sites that will make a significant contribution to conserving the 189 habitat types and 788 species identified in Annexes I and II of the Directive (as amended). The listed habitat types and species are those considered to be most in need of conservation at a European level (excluding birds).
Special Protection Area (SPA)	Strictly protected site classified in accordance with Article 4 of the EC Directive on the Conservation of Wild Birds (79/409/EEC), also known as the Birds Directive. They are classified for rare and vulnerable birds, listed in Annex I to the Birds Directive, and for regularly occurring migratory species.
Straflo type turbines	A more compact turbine compared to Bulb turbine technology. Instead of containing the generator in a bulb, it is located and designed for ebb only operation and not suited to pumping.
Strategic Environmental Assessment (SEA)	Term used to describe environmental assessment as applied to policies, plans and programmes. 'SEA' is used to refer to the type of environmental assessment required under the SEA Directive.
Sub tidal	Areas (particularly with reference to habitats) that lie below the level of the lowest astronomical tide.
Synergistic effects	Effects which interact to produce a total effect greater than the sum of the individual effects, so that the nature of the final impact is different to the nature of the individual effects. Included within cumulative effects (see above).
Temporary effects	An effects which only lasts part of the project lifetime, e.g. is confined to the construction period.
The Shoots	The downstream boundary extends from Undy along the Welsh coast to Severn Beach along the English coast, just to the south of the M4 motorway crossing. The upstream limit extends just to the north of the M46 motorway crossing, between Beachley on the Welsh coast and Aust on the English coast.
Tidal bore	A tidal phenomenon in which the leading edge of the incoming tide forms a wave (or waves) of water that travel up a river or narrow bay against the direction of the current.

Term	Definition
Tidal Prism	The difference between the mean high-water volume and the mean low-water volume of an estuary.
Transboundary effects	An environmental effect upon another EU Member State.
Turbine caissons	Prefabricated concrete structures placed into the water to house turbines.
Two way generation	The operating mode whereby power is generated on both phases of the tidal cycle (ebb and flood)
TWh/year	A unit used to describe how much energy generated, sold, consumed, etc. A terawatt-hour refers to generating or using power at a capacity of 1 terawatt (1012 watts) for one hour. A terawatt-hour per year means the equivalent amount of power sometime within the period of a year.
Upper Severn Estuary	Upstream from the M46 motorway crossing, between Beachley on the Welsh coast and Aust on the English coast, to the tidal limit along the River Severn at Maisemere, Gloucestershire.
Variant	A modified version of the original shortlisted scheme.

SECTION 9

REFERENCES

9 REFERENCES

ABPmer, 2007: Severn Estuary CHaMP Morphological Assessments Part E: Historical Trends Analysis

DCLG, 2006. (Department of Communities and Local Government). Planning Policy Statement 25: Development and Flood Risk. December 2006, 44pp.

DECC, 2009a. Severn Tidal Power Phase 1 Consultation. Issued 26 January, DECC, London.

DECC, 2009b. Severn Tidal Power Phase 1 Consultation Government Response. Issued 15 July, DECC, London.

Defra, 2009. UK Climate Projections, 2009 (UKCP09). Website: http://ukclimateprojections-ui.defra.gov.uk/ui/admin/login.php published 18 June 2009, Crown Copyright 2008.

Environment Agency, 2009a. Water for Life and Livelihoods. River Basin Management Plan, Severn River Basin District. Environment Agency, December 2009. 66pp.

Environment Agency, 2009b. Water for Life and Livelihoods. River Basin Management Plan, South West River Basin District. Environment Agency, December 2009. 2009. 71pp.

Environment Agency, 2009c. Water for Life and Livelihoods. River Basin Management Plan, Western Wales River Basin District. Environment Agency, December 2009. 58pp.

Environment Agency, 2009d. Severn Estuary/ Môr Hafren SAC/SPA. Review of Consents Appropriate Assessment Stage 3 Report: Water Quality Technical Annex.

HMSO, 1981: Energy Paper 46: Tidal Power from the Severn Estuary Volume 1 and 2, HMSO 1981

HMSO, 1989: Energy Paper 57: STPG: Severn Barrage Project: General Report and Detailed Vol I-V, HMSO 1989

HRS, 1981a: The Severn Estuary – Observations of tidal currents, salinities and suspended solids concentrations. Hydraulics Research Station Report No EX 966 January 1981.

HRS, 1981b: The Severn Estuary – Wave climate study; wind wave correlation; Waves April 1978 – March 1981; Winds April 1960 – March 1981. Hydraulics Research Station Report No EX 994 August 1981.

Keiller DC and Thompson G, 1981. One-dimensional modelling of tidal power schemes. Second International Symposium on Wave & Tidal energy BHRA 1981.

Met Office Hadley Centre, 2009: The climate of the United Kingdom and recent trends. http://ukclimateprojections.defra.gov.uk/content/view/830/516/ Revised edition January 2009.

NE, CCW and WAG, 2009. The Severn Estuary / Môr Hafren candidate Special Area of Conservation European marine site Natural England & the Countryside Council for Wales' advice given under Regulation 33(2)(a) of the Conservation (Natural Habitats, &c.) Regulations 1994, as amended. June 2009. Report by Natural England, Countryside Council for Wales and Welsh Assembly Government

ODPM, Scottish Executive, Welsh Assembly Government and Department of the Environment in Northern Ireland, 2005. A Practical Guide to the Strategic Environmental Assessment Directive. ODPM, London.

PSMSL Website, 2009: http://www.pol.ac.uk/psmsl/psmsl_individual_stations.html accessed December 2009

Severn Estuary Aggregates Working Group, 2007: Investigation of Sea Bed Changes in the Estuary since 1847, March 2007

Severn Tidal Power SEA, 2009a. STP SEA Policy, Plan and Programme Review. ENVIRON (PB/BV Consortium) Paper. July 2009. 211pp

Severn Tidal Power SEA, 2009b. Cumulative Effects & Consequential Developments. PB/BV Consortium Paper. July 2009. 17pp

Severn Tidal Power SEA, 2009c: Development of Estuary Bathymetry, PB/BV Consortium, April 2009

Severn Tidal Power SEA, 2009d: 1D Mathematical Modelling – Phases 1 & 2, PB/BV Consortium, July 2009

Severn Tidal Power SEA, 2009e : Climate Change Scenarios, PB/BV Consortium Paper, July 2009

Severn Tidal Power SEA, 2010a: Environmental Report, PB/BV Consortium, April 2010

Severn Tidal Power SEA, 2010b: Strategic Environmental Assessment of Proposals for Tidal Power Development in the Severn Estuary – Options Definition Report, Version 2 – Interim Options Definition, Volume 2, Parsons Brinckerhoff Ltd, February 2010

Severn Tidal Power SEA, 2010c: Hydraulics & Geomorphology Topic Paper, ABPmer for PB/BV Consortium, November 2009

Severn Tidal Power SEA, 2010d: Water Quality Topic Paper, ABPmer for PB/BV Consortium, January 2010

Severn Tidal Power SEA, 2010e: Flood Risk & Land Drainage Topic Paper, PB/BV Consortium, January 2010

Severn Tidal Power SEA, 2010f: Freshwater Environment & Associated Interfaces Topic Paper, PB/BV Consortium, January 2010

Severn Tidal Power SEA, 2010g: Comparison of Results from 1D and 2D Mathematical Modelling, PB/BV Consortium, February 2010

Severn Tidal Power SEA, 2010h: Marine Ecology Topic Paper Annex 3 – Habitat Modelling, ABPmer for PB/BV Consortium, March 2010

Telemac Website, 2010: http://www.telemacsystem.com/index.php?lang=en accessed March 2010

UK Hydrographic Office 2008. Admiralty Tide Tables Volume 1 2009 United Kingdom and Ireland. Crown Copyright 2008

WAG, 2004. (Welsh Assembly Government). Development and Flood Risk Technical Advice Note 15. TSO, 44pp.

WaveNet Website, 2009: http://www.cefas.co.uk/data/wavenet.aspx accessed June 2009

9.1 Supporting Hydraulics and Geomorphology and Marine Water Quality annexes

Hydraulics and Geomorphology

Technical Annex	Title	Prepared by	Date
1	Hydraulics and Geomorphology Technical Summary	HR Wallingford	March 2010
2	Annex Geo 1: Conceptual design for Short-listed Options	ABPmer Ltd	March 2010
3	Annex Geo 2: Analogues	ABPmer Ltd	April 2010
4	Annex Geo 3: Improve baseline understanding of intertidal morphology and dynamics	HR Wallingford	March 2010
5	Annex Geo 4: Improve baseline understanding of suspended sediment regime	HR Wallingford	April 2010
6	Annex Geo 4: Improve baseline understanding of suspended sediment regime (River inputs)	ABPmer Ltd	April 2010
7	Annex Geo 5: Confirm far-field extents of impacts on hydraulics	ABPmer Ltd	April 2010
8	Annex Geo 6: Investigation of changes to hydraulics for short-listed options (water levels and flows) Part A	HR Wallingford	April 2010
9	Annex Geo 6: Investigate changes to hydraulics for shortlisted options (water levels and flows) Part B.	ABPmer Ltd	April 2010
10	Annex Geo 7: Waves	ABPmer Ltd	March 2010
11	Annex Geo 7: Wave conditions for sediment and morphology assessment	HR Wallingford	April 2010
12	Annex Geo 8: Investigation of Mud Transport	HR Wallingford	April 2010
13	Annex Geo 9: Sediment budget	ABPmer Ltd	April 2010
14	Annex Geo 10: Investigation of changes to sand transport	HR Wallingford	April 2010
15	Annex Geo 11: Morphological evolution of the intertidal	HR Wallingford	April 2010
16	Annex Geo 12: Estuary-wide morphological modelling of the Severn Estuary	HR Wallingford	April 2010
17	Annex Geo 14: Construction related issues	ABPmer Ltd	April 2010

Marine Water Quality

Technical Annex	Title	Prepared by	Date
1	Flushing and pH	ABPmer Ltd	April 2010
2	Salinity	ABPmer Ltd	April 2010
3	Temperature	ABPmer Ltd	April 2010
4	Dilution and Dispersion of Thermal Plumes	ABPmer Ltd	April 2010
5	Vertical Stratification – Preliminary Assessment	Coastal Science Ltd	April 2010
6	Nutrients	ABPmer Ltd	April 2010
7	Dissolved oxygen	WRc	April 2010
8	Dilution and Dispersion of Treated Sewage Effluent	ABPmer Ltd	April 2010
9	Contaminants	ABPmer Ltd	April 2010